Cooling Pvt Systems in Arid Regions: An Innovative Method

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Abstract
Increasing temperatures have a significant effect on the performance of PVT. As temperatures increases, PVT systems become less efficient and have a reduced operational lifespan. Therefore, developing an effective cooling system to reduce PVT exposure to high temperatures could improve overall performance. With rising reports of drought and water shortages, it is crucial to conserve and use water more efficiently. This study aims to minimize the water needed for PVT cooling, especially in arid regions of India. A key issue for developers and users is the decrease in PVT output as temperatures increase during operation. This study evaluates the effects of PVT with no cooling versus cooling with moist wood wool cooling. The method uses damp wood wool on the back of the PVT to lower the module's temperature by allowing a thin layer of water to evaporate. The experimental results showed that the overall efficiency with moist wood wool cooling increased to 13.98 % whereas it was 13.39% in case of without cooling of PVT. Adding moist wood wool is highly effective, cost-efficient, renewable, sustainable, and environmentally friendly.

Keywords: Wood Wool, Cooling, Photovoltaic, Evaporative cooling.

1. Introduction

The world's population growth and swift technological advances have led to higher demand and unrestrained use of natural resources, which are both limited and dwindling. Photovoltaic (PVT) power generation offers a viable solution to these issues of resource depletion and air pollution. Utilizing PVT as a clean energy source helps decrease harmful emissions [1],[2].Solar energy, as a clean energy source, does not release harmful greenhouse gases that damage the environment. India has set a goal to achieve net-zero emissions by 2070, marking a significant milestone in the global battle against climate change. Additionally, the country aims to obtain at least 50% of its electricity from renewable sources by 2030 [3].India's renewable energy sector includes a substantial share of solar power, with innovations like rooftop solar panels and floating photovoltaic systems gaining traction. Remarkably, the total amount of sunlight that hits the Earth's surface in just 60 minutes could meet the world's annual energy requirements. Solar energy systems harness this sunlight using mirrors or photovoltaic thermal (PVT) technology, converting it into electrical energy, thermal energy, or stored battery energy[4],[5].

A major challenge with photovoltaic (PVT) systems is overheating due to intense solar radiation and high ambient temperatures, which significantly reduces their efficiency [6].The efficiency of PVT system decreases as temperature rises from 0 °C to 75 °C. Specifically, a temperature coefficient of −0.5%/°C indicates that for each 1 °C increase in temperature, the efficiency drops by 0.5%[7]. This demonstrates that overheating adversely affects PVT performance[8]. Consequently, researchers are seeking effective, low-maintenance, and cost-efficient methods to manage excess heat in PVT systems.Several cooling methods generally classified as active and passive methods are introduced in the literature to keep the low working temperature of PVT

2. Scenario of Green Energy inIndia

Based on REN21Renewables 2022 Global Status Report, India holds the fourth position globally for its installed capacity in renewable energy including significant hydroelectric power. It ranks fourth in both solar and wind capacities. During COP26, India committed to an ambitious goal of achieving 500GW of energy generated from non- fossil fuel sources by 2030 [9]. As of December 2023, the total installed capacity of renewable energy sources, including major hydropower, stood at 180.79 GW. The breakdown of installed capacities is represented in the given pie-chart. (Fig.1)

