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Design, Development and Experimental Study of Solar PV Air Cooler

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ABSTRACT

The article describes the design-development and experimental studies of a solar PV based evaporative air cooler. The solar air cooler has been designed with a DC pump (36 W) and DC motor (36 W). Experiments have been conducted with different wattage solar panels (75W, 100W and 115W) connected to air cooler. Solar charge controller and battery are added to the system for reliable operation. Several experiments were conducted on the developed solar air cooler to assess its performance with different solar panels, with and without battery and with and without tracking. The combination of 40 W and 75 W panel (115 W) with manual tracking without battery backup worked well for the developed solar cooler for 7-8 hours during clear summer days. The solar cooler worked from 10 a.m. in the morning to 5:00 p.m. in the evening. Experiments indicate that a solar panel of power higher than 115 W would work well for the solar air cooler. The cooler can run for around 7-8 hours without battery and battery can provide back up for around 3-4 hours.

Keywords: DC cooler, Evaporative air cooler, Solar air cooler, Solar PV panels, tracking

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1. INTRODUCTION

In hot climatic conditions the need to feel relaxed and comfortable has become one of few needs. Presently most of the cooling systems available are not suitable for villages and remote areas due to longer power cut durations, unavailability of electricity and high cost of products. To improve the quality of life and promote sustainable development it has become essential to meet the increasing power demands in environmentally clean and affordable manner. Solar energy is a favorable option as it can be used for various applications, even as standalone system in remote areas.

Evaporative air coolers work well in hot-dry climatic zones with minimum energy expenditure. A solar based evaporative air cooler can be helpful in improving thermal comfort conditions in hot-dry areas where grid electricity supply is not present or not regular. A study has been reported by S. Elmetenani et.al. on solar based evaporative air cooler in Algerian climate. The results showed that the maximum depression of the dry bulb temperature reached is about 18.86°C [1]. Design and performance analysis of a small solar evaporative cooler with minimum energy consumption of 10 W has been discussed by H. Lotfizadeh and M. Layeghi [2]. A solar air conditioner consisting of a liquid evaporation unit, a heat exchange unit, and a solar power generation unit was patented by H. S. Emam [3]. Solar air conditioning system directly driven by stand-alone solar PV has been studied by Bin-Juine Huang et.al. [4].

Six solar air conditioners with different sizes of PV panel and air conditioners were built and tested outdoors to experimentally investigate the running probabilities of air conditioning at various solar irradiations. G. F. Abdullah studied techno-economic optimization of the size of the components comprising an solar PV system powering evaporative air cooler and heat pump water heater to meet the demand of a typical Australian house model for two different climates [5]. Experimental studies of a direct evaporative cooler with two different cooling pads based on actual weather data in India has been reported by D. Bishoyi and K. Sudhakar [6]. R. Opoku et.al. studied the performance of a hybrid solar PV-grid powered air conditioner for daytime office cooling in hot humid climates with a case study in Kumasi city, Ghana [7].

There have been very few scientific works reported on low cost solar cooling options for remote households/shops. Therefore, present work aimed at systematic scientific study of design-development of a solar air cooler and its on-field testing for performance. The design of the system is described and performance observations have been reported for several days for different panels, with and without battery and with manual tracking.

2. DESIGN DETAILS OF DEVELOPED SOLAR AIR COOLER

The developed solar air cooler consists of a DC motor and a DC pump assembled inside cooler body. Solar panel, charge controller and battery form the rest of the system's part. The specifications for the developed cooler are presented in Table 1. The specifications of the components used with the cooler are presented in Table 2 and Table 3 and the schematic diagram of cooler is shown in Fig.1.

