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Performance Analysis of Photovoltaic Thermal System Combined With Thermal Energy Storage Using Paraffin Wax as Phase Change Material

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ABSTRACT

This paper presents experimental assessments of the thermal and electrical performance of photovoltaic (PV) system by comparing the latent heat-cooled PV panel with the naturally-cooled equivalent. It is commonly known that the energy conversion efficiency of the PV cells declines with the increment of the PV cell temperature. To absorb the temperature of the PV panel by using heat transfer fluid is a way to increase the PV panel outputs. In the experiment, latent heat thermal energy storage was coupled to the rear side of the PV panel to achieve cell cooling passively. Thermal energy storage (TES) using phase change materials (PCMs) has received increasing attention since the last decades, due to its great potential for energy savings and energy management in the building sector. As one of the main categories of organic PCMs, paraffins exhibit favourable phase change temperatures for solar thermal energy storage. Its application is therefore effective to overcome the intermittent problem of solar energy utilisation, thereby reducing the power consumption of heating, ventilation and air conditioning (HVAC) systems and domestic hot water (DHW) systems. This chapter reviews the development and performance evaluation of solar thermal energy storage using paraffin-based PCMs in the built environment.
Keywords : Photovoltaic cell, photovoltaic (PV) system, solar radiation, thermal energy, phase change material, thermal energy storage, latent heat.

I. INTRODUCTION

Thermal energy storage (TES) is a technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation. TES systems are used particularly in buildings and in industrial processes.

Thermal energy storage is like a battery for a building's air-conditioning system. It uses standard cooling equipment, plus an energy storage tank to shift all or a portion of a building's cooling needs to off-peak, night time hours. During off-peak hours, ice is made and stored inside Ice Bank energy storage tanks. Thermal energy storage (TES) is a technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation.

Due to intermittency in availability and constant variation in solar radiation, TES found its place in thermodynamic systems. TES not only reduces the discrepancy between the demand and supply by conserving energy, but also improves the performance and thermal reliability of the system. Therefore, designing efficient and economical TES systems is of high importance. However, few solar thermal plants in the world have employed TES at a large scale. Additionally, the design of TES systems in various domestic solar applications is currently being investigated [20]. Using a computational fluid dynamic approach is also a vastly used method to save money, where FLUENT software seems to be successfully used for different engineering applications