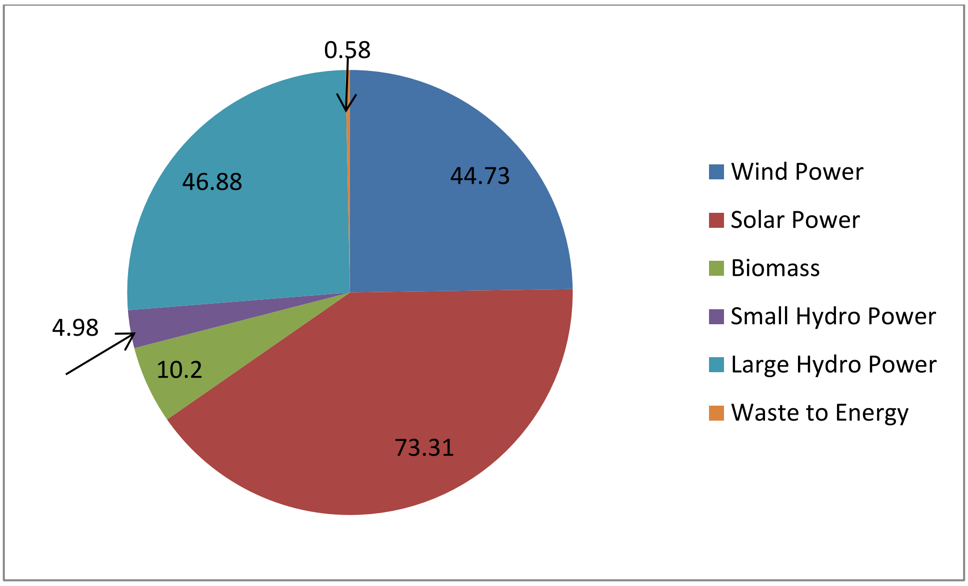

Fig.1 Installed grid-interactive renewable power capacity (In GW)
Source: Renewable Energy in India 2023

3. Literature Review.

Notable advancements have been achieved in materials science, the incorporation of emerging technologies, and both passive and active cooling methods for PVTs. The literature, summarized in Table 1, outlines the technologies explored to date. The following provides a clear summary of the trends and progress made so far.

Table1. Previous studies based on the cooling of PVT

S.No	Cooling Approach	Highlights/Investigation	References
1	Active and Passive cooling	• It is reported that the range of values for ηe and ηth is 7.5 to 45.39% and 12 to 70%, respectively.	[10]
2.	Ferrofluid-filled elliptic ducts have been used for cooling.	• More effective cooling is attained with a rise in Vi, which results in improvements in ηe and ηth of around 4.03% and 30.26%, respectively.	[11]
3.	Water Spray Cooling	• 15.92 percent for maximum electricity efficiency • Power output up to 40.7 W	[12]
4.	Water and Air cooling	• A 38% rise in power output	[13]
5.	Air Cooling	• A 46.54 rise in power output	[14]

6.	Water Cooling	• 90 percent conversion efficiency and 10.66 percent electrical efficiency	[15]
7.	Utilizing PCM and ZnO/water nanofluid	• There was an increase in average electrical output of more than 13% when compared to a standard PV module.	[16]
8.	Active and Passive cooling	• The simplest yet efficient cooling technique was found to be the active cooling method.	[17]
9.	Converging channel heat exchanger	• Efficiency of conversion increased by 36.1% and 35.5% rise in electricity production	[18]
10.	PVT Air Collector	• A 15% improvement in thermal efficiency	[19]
11.	Evaporative cooling by using (i) clay, (ii) clay with wood wool, and (iii) clay with jute fibers.	• The clay coated in jute fiber had the lowest air pressure drop 2.5 to 27.5 Pa while the clay with wood wool had the biggest range of 11 to 33.5 Pa. These three clay designs were followed by one another with drops ranging from 5 to 30 Pa.	[20]
12.	Microchannel heat sink with nanofluids	• There was a 19% increase in electrical efficiency.	[21]
13.	Dew Point Evaporative Cooling	• A DPEC cooling system can boost solar cell efficiency by 11.4–16.5%.	[22]
14.	Water Cooling	• In a hot and dry climate, the panel's temperature is considerably lowered by up to 30 °C when the front and rear surfaces are cooled simultaneously using an active and passive cooling technique.	[23]
15.	Radiative, Evaporative, Reflective Cooling	• During working hours, which are from 9:00 AM to 6:00 PM, the average exterior surface temperature of the evaporative cooling model stayed 1.9 °C higher than the ambient temperature and 2.7 °C higher than that of the radiative cooling model. Radiative cooling therefore demonstrated the highest cooling efficiency.	[24]
16.	Radiative Cooling	• When compared to an aligned, horizontal PV module, the recommended v-PV system maintained a slightly lower operating temperature of 0.2°C, which equated to an increase in the maximum power generation of 16.8% when the solar panel's solar irradiance collecting efficiency was enhanced by 15%.	[25]
17.	Evaporative Cooling	• Electrical efficiency rose in response to forced convection, natural convection, forced evaporative cooling, and naturally evaporative cooling by 4%, 1.2%, 3.8%, and 4.7%.	[26]

