A

Project Report

on

EXPERIMENTAL STUDIES ON HYBRID PHOTOVOLTAIC THERMAL SYSTEM

By

Mr. Shrikant S. Pote   **Mr. Shaikh Mustafeez**

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Sant Gadge Baba Amravati University, Amravati

Session 2022-23

Certificate

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of final year (B.E.) during the academic year 2022-23 is for the partial fulfillment for requirement of the award of the degree of Bachelor of Engineering in Mechanical under Sant Gadge Baba Amravati University, Amravati.

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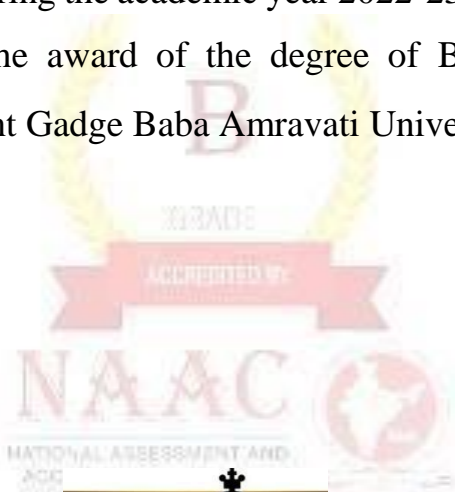**Mr. Anurag N. Kharche**   **Mr. Deepak Sangitrao**

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Internal Examiner   External Examiner

Date: Date:

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ABSTRACT

Climate change, global warming and environmental pollution have forced the world to look for clean energy technology. These problems can be solved by using renewable energy from sun and wind. Hybrid photovoltaic/thermal systems have become an important energy technology due to their capacity of producing electrical and thermal energy simultaneously, their ease of integration into buildings and good overall performance. Conventional PV systems generate waste energy in the form of heat during the conversion of solar radiation into electricity. It has been shown that the electrical efficiency of PV panels decays with the rise in the PV cell temperature. Therefore, PV performance can be optimized if this heat is removed. Air and water are the most common media used for heat removal and the energy can then be used for heating applications in buildings. Sun is the primary source of renewable energy. It is abundant, inexhaustible and clean. It plays a very important role in the present energy crisis. Solar energy can be harnessed by EXPERIMENTAL STUDIES ON HYBRID PHOTOVOLTAIC THERMAL SYSTEM to generate power and heat. These devices generate thermal and electrical energy simultaneously. Hybrid photovoltaic thermal systems have high efficiency. There is ample scope in this area as much work remains to be done. The hybrid system has huge potential in India where the availability of solar energy is spread throughout the country.

Keywords: Hybrid photovoltaic/thermal (PV/T), photovoltaic (PV) thermal (TH)heat transfer efficiency.

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CHAPTER 1

INTRODUCTION

The industrial reformation in the eighteenth century has tremendously hiked energy demand globally. The developed countries around the globe shift their focus towards sustainable power sources, especially solar and wind, to meet the increasing energy demand. Solar thermal energy collectors are special kind of heat exchangers that convert solar radiation into thermal energy through a transport medium and/or moving fluid. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat energy, and transfers it through a fluid (usually air, water, or oil) for useful purpose/applications. In the past 3-4 decades, the market of solar thermal and photovoltaic (PV) electricity generation has been growing rapidly. So were the technological developments in hybrid solar photovoltaic/thermal (PVT) collectors and the associated systems. Generally speaking, a PVT system integrates photovoltaic and solar thermal systems for the co-generation of electrical and thermal power from solar energy.

The European Union (EU), geographic area that is strongly dependent on external primary energy, considers that, relatively to the energy sources, a strong increase of renewable energies in global energy production is desirable, in order to reach a 15% contribution until 2010. The concerns of the EU on energy and environmental politics integration are reported in the new "Energy Politics for the Europe". This politic proposal must be the basic instrument for the reduction of the Greenhouse Gases and the increment of the energy production with renewable sources, among others. Also in Portugal, the Government has defined the "National Strategy for the Energy" to promote energy production on the basis of renewable sources, with the capacity of exploration in the country, being the solar energy one of them.

1.1 OBJECTIVE

1. Photovoltaic/Thermal (PVT) hybrid solar system is obtained by combining solar thermal collectors and solar photovoltaics to enable a simultaneous generation of electricity and production of heat. Thermal (PV-T) hybrid solar systems increase electricity production by cooling the PV panel and using the removed thermal energy to heat water.

2. The main objective is it can produce both thermal and electrical energy.Hybrid Photovoltaic thermal systems were experimentally studied in outdoor conditions regarding their thermal and electrical performance.

3. It used water and air to extract heat from the pv module rear surface and to keep the electrical efficiency of it at satisfactory level by reduction of its operating temperature

4. Solar energy can be harnessed by EXPERIMENTAL STUDIES ON HYBRID PHOTOVOLTAIC THERMAL SYSTEM to generate power and heat.

5. These devices generate thermal and electrical energy simultaneously.

6. Hybrid photovoltaic thermal systems have high efficiency.

1.2 TYPES OF COOLING SYSTEM

Liquid-based systems a liquid can be used to remove the heat in a PV/T system. The liquid is pumped through channels in the heatcollecting plate mounted on the back of the PV module. The heat generated from the PV is conducted through the plate and absorbed by the fluid, cooling the PV module. According to researchers such as Makki et al. (2015), this cools the PV, resulting in higher efficiency yet also creates a lower temperature variation on the surface of the PV module and therefore, a higher overall efficiency. Current research focuses on PV/T collectors cooled with water, bi-fluid and refrigerant.

1.3 WATER COOLING

After reviewing the different components and configurations of a water-based PV/T, Aste, del Pero and Leon forte (2014) reported that this media has a better efficiency due to the higher heat capacity of the water, allowing stable PV temperature control. In most of the literature, researchers have performed a theoretical and experimental analysis of water-based PV/T systems. In most cases, the final use of the heated water is to fulfil domestic needs. These studies included configurations of PV/T with glazing, without glazing, semitransparent PV modules, partially and fully covered by PV modules, and use of different types of coatings, etc.

1.4 AIR-BASED SYSTEMS

As its name suggests, air passes through an air-based PV/T system. This is done using the single or double pass and with an active or passive mode. Many researchers have worked

with this type of collector, testing the efficiencies or optimizing the design and configuration. As in the fluid-based PV/T systems, studies of air-based systems have been carried out using numerical models and simulations. Nowadays, these types of photovoltaic/thermal systems have thermal efficiencies of 32% to 34%, according to (Sathe and Dhoble, 2017). A photovoltaic/thermal integrated greenhouse

System for biogas heating was designed and evaluated by Tiwari et al. (2016) in climatic conditions of New Delhi, India in May. The system was formed by three glazed PV modules mounted on the roof of a single slope greenhouse, with two DC fans installed at the end of the duct. It was observed that the PV/T system can heat the greenhouse up to 47°C, a temperature that is good for biogas production. The thermal and overall thermal energy was 11.18 kWh and 12.76kWh, respectively, for a typical clear day. The electrical and thermal efficiencies reached 14.1% and 35.

CHAPTER 2

LITERATURE REVIEW

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7. Dudal l Das, Pankaj Kalita, Anupam Dewan, Sartaj Tanweer (7) 2019 Both Polycrystalline Unglazed Copper sheet and serpentine copper tube Develop & validate a comprehensive thermal model for a hybrid S&T PVT considering thermal contact resistance and ohmic heat generation. PV cell temperature is highest than other PVT layers (310.56 K – 330.86 K) Tedlar & absorber thermal contact resistance influences outlet temperature. Ohmic resistance reduces electrical efficiency, crucial under hot climatic condition. The developed model can be used for any kind of fluid with known thermo-physical properties. Dynamic model developed considered most of the operating parameters except relative humidity and wind speed.

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CHAPTER 3

PROBLEM IDENTIFICATION& RESAERCH METHDOLOGY

- From the detailed literature survey presented here the following inference were obtained. Expanding the heat transfer area leads to an increase in the outlet temperature of the system.

- Circular coil tube absorber is being considered as it allows more contact area compared to other types of absorbers.

- Nanofluid has better heat transfer properties compared with water.

3.1 RESEARCH METHODOLOGY

- To identify a suitable absorber for a photovoltaic thermal system which is capable of reducing cell temperature due its increased area of contact resulting in higher heat transfer.

- To fabricate a circular tube spiral absorber with suitable dimension using copper as the material of construction. Installation of the setup using proper instrumentation.

CHAPTER 4

VARIOUS COMPONENTS USED IN THE SYSTEM

- Solar Panel

- Water Pump

- Rotameter

- Data logger

- Optical Pyrometer

1. SOLAR PANEL: -

The amount of sunlight that strikes the earth's surface in an hour and a half is enough to handle the entire world's energy consumption for a full year. Solar technologies convert sunlight into electrical energy either through photovoltaic (PV) panels or through mirrors that concentrate solar radiation. This energy can be used to generate electricity or be stored in batteries or thermal storage.
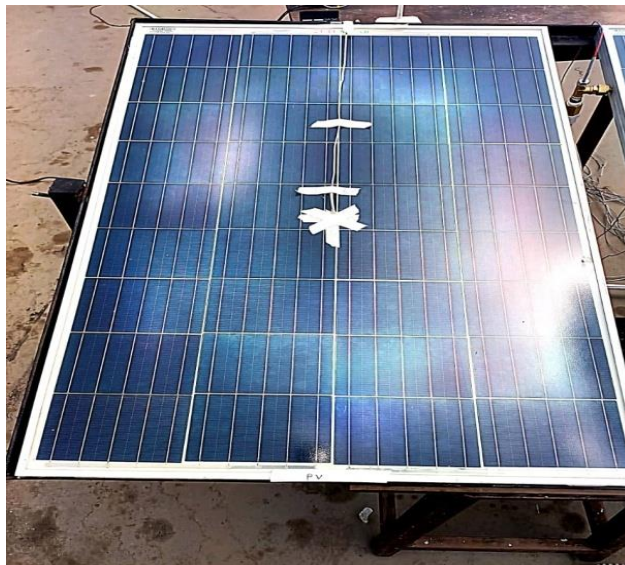
Fig. 3.1 Solar panel

2. WATER PUMP :-

Water pumps are mechanical or electromechanical devices that are designed to move

water through pipes or hoses by creating a pressure differential. The two most common types of pumps used for pumping water are centrifugal pumps and positive displacement pumps. Centrifugal pumps, as their name implies, make use of centrifugal force to take water that enters an impeller and uses the rotational energy generated from spinning that impeller to produce hydrodynamic energy.

Fig. 3.2 Water pump

3. **ROTAMETER :-**

Rotameter is a reliable, simple, and low-cost flow measuring instrument. So this instrument is used to measure the flow rate of a liquid or a gas. This meter includes a tapered tube through a moving internal float. Sometimes, rotameters are also called gravity flow meters, mechanical flow meters or variable area flow meters. In gravity flow meters, the term gravity means, the rotameter must be installed vertically.
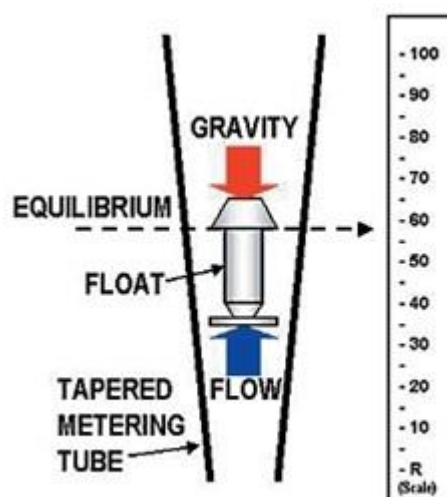
Fig. 3.3 Rotameter

4. Data logger:

Data loggers use a microprocessor, an internal memory for data storage, and a sensor to collect data. They are generally small and battery powered devices. Data loggers can either interface with a computer and use software to view and analyze the collected data or be used as a stand-alone device with a local interface or connect wirelessly to a device. The advantage of data loggers is that they can operate independently of a computer, unlike many other types of data acquisition devices. Data loggers are available in various shapes and sizes. The range includes simple economical single channel fixed function loggers to more powerful programmable devices capable of handling hundreds of inputs.

