Exergy Analysis of a PVT System having Fins in Air Cooled Channel

Thesis

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By

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Human tenure in this universe is sponsored by several others. Acknowledgement might be just a little thing written on a piece of paper for a couple. Nevertheless, it gives us an opportunity, in the real essence, to remember and communicate our feelings to those we love, reverence, and share our secrets. Here I have a great opportunity to express my gratitude to people who have helped and supported me in some way in completing this record.

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This list is obviously incomplete, but allow me to apply it because the omissions are inadvertent and I once again express my sincere gratitude to all those who have supported me directly or indirectly in this endeavor.

Sumit Pal

Pantnagar
March, 2021

(Sumit Pal)
Author

CERTIFICATE-I

This is to certify that the thesis entitled **"Exergy Analysis of a PVT System having Fins in Air Cooled Channel"** submitted in partial fulfilment of the requirements for the degree of **Master of Technology** in **Mechanical Engineering** with major in **Thermal Engineering** of the College of Post-Graduate Studies, G. B. Pant University of Agriculture and Technology, Pantnagar, is a record of *bonafide* research carried out by **Mr. Sumit Pal,** Id. No. **53893,** under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation and source of literature have been duly acknowledged.

Pantnagar
March, 2021

(Lokesh Varshney)
Chairman
Advisory Committee

CERTIFICATE-II

We, the undersigned members of the Advisory Committee of **Mr. Sumit Pal,** Id. No. **53893,** a candidate for the degree of **Master of Technology** in **Mechanical Engineering** with major in **Thermal Engineering,** College of Post-Graduate Studies, G. B. Pant University of Agriculture and Technology, Pantnagar, agree that the thesis entitled **"Exergy Analysis of a PVT System having Fins in Air Cooled Channel"** may be submitted in partial fulfilment of the requirements for the degree.

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(Prashant Verma)
Member

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α	-	Absorptance of the solar cell
T_a	-	Ambient temperature (◦C)
A_{PV}	-	Area of the solar panel (m^2)
b	-	Breadth of the air duct (m)
l	-	Length of the air duct (m)
w	-	Width of the air duct (m)
CFD	-	Computational fluid dynamics
ρ	-	Density (kg/m^3)
v	-	Air velocity at the entry of the air cooled channel
E_i	-	Energy in (kJ)
E_o	-	Energy out (kJ)
h_i	-	Enthalpy in (kJ/kg K)
h_a	-	Enthalpy of air (kJ/kg K)
h_o	-	Enthalpy out (kJ/kg K)
S_a	-	Entropy at average (kJ/K)
S_i	-	Entropy at the inlet (kJ/K)
S_o	-	Entropy at the outlet (kJ/K)
EVA	-	Ethyl vinyl acrelate
y_{EX}	-	Exergy efficiency (%)
Ex_i	-	Exergy in (%)
Ex_o	-	Exergy out (%)
Ex_w	-	Exergy rate (W)
T_f	-	Flowing air temperature (◦C)
T_{in}	-	Flowing inlet air temperature (◦C)

T_{out}	-	Flowing outlet air temperature (^{0}C)
Q_0	-	Heat loss to the ambient (W)
T_i	-	Inlet air temperature (^{0}C)
Q_u	-	Heat rejected by air cooled channel
Ex_{iire}	-	Irreversibility (kJ)
$\dot{m}_i$	-	Mass flow rate in (kg)
$\dot{m}$	-	Mass flow rate of air (kg/s)
$\dot{m}_o$	-	Mass flow rate out (kg)
T_o	-	Outlet air temperature (^{0}C)
PVT	-	Photovoltaic thermal
$\dot{Q}_s$	-	Solar energy absorbed by panel surface (W)
G	-	Solar radiation (W/m^2)
C_p	-	Specific heat of air (kJ/kg K)
T_s	-	Surface temperature (^{0}C)
η_{Th}	-	Thermal efficiency (%)
η_{Ex}	-	Exergy efficiency (%)
R	-	Universal gas constant (kJ/kg K)
Q_u	-	Useful heat (W)
I	-	Turbulence strength
Re	-	Reynolds number

Introduction

Chapter 1 INTRODUCTION

Energy is regarded as a key factor in the production of wealth and a key factor in the economic growth of any nation. The value of energy is widely recognized in economic growth. The actual evidence indicates the strong connection among energy supply and economic activity. At the same time as, economic development is taking place, energy demand is also rising as it is proportional to economic growth. Preventing energy crises is one of most casual issues of the 21st century. World's energy demand is growing fast because of population explosion and technological advancements. Energy consumption rate in developing countries is rising rapidly about 5% per year and 1% per year in developed countries.

The vast majority of energy consumed worldwide comes from fossil fuels. Global demand for energy and fossil fuels is expected to increase. This increasing demand mainly due to decrease in world oil output. Over the past few years, renewable energy developments have gained remarkable international attention due to rising fossil-fuel prices.

As population growth in developing countries is high and industrial development continues to be economically feasible, they are now under pressure to look for energy sources. It is therefore important to ensure that energy demand from renewable energy sources in the future is efficient, cost-effective and sustainable.

In sustainable growth, renewable sources play an important role because they are environmentally friendly sources of energy. Extension and increase of non-conventional and green energy sources, such as wind, wave, solar, tidal, geothermal and bio-energy, etc., are also growing focus. Considering renewable energies such as solar, hydro, wind and geothermal energy, it is of crucial importance in this respect as they are environmentally friendly. High energy demand is leading to the replacement of fossil energy with renewable sources such as solar energy. Solar energy is expected to play a very significant role in the future. Nadarajah and Divagar (2016) gives the various facts about solar energy.

Solar energy is inexpensive and eco sustainable, despite its disadvantages, such as poor efficiency and high installation costs. Solar industry is rising steadily all over the world due to high energy demand, although major energy sources, fossil fuels, are limited and other sources are costly.

The most modest and reliable way of consuming solar energy using solar PVT collectors, energy is transformed into electrical and thermal energy for heating applications. A photovoltaic power generation plant has several parts, such as solar cell arrays and modules, and control systems for both electrical and mechanical connections. The inherent simplicity of solar PVT collectors is inexpensive and most commonly used in collection devices. This system is designed in such a way that could provide higher conversion efficiencies. Electrical energy and heat energy are usually collected separately. PV/T collectors are used to boost the effectiveness of solar energy recovery. PV cells are built in such a way as to produce electricity from solar radiation, while thermal collectors gain heat energy from untapped radiation from such cells and waste energy from PV panels.

Research on the acquisition of electrical energy and heat at the same time by means of an apparatus has been developed and new hybrid systems commercially known as Photovoltaic-Thermal or PV/T collectors have been designed. Due to its higher efficiency and performance reliability compared to single solar devices, hybrid solar energy consumption systems are gaining considerable interest from scientists and engineers over the last years.

1.1 Solar Energy Conversion Techniques

The flux of solar energy which reaches the Earth's surface represents a few thousand times the actual intake of primary energy by humans. The potential of this resource is immense and makes solar power a key component of a renewable energy portfolio that aims to minimize global atmospheric greenhouse gas emissions.

Although the deployment of photovoltaic systems in the last 30 years has been steadily rising, solar technology still suffers some disadvantages that render it poorly competitive on a market dominated by fossil fuels: high capital costs, modest conversion performance and intermittency. From a scientific and technological point of view, the implementation of new technologies with higher conversion efficiencies and low production costs is a crucial prerequisite for the large-scale deployment of solar energy.

Traditionally, depending on the conversion process, solar-powered devices come into two categories: either heat or electricity, such as thermal storage and photovoltaic devices. However, a new area growing rapidly today that combines the two energy transfer methods, which can be referred to as photo thermal conversion. The conversion of sunlight into electricity and heat with a single converter is called a PV/T hybrid thermal collector. Heat and electricity are generated at the same time in this manner, and it appears to be a decent idea. The description of various solar energy transformations techniques is shown in Fig. 1.1.

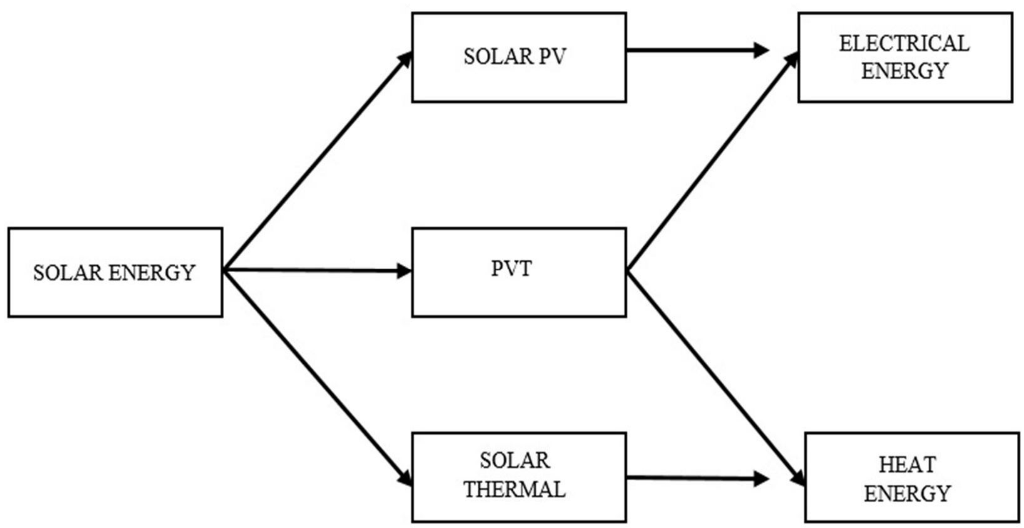

Fig. 1.1 Classification of solar energy transformation technique

1.1.1 Solar Thermal Technology

Solar energy receivers are heat exchangers of a specific kind that transform solar energy into the internal energy of the transport medium. There are primarily two types of solar collectors: non-concentrating or stationery and concentrating. In order to intercept and absorb solar radiation, the non-concentrating type collector has same area, whereas the sun-tracking concentrated type solar collector typically has concave reflecting surfaces for collecting and focusing the solar radiation to a narrower receiving area, thereby improving the flow of radiation flux. A Concentrating type collector and non-concentrating collector shown in Fig. 1.2 and 1.3 respectively.