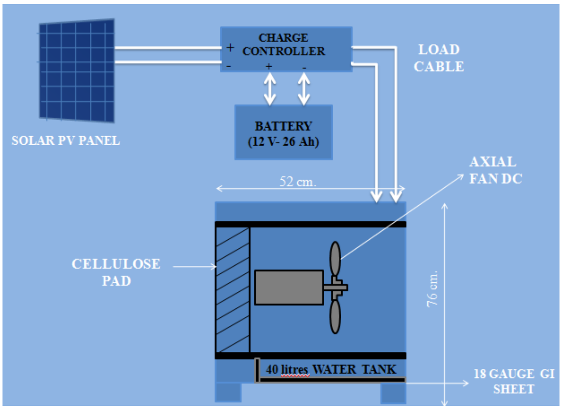

Fig. 1. Schematic figure of the developed solar PV air cooler

Table 1. Developed solar air cooler specifications

Operating Voltage	:	12 V
Operating current	:	6 Amp
Power	:	72 Watt
Load	:	DC
Required Solar Panel	:	~120 Watt
Battery	:	26 A, 12 volt
Charge Controller	:	10 Amp, 12 Volt
Wiring	:	Copper wire SWG 40/48
Control Type	:	Switch
Switch	:	Two way 10 Amp
Air Flow	:	5.20 m/s
RPM	:	1600
Speed	:	Variable
Noise	:	< 80db
Cover Area	:	~ 6 sq.m.
Auto Swing	:	Manually
Fan Type	:	Axial
Body Weight	:	4.5 kg
Water Tank	:	40 Liter
Pad	:	Cellulose
Dimension	:	52 × 52 × 76 cm
Cooler body	:	GI sheet 18 guage

Table 2. Specifications of DC motor, DC pump and charge controller

DC Fan Motor	• Operating Voltage	:	12 V
	• Operating current	:	3 Amp
	• RPM	:	~ 1200 to ~ 1600
	• Weight	:	490g
	• Dimensions	:	13 × 13 × 13 cm
DC Pump	• Operating Voltage	:	12 V
	• Operating current	:	3 Amp
	• Weight	:	Plastic, 450g
	• Water Lifting Capacity	:	1.2 m
	• Dimension	:	12.5 × 11× 9 cm
	• Water Output	:	500 LPH
Charge Controller	• Operating Voltage	:	12 V
	• Operating current	:	10 Amp (max)
	• Port	:	3
	• Weight	:	150g

A DC pump has been used in the developed system for the circulating water in cooler for evaporative cooling purpose. The specifications of the DC pump are reported in Table 3. A Pulse Width Modulation (PWM) charge controller was used for the protection of the battery from deep discharge and overcharging. The specifications are presented in Table 4 and it has been shown in figure 5. In solar air cooler a secondary type battery has been used, which is shown in figure 6. This battery has specifications of current rating 26 Ah and the voltage rating 12 Volt, total power of the battery is 312 Watt. The basic purpose behind using the battery is to provide smooth operation to the solar air cooler because PV panel does not provide fixed range of current and voltage due to variation in solar radiation. In solar air cooler project a two core 40/48 gauge copper wire is used, this wire was coated with insulating material Polyvinyl Chloride (PVC). The length of wire taken was 12 meter as solar PV panel was placed on the roof of the Kota University academic block. In the developed solar air cooler a cellulose pad is used. The cooling efficiency of this pad is more as compared to the traditional (grass type) pad, and the maintenance of this pad is also less as it needs replacement after 2 or 3 years.

For the experiments different range of PV modules are used with developed DC air cooler, which are 40 Watt, 75 Watt and 100 Watt. The modules used are polycrystalline silicon modules. The detailed specifications of these modules are presented in Table 3.

Table 3. Specifications of panels

Parameter	Rating		
Rated maximum power (P_{max})	100 Watt	75 Watt	40 Watt
Serial No. (SM- Solar $_{Maxx}$)	SM10002171342	SM07502171797	SM04001170847
Open circuit voltage (V_{oc})	21.97 V	21.72 V	21.37 V
Short circuit current (I_{sc})	6.07 A	4.6 A	2.5 A
Temperature of panel	25 °C	25 °C	25 °C
Rated voltage (V_{mpp})	17.46 V	17.33 V	17.18 V
Rated current (I_{mpp})	5.73 A	4.33 A	2.1. A

3. ON-FIELD EXPERIMENTS

The experimental studies to analyse the performance of the developed system have been conducted at Kota, Rajasthan, India (25.18°N and 75.83°E). The climate of Kota is hot and dry. The summers here are long, hot and dry, starting from late March till the end of the September month. The average temperatures during day go above 40°C in May and June and frequently exceed 45 °C, with temperatures as high as 48.4 °C have also been recorded.