Fig. 3.4 Data logger

5. OPTICAL PYROMTER :-

Optical pyrometers operate within the visible spectrum to measure temperatures typically in the range from 700°C to 4,000°C by comparing the photometric brightness of the heated object against the brightness of a standard source, such as an incandescent tungsten filament. A monochromatic filter for the red wavelength radiation (630 nm) is used to support the operation; the comparison of the brightness is dependent on the sensitivity of the human eye (on manual versions) to distinguish the brightness difference between two surfaces of the same color.

Fig. 3.5. optical Pyrometer

CHAPTER 4

EXPERIMENTAL SET-UP

4.1 Experimental Setup:

Fig. 4.1 Experimental setup

4.2 SPECIFICATIONS:

- SOLAR PANEL:-Model Type UTL100W,Rated Power-100 W, Rated Current-5.53A, Rated Voltage-18.10V

- WATER PUMP:-Motor Power-0.5HP, Speed-2880rpm, Head Range-10-25m

- WATER STORAGE TANK:-500Litre

- MERCURY THERMOMETERS:- -20°C to 150°C

- MUTIMETER:- 40Hz , 50mV

- PYRANOMETER:- -10°C to +40°C

- DATALOGGER:-Dc Current 4-20mA. D.C Voltage 0-10V

- ROTAMETER:- Float SS 316 /SS304 / 316 / PTFE , Tube- Glass Borosilicate

Range between -0 LPMupto10 LPM

4.3 COST ANALYSIS:

- SOLAR PANEL:- 2000 Rs

- WATER PUMP:- 0.5 HP –2000 Rs

- Copper Coil:- 10 mm – 2000 Rs

- ROTAMETER:- 500 Rs

- Data Logger:- 10,000 Rs

- Optical Pyrometer:- 10,000/-

TOTAL COST:-26,500Rs

CHAPTER 5

OBSERVATION AND CALCULATIONS

1) Readings for 7 LPM (Liter Per Minute)

Sr no	Time	Solar Radiation	Tempera ture	Voltage (V)		Ampere(I)		Power(Watt)= V*I	
				PV	PV Water	PV	PV Water	PV	PV water
1	9:00am	3.06	28.2	20.6	20.4	3.15	2.92	64.89	59.56
2	9:15am	3.42	27.5	20.5	20.2	3.38	3.32	69.29	67.04
3	9:30am	3.78	29.6	20.4	20.1	3.39	3.32	69.15	66.73
4	9:45am	4.11	29.6	20.3	20.0	4.01	4.01	81.40	80.2
5	10:00am	4.46	31.2	19.8	19.9	4.22	4.26	83.55	84.77
6	10.15am	4.71	32.3	19.6	19.6	4.52	4.32	88.59	84.67
7	10.30am	4.93	32.9	19.4	19.8	4.46	4.45	86.52	88.1
8	10:45am	5.22	34.1	19.1	19.3	5.01	5.04	95.69	97.2
9	11:00am	5.38	34.6	19.0	19.2	5.17	5.21	98.23	100.0
10	11:15am	5.78	34.8	19.21	19.3	5.55	5.53	106.2	106.0
11	11:30am	5.78	34.8	19.1	19.3	5.55	5.53	106.0	106.7
12	11:45am	5.92	36.1	19.5	19.3	5.58	5.69	108.81	109.8
13	12:00am	6.01	36.3	19.3	19.2	5.65	5.75	109.0	110.0
14	12:15pm	6.15	35.8	19.5	19.6	5.72	5.84	111.5	114.4
15	12:30pm	6.20	35.4	19.4	19.6	5.78	5.80	112.1	113.6
16	12:45pm	6.22	36.8	19.2	19.4	5.82	5.85	111.7	113.4
17	1:00pm	6.14	37.6	19.1	19.2	5.80	5.85	110.7	112.3
18	1:30pm	5.93	38.3	20.2	19.6	5.45	5.55	110.0	108.7
19	1:45pm	5.62	38.6	19.6	19.2	5.40	5.44	103.6	104.4
20	2:00pm	5.48	37.8	19.9	19.5	4.73	5.26	94.1	102.5
21	2:15pm	5.32	38.7	19.7	19.3	5.07	5.08	99.8	111.9
22	2:30pm	5.03	38.9	20.00	19.4	4.71	4.84	94.2	93.8
23	2:45pm	4.75	38.9	20.0	19.8	4.41	4.60	88.2	91.0
24	3:00pm	4.44	37.3	30.3	19.8	4.21	4.33	127.5	85.7
25	3:15pm	4.24	39.2	20.0	19.7	3.94	4.06	78.8	90.6
26	3:30pm	3.91	38.3	20.4	20.0	3.70	3.81	75.4	76.2
27	3:45pm	3.49	37.6	20.4	20.1	3.34	3.45	68.1	69.3
28	4:00pm	3.23	38.2	20.3	20.0	2.93	3.08	59.4	61.6

29	4:15pm	2.95	37.3	20.3	20.1	2.71	2.84	55.0	57.0
30	4:30pm	2.52	37.1	20.2	20.0	2.40	2.53	48.4	50.6
31	4:45pm	2.00	36.8	20.2	20.0	1.96	2.6	39.5	52.0
32	5:00pm	1.60	37.2	20.0	19.9	1.52	1.60	30.4	31.84

FORMULA:

Power (watt): V*I

V = Voltage   **I = Ampere**

Sr No	Time	Pv Upper Surface Temp	Pv Lower Surface Temp	Pv Water Uppper surface temp	Pv Water Lower Surface Temp	Inlet Water temp	Outlet Water temp	Pv Water Temp Difference (9-10)
		1	**2**	**3**	**4**	**9**	**10**	
1	9:00am	44.2	46.3	35.5	49.2	27.3	27.5	0.2
2	9:15am	33.7	49.7	28.0	52.6	27.8	27.9	0.1
3	9:30am	45.8	49.3	41.0	52.6	27.6	28.0	0.4
4	9:45am	28.7	48.3	10.5	52.2	28.3	28.4	0.1
5	10:00am	26.9	49.2	32.4	53.1	28.5	28.7	0.2
6	10.15am	52.6	46.7	37.4	52.8	28.6	28.8	0.2
7	10.30am	23.9	47.5	36.3	51.1	28.6	28.9	0.3
8	10:45am	24.1	48.5	34.8	55.5	28.6	28.9	0.3
9	11:00am	22.0	43.8	33.6	51.1	28.6	28.8	0.2
10	11:15am	23.5	39.6	34.0	47.8	28.7	28.9	0.2
11	11:30am	26.2	41.0	31.7	48.8	28.8	28.8	0.0
12	11:45am	20.7	39.4	30.5	46.6	29.4	29.7	0.3
13	12:00am	20.7	29.4	30.5	46.6	29.4	29.7	0.3
14	12:15pm	24.3	40.1	24.9	45.8	27.7	29.9	0.2
15	12:30pm	22.5	22.7	37.0	27.4	41.0	29.8	11.2
16	12:45pm	14.1	34.1	27.5	40.3	30.1	30.9	0.8
17	1:00pm	18.9	29.0	12.4	38.2	30.2	30.5	0.3
18	1:30pm	29.3	27.7	9.4	34.0	31.3	31.5	0.2
19	1:45pm	43.2	41.3	19.7	47.6	31.2	31.4	0.2
20	2:00pm	43.7	40.3	11.7	46.1	31.2	31.6	0.4
21	2:15pm	32.7	41.2	5.3	48.3	31.2	31.4	0.2

22	2:30pm	42.0	41.8	32.1	49.3	31.3	31.1	0.2
23	2:45pm	31.6	33.6	6.6	38.9	31.2	31.3	0.1
24	3:00pm	31.3	31.0	21.5	36.3	31.2	31.3	0.1
25	3:15pm	31.5	31.2	38.3	38.2	31.2	31.3	0.1
26	3:30pm	31.7	31.1	24.7	35.3	31.1	31.3	0.2
27	3:45pm	29.7	29.2	10.3	34.1	31.1	31.4	0.3
28	4:00pm	29.7	28.9	25.5	33.7	31.1	31.3	0.2
29	4:15pm	31.1	30.6	17.6	34.6	31.1	31.3	0.2
30	4:30pm	31.0	30.6	16.4	34.8	31.1	31.3	0.2
31	4:45pm	32.0	31.5	23.5	34.8	31.1	31.1	0.0
32	5:00pm	32.0	31.6	22.6	35.4	31.0	31.1	0.1

2) Readings for 8 LPM

Sr no	Time	Solar Radiation	Temperature	Voltage (V)		Ampere(I)		Power(Watt)= V*I	
				PV	PV Water	PV	PV Water	PV	PV Water
1	9:00am	2.98	30.6	20.5	20.1	2.77	2.74	56.7	55.07
2	9:15am	3.31	29.3	20.6	20.1	3.15	3.13	64.8	62.9
3	9:30am	3.66	29.5	20.2	20.8	3.37	3.38	68.0	70.3
4	9:45am	4.02	30.4	20.4	19.9	3.72	3.76	75.8	74.82
5	10:00am	4.38	30.8	19.6	20.4	4.02	4.01	82.3	81.80
6	10.15am	4.66	31.5	20.5	19.9	4.26	4.30	87.3	85.57
7	10.30am	4.98	32.1	20.3	19.7	4.7	4.62	95.4	91.01
8	10:45am	5.17	32.6	20.2	19.9	4.85	4.80	98.4	95.52
9	11:00am	5.19	32.2	19.4	19.8	5.02	5.03	97.3	99.59
10	11:15am	5.61	34.7	20.1	19.4	5.20	5.21	104.5	101.07
11	11:30am	5.82	35.1	19.8	19.4	5.39	5.32	106.7	103.20
12	11:45am	5.84	37.0	19.3	20.0	4.47	4.48	86.2	89.6
13	12:00am	6.02	37.2	19.9	19.9	5.60	5.60	111.4	111.44
14	12:15pm	6.16	37.9	19.8	19.1	5.66	5.67	112.06	108.29
15	12:30pm	6.18	37.6	19.8	19.0	5.73	5.73	113.4	108.87
16	12:45pm	6.15	38.1	18.9	19.6	5.63	5.61	106.4	109.95
17	1:00pm	6.20	37.5	17.5	16.7	5.68	5.71	99.4	95.35

18	1:15pm	6.10	37.3	19.8	19.0	5.57	5.7	110.2	108.3
19	1:30pm	5.92	39.8	19.6	19.0	5.43.	5.45	106.42	103.55
20	1:45pm	4.83	38.7	19.8	19.1	5.28	5.34	104.54	101.99
21	2:15pm	5.64	29.8	19.9	19.2	5.07	5.10	100.89	97.92
22	2:30pm	5.22	38.5	19.8	19.2	4.67	4.78	92.46	91.77
23	2:45pm	4.95	38.7	20.1	19.5	4.40	4.54	88.44	88.53
24	3:00pm	4.69	39.4	19.8	19.4	4.31	4.49	85.33	87.10
25	3:15pm	4.44	38.5	19.9	19.3	3.50	3.48	69.65	67.16
26	3:30pm	4.46	36.6	20.2	19.6	3.90	3.08	78.78	60.36
27	3:45pm	4.0	39.2	20.0	19.5	3.65	3.64	73	70.98
28	4:00pm	3.63	38.4	19.2	19.9	1.70	1.72	32.64	34.22
29	4:15pm	1.12	36.2	19.4	19.8	1.63	1.83	31.62	36.23
30	4:30pm	2.97	37.8	20.2	20.1	2.60	2.15	52.52	43.21
31	4:45pm	2.15	37.4	20.0	19.8	5.53	1.66	110.6	32.86
32	5:00pm	1.72	37.2	19.9	19.8	1.20	1.60	23.88	31.68