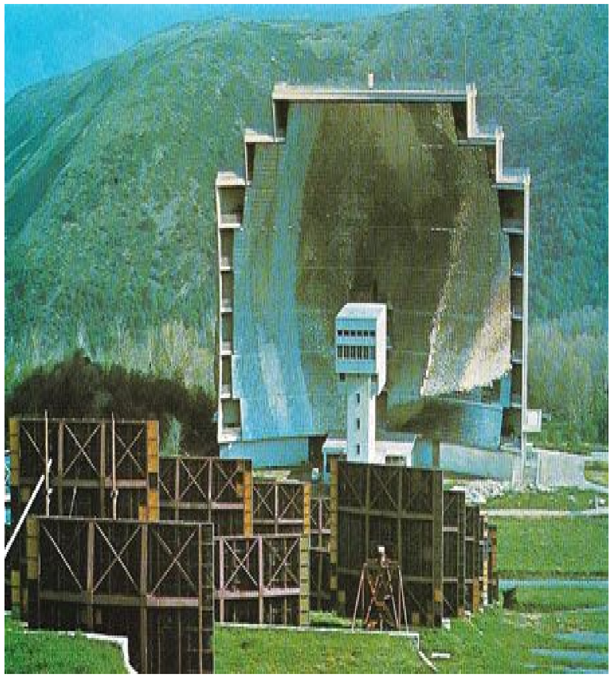

Fig. 1.2 Concentrated type solar collector

Fig. 1.3 Non concentrated type solar collector.

1.1.2 Solar Photovoltaic (PV) Technology

Photovoltaics (PV) is a technology for directly converting radiation from solar energy to electrical energy. The Greek word "photo" refers to light and "voltaic," meaning voltage. A photovoltaic cell is a semiconductor structure that generates electricity when light falls on it, also known as a 'solar cell.' The photons of the radiation absorbed transfer the electrons from the atoms of the cell as solar radiation hits a PV cell. The free electrons then travel into the cell, forming gaps in the cell and filling them in. This movement of holes and electrons creates electricity. A photovoltaic effect is defined as the physical process by which the PV cell converts sunlight into electricity.

There must be a junction between two separate semiconductors for a solar cell. The electrical conductivity of semiconductors is lower than that of conductors and higher than that of insulators. Elements such as silicon (Si) and germanium (Ge) may be semiconductors. The principle of photovoltaic effect is shown in Fig. 1.4.

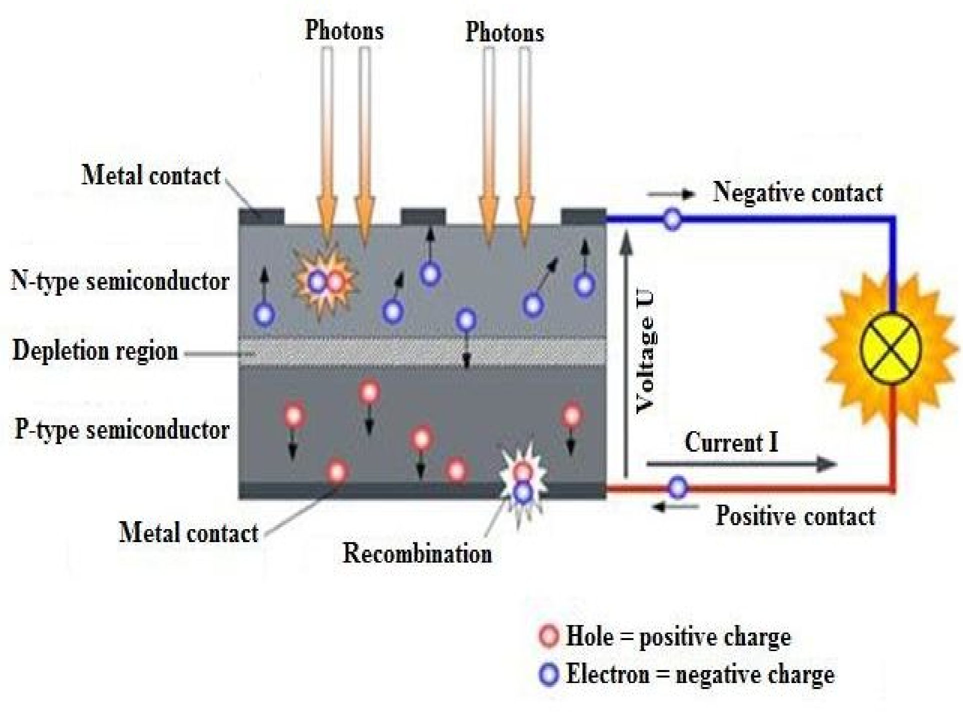

Fig. 1.4 Photovoltaic cell working principle

Most active solar cells are made of amorphous-crystal silicon. As the sun's rays strike the solar cell, fraction of the photo source emits sufficient energy to create pairs of electron holes in the conductors in the conductor. A potential barrier to a PV cell is developed by forming interactions in between semiconductor layers. This polarized the electrons from the holes and leads to a mass generated energy. The charge flow rate is the function of the PV cell space and the intensity of the sun's rays.

Photovoltaic (PV) cells are organized into modules by connecting them in series joining system to generate more energy and current. PV modules can be linked by groups to build a list of the highest power ratings. The DC electricity produced by a group of solar cells is usually transmitted through a power supply and power control spray and then converted to a changing current. The simple PV system is shown in Fig. 1.5.

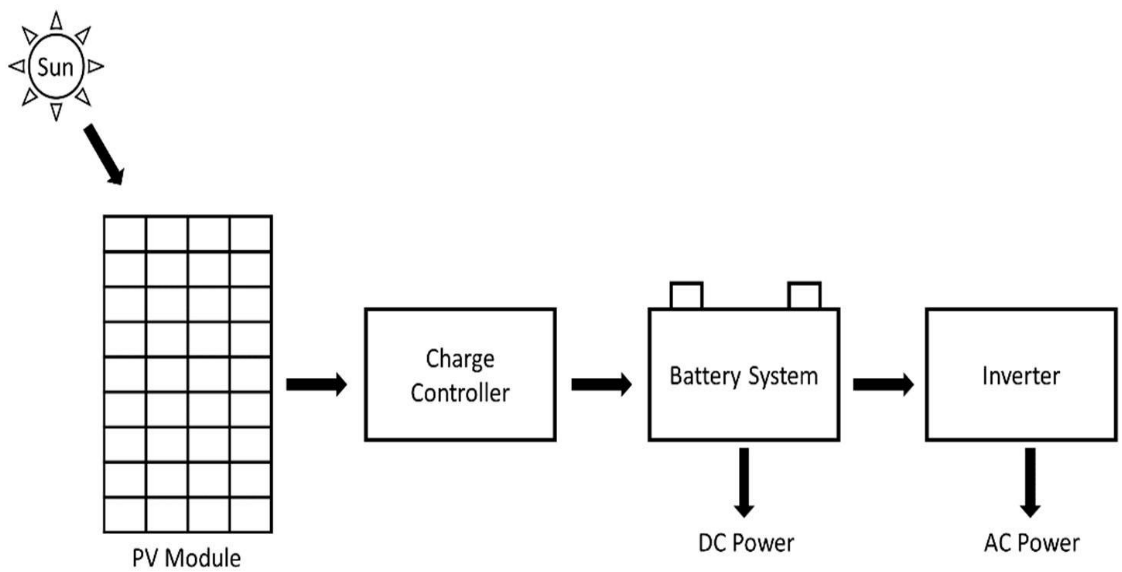

Fig. 1.5 Simple PV system.

Solar panels are actually photovoltaic modules that convert solar energy into electrical energy. Charging controls are used to increase power output from solar panels, to charge from batteries, to monitor current and charging levels. Battery power is stored and used when solar power is not available. Inverters rectifiers DC power to AC power through the use of AC systems.

Commercially available PV modules can convert sunlight into electrical energy with an efficiency of from 6 to 16%. The cost of photovoltaic cells has dropped rapidly in recent times to make it easier as compare to latest technologies. With the exploration of the space system, photovoltaic cells made of semiconductor-grade silicon quickly became a major source of energy for satellite use.

1.1.3 Solar Photovoltaic Thermal (PV/T) Technology

PV-thermal collector (PV / T) is a system that can not only be supplied with electrical energy by PV but also acts as a heat exchanger. Heat and energy are produced in this way simultaneously. With ever-increasing demand for solar heat and solar energy, it seems prudent to devise a system that can meet both needs.

Photovoltaic (PV) cells use a portion of the sun's rays to generate electrical energy and the remaining is mainly converted into waste heat to cells and a substrate that increases the temperature of PV cells due to a decrease in modular efficiency. Part of this heat is obtained through photovoltaic / thermal technology (PV / T) and used for efficient use. In order to cooling of the photovoltaic system (PV) ensures an acceptable level of electricity efficiency and thus the PV / T collector provides a safe way to use solar energy with the highest efficiency. Fig. 1.6 shows the standard solar photovoltaic thermal (PV / T) system.

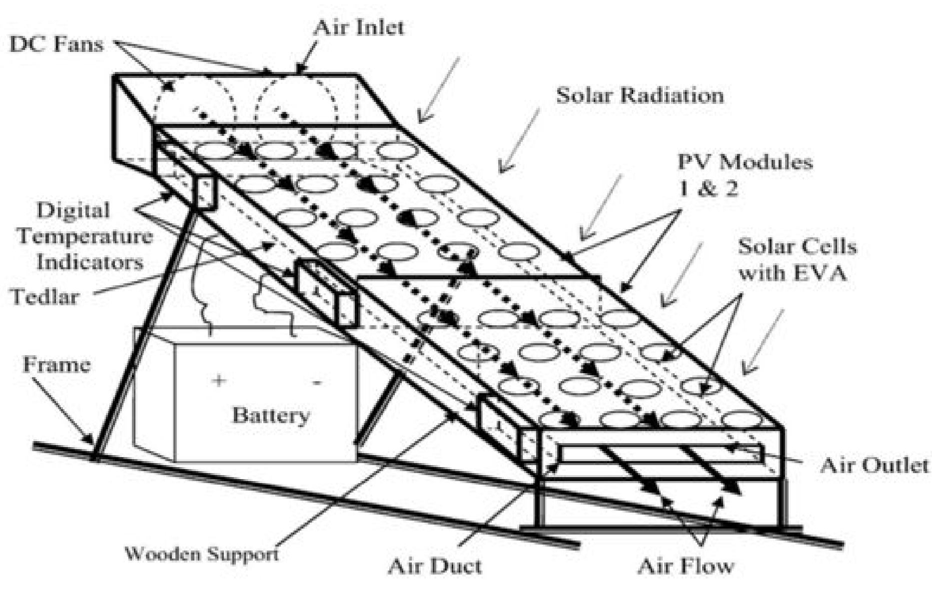

Fig. 1.6 Typical solar photovoltaic thermal system

Other PV / T assembly methods are available. Among many other things, air, water, vapor collectors, amorphous silicon, mono crystalline, polycrystalline, solar films with thin film, glossy or non-glazed panels, flats or concentrated, natural or forced flow, structural or compact elements etc. selected. Some of the silent property of the PV / T system are described; Dual purpose (i.e.), therefore electrical and thermal energy can be generated using the same device. It has many types of applications: heating and cooling (desiccant cooling) applications, heat exchanger can be used seasonally and is sufficient for home applications. It is cheap and physically possible: it can be installed quickly in the building without major changes, and the recovery time can also be shortened by replacing the roofing material with a PV / T system.