The experimental setup for testing solar air cooler was at the academic block Nagarjun Bhawan of University of Kota. The various instruments used during the experimental observations were pyranometer, weather monitoring system, digital multimeter, anemometer, tachometer, digital thermometer, thermocouples and sound level meter. Kipp and Zonen CMP10 pyranometer has been used to record the solar radiation during experiments. The cooler was tested with 75 W, 100 W and 115 (40+75) W panels. The results of the observations have been reported in Tables 4-10. The experiments were performed on several days; here some representative observations have been presented.

4. RESULTS AND DISCUSSION

Experimental observations related to experiment performed on 3rd April with 75 watt, charge controller and battery connected with the DC air cooler are presented in Table 4. The solar panel was placed in south direction with the angle of inclination of 45°. At 2:30 PM battery started to show low indication so cooler was stopped. The experiment was repeated with the panel of 75 W but this time instead of keeping orientation of the panel fixed, it was manually tracked three times. Initially the module was in South-East direction, at 12 PM it rotated manually in South direction, after three hours at 3 PM it was rotated to South-West direction. The observations are presented in Table 5.

Table 4. Observation Table for 75W Module 3rd April (With battery)

Time (h)	S (W/m^2)	V_p (V)	I_p (A)	T_a (°C)	T_{sc} (°C)	v_{sca} (m/s)	u_{sca} (m/s)	N (rpm)
11:30 AM	934	20.0	4.31	38.1	34.1	3.73	1.06	1400
12:30 PM	977	19.97	4.57	39.6	33.3	3.74	1.22	1504
1:30 PM	936	19.60	4.51	39.3	31.1	3.87	1.22	1508
2:30 PM	825	19.55	4.06	39.3	30.2	2.99	1.11	1400
Low battery indication, cooler was stopped.								

Table 5. Observations of 75W Module 5th April with manual tracking (With battery)

Time (h)	S (W/m^2)	V_p (V)	I_p (A)	T_a (°C)	T_{sc} (°C)	v_{sca} (m/s)	u_{sca} (m/s)	N (rpm)
11: 00 AM	944	20.0	4.31	36.0	34.1	4.25	2.20	1504
12:00 PM	1010	20.2	4.67	38.6	33.0	4.20	2.11	1600
1:00 PM	1025	19.90	4.60	39.6	32.2	4.02	1.57	1600
2:00 PM	980	20.2	4.20	39.3	32.1	3.80	1.04	1504
3:00 PM	800	20.2	4.57	38.0	32.0	2.02	0.88	1442
4:00 PM	636	20.0	4.30	35.9	32.2	2.02	0.70	1400
Low battery indication, cooler was stopped due to low battery.								

Table 6. Observation Table of 100 W Module 10th April (With battery)

Time (h)	S (W/m^2)	V_p (V)	I_p (A)	T_a (°C)	T_{sc} (°C)	v_{sca} (m/s)	u_{sca} (m/s)	N (rpm)
11: 00 AM	950	19.70	5.52	35.70	31.7	4.25	2.22	1508
12:00 PM	1008	19.63	6.11	36.2	31.3	4.55	2.31	1600
1:00 PM	1017	19.56	6.13	37.70	31.2	4.55	2.10	1600
2:00 PM	946	19.75	5.95	38.3	30.7	3.80	1.80	1504
3:00 PM	805	19.80	4.99	36.7	30.9	2.99	1.23	1504
4:00 PM	786	19.75	3.92	36.1	31.4	2.50	0.70	1400
Low battery indication, cooler have been stopped due to low battery.								