FORMULA :

Power (watt) : V*I

V = Voltage

I = Ampere

Sr. No.	Time	Pv Upper Surface Temp	Pv Lower Surface Temp	Pv Water Uppper surface temp	Pv Water Lower Surface Temp	Inlet Water temp	Outlet Water temp	Pv Water Temp Difference (9-10)
		1	**2**	**3**	**4**	**9**	**10**	
1	9:00am	14.4	18.9	29.9	21.4	27.0	27.2	0.2
2	9:15am	16.8	19.8	29.5	23.5	27.3	27.5	0.2
3	9:30am	18.5	21.0	18.4	25.3	28.0	28.4	0.4
4	9:45am	18.9	22.2	22.4	29.4	29.3	29.4	0.1
5	10:00am	40.7	42.5	30.3	47.2	29.2	29.5	0.3
6	10.15am	44.1	42.7	37.0	47.3	29.5	29.6	0.1
7	10.30am	28.5	28.8	23.5	34.1	29.7	29.9	0.2
8	10:45am	16.30	27.9	22.7	36.2	29.6	29.8	0.2
9	11:00am	16.5	15.1	12.0	23.3	30.4	30.6	0.2

10	11:15am	18.9	19.1	12.6	26.5	30.1	30.7	0.6
11	11:30am	21.70	21.3	17.3	29.4	30.5	30.9	0.4
12	11:45am	24.1	24.3	17.9	31.8	31.1	31.3	0.2
13	12:00am	25.8	25.1	19.1	32.6	31.1	31.8	0.7
14	12:15pm	25.1	26.6	13.4	34.4	31.2	31.3	0.1
15	12:30pm	24.6	25.3	17.6	34.6	31.2	31.3	0.1
16	12:45pm	23.9	26.8	16.6	35.9	31.0	31.34	0.3
17	1:00pm	30.6	30.5	23.9	38.8	31.5	31.6	0.1
18	1:15pm	27.9	28.4	21.6	37.4	31.5	31.6	0.1
19	1:30pm	24.8	25.5	17.1	34.9	31.7	31.8	0.1
20	1:45pm	27.1	28.2	19.7	34.5	31.9	31.8	0.1
21	2:15pm	25.1	23.8	18.7	30.5	32.6	32.6	0.0
22	2:30pm	26.5	26.4	9.3	32.4	32.5	32.5	0.0
23	2:45pm	25.1	26.4	3.8	31.3	32.4	32.4	0.0
24	3:00pm	22.4	22.6	9.8	30.6	32.4	32.3	0.1
25	3:15pm	25.3	25.5	3.6	30.5	32.1	32.2	0.1
26	3:30pm	27.8	27.1	22.8	32.2	31.9	32.0	0.1
27	3:45pm	24.4	25.3	10.0	36.5	31.8	32.0	0.2
28	4:00pm	28.5	28.5	24.4	33.2	31.7	31.9	0.2
29	4:15pm	37.5	36.9	35.4	39.1	32.1	31.7	0.6
30	4:30pm	33.5	34.8	33.7	38.1	32.0	32.1	0.1
31	4:45pm	36.7	36.0	36.0	39.1	32.0	32.0	0.0
32	5:00pm	33.4	34.9	31.8	38.1	32.0	32.0	0.0

3) Readings for 9 LPM

Sr no	Time	Solar Radiation	Temperature	Voltage (V)		Ampere(I)		Power(Watt)= V*I	
				Pv	Pv Water	Pv	Pv Water	PV	PV Water
1	9:00am	2.94	30.1	20.5	20.0	2.69	2.37	55.14	47.4
2	9:15am	3.27	29.5	20.4	20.0	2.98	2.65	60.79	53
3	9:30am	3.63	30.3	19.9	20.3	3.39	2.95	67.46	59.88
4	9:45am	3.94	32.9	20.2	19.8	3.56	3.36	71.91	66.52
5	10:00am	4.18	31.9	20.2	19.8	3.85	3.54	77.77	70.09
6	10.15am	4.61	31.0	20.3	19.7	4.14	3.83	84.04	134.55

7	10.30am	4.79	32.0	20.4	19.8	4.25	4.12	86.7	81.57
8	10:45am	5.13	32.3	20.3	19.8	3.16	4.22	64.14	83.55
9	11:00am	5.28	34.8	20.0	19.4	4.71	4.58	94.2	88.85
10	11:15am	5.46	35.0	19.1	19.2	4.95	4.75	94.54	91.2
11	11:30am	5.52	35.7	19.7	19.1	5.6	4.91	110.32	93.78
12	11:45am	5.67	34.7	19.8	19.1	5.18	5.1	102.56	97.41
13	12:00am	5.77	37.1	19.6	19.0	5.29	5.12	103.68	97.28
14	12:15pm	5.80	37.1	19.6	18.9	5.33	5.25	104.46	99.22
15	12:30pm	5.81	35.8	19.7	19.0	5.34	5.27	105.19	100.13
16	12:45pm	5.75	38.0	19.4	18.8	5.34	5.30	103.59	99.64
17	1:00pm	5.79	36.7	19.7	19.0	5.31	5.28	105.19	100.32
18	1:15pm	5.70	38.5	19.6	19	5.21	5.23	102.11	99.37
19	1:30pm	5.59	39.4	19.6	19	5.25	5.17	102.9	108.49
20	1:45pm	5.47	38.7	19.5	18.9	5.60	5.11	109.2	96.57
21	2:00pm	5.36	39.8	19.6	19.0	4.94	4.95	96.82	94.05
22	2:15pm	5.22	38.1	19.6	19.0	4.65	4.67	91.14	88.73
23	2:30pm	4.90	39.12	19.8	19.1	4.49	4.51	88.90	86.14
24	2:45pm	4.50	39.1	19.7	19.2	4.19	4.14	82.54	79.48

FORMULA:

Power (watt) : V*I

V = Voltage

I = Ampere

Sr No	Time	Pv Upper Surface Temp	Pv Lower Surface Temp	Pv Water Uppper surface temp	Pv Water Lower Surface Temp	Inlet Water temp	Outlet Water temp	Pv Water Temp Difference (9-10)
		1	**2**	**3**	**4**	**9**	**10**	
1	9:00am	16.5	19.2	13.3	21.4	28.1	28.0	0.1
2	9:15am	15.6	17.3	12.5	20.6	28.2	28.0	0.2
3	9:30am	15.2	16.5	12.5	20.6	28.4	28.2	0.2
4	9:45am	12.1	15.2	11.2	20.2	28.4	28.3	0.1
5	10:00am	11.0	14.2	10.2	21.0	28.8	28.6	0.2
6	10.15am	13.0	14.6	10.1	21.1	28.8	28.7	0.1

7	10.30am	15.0	16.1	12.9	21.5	28.8	28.7	0.1
8	10:45am	12.9	15.1	11.9	21.0	29.2	28.9	0.7
9	11:00am	14.6	16.4	10.2	21.6	29.7	29.8	0.1
10	11:15am	10.8	13.5	6.3	21.7	29.4	29.9	0.5
11	11:30am	12.1	12.4	6.2	21.2	29.6	29.3	0.3
12	11:45am	11.1	12.0	4.2	20.8	30.9	29.7	1.2
13	12:00am	11.0	12.5	5.3	21.6	30.3	29.9	0.4
14	12:15pm	11.0	12.4	8.1	22.0	30.5	30.2	0.3
15	12:30pm	20.8	18.8	10.0	27.0	30.6	30.3	0.3
16	12:45pm	20.6	22.3	15.0	30.2	30.8	30.7	0.1
17	1:00pm	25.0	21.4	15.1	30.0	30.7	31.0	0.1
18	1:15pm	21.0	25.7	20.2	30.7	31.0	31.1	0.1
19	1:30pm	20.6	22.4	16.0	34.1	31.1	31.2	0.1
20	1:45pm	17.1	23.2	16.0	33.1	31.2	31.3	0.1
21	2:00pm	16.5	18.7	11.6	32.5	31.3	31.4	0.1
22	2:15pm	27.1	18.9	13.6	30.0	31.4	31.4	0.0
23	2:30pm	22.1	21.9	17.2	30.1	31.4	31.6	0.2
24	2:45pm	10.5	23.3	19.7	30.1	31.6	31.9	0.3
25	3:00pm	21.4	23.0	17.0	32.1	31.9	32.3	0.6
26	3:15pm	24.7	24.6	20.5	33.4	32.3	33.0	0.7
27	3:30pm	27.4	28.2	22.3	34.1	31.9	32.6	0.3
28	3:45pm	32.0	31.6	28.5	36.2	31.6	32.0	0.4
29	4:00pm	31.3	31.6	28.7	36.5	31.6	31.7	0.1
30	4:15pm	34.0	33.1	31.1	38.2	31.5	31.7	0.2
31	4:30pm	33.7	31.6	32.8	38.2	31.3	31.6	0.3
32	4:45pm	35.5	35.0	34.0	39.3	31.2	31.3	0.1
33	5:00pm	35.6	35.4	34.3	39.6	31.1	31.3	0.2

CHAPTER 6

RESULT

Flow rate	Power		Water Difference
	PV	PV Water	
7 LPM	111.7	113.7	0.8
9 LPM	99	95.35	0.7
9 LPM	104.46	99.22	0.7

- We get maximum water temperature difference in 7 LPM flow rate.

- We get maximum Power in 7 LPM as compare to other flow rate.

- Therefore 7 LPM flow rate is the best flow rate thermal and electrical efficiency.

CONCLUSION

- We get maximum solar plate power/ electrical efficiency at 7 LPM flow rate as compare to other flow rate.

- We get maximum thermal efficiency at 7 LPM flow rate as compare to other flow rate.

Future Scope

- Either used water use nano fluid in the place of water as a cooling medium. Also use phase change material (PCM) for increase efficiency.

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List of Publication

A Review of Recent Photovoltaic/Thermal (PV/T) System Development

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Mr. Shahebaz Khan[4], Mr. Mahemud Aalam[5], Mr. Mangesh R. Kharate[6], Mr. Wajahat Saudagar[7], Mr. Anurag N. Kharche[8], Mr. Deepak Sangitrao[9]

A Review of Recent Photovoltaic/Thermal (PV/T) System Development

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Abstract: -

Hybrid photovoltaic/thermal systems have become an essential energy technology since they can produce electricity and heat simultaneously, are easy to install in buildings, and work well overall. Conventional photovoltaic (PV) systems waste energy in the form of heat as they turn sunlight into electricity. It has been established that as the temperature of a PV cell goes up, the panels' efficiency goes down. So, this heat can be reduced to improve the performance of PV. The most frequent ways to get rid of heat are through air and water, and the energy can subsequently be used to heat structures. Over the past 50 years, scientists worldwide have tested, simulated, and used numbers to model many PV/T systems. In addition to water and air, other ways to eliminate heat have been looked at. These include refrigerants, PCM, heat pumps, and nanofluids. This article overviews and discusses the research done over the last five years on the different PV/T thermal control systems. The current study looks at the most essential parts of the various techniques, such as how well they perform overall, their parameters and settings, the type of system, the sort of work, where they were developed, and how they are used. Based on this study, it was decided that PV/T systems are a good idea and that further effort should be made to make them look better so that they are more widely used and their efficiency improves.