It is flexible and efficient: overall performance is often more than the use of two different systems and when the roof panel space is reduced, it is more attractive to integrated PV (BIPV) construction.

1.2 Solar PVT cooling techniques

1.2.1 Need for cooling

As is well known, valuable factor affected the energy performance of PV cell is the temperature of photovoltaic (PV) cells. The solar energy incident, which transforms into electricity, absorbs only about 16% of the photovoltaic (PV) panel. The remaining absorbed insolation is transformed into heat. The efficiency photovoltaic cells decrease with an increase in temperature. This can usually result in a decrease in efficiency, as increase of the working temperature of the cell by 0.5% per °C.

This issue can be avoided by keeping temperatures uniform around the plate. Dwivedi *et al.* (2020) gives the various information related to various cooling method for solar PVT system. A substantial improvement in the overall conversion efficiency of the receiver will result from the use of the extracted thermal energy from cooling.

1.2.2 Classification of cooling techniques

Researchers working on cooling system known as active and passive cooling systems for reducing solar cell operating temperatures. Active cooling involves a coolant that usually includes in fan or pump power, such as air or water, whereas passive cooling does not require specific power.

Cooling technology has evolved into more sophisticated techniques, including heat sinks, phase change materials (PCMs), Nano-fluids, micro channels, thermoelectric generators (TEGs), or integration with other devices.

1.2.2.1 Air-based cooling

Air is constantly transferred behind PV modules, which help to keep cell temperatures low and cell performance higher. A passive PV cooling technique, the panels and balancing of structures by air are naturally carried out without any mechanical technique. Due to its simplicity, natural convection is perhaps the most common PV method. No additional materials are needed for module cooling and the cost is relatively small. The passage of air through the PV Via convection, panels eliminate the heat and the air flowing over the panel is more productive than the air moving under the PV panels.

1.2.2.2 Liquid based cooling

As a cooling station in lowering the temperature of the PV panels, air and water are used. Since air has its own low specific heat output, it finds limited application and therefore water is often used as a cooling medium to boost the efficiency of the solar PVT system. Through the method, water is constantly required; additional pumping energy is needed, and the techniques are bulky. In both of these systems, water circulation can be controlled using solar-powered D.C. Active cooling technology pumps.

1.2.2.3 Phase change material

Cooling with phase change materials (PCM) is a different type of passive conductive cooling. PCM is a material capable of maintaining thermal energy, allowing stability of temperature. If they undergo a shift in their physical state, such as during the melting and freezing period, they can absorb or release large amounts of so-called 'latent' heat. As organic oil, inorganic salt hydrates and eutectics PCM is classified.

1.2.2.4 Nano-fluid based cooling

Nano fluids are an emerging technology that has recently been adapted to provide greater efficiency than traditional fluids. Different nanoparticles mixed with water are used as nano fluids to cool the PV Panel and improve the efficacy of the unit. In varying weight percentages, various nanoparticles are used to optimize heat transfer.

1.2.2.5 Extended surfaces/fins/heat sinks

Some parts, such as heat sinks, metallic materials such as fins attached to the back of PV will improve the passive cooling of photovoltaic panels to ensure the convective transfer of heat from the air to the plates. Generally, high thermal conductive heat sinks are located behind the solar cell. The heat sink increases the region of heat transfer from the solar cell to the atmosphere. It's got a big chance of PV Cooling panels due to their versatility and low cost.

1.3 Objectives of the Thesis

The aim of present work is to study the exergy and thermal performance analysis of the air cooled PVT system. However, for all previous cooling technique, the decrease in the panel surface temperature is found in air cooled channel having circular, rectangular and perforated fins to improve performance of the PVT system. But present study mainly based on the feasibility of taper fins on the basis of shape, size and arrangements which is relatively new in the particular field.

The primary goals of the current research study are:

1. To establish a computational model for the analysis of thermal characteristics and the visualization of the PV/T systems' temperature distribution using Computational fluid dynamic (CFD).
2. To investigate efficiency of the solar PVT system having air cooled channel with and without fins, at the back of the solar panel.
3. To investigate the exergy of the solar PVT system by using air cooled channel with fins and without fins at the back of the solar panel.

1.4 Organization of the Thesis

This thesis consists **5 chapters**. The existing **chapter 1** gives background information related to the research work. The motive of the study is described in this chapter.

Chapter 2 reviews the past work in the current literature relevant to this research. A literature review of the solar photovoltaic thermal (PV/T) systems is described.

Chapter 3 presents the numerical analysis of photovoltaic solar systems. The need for accurate estimates of the thermal efficiency of a PV/T system is the impetus for designing a computational model. Various operational modes are conducted. Often, the computational approach currently followed, assumptions made, mesh generated, grid independence, boundary conditions and the solver's numerical procedure are discussed.

Chapter 4 discusses the findings reported for the current photovoltaic thermal system efficiency analysis from the computational model. The performance comparison of the both the modes of air cooling (fins and without fin) system with different mass flow rate of air is reported. Additional information like the air flow temperature at inlet and outlet of the air cooled channel systems is also reported.

Chapter 5 it summarizes the conclusions of the computational outcomes obtained. Recommendations for future opportunities have also been proposed to enable research aspirants to take their research into account.

Review of Literature

Chapter 2 REVIEW OF LITERATURE

In the scope of global climate change, various steps are being taken to improve renewable energy. Particularly solar energy with promise of future energy conversion. The most recent popular technology independently transforms solar power to thermal power and electricity. The thermal photovoltaic (PVT) device is designed to simultaneously produce electrical and thermal energy.

Over the last 30 years, research and development work has already been carried out on hybrid photovoltaic thermal technology (PVT). Many kinds of solar thermal collectors and new PV cell materials have been produced for the efficient use of solar energy. Photovoltaic (PV) cells are suffering from a drop in efficiency as their operating temperature rises, particularly under high levels of insolation. By reducing the temperature of the PV device by removing the heat energy connected to the PV module, the overall electrical performance of the photovoltaic (PV) module can be reduced. For PV cooling by forced or natural flow through a heating source connected to the rear of the PVT system, both air and water are used. The primary function of the heat extraction system is to eliminate heat from photovoltaic panels so that it can function effectively and retain its temperature to a good extent.

A lot of work has been done to date by many researchers and a number of researches have been carried in the design, simulation, modeling and testing of these systems. This chapter examines in depth the work of the various researchers in the field of state-of-the-art and development of PVT technology.

Hendrie (1980) examined the thermal and electrical performance of an air and liquid type hybrid solar photovoltaic collector. For liquid collectors with no electrical output overall efficiency decreases 45.25 % to 40.4 % and for air collectors with no electrical output the overall efficiency decreased 40 % to 32.9 %. when electrical power was produced maximum electrical efficiency was estimated 6.8 %.

Cox and Raghuraman (1985) implemented the concept of photovoltaic/thermal (PV/T) collectors in order to determine their performance and interface in terms of computer simulation of flat-plate PV/T collectors that is suitable to a wide variety of designs. His study was based on two things; increasing sun absorption and reducing the infrared emissions. The results of the analyses can be concluded as follows: for PV cells covering about 65 % of the total covering area, when grid-back cell used, a selective absorber actually reduces thermal efficiency.

Bergene and Lovvik (1995) introduced hybrid photovoltaic/thermal system in the physical model, and algorithms were given to make quantitative predictions about the efficiency of the system. The model was based upon the analysis of energy transfers due to conduction, convection and radiation and predict the amount of heat that can be drawn from the system as well as the (temperature-dependent) power output. The model shows that the system efficiency i.e., thermal + electrical about 60-80 %.

Sopian *et al.* (1996) determined the effectiveness of single-pass and double-pass photovoltaic thermal collectors at steady-state conditions. The working fluid was air and the systems were focused on conservation of energy at different collector points. Simple analytical solutions were achieved for the differential equations of single-pass and double-pass collectors. Performance analysis shows that the double-pass photovoltaic thermal solar collector produces more output over the single-pass model for a normal operating collector mass flow rate range.

Kalogirou (2001) proposed the simulation and modelling of a photovoltaic/thermal (PV/T) solar energy device. The System consists the standard PV panel at the backside of which a exchanger of heat with fins was attached. The hybrid system raises the PV solar system's average annual efficiency from 2.8% to 7.7% and also covers 49% of a house's hot water requirements, thereby raising the system's average annual efficiency to 31.7%. Hybrid PVT system taken by him shown in Fig. 2.1

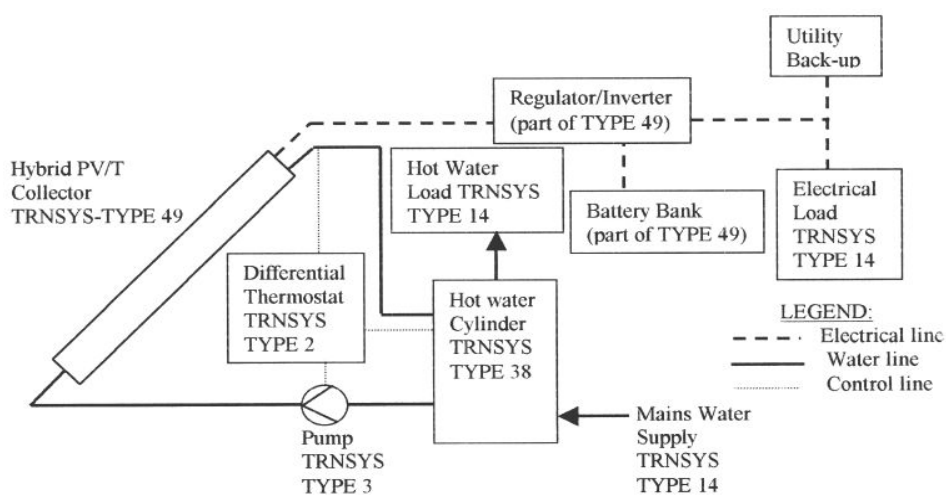

Fig. 2.1 Hybrid PV/T system schematic

Huang *et al.* (2001) examined the efficiency of the integrated photovoltaic and thermal solar system (IPVTS) compared to the traditional solar water heater and illustrate the concept of the IPVTS model. It was noted that the main energy saving efficiency of the IPVTS was higher than 0.60, which is greater than standard solar water heaters or pure PV systems.

Sandnes and Rekstad (2002) introduced a system in which solar heat capacitor was coupled with silicon PV cells of single crystal. Electricity and Low-temperature heat are obtained by a hybrid energy-generating device. They proposed that the combined PVT model be used for low-temperature thermal applications to improve the electrical performance of the PV system, e.g., the space heating of the house.