18.	PCM-(OM37P)	• When the PV panel is cooled with the PCM during peak hours, the voltage drops by at least 0.6V.	[27]
19.	Evaporative Cooling	• The integration of ECS with heat pipe results in a maximum temperature decrease of around 17 °C.	[28]
20.	Passive cooling using a cotton wick structure	• Module efficiency is increased by 1.4% with the cooling arrangement.	[29]
21.	Evaporative Cooling Using Porous Clay	• PV cell efficiency was subsequently increased by 9.8%.	[30]
22.	PCM with Graphite Cooling	• When PCM with graphite was employed to cool the PV cell, there was an approximate 13% gain in total efficiency.	[31]
23.	Aluminium fins with water-immersed cotton wicks	• PV module temperature dropped by 22.3%.	[32]
24.	Evaporative Cooling Using Moist Jute Cloth	• A rise in electrical efficiency of 10.31% and a decrease in average temperature of 18°C.	[33]
25.	Evaporative Cooling Using a Jute Sack with solar still	• There was a 5.6% rise in output power and a 14.51% gain in electrical efficiency.	[34]
26.	Compressed Air Cooling	• The use of compressed airflow to clean and cool the PV simultaneously is investigated.	[35]
27.	Evaporative Cooling Using Hydrogel	• With a 5.93% improvement in efficiency, the average cooling power is 266.9 W m2.	[36]
28.	Active and Passive Cooling	• Liquid spraying lowers the temperature, which enhances electrical performance. • Fins collect the heat that the panel has dissipated and boost conversion efficiency.	[37]
29.	Nanofluid +SiC-PCM cooling	• Approximately 17 °C was dropped in temperature between 12:30 and 2:30 pm, which is considered peak time.	[38]
30.	Sprinkler	• After cooling, the temperature of the cell was reduced from 52° C to 32° C. • Total output is boosted by an average of 5%	[39]
31	Cooling with Ice	• In cooled conditions, solar PV efficiency may increase at a rate of 47%.	[40]
32	Concentrated Photovoltaic with Active Water Cooling	• According to the testing results, the CPV module's working temperature may be lowered to 60°C using water cooling. • As a result, the CPV's efficiency has increased and it can produce more electricity.	[41]
33	Heat Pipe Cooling	• The finned heatsink, water cooling	[42]

	method	module, and heat pipe had average temperatures of 22.2 °C, 25.9 °C, and 41 °C during the test, respectively. • The CPV cell using the heat pipe cooling technique has the maximum output power (8.27 W).	
34	Water Immersion Method	• At water, efficiency has increased by roughly 11%.	[43]
35	Aluminium heat sinks	• Heat sinks allow for an average temperature drop of 7.5 °C, which results in an increase in open-circuit voltage of 0.27 V above the reference panel.	[44]
36	Evaporative cooling using Synthetic clay	• A maximum rise of 19.1% in output power and 19.4% in output voltage.	[45]
37	PCM with free/forced convection	• In comparison with a standard PV panel, IEF-PCM-Forced-PV demonstrated the greatest relative gains in energy dissipation efficiency, with rates of 20.36 percent and 62.24%, respectively.	[46]
38	Natural water and phase change material (PCM)	• The top-to-bottom continuous water supply cooling technique performed better than other cases with an increase in average electricity generation, electrical efficiency, power enhancement percentage, average temperature reduction, maximum overall exergy output, and exergy efficiency of 11.92%, 12.4%, 13.54%, 5.4 C, 26.07%, and 8.08%, respectively.	[47]
39	Evaporative Cooling	• About 6°C drop in temperature at the PV panel	[48]
40	Evaporative Cooling	• With a DPEC cooling system, solar cell efficiency can rise by 11.4–16.5%.	
41	Water back cooling, air cooling, nanofluid back cooling, and waterfront cooling	• The most effective cooling method is forced water cooling from dispersed nozzles on the front surface. • PV energy conversion efficiency increased by 2.94%, 2.46%, 2.2%, and 6.84% when air cooling, water back cooling, nanofluid back cooling, and waterfront cooling were used, respectively.	[49]
42	Thermoelectric Cooling	• When solar insolation is between 0.8 and 1 kW/m2 and temperature is between 25 and 45 °C, improvements in PV module electrical efficiency have been reported, countering TEC power consumption.	[50]
43	Nanofluid Cooling (Al_2O_3, TiO_2, and CuO)	• With an amount of 1.467% or a 5.49% increase rate, the 0.2% nanofluid Al_2O_3-water showed the most gain in electrical efficiency.	[51]