Keywords: photovoltaic, thermal, efficiency, air-based, and water-based

Introduction

Since the 1970s, one of the most important goals has been reducing greenhouse gases (GHG). This has made people more interested in finding other sources of energy that can help us fulfill our future goals for sustainability and safeguarding the environment. Olivier and Peters (2018) summarized the growth of global GHG in 2018, and it shows that emissions went up 1.3% in 2017 but only 0.2% and 0.6%, respectively, in 2015 and 2016. According to the same report, greenhouse gas emissions today are around 55% greater than in 1990. This tremendous amount of GHG comes from the need for electricity. The International Energy Agency says buildings use 33% of the energy worldwide and release 28% of the carbon dioxide (CO_2). About 77% of the energy used in buildings comes from heating and cooling. This includes heating and cooling the area, heating and cooling the water, and cooking. (International Energy Agency, 2019).To help reduce emissions, some governments have promised to use less fuel and more efficient technology and renewable energy sources, such as solar power, instead. Solar power can be harnessed to make electricity or heat using photovoltaic modules or thermal collectors. Installing these devices in buildings can assist in cutting down on the amount of energy used to provide electricity, domestic hot water (DHW), and heat.Solar photovoltaic (PV) is a type of power system comprising a series of connected parts that work together to turn the energy from the sun into electricity, use that electricity, store it, or turn it around (Shubbak, 2019). Over the years, this technology has been one of the first to use renewable energy. Solar PV achieved 480 GW of installed capacity worldwide by the end of 2018, making it the second-largest renewable source of electricity behind wind. (IRENA, 2019).Solar thermal collectors are made to gather heat from the sun. They can be used to heat air or water to heat a building. The sun's rays heat up a liquid that enters a hot water tank. The fluid heats the water, and then flows back to the solar collector. Solar collectors are one of the most cost-effective ways to get energy from the sun. Photovoltaic technology and thermal collectors can be integrated into a single device called Photovoltaic/Thermal (PV/T). This device comprises a PV module and a heat exchanger, and it can produce energy and heat. Since a PV panel's efficiency goes down when the cell temperature goes up, eliminating the heat from the photovoltaic module by running fluid through the collector keeps the efficiency from decreasing. Combining both technologies solves roof space problems when PV and thermal solar are used separately.

(Dean et al. 2015). Even while non-concentrated and concentrated collectors can be utilized to make a PV/T device, this study will focus on non-concentrating PV/T systems because they

are easier to put into buildings. But Singh and Tiwari (2017) and El-Samie et al. (2020) are new studies that have been added. Photovoltaic/thermal devices are an excellent way to use solar energy. Because of this, researchers have been looking at them since the late 1970s, when Kern and Russell (1978) and Florschuetz (1979) studied flat plate, PV/T collectors.At the beginning of the decade, authors like Agrawal and Tiwari (2010), Bhattarai et al. (2012), and Adeli et al. (2012) studied water-based and air-based PV/T systems. These conventional systems were the ones that were reviewed the most in the years that followed. In the last five years, scientists have been working on several configurations of nanofluid, phase change materials (PCM), and heat pump PV/T systems.Recent review papers by Jia, Alva, and Fang (2019), Diwania et al. (2020), and Rukman et al. (2019) give an overview of the different types of PV/T systems listed above. Even though some recent work is mentioned, they all discuss experiments and simulations in the last ten years. This review focuses on the previous five years and is meant to show other researchers what has changed and will change in this technology. The following sections will give a quick appraisal of the state-of-the-art liquid-based, air-based, bi-fluid, refrigerant, heat pump, nanofluids, phase change materials, and concentrated PV/T systems.

Types of PV/T systems

Over the years, researchers have developed many sorts of PV/T systems. This part looks at some of the most recent changes to the PV/T collector, focusing on how they can be used in buildings as shown in Fig.1.
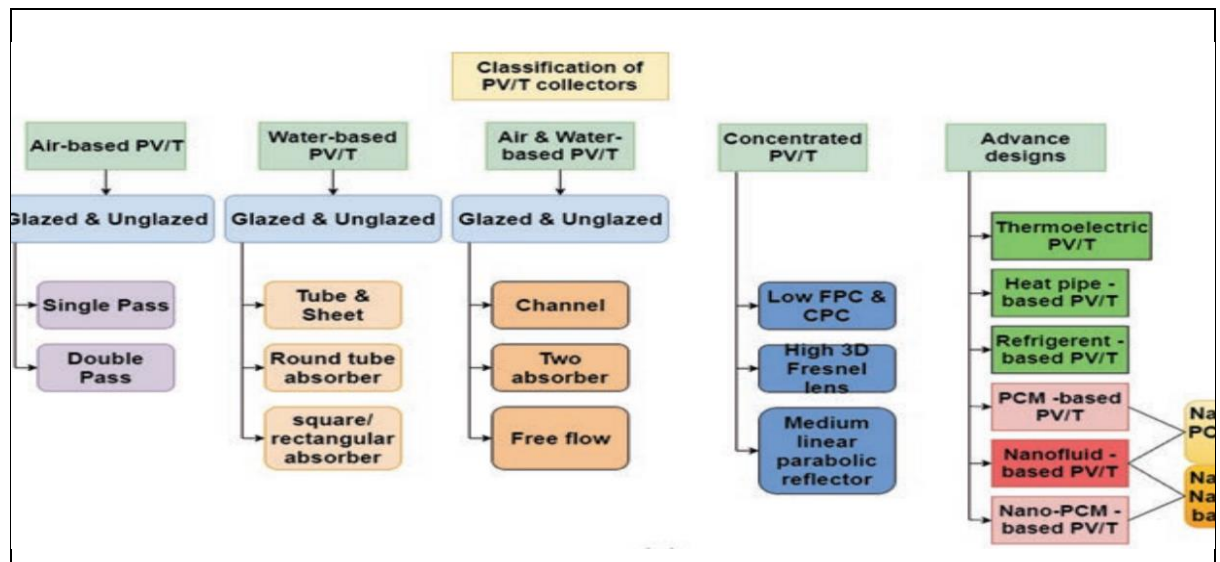
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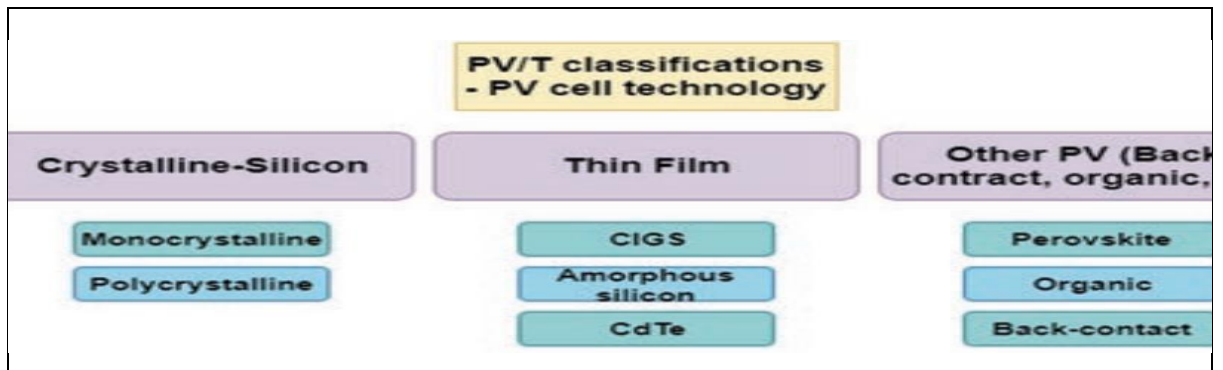
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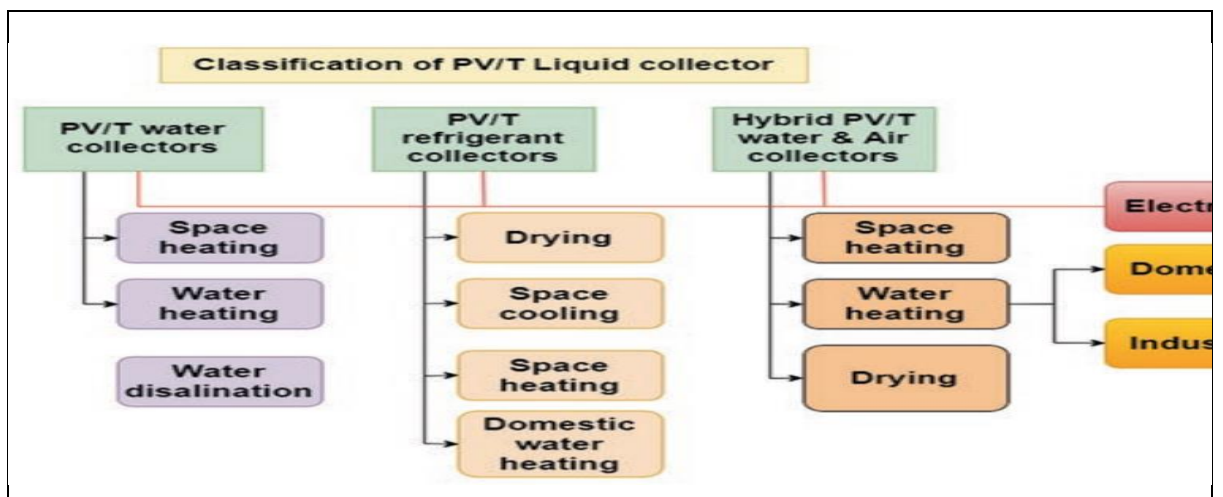
(c)

Fig.1 Classifications of PV/T collectors (a) according to design, (b) according to PV cell technology, (c) according to application.

1.1 Water cooling

Aste, del Pero, and Leonforte (2014) looked at the different parts and configurations of a water-based PV/T and found that this media is more effective since water can hold more heat. This makes it possible to keep the PV temperature stable.Most of the time, researchers have looked at water-based PV/T systems from both a theoretical and an experimental point of view. Most of the time, heated water is used to meet household needs. These studies examined how PV/T may be set up with or without glazing, with or without semitransparent PV modules, partially or entirely covered by PV modules, with or without different coatings, and so on.To simulate a mathematical model in TRNSYS, Aste et al. looked at how well an open PV/T collector worked. (2016). The PV/T comprised an uncovered mc-Si PV module with a roll-bond aluminum absorber, a cylindrical storage tank, a loop for forced water circulation, and a pump. (Figure 2). The test was done over two years in Milan, Italy.