Chow (2003) introduced the dynamic model of explicit type for a single-glazed flat plate water heating PV/T collector based on the control finite-difference method. It enables a thorough explanation of the transient energy flow across the numerous collector components and encapsulates instantaneous energy outputs. The tube with the metal bond collector under the flat plate was used. Fig. 2.2 show the model used by the chow. On the behalf of the model, he recorded a thermal + electrical efficiency of 60 %.

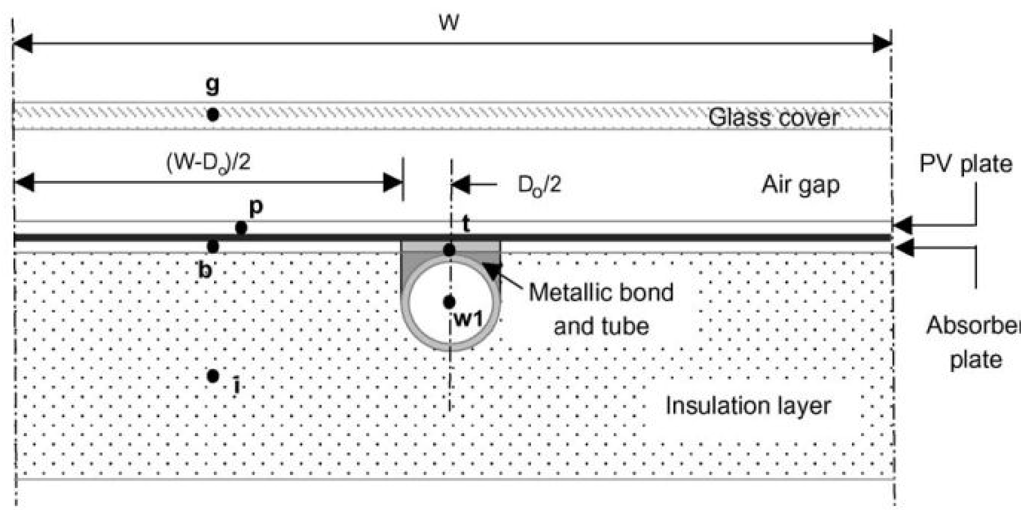

Fig. 2.2 PV/T collector with single glazing

Solanki *et al.* (2009) described the typical indoor investigation methodology for electrical and thermal observation of PV/T collectors joint in series system. The PV/T solar air heater was developed, manufactured and produced for this purpose and various operating parameters studied. He developed the thermal model on the steady state case. A distinction between experimental and theoretical results was also made.

The electrical and thermal performance of the solar heater is 8.4 % and 42 % respectively and the overall efficiency observed nearly 50%.

Joshi *et al.* (2009) examined the performance characteristics of the photovoltaic (PV) and photovoltaic-thermal (PV/T) systems related to exergy quality and energy efficiency. Exergy analysis was applied to a PV system and its components to evaluate the exergy flow losses and different efficiencies; electricity, exergy, and power conversion performance. The system's energy performance was determined on the basis of the thermodynamics first law and the exergy quality, basis of the second thermodynamics and solar irradiation law. The findings demonstrate that energy efficiency varies from a minimum of 33% to a maximum of 45% and PV/T exergy quality varies from a minimum of 11.3% to a maximum of 16%, whereas PV exergy performance varies from a minimum of 7.8% to a maximum of 13.8%.

Akpinar and Kocyigit (2010) examines the experimental performance of a new flat-plate solar air heater (SAH) with and without obstacles. For the experiments, two air mass flow rates of 0.0074 and 0.0052 kg/s were used. The first and second laws of efficiencies for SAHs were determined, and comparisons were made. The values of first law efficiency ranged from 20% to 82 %. The values of second law efficiency changed from 8.32% to 44.00%. The findings revealed that the efficiency of solar air collectors is highly dependent on solar radiation, collector surface geometry, and the length of the air flow line. The greatest irreversibility was observed at the SAH without obstacles collector, which has the lowest collector efficiency.

Fernandes and da silva (2010) introduced a thermodynamic modeling of photovoltaic–thermal (PV/T) solar systems for this Simulink/MATLAB was followed. They observed, for a typical 4-person family residence in Lisbon with p-Si cells and a collection area of 6 m^2 an average annual solar fraction of 67 % and a global overall efficiency of 24 percent (i.e., 15 % thermal and 9 % electric). The sensitivity assessment conducted on the PV/T collector indicates that the most significant factor to be addressed in order to improve thermal performance was the photovoltaic (PV) emittance of the module. Some additional changes, such as the use of vacuum or low-pressure noble gas, have been suggested on the basis of these findings, in order to allow the extraction of PV cell enumeration without air oxidation and degradation and thus to reducing PV module emissions. Results suggest that this option makes it possible to increase optical thermal efficiency by 8 percent and to massively reduce thermal losses, indicating the possibility of operating at higher fluid temperatures. The negative effect of higher operating temperatures on electrical performance was marginal due to accounting for enhanced optical properties.

Teo *et al.* (2012) developed a solar hybrid photovoltaic/thermal (PV/T) system and examined. A parallel series of inlet/outlet conduit ducts built for the homogeneous distribution of airflow was installed to the back side of the PV panel through active cooling of the PV panel. With and without active cooling, analysis was carried. Between efficiency and temperature, a linear trend was observed. The module temperature was inflated without active cooling and the solar cells could only achieve an output of 8.5-9.5 %. However, the temperature dropped significantly when the module was run under active cooling conditions, leading to an increase in solar cell efficiency of between 12 and 14 %.

Chabane *et al.* (2013) investigated experimentally, the thermal performance of a single pass solar air heater with five fins. To promote heat exchange and make the flow fluid in the channel uniform, longitudinal fins were used inferior to the absorber plate. Experiments were carried out at 0.012 and 0.016 kg/s air mass flow rates. Furthermore, for the 0.012 and 0.016 kg/s with and without fins, the maximum efficiency values were 40.02%, 51.50%, and 34.92%, 43.94%, respectively. When the findings of mass flow rates by solar collector with and without fins are compared, the thermal efficiency of the solar collector with fins is significantly improved.

Kim *et al.* (2014) designed an air-based PVT collector with a mono-crystalline PV module and tested its electrical and thermal performance using experimental results. As per results of the experiments, heated air from air-based PVT collectors had an average temperature of around 5°C greater than outdoor air. For the used system, the thermal and electrical efficiencies of the PVT collector were, on average, 22% and 15%, respectively. As a result, it was determined that heated air from the PVT collector could be supplied into the building's ventilation system as pre-heated fresh air while also contributing to improved electrical performance.

Chen *et al.* (2014) investigated electrical performance of a PV panel with passive fin cooling of natural ventilation. Also observed, effect of PV panel tilt angle, solar radiation, air temperature, wind velocity, and fin size on PV thermal performance. The research found that there was a PV tilt angle that resulted in the lowest electrical efficiency and the highest power output. The PV electrical efficiency fell linearly as the air temperature rose, but it increased as the wind speed rose. Fin height appeared to have just a little impact on electrical efficiency. Under various conditions in this study, the average electrical efficiency of PV panels with fins was 0.27-1.14 % higher than that of PV panels without fins.

Elsafi and Gandhidasan (2015) presented a comparative study between compound parabolic concentrated (CPC) and traditional flat hybrid double-pass photovoltaic–thermal (PVT) systems. An analytical thermal and electrical model has been developed for this investigation. Using various parameter electrical modeling in the study, they determine the electrical parameters of PV cells, such as voltage and current. In addition, they investigated the performance of the proposed systems with attached fins and the effect of their material and type on performance. The model is used to simulate and evaluate thermal and electrical output of finned (F) and un-finned (UF) flat and CPC photovoltaic systems for the selected case in Dhahran, Saudi Arabia. The results shows that the annual thermal gain is 1 % higher for flat-PVT (F) than for flat-PVT (F) (UF). Though on the other hand, for flat-PVT(F), the annual electrical benefit is 3 % higher than for flat-PVT(F) (UF). Compared to CPC-PVT, CPC-PVT (F) is stated to have more than 3 % thermal and 8 % electrical gain (UF). Among the four configurations studied, the CPC-PVT(F) system will have the best results.

Gotmare *et al.* *(*2015) experimented the performance optimization of PV plate using passive fins cooling under free convection. In order to better cool the PV plate, separate cross-section fins with perforation were mounted rear of the panel. A comparative experimental analysis on PV panels with and without fin cooling was done to investigate the impact of the operating temperature on the voltage, current and power output of the panel. Cooling the PV plate help to reduce the cell temperature by 4.2%. The analysis also indicates that under free convection power output was improved by 5.5%.

Huang *et al.* (2015) discussed the three-dimensional (3D) inverse interface problem using the general-purpose commercial code CFD-ACE++ and the Levenberg–Marquardt Method (LMM) to evaluate the optimum perforation diameters of the perforated pin fin array based on the desired temperature difference between the base plate average temperature and the ambient temperature (DT) and the device pressure drop array (DP). The analysis consists of three cases. In design #1, five design variables were used to estimate the optimal perforation diameters and the objective is to minimize DT and DP of the pin fin array. In design #2, four design variables were considered to determine the optimal perforation diameters based on the minimization of DT and DP. In design #3, all the perforation diameters were assumed identical and use only one parameter to determine the optimal perforation diameter based on the minimization of DT and DP. The empirical design findings confirm that, for all six designs considered here, the optimum heat sink design often has the lowest average base plate temperature, it can decrease from 6.3 % to 7.3 % compared to the solid pin fin array.

Gandhidasan *et al.* (2015) examined the numerical and experimental analysis of PV plate surface. A cooling technique was used to get low and uniform temperatures on the plate. During the months of June and December, an experimental analysis of the uncooled PV system and the converged channel cooled PV system was conducted in the hot climate of Saudi Arabia. Using a numerical approach, comprehensive modeling was carried out to analyze the effect of the change in the converging angle on the PV model's thermal behavior. Based on the model established, the two-degree angle exhibited the greatest output in terms of temperature distribution and average cell temperature with a standard deviation of 0.91 ˚C. A detailed system model was developed to evaluate the performance of PV modules numerically by linking optical, radiation, thermal, computational fluid dynamics and the electrical system. Thermal tests for uncooled PV showed a cell temperature of 71.2 ˚C and 48.3 ˚C for the months of June and December, respectively. By using converging cooling, the temperature of the cells decreased significantly to 45.1 ˚C in June and to 36.4 ˚C in December. The overall change in power output percentage was 35.5 %, while the maximum improvement in conversion efficiency percentage was 36.1 % respectively to the uncooled PV system output.

Bijjargi *et al.* (2016) introduced a system in which single pipe was mounted on the PV plate as a spiral heat exchanger in order to provide active cooling, to effectively cool the PV cells. A parallel series of inlet/outlet manifold ducts designed for uniform distribution of air flow was connected to the rear of the PV panel, liquid, phase-change materials (PCMs) and thermoelectric (TE) devices were used for cooing of PV cells. However, when the module was tested under active cooling conditions, the temperature fell dramatically, leading to an improvement in solar cell performance of between 12 and 14 %.