4.

44	Thermoelectric Cooling	• Through self-cooling, the temperature of the solar cell was lowered from 69.3 °C to 56.6 °C. • Four thermoelectric module arrangements reduced the temperature even further, to 42.5 °C	[52]
45	Active Cooling and Passive Cooling	• The PV panel with hybrid cooling has an average power output of 34.66 W.	[53]
46	Water Immersion Cooling	• At a water depth of 1 cm, panel efficiency has increased by roughly 17.8%.	[54]
47	Air Cooled heat sinks	• At least 10 °C is dropped in temperature.	[55]
48	Nanofluid with Aluminium particles	• When comparing the efficiency and output power of solar PV panels with nanofluid containing aluminum nanoparticles to water cooling without aluminum nanoparticles, the improvements were on average 13.5 and 13.7%, respectively.	[56]
49	PCM with fins	• With a fin spacing of 6 mm, the cooling effect was optimal, lowering the battery plate temperature by 31.9 ◦C as compared to natural convection circumstances without fins.	[57]
50	PCM Cooling	• In the end, PCM was able to average a 10.5 C reduction in PV temperature during peak time, which led to a 5.9% annual gain in PV power output.	[58]
51	Al2O3/PCM with water	• The compound approach (Al2O3/PCM combination water) is superior to cooling with 100% water since it contains 4 ¼1% Al2O3 nanoparticles	[59]
52	Fins with Iron nanoparticles	• When compared to the traditional system, the system with six fins and nanoparticles had a 15.51% increase in electrical (module) efficiency. Additionally, the PV panel's surface temperature dropped by 7.28–17.33%.	[60]

Methodology

The following formulae are used to determine the PVT efficiency. The definition of the electrical efficiency equation is:

$$\eta = (Poutput/Pinput) * 100 \quad (1)$$

$$\eta = \quad Pmax/ Pin = \{(I_{SC} * V_{OC} * FF)/P_{in}\} * 100\% \quad (2)$$

$$\eta_P = (P_{avg}/P_{max}) \times 100\% \quad (3)$$

$$\eta_{avg} = (P_{avg}/PVA.H) \times 100\% \quad (4)$$

$PR= \{(P_{avg}/P_{max})/(H/GSTC)\}$ (5)

where,
ɳ= Efficiency of PVT Panel (%).
I_{SC}= Short circuit current of PVT
V_{OC}=Open circuit voltage of PVT
ηP=Power output efficiency (%)
P_{avg}=Average power output (W) measured on-site in the given period
P_{max}= Maximum power output (W) of panel
η_{avg} = Average module efficiency (%)
H = Average incident radiation (W/m2) on-site in the given period
PVA =Surface area (m2)
PR =Performance Ratio
GSTC= Irradiance at STC (W/m2) = 1000W/m2
P_{in}= Input power
FF=fill factor
P_{output} = Output power in Watt
P_{input}= Solar Energy in Watt

5. Case Study

From 20th-21st September 2023, experiments have been conducted under clear sky conditionsThe setup is installed at MaharshiDayanand University, Rohtak, India. The experimental investigations were put to the test in Rohtak, India's weather experimental work was carried out every day from 9:00 A.M. to 4:30 P.M., after half anhour.The cooling began at 11:00 A.M. and ran until 3:00 P.M. except in Case 1. An experimental setup has been built to investigate how moist wood wool cooling affects PVT performance. In the experiments, one polycrystalline panel of 40W was used. Thermal radiation (Wb/m2), output voltage, output current, top and bottom cell temperatures, output power, input power, and efficiency were all monitored during the experiment. Table2.displays the electrical properties of the PVT used for the analysis. Power Specification is measured at standard test condition insolation 1000Wb/m2, Temperature 25° C.