The results showed that the system can have about 15% thermal and 10% electrical efficiency. Shyam et al. (2016) did tests in New Delhi, India, with a PV/T water collector comprising three single-glazed tubes partially covered by semi-transparent PV modules. MATLAB was used to run some simulations with varied sky conditions. The results showed that the total amount of thermal energy used in a year was 3561.9 kWh and that the water in the storage tank could reach 80°C when the sky was clear. He and his colleagues made four experimental PV/T solar systems in 2017 with 0.4, 0.56, 0.7, and 0.82 PV cell coverage. Analyses of the effect of PV cell coverage on the photo thermal properties of a PV/T system showed thermal efficiencies of 58%, 51%, 64%, and 67%, heating 250 L of water to 50°C in 5 hours (matching local demand). It was decided that it is possible to increase the thermal performance of the PV/T solar system by making sure that the PV cells are covered as much as possible. Sainthiya and Beniwal (2019) did tests to see how front surface water cooling affected the performance of a PV/T module in India during the summer and winter. The electrical and thermal efficiency of PV modules with and without water flow in the summer and winter were found using energy balance equations. Every day from 9:00 to 17:00, the required parameters were measured every hour from 9:00 to 17:00. It was found that the difference between the analytical and experimental results was slight, and both showed that water flow on the front side of the PV module dramatically lowered the temperature on the back surface. This makes electricity use 11–14% more efficient in the winter and 9–12% more efficient in the summer. The thermal efficiency was also raised by 22–25% in the winter and 17–22% in the summer.After running a CFD simulation with ANSYS, Misha et al. (2019) looked at an experimental configuration of a PV/T water system in the weather of Melaka, Malaysia. The PV/T system comprised a solar panel connected to two copper absorbers that moved back and forth. (Figure 3). The PV module was linked to a 100-liter water tank attached to the flat plate collector's intake. The outflow of the collector was connected to the heat exchanger, and the cold water was transported to the storage tank. The cold water was piped from the storage tank to the flat plate collector. The average thermal efficiency was 59.6%, and the average electrical efficiency was 11.7%.
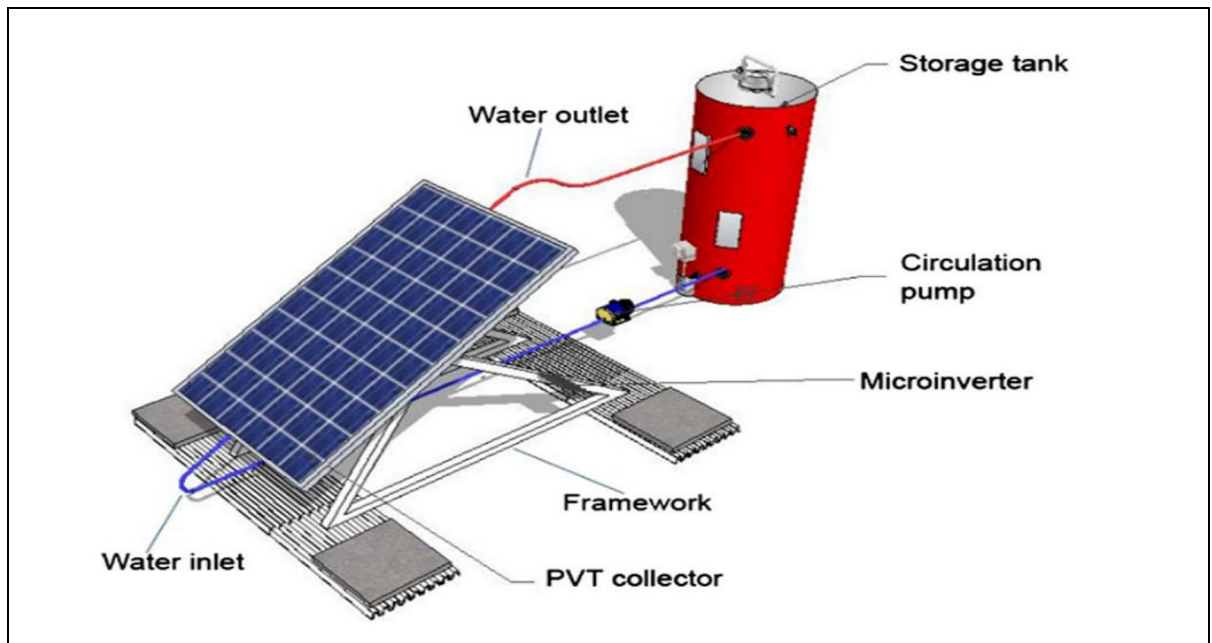
Figure 2: Uncovered PV/T collector configuration (Aste et al. 2016).
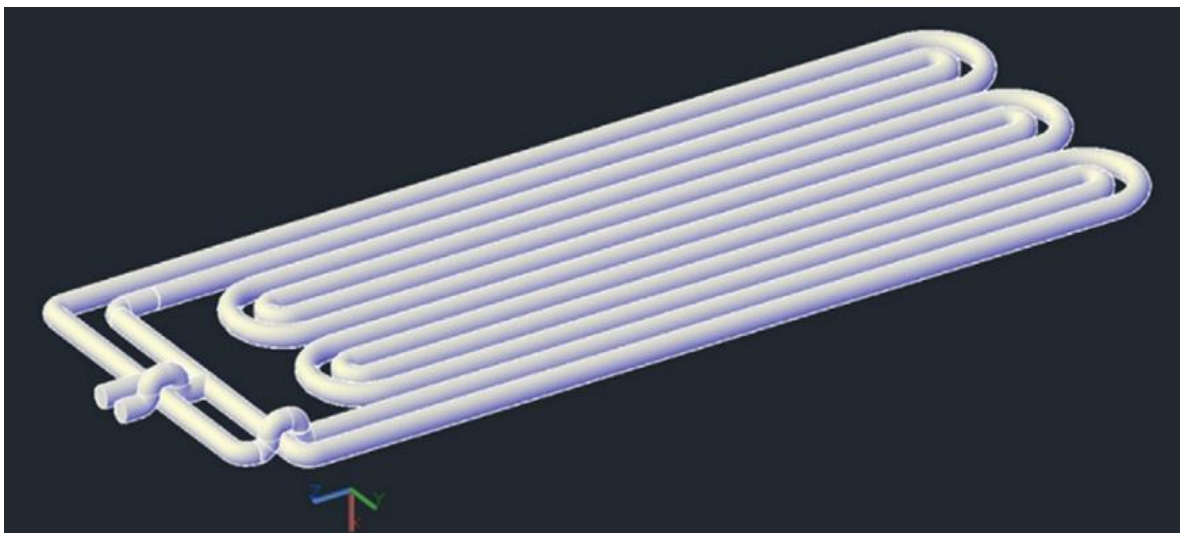

Figure 3: Dual oscillating absorber designed by Misha et al. (2019).

When there isn't much contact between the cooling channel and the PV module, heat also doesn't move. Ma et al. looked at an iron scrap-filled tube-plate PV/T system because of this. (2020). By adding a filling medium, the heat exchange effect of the system was increased since there was more heat transfer between the backplane of the PV plate and the fluid in the tube. The filler material makes the module better at transferring heat. Thus it can be used as a construction material. In this example, iron scraps were chosen as the filler material since they were cheap, could be made from other metals, and had a high thermal conductivity. This experiment used a layer of conductive cement to stick a commercial monocrystalline module

and an absorbent plate together. The heat-collecting module, which was packed with scrap iron, was put under it. Figure 4 combines the PV/T system and the iron scrap bed. The filled tube plate had an average electrical efficiency of 15.5% and a thermal efficiency of 65.7%.
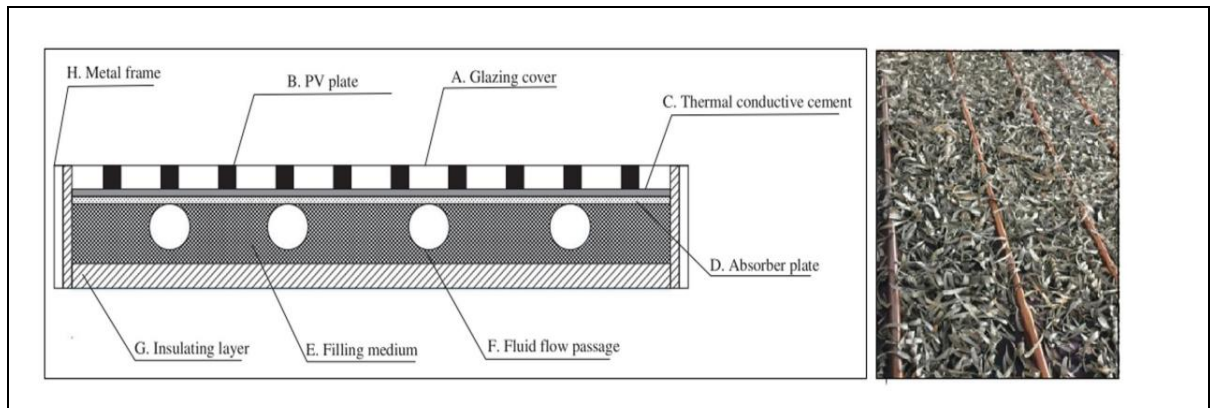
Figure 4: Cross section of the PV/T system and iron scrap filling (Ma et al. 2020).

2.1.2. Refrigerant cooling

Refrigerant-based PV/T has a high heat transfer rate and good thermal properties. It can be utilized in icy places without concern about freezing, depending on the refrigerant. The collectors can be made as heat pipe-based PV/T systems, where the direct expansion evaporation coils are put under the PV module, and the refrigerant evaporates as it goes through. So, the rings are part of the heat pump that deals with evaporation. The water might evaporate at depths like 0–20 °C. So, the temperature of the PV module would go down. The heat pump's compressor raises the pressure of the vapor made by the module and sends it to where it will be used to heat.

Tsai [52] constructed a mathematical model of a refrigerant-based PV/T-assisted heat pump water heater (HPWH) system and used MATLAB/Simulink software to simulate the performance of the PV/T. Data from experiments done outside were compared to numerical research results. The collector was set up at a tilt angle of 23.5°. The authors employed a model-based control strategy to get the electricity from the PV to flow into the HPWH system. We can see how accurate the model is by comparing the numerical and experimental results. The scientists say that the model-based prediction control strategy enabled the PV to power the HPWH system's compressor. In the end, it was observed that the PV/T efficiency and COP of PVTAHPWH were 86% and 7.09, respectively. The average electrical efficiency was 12.37%, and the average thermal efficiency was 73.90%.

Ji et al. [53] showed a new PV/T-solar-assisted heat pump (PV/T-SAHP) with a specific design of a direct expansion evaporator with PV cells utilized as lamination (thus, PV evaporator) and a thermal absorber. In Fig. 5, you can see how the system is set up. A dynamic model of the system was made with the help of the distributed model approach. Solar irradiance and temperature variables are placed into the model, and the regional distributions of refrigerant conditions emerge. Figure 6 shows the things that go into the model. Experiments were also done to compare the measured data with the anticipated data and prove that the model was correct. The tests were done to see how the weather is in China. Based on the findings of the tests, the heat gain is more than 2500 W from 11 a.m. to 1 p.m. When measured and anticipated values are compared, the results are the same, with a difference of less than 8% between predicted and measured output electricity and PV efficiency. Ultimately, it was determined that the PV and thermal efficiencies were higher than 12% and 50%, respectively .Zhao et al. [54] produced a new PV/e roof module that may be used as a roof part to make electricity and cool a heat pump system. The model comprises flat-plate glazing, photovoltaic cells, a copper plate, an evaporation coil, insulation, and hose connectors for the intake and output. The study looks at the proposed hybrid system's energy profile and how the temperature changes between its layers. Using computer software, a mathematical model shows how energy is transferred, changed, and set up. Experiments from another research project were used to confirm the model. The authors looked into things including the type of glazing, the type of solar cell (monocrystalline or polycrystalline), and how the system works in the UK. The prototype of the system is made up of 10 PV/e modules and a 5 kW heat pump.
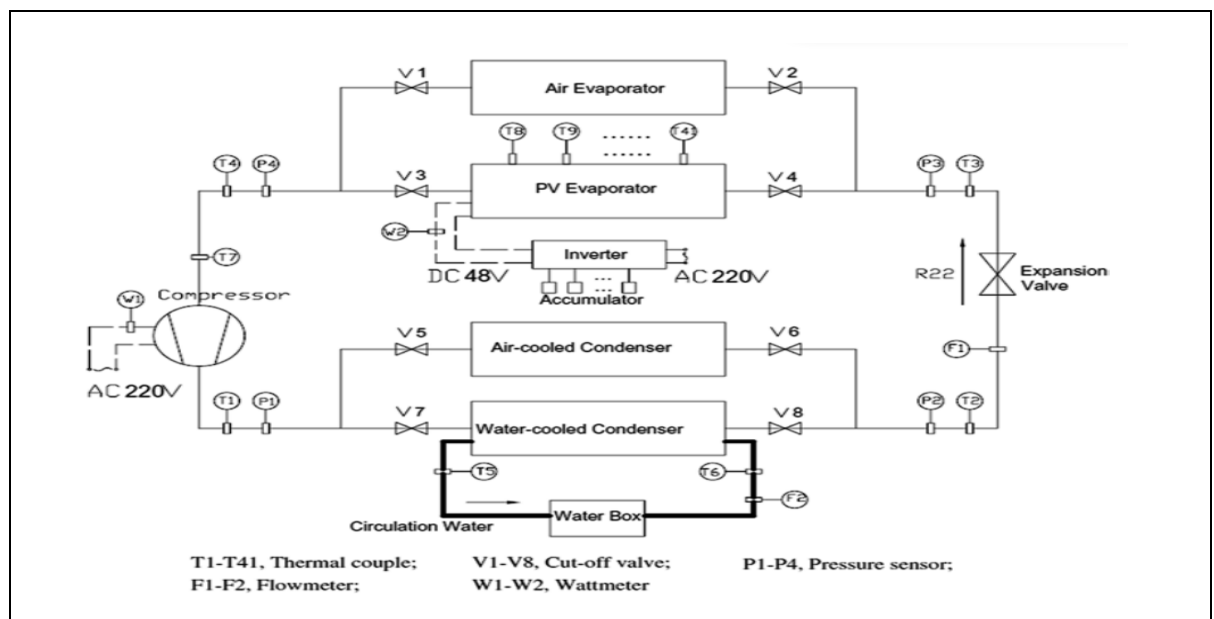