Gandhidasan *et al.* (2016) analyzed the cooling approaches with low average cell temperature and uniform temperature distribution in the PVT system. Immersion cooling claimed the promising solution for uniform cooling and recorded reduction cell temperatures for CPV systems 20-45 °C. Heat pipes decreased the temperature to 32 °C With temperature non-uniformity of 3 °C. Passive cooling by heat sinks results to reduce cell temperatures by 37°C. For hybrid cooling, a deviation of 0.46 °C surface temperature was observed. The PCM material temperature of the plate was monitored at 28–65 °C while the optimization of the heat exchanger designs also showed a low and uniform temperature across the board. The impact of non-uniformity was significantly linked for all PV systems, but in CPV systems the effect was more pronounced.

Chandel and Agarwal (2017) described the photovoltaic cooling techniques using phase-change materials (PCMs). The main objective of the analysis was to define useful research areas in order to ensure the technology's reliable performance and commercial viability. Researchers indicated that with PV-PCM integrated systems, electrical performance improved by 5 %. He suggested that Inorganic PCMs reasonable potential for PV cooling. The proposed study claimed that PCM for PV systems was still not an effective cooling strategy and further research required.

Omeroglu (2018) investigated an experimental and computational fluid dynamics (CFD) research for thermal and electrical performance of a custom-built PV/T panel cooled by forced air circulation. He used different configurations to check the quality with continuous irradiation of 1100 W/m^2 and three different air velocities (3.3 m/s, 3.9 m/s and 4.5 m/s). From results, cooling done up to 60–65 °C from the plate temperature of 120°C, so the decrease in the electrical current was prevented to a great level and the e□ciency could be reach at 12.02%.

Zohri *et al.* (2018) analysed the PVT based on air collector system with and without fins collector. The mass flow rate varied in ranges of 0.01-0.05 kg/s, and the radiation intensity of 600 W/m^2 and 800 W/m^2. To develop predictive model, a mathematical model was constructed for PVT system with and without collectors. Energy balance equation has been solved by using the matrix inversion method. The PVT system with fins collector is higher efficiency then without fins collector. The increasing of PVT system efficiency with fins collector is 7% and efficiency exergy is 1%.

Thakur *et al.* (2019) investigate the most recent writing research works setting to accomplishing improved effectiveness through cooling frameworks. It was found while perusing that with the aloof cooling frameworks temperature of PV module in the scope of 6-200 °C was diminished with an improvement in electrical productivity up to 15.5% maximum and with dynamic cooling frameworks temperature decrease by 300 °C also improves in electrical effectiveness up to 22% most extreme. With dynamic extra warm vitality yield with effectiveness coming to as high as 60%. In light of audit, it might be anticipated that with the swelling development of sun-oriented PV power around the world, the perfect cooling framework was getting to be critical so as to guarantee better vitality reap and use.

Kaya and Ozakin (2019) investigated energy and exergy analyzes of the air-based PVT system. Also, the temperature distribution of the panel surface and the air velocity distribution of the cooling channel were studied with ANSYS Fluent and experimental results were compared. Experiments were carried out for the empty, frequent, and sparse fins states. The exergy efficiency of the polycrystal and monocrystal panels is raised by roughly 70% and 30%, respectively, when sparse and frequent fins are used over to the empty state. There is an approximated improvement in thermal efficiency of 55 % and 70 %, respectively. The panel surface temperature has been seen to reduce between 10 and 15 °C for all arrangements.

Kim and Nam (2019) developed a CFD (computational fluid dynamics) simulation model to investigate a passive cooling method that employs fins mounted to the back of the PV module. In addition, a strategy for improving airflow at the back of the PV module by making slits in the frame was investigated. Under nominal working

cell temperatures ranging, the surface temperature and estimated electrical efficiency without cooling were 62.78°C and 13.24%, respectively, in the simulation findings. Furthermore, because the fins attached to the bottom of the PV module enhanced the heat transfer area with airflow, the temperature was reduced by roughly 15.13°C. As a result, the electrical efficiency based on PV module temperature was expected to be 14.39%. Furthermore, installing slits between the fins enhanced the airflow velocity and expedited the production of turbulence, enhancing the cooling performance of the fins. At a lower air velocity, the temperature might be decreased by another 8.62°C, according to the modelling results.

Nizetic *et al.* (2019) investigated a passive air based cooling solution for photovoltaic (PV) panels was examined. Cooling is accomplished by the use of aluminium fins, and its primary goal is to boost the electrical efficiency of the PV panel. After the analysis of the data, no significant raise in electrical efficiency was recorded throughout the experiment. Later on, developed numerical model was used to propose new cooling variations of the fin□based technique and to further examine the overall potential of air based passive cooling techniques. It was shown that cooling effect by up to 5°C is a realistic expectation for this technique in described operating conditions.

Rao *et al.* (2020) conducted the experiment analysis was with different fin design with PCM, without PCM material. And efficiency enhancement of PV integrated model was developed. The experimental models were compared with theoretical models and derating factor was determined. The derating factor decrement can enhance the solar panel electrical output along with thermal storage. Using different Fin design, layout and PCM material, we are able to reduce the temperature of solar panel. It was found that the proper selection of PCM material with desirable properties can enhance the thermal conductivity. Integrating the PCM on back side of the solar panel module results and decrease the temperature of panel modules propagates the increase in electrical power and thermal efficiency. The PVT-PCM system efficiency can be easily increased by increasing the PCM volume to store more heat without increasing the panel temperature during the day time. It was also found that PVT-PCM system with nano materials inclusion in the PCM can drop the temperature further and increase its efficiency by 6 to 12 %.

Barbu *et al.* (2020) investigated impact of the variation of thermal parameters of a domestic hot water tank on the electrical quality of a photovoltaic-thermal panel. The design of a photovoltaic-thermal panel system was developed in the Transient Systems Simulation Software (TRNSYS) and a one factor by time study was carried out for the main cold-water temperature, the tank size, the outlet flow and the market demand curve. The findings show that the variance of the outlet flow to the user has the greatest effect on the electrical output of about 6.8 %. The second highest impact factor was the scale of the tank with a difference of 4.7%. Consequently, the instantaneous variation of the thermal and electrical power of the device was analyzed as a function of the temperature at the inlet of the photovoltaic thermal plate.

Khordehgah *et al.* (2020) presented a standalone photovoltaic-thermal solar system, for modelling TRNSYS simulations system was used. Furthermore, he investigated how by reducing the temperature of the solar plate, the electrical power and performance of the panel was improved. He also observed the performance of the system and check the amount that the solar panel was able to convert the solar energy into electricity. Through this, they discovered that the electrical power output increased by almost 12% when the panel temperature was decreased, on average, by 20 %. In addition, it has been shown that, under various solar radiation conditions and during all seasons of the year, the model system can provide warm water.

Closure

A thorough review of literature in the field of solar PV/Thermal system is presented. Use of fins or extended surface can be considered as an effective way for cooling of solar PV/Thermal system. Study of the previous literature encourages the use of fins or extended surface and heat exchanger in the simulation of thermal solar PVT system.

Materials and Methods

Chapter 3 MATERIALS AND METHODS

This chapter presents computational analyzes to investigate the reduction of the operating temperature of PV panels with an air cooled channel including with and without fins attached at the back of the PV panel. Also analyzes the thermal efficiency and exergy of the system. The proposed air cooled channel is modeled as an aluminum plate with tapered fins attached to the back of the PV panel. Further, the chapter also explains the enhancement of air cooling at various inlet speeds in air cooled channel with and without fins. Comprehensive computational fluid dynamics (CFD) is used for simulation using the ANSYS software.

3.1 Numerical Setup

For this study, a 1510mm x 880mm scale photovoltaic panel is taken into account. For the cooling of the photovoltaic panel, two types of air cooled channels are developed. First, the rectangular air cooled channel has no fins, while second, the rectangular air cooled channel has fins within. Since the temperature of the photovoltaic cell is significant in the performance conversion process, the air cooled channel is therefore connected to the back of the photovoltaic plate. Fig. 3.1 shows the air cooled channel without fins and Fig. 3.2 shows the air cooled channel with fins below.

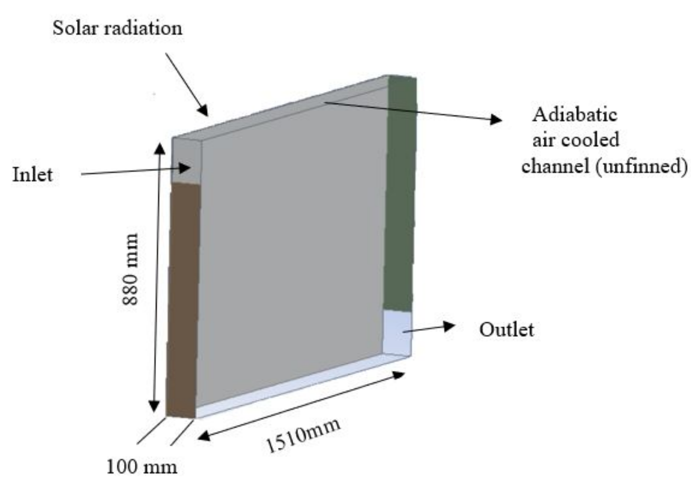

Fig. 3.1 Air cooled channel without fins

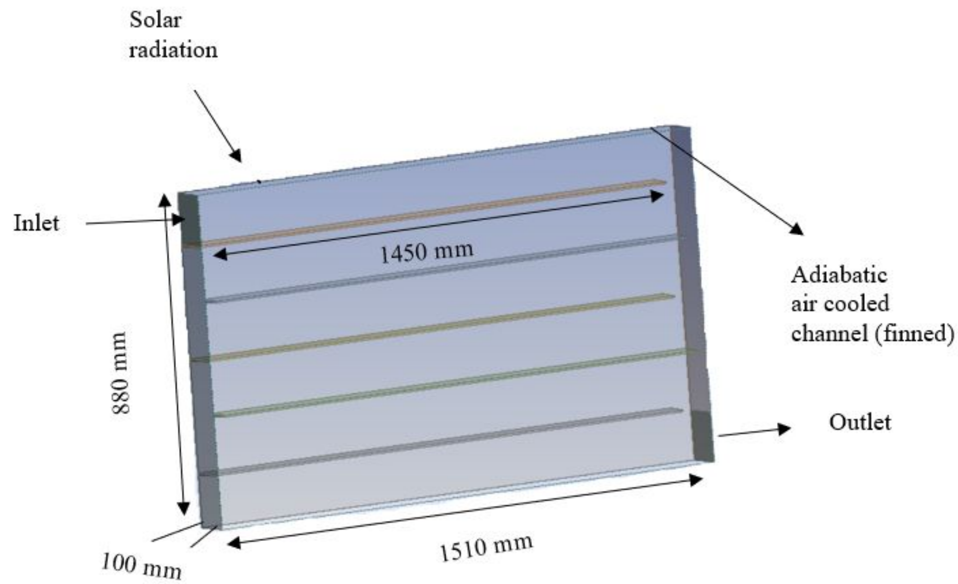

Fig. 3.2 Air cooled channel with fins

A three-dimensional (3-D) CFD simulation of the solar PV/T system is investigated in this section in two modes:

(1) Rectangular air cooled fins-free channel.