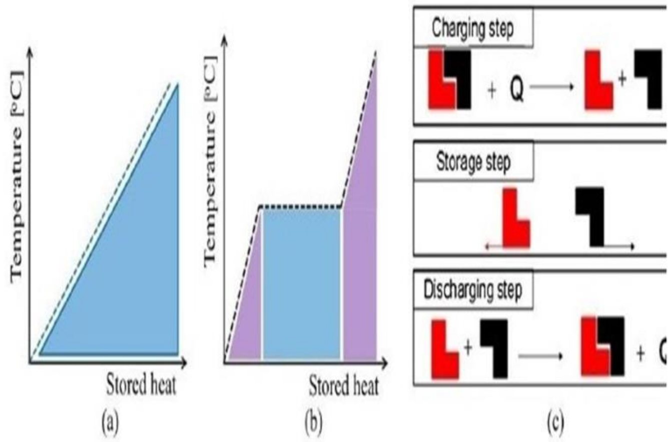


Figure 1 Methods of thermal energy storage:
(a) sensible heat; (b) latent heat

II. RESEARCH METHOD

The use of photovoltaic's has spread widely, and government agencies have begun adopting plans to deploy plants with large capacities, due to their environmental friendliness, low manufacturing costs, and high productivity. In the sunny countries where this technology should spread, the photovoltaic's' energy conversion efficiency decreases due to the high temperature of which the cell's operate at; because a large part of the solar radiation is absorbed by the solar panels as heat, while the smaller part converts it to electricity. From here, the benefit of the shift towards the PV/T technology that works to reduce the photovoltaic modules temperature and improve their electricity produced along with yielded thermal energy which can be utilized in other applications. In this study, a thorough review of many recent research and studies published in the field of PV/T has been carried out. The present study was divided into several sections to clarify and focus on the effect of each technology separately. Researchers used one or more fluids to cool the solar panels, and their research dealt with many of these fluids, starting with air, water, oil, etc. Other researchers have tended to increase the thermal conductivity of liquid cooling fluids by adding many types of nanoparticles with high thermal conductivity. Other researchers have used variable-phase materials to take advantage of the large storage of the latent heat of these materials. Other researchers have studied improving heat transfer of PCMs by mixing it with nanomaterials with high thermal conductivity. Others have also combined nano-PCMs and nanofluids together in one system, and they have demonstrated, in theory and practice, that this technique exhibits higher energy collection and utilization than the other types of PV/T. At the conclusion of the study, some critical points are identified that work is still limited and needs more research efforts and studies.

P (power) = V (voltage) x I (current).

Power rating		200 Watt
Open circuit voltage (Voc)		36.6 Volt
Short circuit current (Isc)		7.52 Amps
Voltage at Pmax (Vmp)		29.7 Volt
Current at Pmax (Imp)		6.73 Amps
Size	Length	1640 mm
	Width	992 mm
	Height	50 mm
Weight		19.0 kgs
Life span		20 -25 Years

Table 1 MONO CRYSTALLINE MODULE 300-350 Watt

Using the data obtained from the meters, the electrical power output is calculated using the power formula:

P=I×V

The panel efficiency, defined as the electrical output over the irradiance from the sun, is calculated using:

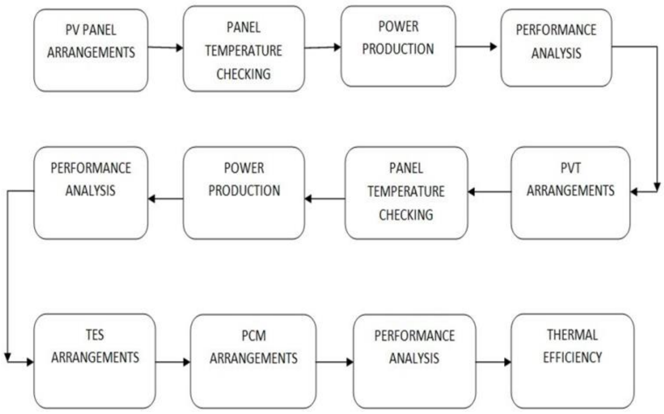
5=Pelectrical / Pirradiance=(I×V/E×A) ×100%

where:

I=current;V=voltage; E=solarirradiance/N2 ; A=eanel area

In an air-assisted PVT system, air passes through the photovoltaic panels either on a passive or active mode by means of natural convection or forced convection. Generally, a blower or fan is used in forced convection mode to get a higher flow rate of air [7]. Tubes or channels are used to help circulate the air, and it is mounded on the bottom of the PV module. The air can also extract heat from the PV module. With the removal of heat, the efficiency and life span of the panel will be increased. The extracted heat can be used as a medium for a heating appliance. Generally, with high temperature applications, the air- cooled PVT system cannot work efficiently due to their low thermal properties. Water has better thermal properties like thermal conductivity, specific heat than air. The water cooling PVT system employs two methods: passive and active cooling methods [7]. In this system, water tubes are fixed on the rear side of the PV module, and water flows inside the tubes. The water absorbs the heat from the PV panel so that the reduction in PV panel temperature and panel life also increases. Out of many studies conducted, only a few studies had focused on the passive cooling PVT system. Wu et al. [38] analyzed passive water- cooling technology for domestic PV panels using rainwater. The gas expansion technique was used to distribute the rainwater to cool the PV panel. The results showed that, as temperatures of panel decreases, the electrical efficiency increases up to 8.3%. Studies on the natural cooling system had been studied by various authors such as Kazemian et al. [39], Aste et al. [40], Herrando et al. [41], Rajoria et al. [42], Yazdanpanahi et al. [43], Shyam et al.