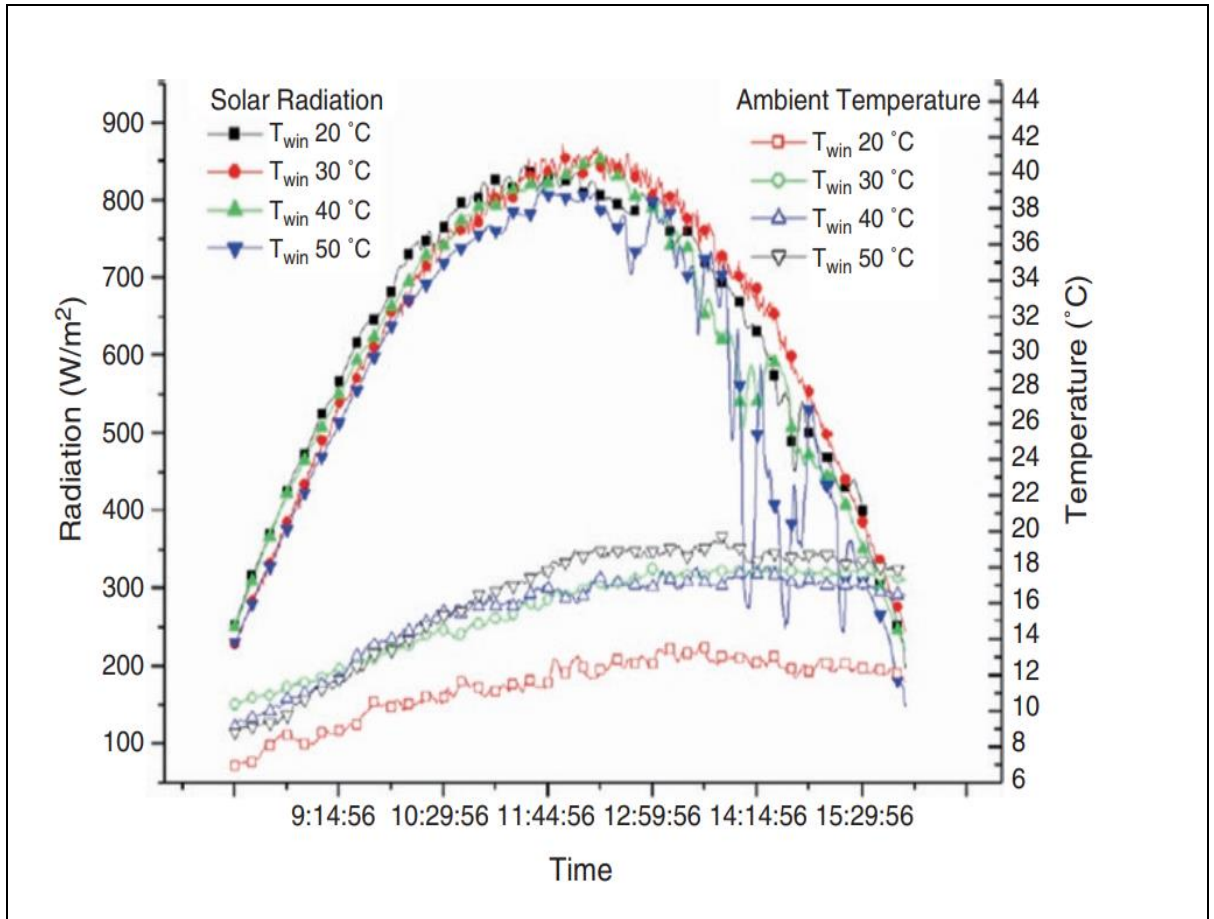Fig. 5 Schematic diagram of the PV-SAHP experimental setup

Fig. 6 Daily variation of solar irradiance (referred to as solar radiation) and ambient temperature during the experiment period [53]

2.1.3. Nanofluid cooling

Nanofluids are fluids with particles the size of a nanometer, called nanoparticles. Most of the time, these nanofluids are made of metals, oxides, carbides, or nanotubes made of carbon. They have better thermal conductivity and convective heat transfer coefficients than the base fluid. Nanofluids are a new technology used in PV/T systems to improve thermal management and increase overall energy production.Rejeb et al. (2016) looked at the performance of a monocrystalline silicon PV unit illustrated in Figure 7, employing nanoparticles of Al_2O_3 and Cu at varying concentrations (0.1, 0.2, and 0.4 wt%) and ethylene glycol and water as base fluids. The numerical model was made using the FORTRAN programming language. Experiments were done to mimic the weather in Mashhad, Iran, from 9:30 to 15:30 on the last day of September. It has been seen that as the number of nanoparticles increases, the specific heat of the nanofluid goes down. The results showed that CuO/H_2O at 0.4 wt% had the best thermal performance (76.88%) and electrical efficiency (13.5%).Hamdan et al. (2017) did

experiments to see if controlling the temperature with nanofluids may increase the performance of PV. One of the modules was used as a baseline. The second module utilized water to cool it down, while the third module employed nanofluids. The main idea behind using nanofluids is that they will remove more heat from the PV because they are better at transferring heat than water. Because the solar cell is cooled more efficiently, it will produce more power. There were different amounts of Al2O3 and CuO utilized. Al2O3 and CuO cooled best when their concentrations were 0.4% and 0.6%, respectively. For cooling with water, Al2O3, and CuO, the increase in electrical efficiency was found to be 11%, 20%, and 23%, respectively. The results showed that using nanofluids to control the temperature of a PV module will make it work better electrically.Samylingam et al. (2020) used COMSOL to study the thermal performance of a PV/T system with a heat transfer fluid made of MXene (Ti3 C2) suspended in pure olein palm oil (OPO). It was seen that this nanofluid increases thermal efficiency, enhances heat transmission, and lowers the temperature of the PV. Six different amounts of MXene-OPO were employed for the study: 0.01%, 0.03%, 0.05, 0.08, 0.1, and 0.2 wt%. The calculations revealed that a concentration of 0.2 wt% with a flow rate of 0.07 kg/s has the best thermal and electrical performance (79.13% and 13.8%, respectively) in the 25–70°C. It was also noticed that this concentration made the viscosity less, meaning less pumping power was needed.Rubbi et al. (2020) made a nanofluid out of particles made of soybean oil (SO) and MXene (Ti3 C2). With concentrations of 0.025, 0.075, and 0.125 wt%, the numerical study was done in COMSOL. This study found that a 0.125 wt% attention of MXene-SO is superior to the 0.2 wt% concentration of MXene-OPO that Samylingam et al. looked at. (2020). Compared to MXene-OPO, MXene-SO was 12.11 percent better at removing heat. This was because MXene nanoparticles and soybean oil as a base fluid were better at moving heat than palm oil. At a mass flow rate of 0.07 kg/s, it was found that the thermal efficiency could be as high as 84.25%, while the electrical efficiency was only 14.20%. (Figure 8).
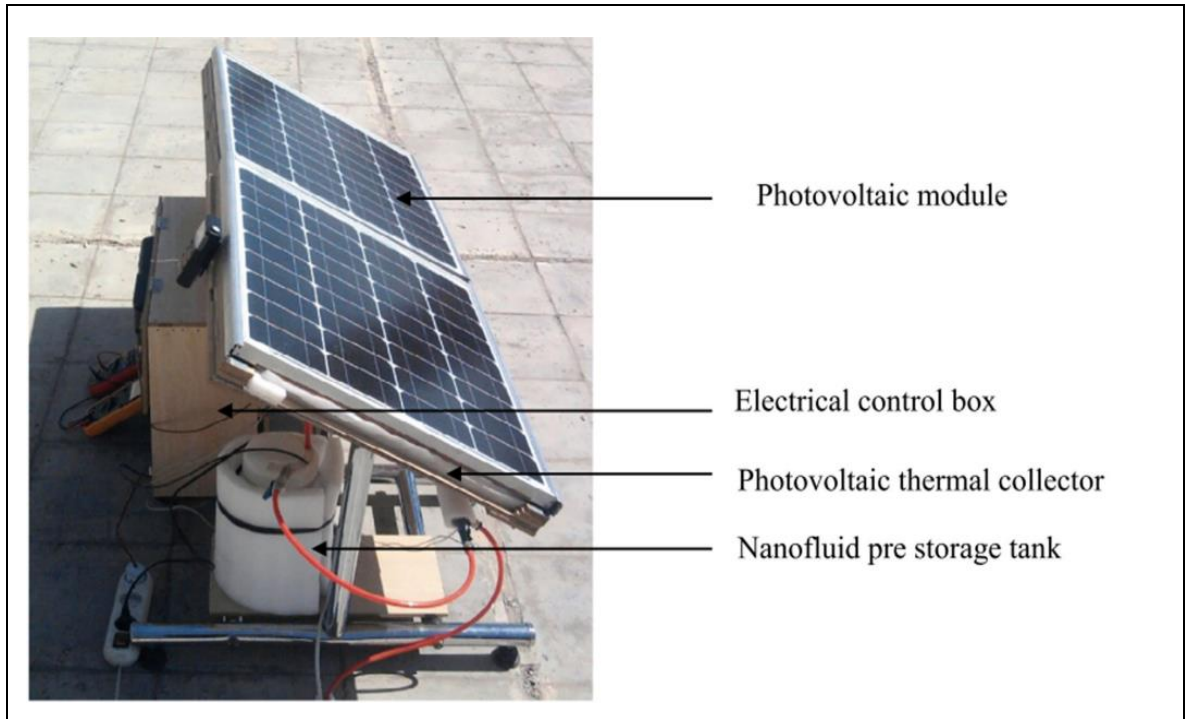
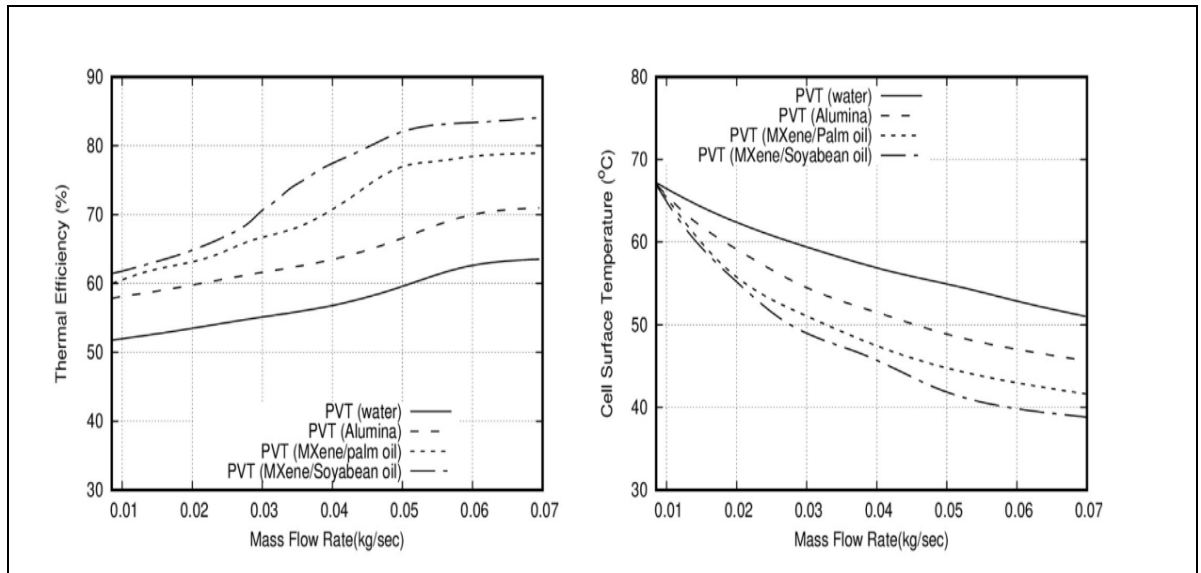Figure 7: Experimental setup of the PV/T system studied by Rejeb et al. (2016).