Table2. Electrical properties of the PVT

Maximum Power (Pmax)	40Wp
Vmax(V)	18.69 V
Imax(I)	2.30A
FF (%)	76.21
Insol (W/m2)	1000 W/m2
Temp Corr	25°C
Module efficiency (%)	15%
Voc(V)	22.68V
Isc(I)	2.49A

5.1 Case-1Without Cooling

Table 3 provides detailed results for the period without cooling. Data was collected hourly on September 20th, 2023, from 9:00 A.M. to 4:30 P.M.

Table 3. Detailed results without cooling

TIME (20/09/2023)	THERMAL RADIATION	VOLTAGE	CURRENT	TOP CELL TEMP.	BOTTOM CELL TEMP.	AREA(m2)	AMBIENT TEMP.	POWER(OUTPUT)	POWER(INPUT)	EFFICIENCY
09:00	532.7	19.01	1.05	35.4	37.6	0.216	34.50	19.96	115.06	13.22
09:30	539.4	19.02	1.06	45.6	45.9	0.216	36.50	20.16	116.51	13.18
10:00	633.6	19.23	1.4	53.4	55.2	0.216	37.00	26.92	136.85	14.99
10:30	691.8	19.37	1.21	56.4	57.6	0.216	36.00	23.43	149.42	11.95
11:00	802.4	19.81	1.57	57.6	58.2	0.216	37.50	31.10	173.31	13.67
11:30	815.6	20.06	1.6	57.3	58.2	0.216	39.00	32.09	176.16	13.88
12:00	873.2	20.6	1.71	59.4	60.4	0.216	38.50	35.22	188.61	14.23
12:30	886.1	20.67	1.77	60.4	61.2	0.216	39.00	36.58	191.39	14.56
13:00	950.1	20.68	2.1	61.4	62.4	0.216	40.50	43.42	205.22	16.12
13:30	911.3	19.51	1.82	61.9	62.3	0.216	41.00	35.50	196.84	13.74
14:00	931.7	19.62	1.73	63.2	64.7	0.216	41.50	33.94	201.24	12.85
14:30	923.4	19.12	1.63	62.3	65.8	0.216	42.50	31.16	199.45	11.90
15:00	954.1	19.67	1.89	60.6	61.60	0.216	38.00	37.17	203.22	13.93
15:30	885.6	19.7	1.45	59.2	61.4	0.216	37.50	28.56	191.28	11.37
16:00	666.5	19.31	1.24	53.6	57.6	0.216	36.50	23.94	143.96	12.67
16:30	550.1	18.98	0.98	57.6	58.8	0.216	36.00	18.60	118.82	11.92
										13.39

From the given graph as shown in Fig.2. observed that the overall efficiency of PV T is 13.39% without any cooling