[44] and Chemisana et al. [45]. They analyzed the direct immersed PVT system with different liquids. The liquid-based spectrally selective filters for direct contact with the PVT system has several benefits. The liquid-based filters select the photons effectively, converting it to electricity and it does not allow an increase in PV panel temperature. The results concluded that de ionized water and isopropyl alcohol solution gives optimum electrical, thermal and overall efficiency. The air or water-based PVT systems outcome was not achieved as expected. Due to this, some researchers [46– 48] worked on two fluids, like air and water, which was used in a single PVT system known as the bi-fluid system. The working principle of the PVT system is like air or water-based system. However, in this system, both air and water were simultaneously used in separate channels or pipes; when one fluid passes through above the photovoltaic panel, the other fluid passes through the rear side of the photovoltaic panel. Most of the authors had worked on water and air as a bi-fluid for cooling the PV panel simultaneously, obtaining hot water, hot air, and electrical efficiency. This system overcomes the drawbacks of having separate air and water- assisted PVT systems. The processes carried out in this project are explained below.



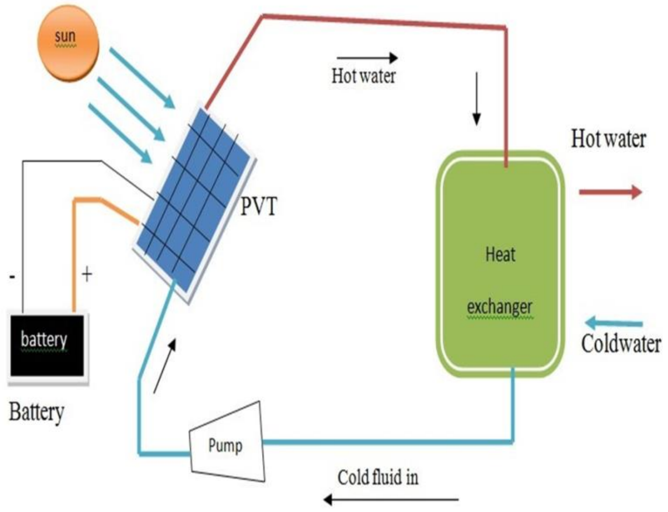


Figure 2 PVT SYSTEM

Jet impingement is one of the powerful methods of heat transfer high velocity of heat transfer fluid passes through the bottom of the PV panel, the cooling fluid absorbs large amounts of heat as well as reduces the panel temperature. It is an effective method of improving the convective heat transfer, and this method is useful for the food processing industry, electronic equipment cooling, and turbine blade cooling. It is also used for cooling PV panels, improving electrical efficiency, and improving thermal efficiency [7]. Jaaz et al. [49], had. implemented a PVT water impingement cooling and compound parabolic concentrator (CPC). The results confirmed that electrical output increases as any increase in mass flow rate.

III. RESULTS AND ANALYSIS

A typical solar panel produces about 150 - 200 watts of electricity per square meter. A number of factors can affect how much power you can generate from any solar panels installed. Some of these are controllable. They are size, number and position of panels can determine the power output. The kind of panel and its rating also matters.The less predictable factors are the number of hours of daylight which can depend upon time of year and weather. The net amount of the sunlight received during a day varies significantly with geographical locations and the weather patterns

Amount of captured solar energy depends critically on orientation of collector with respect to the angle of the Sun.

- Under optimum conditions, one can achieve fluxes as high as 2000 Watts per sq. meter
- In the Winter, for a location at 40 degrees latitude, the sun is lower in the sky and the average flux received is about 300 Watts per sq. meter

A typical household Winter energy use is around 2000-3000 KWHs per month or roughly 70-100 KWH per day.

Assume our roof top area is 100 square meters (about 1100 square feet).
In the winter on a sunny day at this latitude (40o) the roof will receive about 6 hours of illumination.