(2) Rectangular air cooled channel with fins.

In the both modes of investigation, effect of an air cooled channel in the back of the photovoltaic panel with different inlet mass flow rate in air cooled channel is presented. In this study we consider two mass flow rate of air 0.0085 kg/s and 0.0137 kg/s for investigation in the both air cooled channel. Since the performance and lifetime of PV panels can be affected by a rise in the operating temperature of photovoltaic (PV) panels due to high levels of solar irradiation, we considered the solution of air cooling the panels by using an air cooled channel connected to the PV panel. Using the ANSYS-Design Modeler, the air cooled channel is designed with and without fins. Panel dimension is same in both cases of study. Air cooled channel is made of aluminum. Table 3.1 represents system and operating specifications of the solar PVT system.

Table 3.1 System and operating parameters of the solar PVT system

System specifications	
Absorptance of the glass cover, α	0.85
Area of the panel, A_{PV}	0.98042 m^2
Air duct length, l	1.51 m
Air duct breadth, b	0.880 m
Air duct width, w	0.100 m
Cross section of air entry, l x b	0.140 x 0.100 m^2
Operating specifications	
Air velocity at the entry of the channel	0.5 & 0.8 m/s
Ambient temperature (T_a)	286 - 297 K
Solar radiation	344-987 W/m^2

In the photovoltaic system, the PV panel has a unique composite layer. Shown in Fig. 3.3. In the modeling program, the photovoltaic panel is considered as a single layer with thermal characteristics of the PV cells.

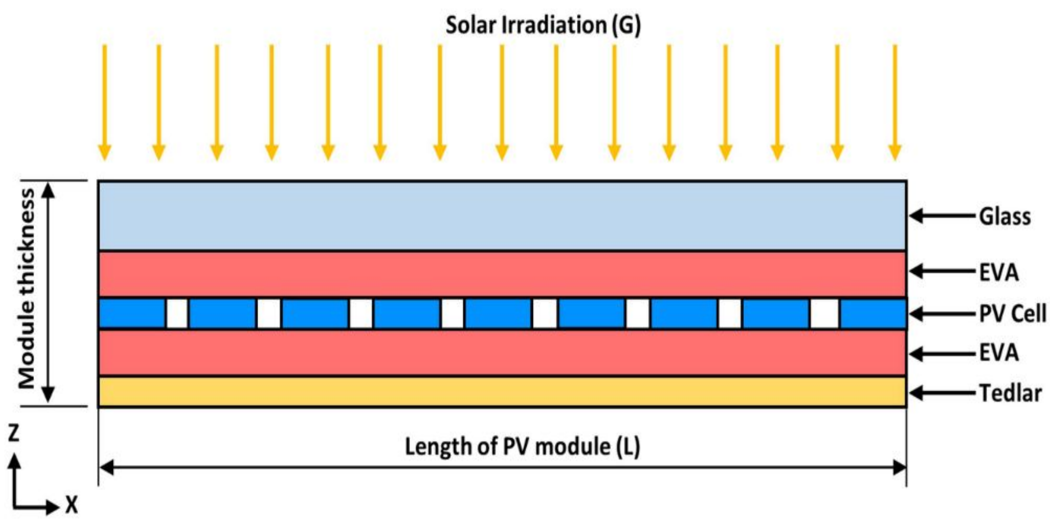

Fig. 3.3 Schematic longitudinal section view of PV module

Table 3.2 shows the properties of each layer in the solar module. The characteristics of these layers are assumed to be independent properties with changes in temperature and pressure.

Table 3.2 Thermophysical property of the PV panel Layers

Layer	Thermal Conductivity (w/m-k)	Density (kg/m^3)	Specific heat capacity (j/kg-k)
Glass	1.8	3000	5005 500
ARC	32	2400	691
PV cell	148	2330	677
EVA	0.35	960	2090
Rear contact	237	2700	900
Tedler	0.2	1200	1250

The air flow velocity (V) at the inlet of air cooled channel with and without fins are 0.5 and 0.8 m/s considered for this study. Solar flux and ambient temperature are taken on real condition of the pantnagar city in the month of January. Equations (1) and (2) below were used to measure the Reynolds (Re) number and turbulence strength (I):

$$\mathrm{Re} = \frac{\rho V L}{\mu} \tag{3.1}$$

$$I = 0.16\ \mathrm{Re}^{-1/8} \tag{3.2}$$

Where,

ρ and μ are density (kg/m^3) and viscosity (kg/m-s) of fluid, respectively. The Reynolds number for the imposed air velocity is between 4310 and 13100 and the estimated turbulence intensity was 5.42%. Therefore, the flow regime considered is turbulent one.

3.2 Computational domain

In this study, the air-cooling solution for PV panels by installing an air cooled channel behind them is an interesting solution for photovoltaic panel cooling. In order to cool the solar photovoltaic panel with fins, the tapered outline of the fins is considered and connected to the back of the panel surface. This extended surfaces or fins increases the heat transfer area of the solar panel.

The air cooled channel can be realized naturally, determined by the thermal circulation or pressure differences, or mechanically for achieving velocities over 0.5 m/s. The working temperature of the photovoltaic panel is considered a day of month of January depending on the time of that day. The intensity of solar radiation flux varies from 344-987 W/m^2 depends on the timing. The orientation of the panel shall be considered vertical, integrated into the air cooled channel.

The width of air cooled channel is considered constant, of 100 mm. The photovoltaic panel has the following dimensions: L (length) = 1510 mm, H (height) = 880 mm. In both cases, air cooled channels with and without fins are tested for the cooling of the PV panel. The air cooled channel is made of aluminum, while the copper fins are connected to the rear of the PV panel. Air cooled channel having the following dimensional characteristics with fins:

- Height of the fin 60 mm
- Step between fins 150 mm
- Length of air cooled channel 1510 mm
- breadth of air cooled channel H = 880 mm
- Width of the air cooled channel = 100 mm
- Thickness of tapered fin left side 9 mm and right side 4.5 mm
- Length of fins 1450 mm.

3.3 Grid Generation

Domain meshing is performed using ANSYS CFD 2020R1 software. It uses a uniform mesh with a very fine mesh dimension. This is important in order to obtain reliable and accurate results. The fine mesh, however, has need a lot of calculation capacity and time.

Mesh size is adjusted by performing independent grid tests for each model. The mesh size will be optimized until the simulation results are no longer influenced by any further improvement of the mesh size. In this study after grid independent test, we choose the optimum mesh size to get better result.

Meshing is done under the quality criteria of the mesh to get the best and effective result. Cell angle, skewness, expansion rate etc. are in good agreement with the mesh quality criteria. Output generated grid for the air cooled channel with fins is shown in Fig. 3.5 and air cooled channel without fins shown in Fig. 3.6. The present standardized rectangular mesh comprised 195520 nodes and 177444 elements for the air cooled channel with fins and 192558 nodes and 173236 elements for the air cooled channel without fins. In order to preserve the consistency of the mesh, the cell angle is 18^{o}, the skewness is 0.9 and the growth rate is 1.2, which satisfies the quality requirements of the mesh.

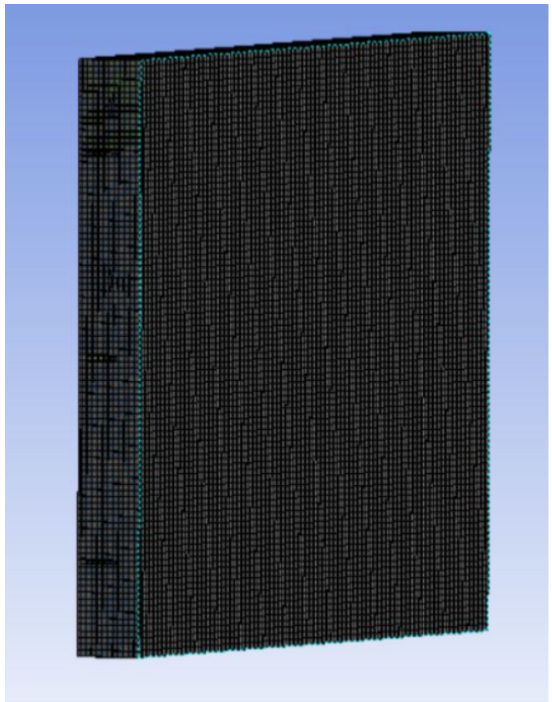

Fig. 3.5 Meshing of air cooled channel with fins

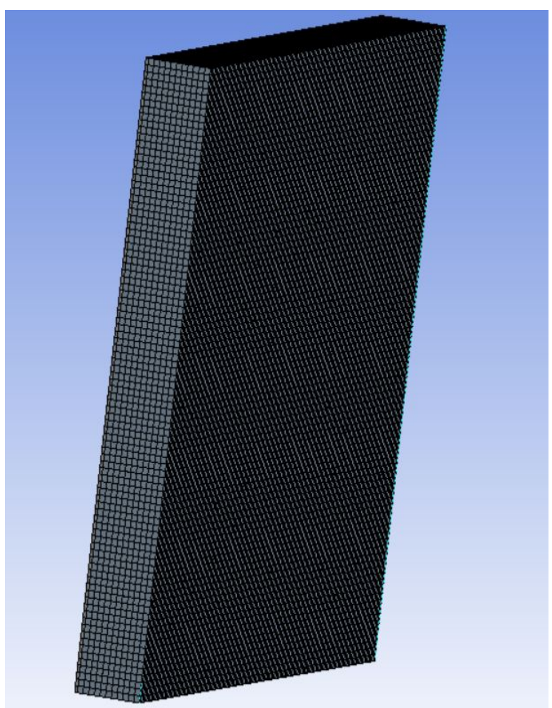

Fig. 3.6 Meshing of air cooled channel without fins

The quality criteria of the mesh maintained in the models are shown in Table 3.3.

Table 3.3 Mesh Quality criteria

Parameter	Quality Criteria
Cell angle	$\geq 18^{o}$
Cell skewness	0.8 to 0.95
Cell expansion rate	≤ 10
Orthogonal quality	>0.01

3.3.1 Grid independence test

Besides the quality of the mesh, there is also a need to perform a grid independence test so that the refined results can be achieved as we reduce the size of the cells. While the grid is refined, more computing power requirements are needed, so the variation in values must be taken into account during the grid independence test, and the refining must be stopped when the variation in output values becomes negligible. From the Table 3.4 and Table 3.5, the grid independence test is shown for the used computational model with fins and without fins respectively.