This observation was taken with the 100 watt module. The module was placed at 23° inclination angle, the weather was clear and the module was getting proper radiation. The module was tracked, the panel was in south-east at 11 am, in south at 12 pm and in south-west direction at 2 pm, but after 2 pm it was not rotated, so the cooler stopped to run at 4 pm, due to low battery.

Table 7. Observation Table of 100W Module 13th April (without battery)

Time (h)	S (W/m^2)	V_p (V)	I_p (A)	T_a (°C)	T_{sc} (°C)	v_{sca} (m/s)	u_{sca} (m/s)	N (rpm)
11: 00 AM	969	20.7	5.97	36.2	31.4	4.11	2.22	1504
12:00 PM	1006	20.0	6.03	40.1	34.4	4.32	2.11	1600
1:00 PM	1002	20.2	5.78	40.6	35.0	4.12	2.10	1508
2:00 PM	860	20.1	4.99	40.4	34.4	3.62	1.81	1504
3:00 PM	680	20.2	5.44	40.3	32.5	2.99	1.13	1504
4:00 PM	446	20.4	4.46	37.2	32.9	2.62	0.60	1400
Solar air cooler stopped, due to cloudy weather, module output current decreased suddenly.								

This observation was done with 100W panel and the angle was 45°, but the important thing about this experiment was that the solar air cooler ran without battery till 4 pm, no battery backup was used. Another important thing to be noted is tracking, because at 11 am the module face was in south direction, at 3 pm module was tracked completely to the west direction. Due to sudden change in weather at 4 pm the output current decreased, and the solar cooler was stopped.

Table 8. (40W+75W parallel connection) Module on 20th April (without battery)

Time (h)	S (W/m^2)	V_p (V)	I_p (A)	T_a (°C)	T_{sc} (°C)	v_{sca} (m/s)	u_{sca} (m/s)	N (rpm)
10:30 AM	877	20.4	5.81	36.2	33.3	4.11	2.22	1504
11:30 AM	936	20.3	6.40	38.0	34.1	4.32	2.11	1600
12:30 PM	967	20.0	6.57	40.0	33.4	4.12	2.10	1508
1:30 PM	957	20.2	6.47	41.0	33.2	3.62	1.81	1504
2:30 PM	801	19.9	5.29	39.37	33.0	2.99	1.13	1504
3:30 PM	650	20.4	5.23	38.0	33.1	2.62	0.60	1400
4:30 PM	434	20.4	4.70	36.2	33.3	2.62	0.70	1400

In this experiment, two modules one of 75 W and other of 40 W were used. 40W and 75W modules were put in east-south and south west direction and cooler was running continuously. The tilt angle was kept at 23°. At 3 pm manual tracking was done of 40 watt panel in west direction because output current decreased at 4.92 ampere so the pump stopped to push water in air cooler, after tracking of 40 watt panel the current increased to 5.24 ampere and cooler ran again. But at 3:30 pm same problem occurred, the current decreased to 4.82 ampere and pump again stopped to throw water, so 75 watt panel was also rotated in west direction. But simple moving of panels to south direction was not enough as the increase in current was small (4.82 to 5.02). Therefore, a change in tilt angle was done which was from 23° to 30°, suddenly the current increased to 5.24 ampere and the cooler again started to run and ran till 4:30 pm.

Fig. 2. Parallel Connection of 40W+75W Modules in East-South and South-West direction

Fig. 3. 40W+75W Module at 3 pm in West Direction with 45° Angle at 21st April

Table 9. (40W+75W parallel connection) Module on 21st April (without battery)

Time (h)	S (W/m^2)	V_p (V)	I_p (A)	T_a (°C)	T_{sc} (°C)	v_{sca} (m/s)	u_{sca} (m/s)	N (rpm)
10:30 AM	881	21.4	5.91	37.8	33.3	4.84	2.22	1600
11:30 AM	959	21.0	6.44	39.2	34.1	4.67	2.11	1508
12:30 PM	979	20.6	6.66	40.8	34.6	4.90	2.42	1600
1:30 PM	943	20.7	6.45	42.5	35.3	3.84	1.81	1504
2:30 PM	819	20.7	5.77	40.3	35.7	2.99	1.13	1504
3:30 PM	604	20.6	5.88	39.2	33.7	2.75	1.11	1400
4:30 PM	455	20.8	4.82	38.0	33.7	2.62	0.70	1400