Figure 8: Performance evaluation of the thermal and electrical efficiency of a PV/T system studied by Rubbi et al. (2020).

2.8.1 Studies on Air-Based PV/T

The fluid that moves around or does the work with these collectors is air. It works best for hot air applications, like drying, etc. The main benefit of utilizing air instead of water is that it is cheaper, less likely to freeze or boil, and less likely to cause harm if it leaks. The problem with

these collectors is that their thermal performance could be better than water-based or other liquid-based PV/T systems. This is because air has a lessened heat capacity; thus, less heat is transferred when it moves through the tubes or pipes. Also, the air is not very dense, so it has a far more enormous transmission volume than liquid or water-based forms. Since more capacity is needed, the pipes or tubes would be more significant, which means they wouldn't work well in compact spaces and wouldn't look good either. Even with these problems, it is still a good choice for systems that need to heat air and have reduced prices.Ahn et al. [35] showed an air-type PV/T collector to help a heat recovery ventilation (HRV) system. The PV/T is used to heat the air before it enters the HRV system instead of letting outside air in. The authors say that combining the two technologies should improve ventilation. Experiments were done on the system in a building using a 1 kW array of four air-based PV/T collectors positioned at it has a 30° tilt and faces south. To show the difference between a traditional HRV system and a PV/T-assisted HRV system, the authors devised OA mode and PV/T mode. In OA mode, outside air is fed directly into the HRV, while in PV/T mode, the air from the PV/T outlet is fed into the HRV. The study's results suggest that the heat transfer efficiency of the HRV system was 80%. The authors say that the heat transfer efficiency was enhanced by about 20%. Also, the thermal and electrical efficiency of the PV/T collector was 23% and 15%, respectively. So, the study concludes that putting an air-based PV/T collector into an HRV system makes it work better.Hu et al. [36] developed an ETFE (ethylene tetrafluoroethylene) cushion roof-integrated PV/T system that uses air as its working fluid and then tested it in the lab. Figure 9 demonstrates the way the system is set up. The tests were done. They were made over 8 months, and each day has about 6–7 hours of work. It was determined that the system worked smoothly and steadily. Also, the performance test was done over 4 days, including both summer and winter. The authors stress how important it is to choose days with clear skies. The process for the experiment was broken up into three primary phases. First, connect the batteries to the PV module and blow on the solar controller.
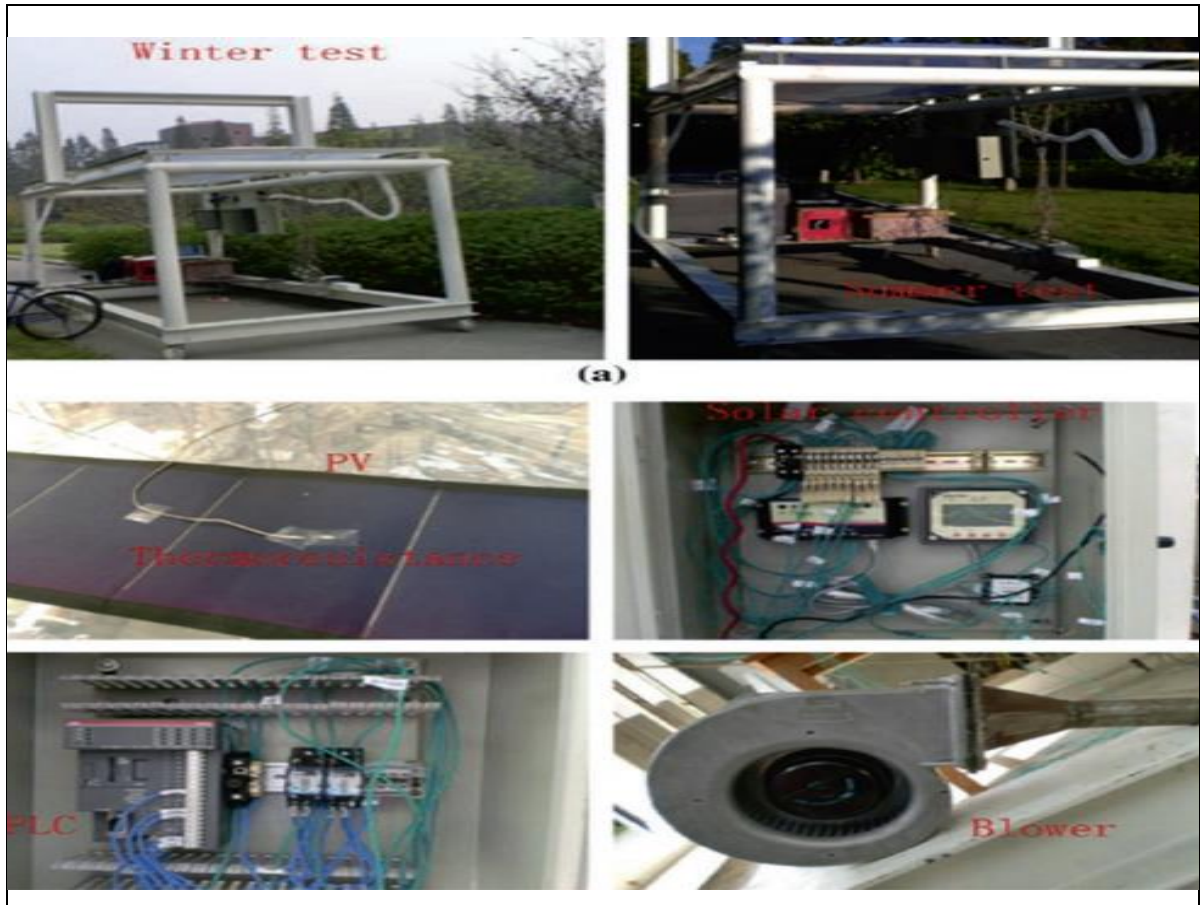
Fig. 9 Photographs from the experiments (a) test mockup (b) equipment [36]

2.8.3 Studies on Air- and Water-Based PV/T

Through distinct channels (called "dual channels") or pipelines, air and water could be used at the same time. Another way is to run the collector in either water- or air-only mode, depending on the time of year. The air-based and water-based PV/T collectors are handy since they have a higher cooling rate and can heat air and/or water. The biggest problem with this kind of system is that it is hard to understand and has extra costs and space because it has more than one pipe or channel. Also, more money must be spent on pumps (for the water) and blowers/fans for the active parts. (For the air).Su et al. [49] studied PV/T collectors with two channels so that different fluids might be used. Figure 10 shows the collector. Comparing the use of (1) air-air, (2) air-water, (3) water-water, and (4) water-air-based PV/T in terms of electrical and thermal properties helped find the best fluid combination. Such as how much power is made, how hot the fluid comes out, how efficient it is, etc. This was proven by making a collector with a glass cover (top layer), flow passage (for either air or water), solar cells, backplane, flow passage (for either air or water), shell, and flow passage (for either air or water). (Lower outer layer). The study makes a mathematical model of the system and then

runs simulations based on that model. The simulation's results are checked against experimental and numerical work from another study. The survey results demonstrate that employing the PV/T cooled by water helps heat water better. For air-water, the temperature of the water was the greatest, while the air-air-cooled PV/T made the hottest air. According to the research, the influence of mass flow rate on the overall efficiency of the water-water-cooled PV/T is that it increases the efficiency value. The authors also showed that increasing the height difference between the upper and lower pipes makes the system more efficient. With a mass flow rate of 0.15 kg/s and a height ratio of 3:1, the water-water-cooled PV/T has an electrical efficiency of 7.8% and a total efficiency of 83.4%. Figure 11 shows the thermal power for each arrangement of the working fluid.Jarimi et al. [48] did a 2D steady-state thermal modeling of a new PV/T collector that utilized air and water as working fluids. The collector mainly comprises a finned air collector and water-based tubes and sheets. The water will flow through pipes and stand between the lines (at the top part) and the fins. (lower area). The standard operating condition (NOCT), given by the manufacturer, is used to validate the thermal model without working fluids. But for the cooled model, the results are confirmed by research done in the past, and the collector model is then simulated. Under irradiance levels of 500 W/m2 to 800 W/m2, the average temperature of the PV cells was anticipated to be 20, 16, and 14 °C for water and air, only water and only air, respectively. Theoretically and in the literature, these results show that air has the most negligible cooling impact, followed by water, and then using both air and water simultaneously. It was revealed that the PC cells work better when kept at a low temperature. So, it was thought that the overall energy efficiency would be 40% greater because the thermal component would cover the whole area of PV. The authors say it is helpful to use the hot air and water to pre-heat the water for fish breeding and other uses like drying clothes and getting hot water.
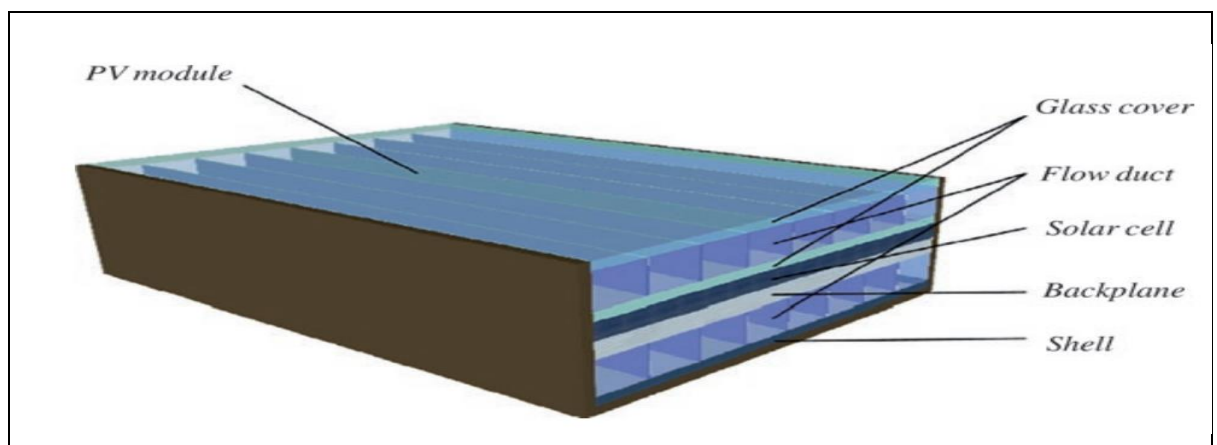