Table 3.4 Grid independence test of panel temperature for air cooled channel with fins

Number of elements	Panel temperature (°C)	% Variation in panel temperature
46512	18.36	-
64512	19.02	3.59
80615	19.62	3.15
177444	20.09	2.41
235652	20.10	0.04

Table 3.5 Grid independence test of panel temperature for air cooled channel without fins

Number of elements	Panel temperature (°C)	% Variation in panel temperature
32876	19.01	-
54064	20.36	7.10
79056	21.22	4.22
173236	21.92	3.31
226351	21.96	0.17

It, clearly shows that after 177444 number of elements the variation in the values of panel temperature is negligible. Hence the analysis is done choosing 177444 number of elements for air cooled channel with fins. For the air cooled channel without fins analysis is done choosing 173236 elements.

3.4 Boundary Conditions

The solution domain of the three- dimensional, rectangular duct flow considered in the case of an air cooled channel system with fins and without fins. It is surrounded by inlet, outlet and wall boundaries. Air is the working fluid for each device. The properties of the working fluid and various materials of the PV module is assumed to remain constant at average bulk temperatures. The properties of the air used are shown in Table 3.6 below.

Table 3.6 Property of air or fluid

Parameters	Value
Density	1.225 kg/m^3
Specific heat	1006.43 m^2/s
Thermal conductivity	0.0242 kJ/kg K
Viscosity	1.7894e-0.5 W/m K

In the solar PVT system, the photovoltaic panel is the input of solar radiation. While the right wall is related to the atmospheric environment and is adiabatic to the environment. The inlet and outlet section are open to atmosphere in the air cooled channel. In the inlet and outlet air entry and exit area is 0.140 x 0.100 m^2. In the inlet of air cooled channel different mass flow rate is used to check the efficiency and exergy of the system. The top wall and the bottom wall of the air cooled channel are adiabatic.

3.5 Solution Method

The specialization tool Solar Ray Tracing from Fluent Software is the model used to simulate solar radiation. In order to overcome continuity, momentum and energy equations, a computational program called Fluent, based on the control volume method, is used with SIMPLE pressure-velocity coupling. The simulation is performed under steady-state conditions using the turbulence model of the k-ε re-normalization group (RNG). This method uses the relationship between velocity and pressure corrections to ensure mass preservation and to achieve a pressure field. The computer is set up in the equation solver for the First Order Upwind. A fully implicit numerical scheme is used in which upwind differences are used for convective terms and central differences for diffusion terms. The calculation is iterative, the convergence parameters chosen are 10^{-6} for the energy equation and 10^{-3} for the strain, velocity and continuity equations. The taken assumptions are given following;

1. A three-dimensional specific problem considered as steady state condition.
2. In the PV/T system its top and bottom walls are assumed as an adiabatic.
3. The flow of fluid is uniform towards the length of PV panel.
4. The value of atmospheric pressure is 101325 Pa.

3.6 Governing Equations

CFD simulations executed to predict the flow characteristics are governed by following equations:

1. The continuity equation - mass conservation

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \tag{3.3}$$

2. Navier-Stokes equation for the conservation of x-momentum, y-momentum, z-momentum were considered during analysis.

$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial w}{\partial z}\right) = \rho g_x - \frac{\partial P}{\partial x} + \frac{\partial}{\partial x}\left[2\mu\frac{\partial u}{\partial x} + \lambda \mathrm{div}\vec{V}\right] + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)\right] \tag{3.4}$$

$$\rho\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}\right) = \rho g_y - \frac{\partial P}{\partial y} + \frac{\partial}{\partial x}\left[\mu\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right] + \frac{\partial}{\partial y}\left[2\mu\frac{\partial v}{\partial y} + \lambda \mathrm{div}\vec{V}\right] + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)\right] \tag{3.5}$$

$$\rho\left(\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\right) = \rho g_z - \frac{\partial P}{\partial z} + \frac{\partial}{\partial x}\left[\mu\left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)\right] + \frac{\partial}{\partial y}\left[\mu\left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)\right] + \frac{\partial}{\partial z} 2\mu\frac{\partial w}{\partial y} + \lambda \mathrm{div}\vec{V} \tag{3.6}$$

3. Heat transfer equations

$$\rho C_p\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = k\frac{\partial^2 T}{\partial y^2} \tag{3.7}$$

3.7 Thermal Efficiency Performance

The equation of mass flow rate of air is expressed by,

$$\dot{m} = \rho A v \quad (3.8)$$

$$Q_u = \dot{m} C_p (T_o - T_i) \quad (3.9)$$

$$\square_{Th} = \dot{m} \frac{C_p (T_o - T_i)}{A_{pv} G} \quad (3.10)$$

Where,

ρ = density of air

A = cross-sectional input area of air

v = input velocity

Q_u = heat rejected by air cooled channel

A_{pv} = solar panel incident radiation area

T_i = input temperature

T_o= outlet temperature

3.8 Exergy analysis

The following assumptions are made during analysis which are presented as given below:

1. Quasi-steady-state condition is considered in the system.
2. Specific heat of air considered constant.
3. The temperatures of the glass cover, solar cells, tedlar, duct, and insulation vary only in the direction of flow of the air.

The mass balance equation can be expressed in the rate form as;

$$\Sigma \dot{m}_i = \Sigma \dot{m}_o \quad (3.11)$$

The effects of kinetic and potential energy are neglected, the energy and exergy balances can be expressed in rate form as given below.

$$\Sigma \dot{E}_I = \Sigma \dot{E}o \quad (3.12)$$

$$\Sigma \dot{E}x_i - \Sigma \dot{E}x_o = \Sigma \dot{E}x_{irre} \tag{3.13}$$

Using Equation (3.12) the rate form of the general exergy balance can be expressed as follows:

$$\Sigma \left(1- \frac{T_a}{T_s} \right) \dot{Q}_s - \dot{W} + \Sigma \dot{m}_i \psi_i - \Sigma \dot{m}_o \psi_o = \dot{E} \tag{3.14}$$

Where,

$$\psi_i = (h_i - h_a) - T_a (S_i - S_a) \tag{3.15}$$

$$\psi_o = (h_o - h_a) - T_a (S_o - S_a) \tag{3.16}$$

Substituting Equation (3.15) and (3.16) in Equation (3.14), it can be rearranged as,

$$\left(1- \frac{T_a}{T_s} \right) \dot{Q}_s - \dot{m} \left[(h_o - h_i) - T_a (S_o - S_i) \right] - \dot{E}x_w = \dot{E}x_{irre} \tag{3.17}$$

Where

"$\dot{Q}_s$" is the solar energy absorbed by the panel absorber surface and it is evaluated with the expression given below.

$$\dot{Q}_s = G (\alpha\tau) A_{pv} \tag{3.18}$$

The changes in the enthalpy and the entropy of the system are expressed by:

$$\Delta h = h_o - h_i = C_p (T_o - T_i) \tag{3.19}$$

$$\Delta s = S_o - S_i = C_p \ln \frac{T_o}{T_i} - R \ln \frac{P_o}{P_i} \tag{3.20}$$

By substituting Equations (3.19 – 3.20), into Equation (3.17) the above Equation can be derived as given below.

$$\left(1- \frac{T_a}{T_s} \right) G (\alpha\tau) A_p - \dot{m} C_p (T_o - T_i) + \dot{m} C_p T_a \ln \frac{T_o}{T_i} - \dot{m} R T_a \ln \frac{P_o}{P_i} = \dot{E}x_{irre} \tag{3.21}$$

The exergy destruction or the irreversibility may be expressed as follows:

$$\dot{E}x_{irre} = T_a \dot{S}_{gen} \tag{3.22}$$

$$\dot{S}_{gen} = \dot{m} C_p \ln \frac{T_o}{T_i} - \frac{\dot{Q}_s}{T_s} + \frac{\dot{Q}_o}{T_a} \tag{3.23}$$

$$\dot{Q}_o = \dot{Q}_s - \dot{m} C_p (T_o - T_i) \tag{3.24}$$

The exergy efficiency or second law efficiency may be expressed as follows:

$$\eta_{Ex} = 1 - \frac{Ta\,\dot{S}gen}{\left[1-\left(\frac{T_a}{T_s}\right)\right]\dot{Q}s} \tag{3.25}$$

Closure

A numerical model is formulated to find the cooling effect on the photovoltaic panel and check the efficiency and exergy of the PVT system. A Fluent program is developed on ANSYS software. Air cooled channel with fins and without fins is introduced at different mass flow rate of air in the system. Meshing is done in order to obtain accurate and precise results. The problem is formulated and complete solution procedure is discussed in this chapter.

Results and Discussion

Chapter 4 RESULTS AND DISCUSSION

This chapter presents and discusses the results obtained by solving the previously explained computational model in ANSYS software. In ANSYS software computer fluid dynamic (CFD) program is used for simulation. Grids are kept fine enough so they can obtain reliable and accurate result. An implicit scheme is used for the simulation. Variation of temperature of panel is calculated in both case air cooled channel with finned and without finned at different mass flow rate of air in air cooled channel. The simulation is done for two values of mass flow rate of air, one is 0.0085 kg/s and other is 0.0137 kg/s. The reduction in the solar panel temperature is observed at the various input flux during day hour of the day. Also, calculation of the efficiency and exergy is done for the various input flux of the day in month of January. The simulation results are validated with the results of **Natarajan *et al.* (2015).** A good agreement is found between the result of Natarajan *et al*. and CFD result with max. error of ± 3.79. For the validation same system is made on the ANSYS which is used by Natarajan *et al.* in his study. Validation between Natarajan *et al*. and present CFD simulation work is presented in Fig. 4.1. The motive of the study is to reduce the solar PVT system temperature by adding fins in the air cooled channel behind the solar panel and check the thermal efficiency and exergy variation on the basis of temperature reduction of the solar panel.