This experiment was repetition of previous experiment for finding best setup of direction and angle, without battery backup and charge controller. At 3:30 pm modules were rotated in west direction with 23° angle, but the output current was increased just at 5.02 A from 4.84 A, so we changed the tilt angle from 23° to 45°. The change in tilt angle resulted in increase in output current from 5.02 ampere to 5.88 ampere as shown in observation Table. Tracking of module in west direction with 45° at 3 pm is the best way of increasing the output current in clear weather condition.

Table 10. Parallel connected modules (40W+75W) without battery 24th April

Time (h)	S (W/m^2)	V_p (V)	I_p (A)	T_a (°C)	T_{sc} (°C)	v_{sca} (m/s)	u_{sca} (m/s)	N (rpm)
10:00 AM	760	20.4	5.60	36.8	33.3	4.77	2.22	1600
11:00 AM	902	21.0	6.42	38.2	34.2	4.62	2.11	1508
12:00 PM	989	20.4	6.55	39.8	34.4	4.87	2.09	1600
1:00 PM	943	20.7	6.52	41.5	35.1	3.84	1.81	1504
2:00 PM	820	20.7	5.77	39.3	34.9	2.99	1.10	1504
3:00 PM	604	20.4	5.88	38.2	33.8	2.65	1.09	1400
4:00 PM	455	20.4	4.75	36.4	33.5	2.62	0.70	1400
5:00 PM	402	20.2	4.64	34.7	31.4	1.99	0.60	1400

This experiment was repetition of observations as on 21st April. The observations confirmed that under clear sky conditions the cooler can run from 10 am in the morning without battery continuously till 5 pm in the evening with slight manual tracking two to three times.

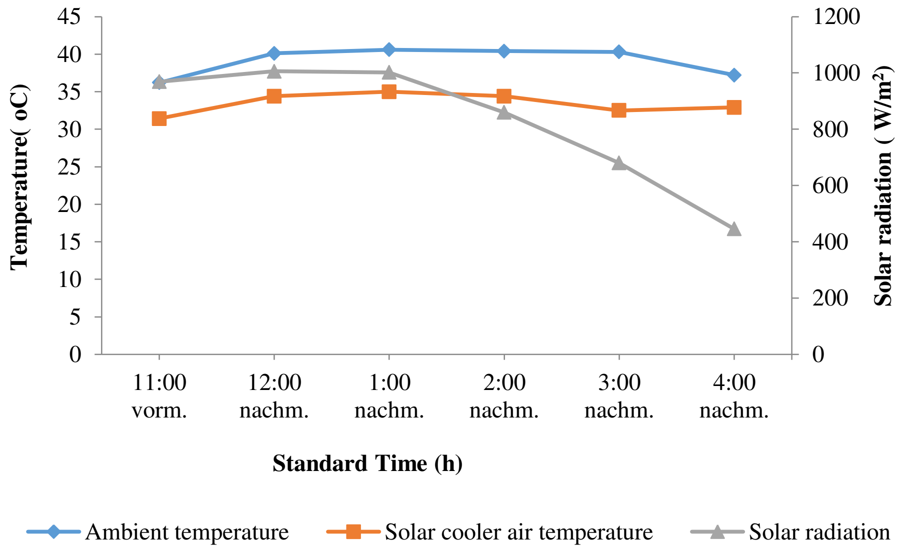

Fig. 4. Solar cooler air temperature, ambient temperature, solar radiation plotted with standard time for13th April