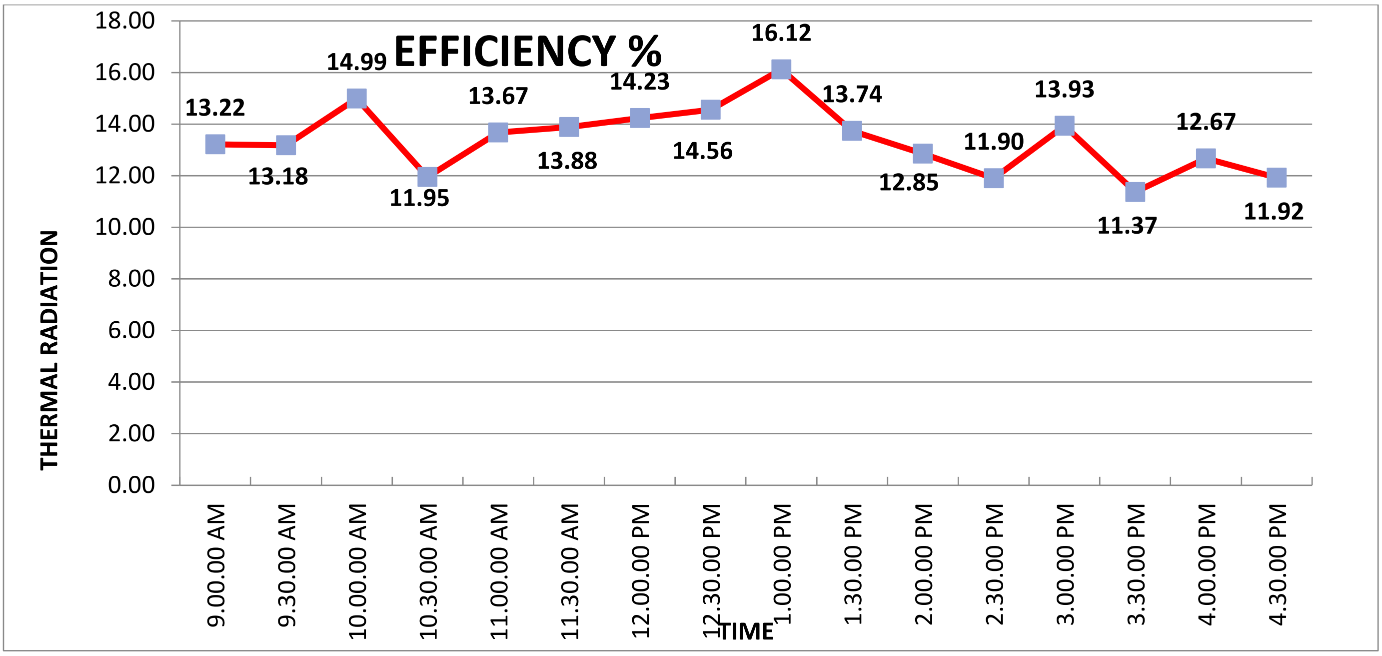

Fig.2.Graphical representation of Without Cooling

5.2 Case -2 With Moist Wood Wool Cooling

On September 21st, 2023, from 9:00 A.M. to 4:30 P.M., the PVT was cooled using moist wood wool.Table 4. provides detailed results for the period with moist wood wool cooling. The wood wool was placed on the back of the PVT with the aid of a supporting wire mesh. Cooling commenced at 11:00 A.M. and continued until 3:00 P.M.From the given graph as shown in Fig.3observed that the overall efficiency of PV T is 13.98% with moist wood wool cooling

Table 4. Detailed Results with moist Wood Wool Cooling

TIME (21/09/2023)	THERMAL RADIATION	VOLTAGE	CURRENT	TOP CELL TEMP.	BOTTOM CELL TEMP.	AREA(m2)	POWER(OUTPUT)	POWER INPUT	EFFICIENCY
09:00:00	538.7	19.12	1.05	36.8	39.5	0.216	20.08	116.36	13.15
09:30:00	538.2	19.01	1.21	49.7	51.6	0.216	23.00	116.25	15.08
10:00:00	635.6	19.24	1.46	56.1	57.3	0.216	28.09	137.29	15.59
10:30:00	730.8	19.4	1.56	55.3	57.8	0.216	30.26	157.85	14.61
11:00:00	817.1	20.05	1.86	48.2	50.4	0.216	37.29	176.49	16.10
11:30:00	796.6	20.08	1.9	57.6	58.2	0.216	38.15	172.07	16.90
12:00:00	862.3	20.7	1.99	58.6	59	0.216	41.19	186.25	16.85
12:30:00	898.4	20.71	2.01	59.6	60.6	0.216	41.63	194.05	16.35