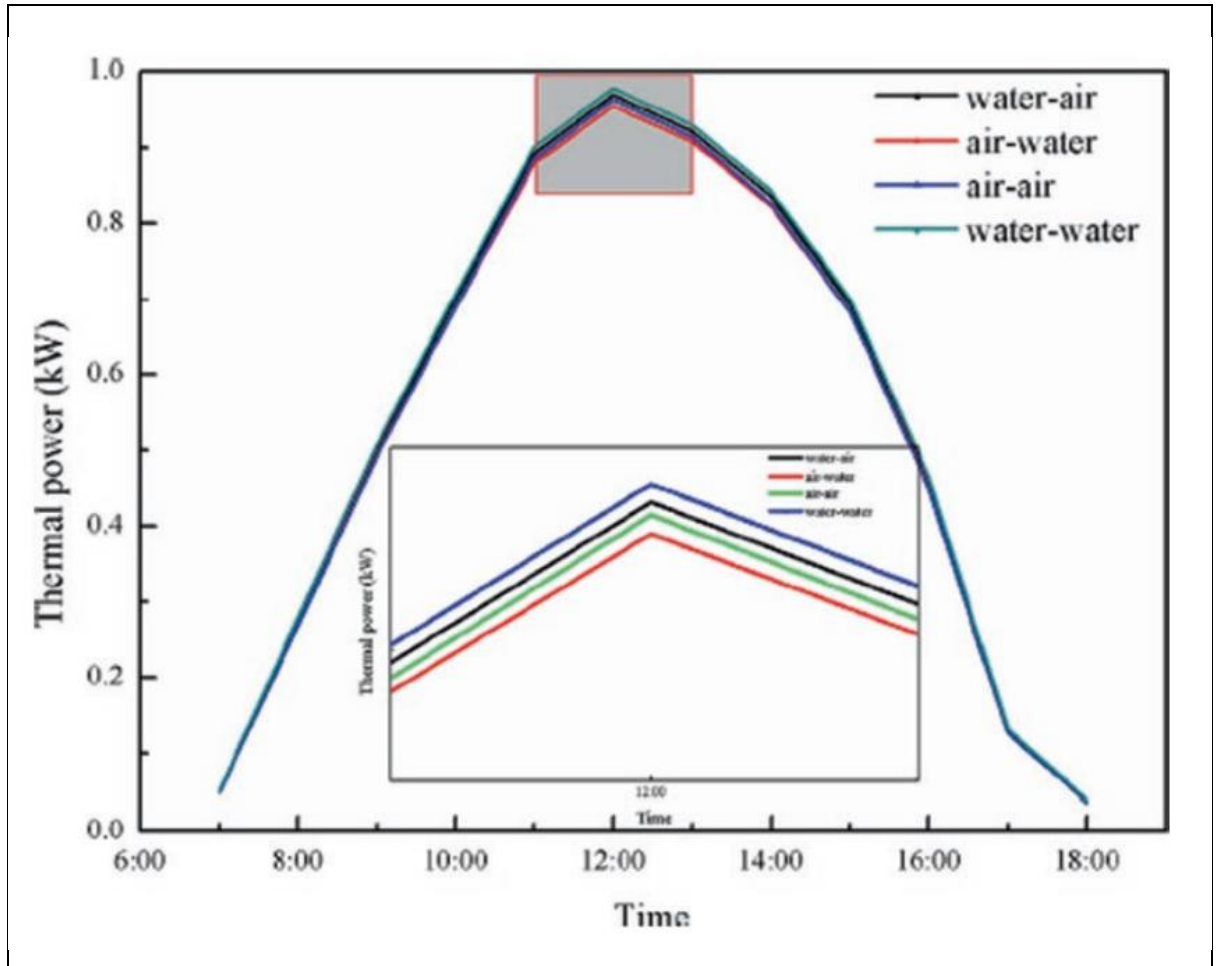Fig. 10 The schematic diagram of the PV/T collector with dual channels [49]

Fig. 11 The hourly variation of thermal power corresponding to different working fluid configurations [49]

2.5. Concentrated PV/T Systems

Using reflectors, these systems focus the sun's light on a PV receiver. CPV/Ts can sometimes get as much sunlight as 100 suns, and they need more Some of the complicated parts are dual-axis tracking and PV cells with more than one junction. A cooling fluid usually moves in a closed loop between the PV receivers and a heat exchanger. As long as there is a significant demand for heat, CPV/T systems can have an overall efficiency of up to 80%, collected as electricity and heat. PV/T collectors are helpful because they use reflector material, which is less expensive than PV panels. This means that pricey PV panels may be replaced with less expensive reflector material, which lowers the overall cost of the system. Due to the high temperatures, which might damage PV cells, it is essential to have stable cooling. Some CPV/T designs have an extra power-making cycle, like the Rankine cycle, that uses additional thermal energy. Singh and Tiwari (2017) examined how well basin-type solar stills worked when combined with N identical partially covered CPV/T systems. The influence of water depth was

taken into account. Solar distillation is a way to extract water from the sun. Using heat energy, you may make drinkable water out of salt water. Figure 12 illustrates a diagram of how the system works. It can be seen that 25% of the N identical CPC water collectors have PV/T on them. The single slope active solar still featured a 2 m × 1 m basin manufactured of glass-reinforced plastic with a clear glass cover. The inside surfaces were painted black to absorb as much sunlight as possible. The best mass flow rate was 0.04 m/s, while the best water depth in a single-slope basin was 0.70 m, and 0.31 m in a double-slope basin.El-Samie et al. (2020) used finite volume CFD to predict the optical, thermal, and electrical performance of the low CPV/T collector, and the results were confirmed using the Monte Carlo method. Way of tracing rays. The authors examined different coolants and heat sink designs (U-type and Z-type). (water, ethylene glycol, and Therminol VP-1). It was observed that changes in irradiance significantly affect electric performance, but that high thermal efficiency of 48–51% may be reached at any time of day. The temperature of the PV cell was observed to drop more with the Z-type heat sink than with the U-type. The water-cooling system was the most efficient, with an average thermal efficiency of 48.8% and an average electrical efficiency of 7.1%.
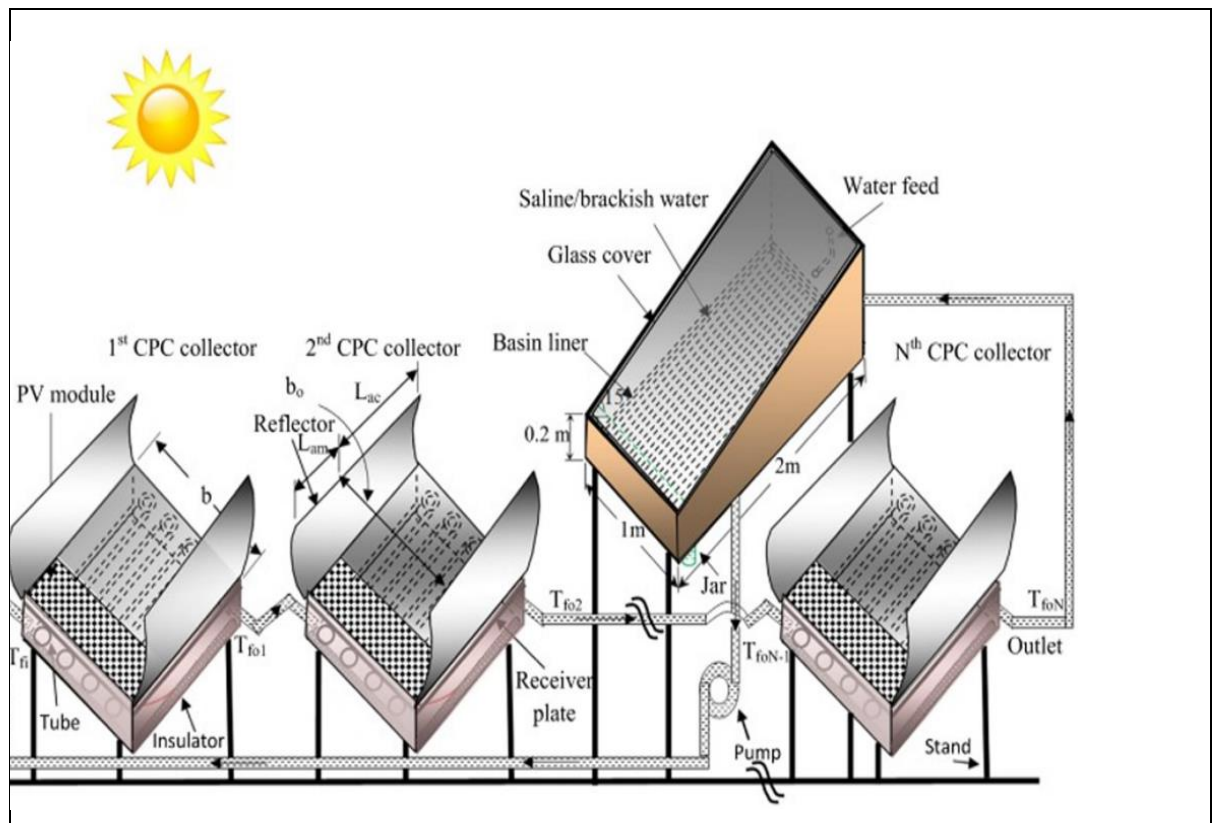

Figure 12 Diagram of a single slope active solar still partially covered by CPV/T (Singh and Tiwari 2017).

Conclusion

Compared to standard solar modules, PV/T systems are more efficient in both heat and electricity. You can get more energy overall if you put PV/T collectors on your roof instead of individual photovoltaic modules and solar thermal collectors. In the scientific literature, indoor studies with PV/T collectors show higher efficiency than outdoor experiments. Refrigerant-based, air- and water-based, and water-based PV/T systems have the highest total efficiencies. Air-based PV/T systems have the lowest real efficiencies. Most of the time, electrical, thermal, and overall efficiency increases as solar irradiance increases. But even when there is a lot of sunlight, the collector's efficiency will go down if the heat transfer isn't enough to lower the temperature of the PV module or if something else goes wrong in the process. Then, a rise in solar irradiation will likely have the opposite effect. When the mass flow rate increases, heat transfer between the PV module and solar thermal collector usually improves overall. This means the electrical, thermal, and total PV/T efficiencies improve. Nanofluids have more excellent thermophysical capabilities for transferring heat than pure water or regular fluids. The thermal conductivity of the nanofluid goes up as the volume percentage of nanoparticles goes up. This means the overall heat transfer between the PV module and thermal absorber also increases. There are two ways to compare the performance of different PV/T systems: on an equal Reynolds numbers basis or an equal pumping power basis. When nanoparticles are mixed into phase change material (PCM), the PCM's thermal conductivity increases, and its recovery time decreases. The performance of the nanofluid and nano-PCM-based PV/T system is better than that of the traditional PV and nanofluid-based PV/T system.

Recommendations

Photovoltaic-thermal (PV/T) collectors need a global standard for designing, testing, assessing, and installing them because there is yet to be an agreement on how long trials should last, how testing should be done, and what range of mass flow rates should be To do further long-term studies on PV/T collectors to find out things like how long the PV module will last. Since thermal stress causes PV modules to break down and PV/Ts help reduces this stress, it is best to evaluate a PV module's power yield, energy, and efficiency over lengthy periods. To learn how different geometries and base fluids work with the same geometries to understand more about how PV/T designs parameters affect performance. Most of the research written about is of natural systems that can be used immediately and have active parts. Most people must

discuss controlling or connecting these parts to a thermal load. Types of valves, connecting parts and their materials, and the controller (if there is one) should also be discussed regarding how much power they need and how they are made. In the realm of PV/T, most studies don't look at pressure drop and pumping power requirements. It's best to work using metrics to aid a complete system evaluation. In indirect systems, you should also talk about the sort of heat exchanger and how effectively it works. This is because it can help people see how hot the water is before they use it, and it can also help other researchers find the best type of water for their studies, which will improve the field.To learn more about how improved nanofluids can improve the way the PV/T collector transfers heat. This will contain things like magnetic nanofluid and Boehmite nanofluid. To determine how stable nanofluids are over time when utilized as working fluids in PV/T systems.To figure out how many cycles of melting and hardening nano-PCM can handle.To determine if the advanced type of PV/T systems in the literature are possible and their life cycle costs. Even though they are pretty effective, you must look at their expenses and how they affect the environment.

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