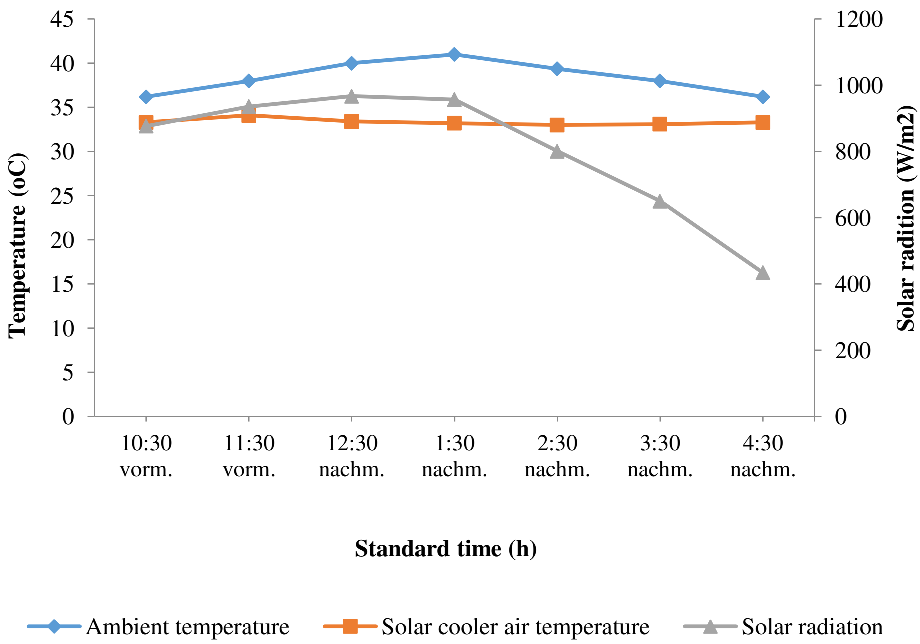

Fig. 5. Solar cooler air temperature, ambient temperature, solar radiation plotted with standard time for 20th April

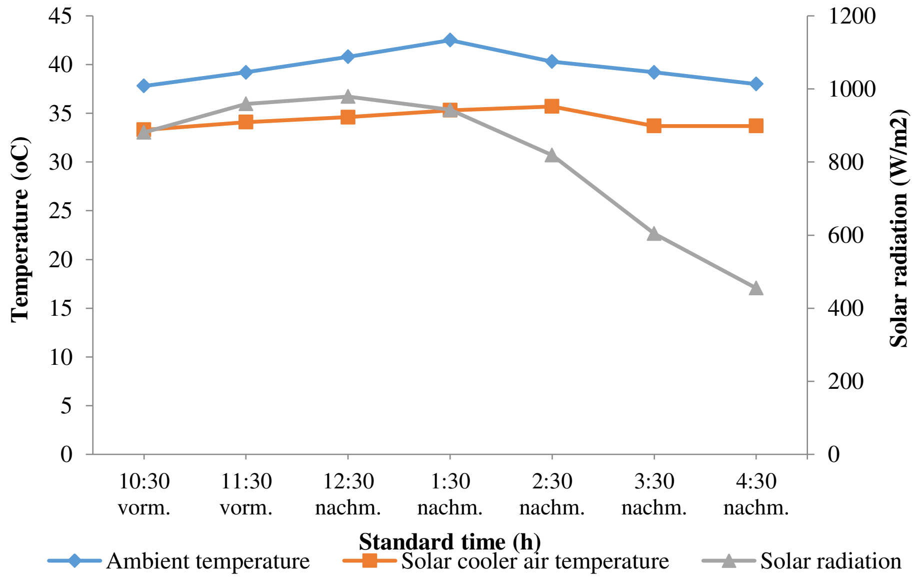

Fig. 6. Solar cooler air temperature, ambient temperature, solar radiation plotted with standard time for 21st April