13:00:00	958.9	20.71	2.23	60.6	65.6	0.216	46.18	207.12	16.99
13:30:00	915.2	19.48	2.12	57.6	59.2	0.216	41.30	197.68	15.92
14:00:00	835.1	20.81	1.88	55.5	57.6	0.216	39.12	180.38	16.53
14:30:00	829.9	20.35	1.9	47.2	49.4	0.216	38.67	179.25	16.44
15:00:00	965.1	19.57	1.58	44.4	45.4	0.216	30.92	208.46	11.30
15:30:00	887.6	19.27	0.89	40.6	41.8	0.216	17.15	191.72	6.82
16:00:00	606.5	19.71	0.78	39.7	41.2	0.216	15.37	131.00	8.94
16:30:00	551.1	18.92	0.5	36.7	39.6	0.216	9.46	119.03	6.06
									13.98

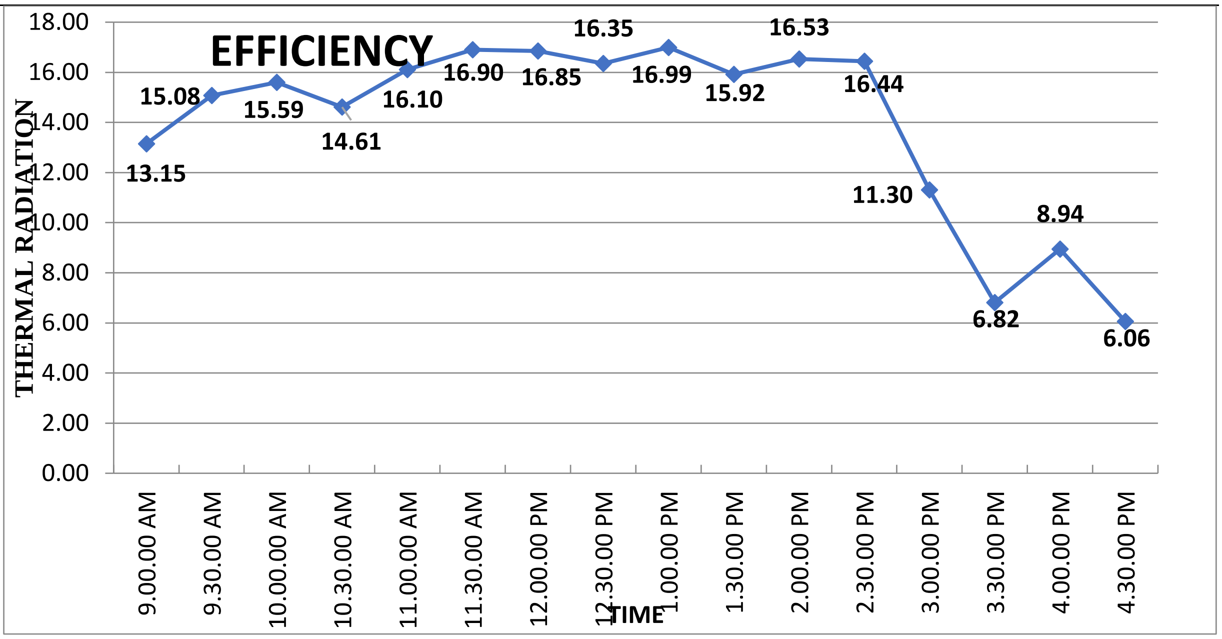

Fig.3.Graphical representation of moist wood wool cooling of PVT

6. Conclusion

The aim of this study is to minimize water usage while cooling the PVT system. The result shows that using moist wood wool for cooling PVT increases efficiency to 13.98% from 13.39%. The case study underscores the benefits of Wood Wool cooling in PVT systems, as it effectively reduces the operating temperature of the PVT, thereby enhancing energy production. The findings indicate that moist wood wool cooling significantly improves PVT performance compared to systems without cooling method. This cooling technique not only boosts energy output but is also environmentally friendly. Preliminary results suggest that this cooling approach could be a valuable addition to PVT systems, though further research may be necessary to assess its long-term durability and cost-effectiveness.

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