So energy generated over this 6 hour period is:

300 watts per square meter x 100 square meters x 6 hours

= 180 KWH (per day) more than you need.

But remember the efficiency problem:

- 5% efficiency 9 KWH per day
- 10% efficiency 18 KWH per day
- 20% efficiency 36 KWH per day

At best, this represents 1/3 of the typical daily Winter energy usage and it assumes the sun shines on the rooftop for 6 hours that day.

With sensible energy conservation and insulation and south facing windows, its possible to lower your daily use of energy by about a factor of 2. In this case, if solar shingles become 20% efficient, then they can provide 50-75 % of your energy needs

Another example calculation for Solar Energy which shows that relative inefficiency can be compensated for with collecting area.

A site in Eastern Oregon receives 600 watts per square meter of solar radiation in July. Asuume that the solar panels are 10% efficient and that the are illuminated for 8 hours.

How many square meters would be required to generate 5000 KWH of electricity?

Each square meter gives you 600 x.1 = 60 watts
In 8 hours you would gt 8x60 = 480 watt-hours or about .5 KWH per square meter

You want 5000 KWH

You therefore need 5000/.5 = 10,000 square meters of collecting area

S.No	Time	Panel Temparature	Power Production
1	9.00 AM	23°C	100 W/n²
2	10.00 AM	25°C	135 W/n²
3	11.00AM	28°C	170 W/n²
4	12.00PM	33°C	200 W/n²
5	1.00PM	35°C	180 W/n²
6	2.00PM	34°C	160 W/n²
7	3.00PM	30°C	140 W/n²
8	4.00PM	28°C	100 W/n²
9	5.00PM	27°C	40 W/n²
10	6.00PM	25°C	20 W/n²

Table no 2 Power production evaluations in summer

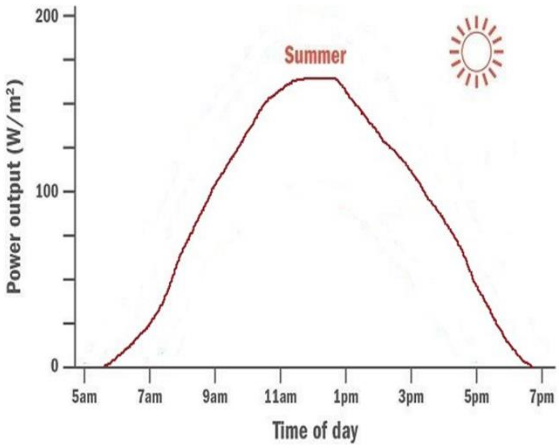


Fig no 3 Power output graph

S.No	Time	Panel Temparature	Power Production
1	9.00 AM	18℃	120 W/N2
2	10.00 AM	20℃	145 W/N2
3	11.00AM	22℃	185 W/N2
4	12.00PM	24℃	250 W/N2
5	1.00PM	25℃	230 W/N2
6	2.00PM	25℃	200 W/N2
7	3.00PM	24℃	150 W/N2
8	4.00PM	22℃	120 W/N2
9	5.00PM	21℃	80 W/N2
10	6.00PM	19℃	50 W/N2

Table no 3 Power production evaluation with PQT system in summer

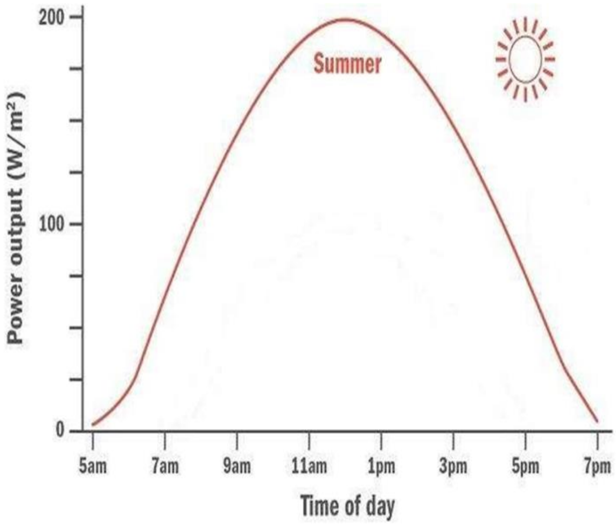


Fig no 4 power output of PVT system

Solar panel output per month

For a monthly total, calculate the daily figure then multiply it by 30:

- 1.44 x 30 = **43.2 kWh per month**

Solar panel output per square metre the most popular domestic solar panel system is 4 kW. This has 16 panels, with each one:

- around 1.6 square metres (m^2) in size
- rated to produce roughly 265 watts

(W) of power (in ideal conditions)

To work out the output per square metre, use this formula:

Number of panels x Capacity of solar panel system

Capacity ÷ Total size of system (number of panels x size of one panel)

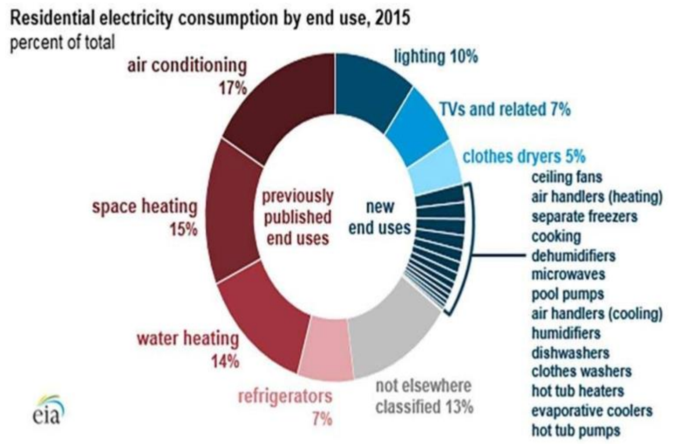


Figure no 5 Residential electricity consumption

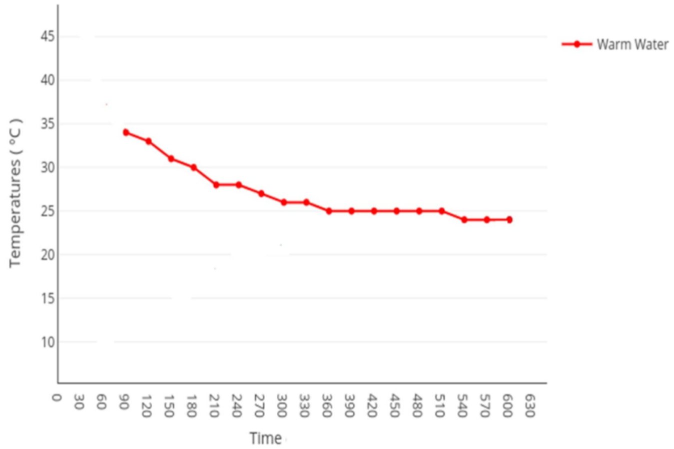


Figure no 6 Time vs Temperature relation of thermal energy storage

IV. CONCLUSION

In this research, a detailed experiment on integrated photovoltaic thermal system is conducted through numerical and experimental analysis. The system is tested under the climatic condition of Tamilnadu. Paraffin's, as one of the main categories of phase change materials, offer the favourable phase change temperatures for solar thermal energy storage. The application of paraffin-based PCM TES in buildings can effectively rationalise the utilisation of solar energy to overcome its intermittency. Using PCM to absorb heat from the solar panel back plate affects the temperature of the panel by cooling it down, hence decreasing the temperature and producing higher electrical output. The paper mainly focus on phase change material (PCM) based on thermal energy storage system. Various types of phase change materials (organic, inorganic and eutectic) are available in a wide range of applied temperature. Thermal energy storage is very important in many engineering applications such solar water-heating systems, space heating, solar air heating systems, solar cookers, greenhouse heating, space cooling, waste heat recovery system, and buildings.

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