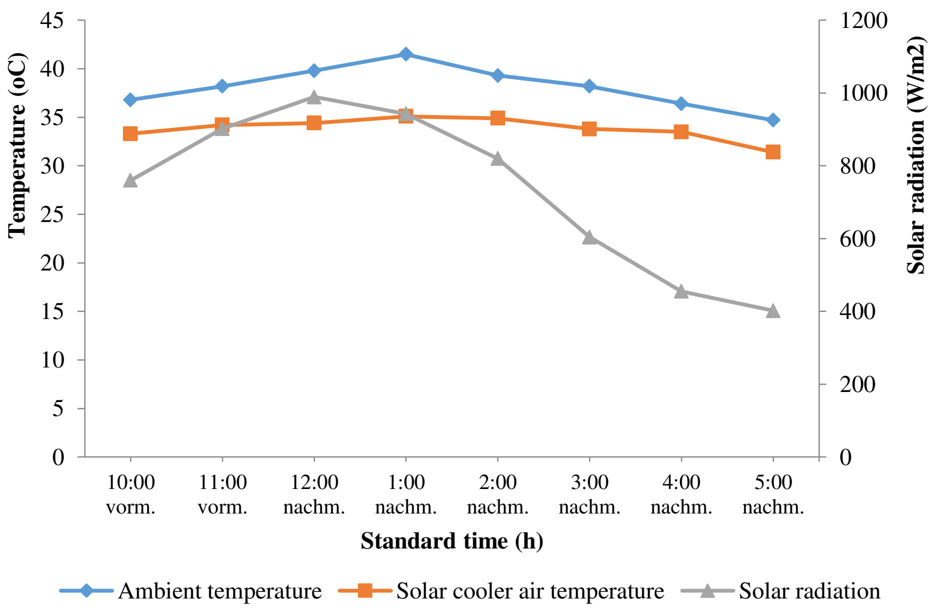

Fig. 7. Solar cooler air temperature, ambient temperature, solar radiation plotted with standard time for 24th April

From the Figure 4 to Figure 7, it can be seen that a reduction of around 5-6 ^{o}C can be achieved with solar air cooler. Solar radiation tends to decrease from 1:00 pm onwards and values reach around 400 W/m^2 around 4:00 pm. The direction of sunrays shifts towards west as solar azimuth angle increases, therefore it becomes important to manually track the solar panel towards south-west and west direction for appropriate use of solar energy. Further, as the angle of incidence also increases in the evening, it is desired that the solar panels are inclined for better reception and absorption of solar radiation.

As mentioned earlier, very few works have been reported about performance of solar air cooler and there is lack of any work, which clearly demonstrates the performance variation of the solar air cooler with standard time and tracking requirement. This work is a step towards filling the research gap. In this work, an understanding has been developed about the performance variation of solar PV cooler with different combinations of solar panels, with and without battery, and with and without tracking. Future work will be conducted to optimize the solar panel size, battery size according to climatic parameters of location and a detailed study with and without tracking will be undertaken.

5. CONCLUSIONS

The study reports the design-development and experimental studies of a solar DC evaporative cooler which may be suitable for rural shops, households in remote areas. As there is lack of studies on detailed performance prediction of solar PV air coolers, present work is a small step to enhance understanding based on the on-field experiments. The cooler uses 36 W DC pump and 36 W DC motor powered by solar PV panels. A combination of 40 W and 75 W panel (115 W) with manual tracking for two to three times in a day without battery backup was found to work well for the developed solar cooler. For the system to work without tracking, the solar panel capacity should be increased. The cooler can run for around 7-8 hours without battery on clear summer days and battery can provide back up for around 3-4 hours. There is scope of further work to optimize the solar panel capacity, battery back up requirement and tracking needs for the developed cooler according to the climatic parameters of the location. Both simulation and experimental studies will be taken up in future to develop an efficient performance model for solar PV based DC air cooler.

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NOMENCLATURE

I_p	:	Panel current (Amp)
N	:	Rotational speed (rpm)
S	:	Solar radiation (W/m^2)
T_a	:	Ambient temperature (^{o}C)
T_{sc}	:	Solar cooler air temperature (^{o}C)
u_{sca}	:	Solar cooler air velocity at 1 meter distance (m/s)
V_p	:	Panel voltage (Volts)
v_{sca}	:	Solar cooler air velocity (m/s)

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