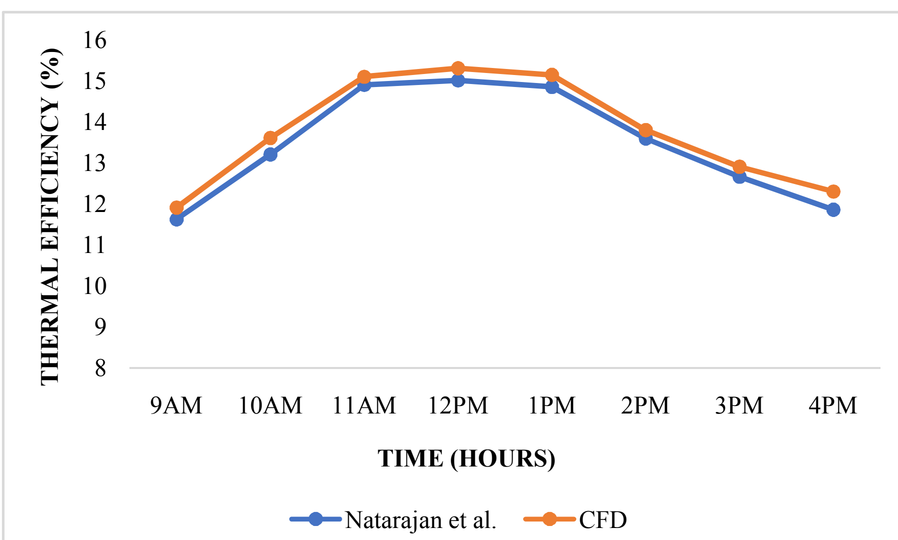

Fig. 4.1 Validation of Thermal efficiency with Time

4.1 Timely Variation on Solar Radiation and Ambient Temperature

Timely variation on solar radiation and ambient temperature is measured with the help pyranometer and digital thermometer. Variation on solar radiation and ambient temperature with day hours is represented in Fig. 4.2. Figure clearly divulge that solar radiation and ambient temperature following dome shape structure between 9:00AM to 4:00PM. Solar radiation and ambient temperature of day hours from 9:00AM to 4:00PM is set with 1 hour interval. Solar radiation is higher during noon, resulting in higher output air temperature, whereas morning and evening temperatures are generally lower, resulting in lower outlet air temperature. The maximum solar radiation and ambient temperature found 987 W/m^2 and 20.83°C respectively at noon 12:00PM. At the morning time 9:00AM solar radiation is 372 W/m^2 and corresponding ambient temperature is 13.23°C. In the evening time solar radiation drop down rapidly from 3:00PM to 4:00PM i.e., 344 W/m^2. But in case of ambient temperature its drop down gradually. Solar radiation is higher at noon and low in the morning and evening hours. The atmospheric temperature ranges between 13.09°C and 20.83°C and solar radiation ranges between 372 W/m^2 to 987 W/m^2 during day hour. The average temperature during day hours is 16.45 °C and average solar radiation is during day hours is 617.25 W/m^2.

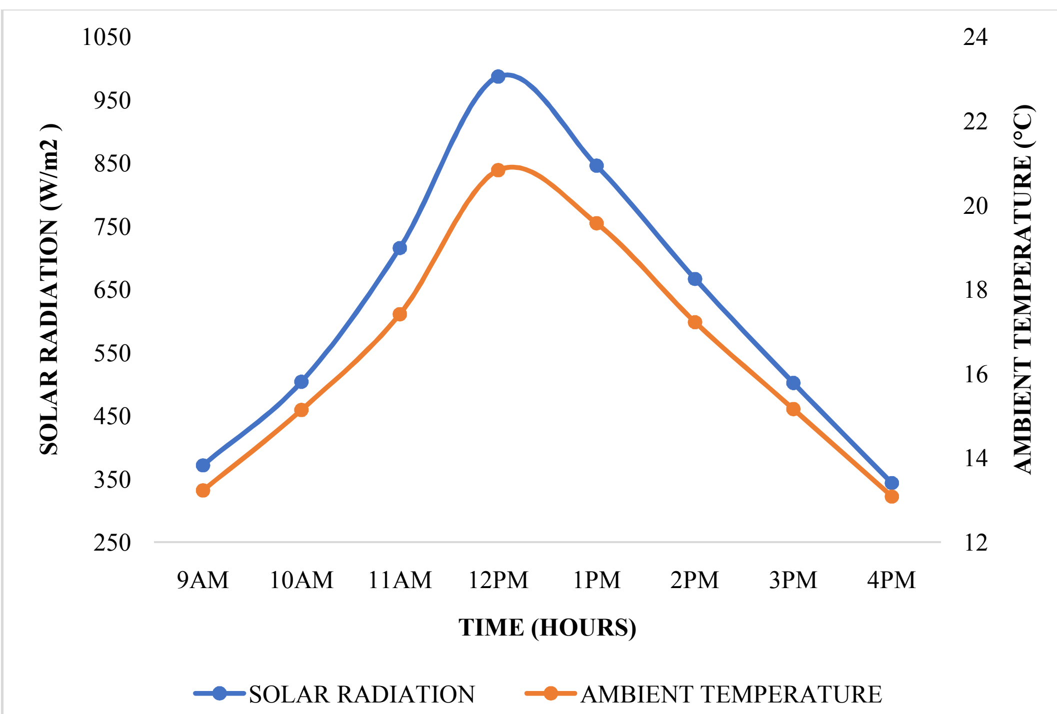

Fig. 4.2 Solar radiation and Ambient temperature Vs Time

4.2 Air outlet temperature of Air cooled channels

The timely variation in entering and exiting air temperature is obtained via simulation for both air cooled channels with fins and without fins at mass flow rate 0.0085 kg/s and 0.0137 kg/s are shown in Fig. 4.3 and Fig.4.4 respectively. The maximum outlet air temperature is found between 11 AM and 1 PM for both air cooled channel with mass flow rate 0.0085 kg/s and 0.0137 kg/s during day hours. This can be attributed to the maximum solar radiation during the specified time period. The inlet air at the entry of the air cooled channel followed by the flow inside the channel with extraction of heat from the back side of the panel and passes along the entire length of the solar PV panel to escape into the atmospheric through the exit of the air channel.

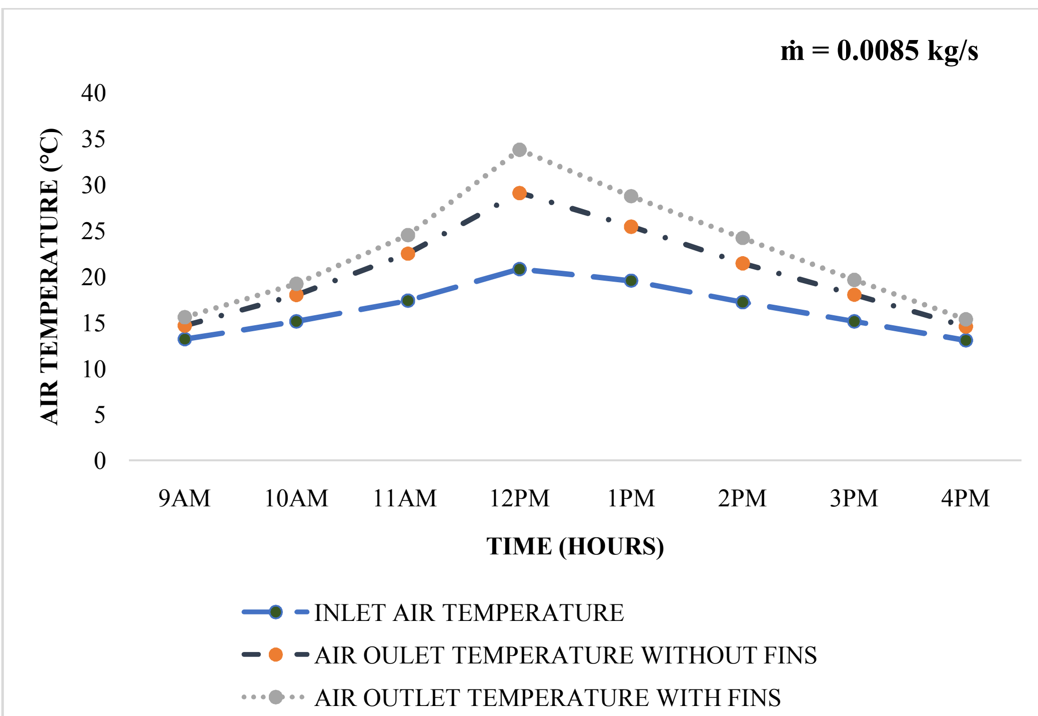

Fig. 4.3 Outlet and Inlet air temperatures for air cooled channel with fins and without fins for mass flow rate 0.0085 kg/s

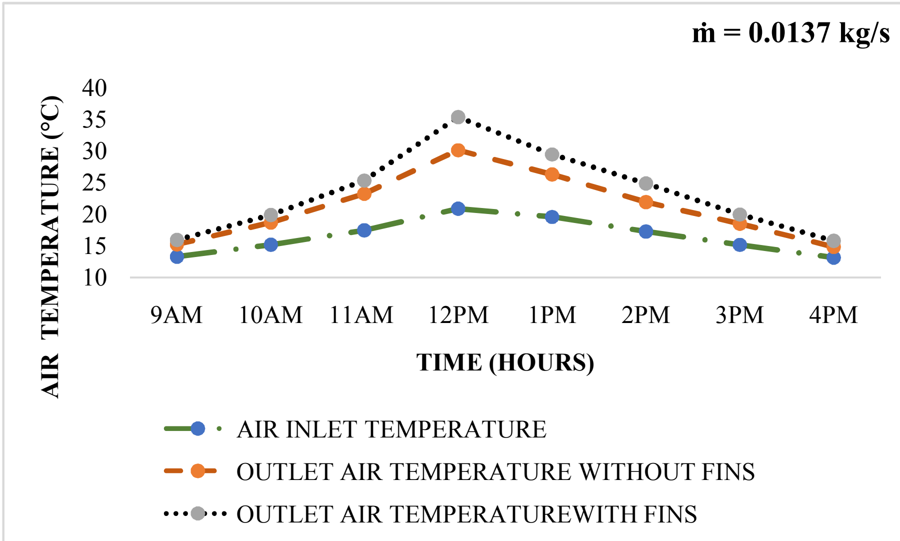

Fig 4.4 Outlet and Inlet air temperatures for air cooled channel with fins and without fins for mass flow rate 0.0137 kg/s.

The inlet air temperature is maximum up to 20.83 °C at 12.00 PM then started to decrease during next hours of the day for both the mass flow rates of air. The rate of heat transfer depended on the panel surface temperature and mass flow rate of air. However, it is also found that the thermal losses (conductive, convective and radiative) increased with increase in PVT system temperature. The air cooled channel without fins maximum outlet air temperature is found to be 29.12 °C at 12 noon for mass flow rate 0.0085 kg/s. The air cooled channel without fins, minimum outlet air temperature is 14.59 °C at 4 PM in evening for mass flow rate 0.0085 kg/s. The air cooled channel without fins, average outlet air temperature is 20.49 °C for mass flow rate 0.0085 kg/s. Similarly, the air cooled channel with fins maximum outlet air temperature is found to be 33.82 °C at 12 noon for mass flow rate 0.0085 kg/s. The air cooled channel with fins minimum outlet air temperature is found 15.36 °C at 4 PM in evening for mass flow rate 0.0085 kg/s. The air cooled channel without fins, mean outlet air temperature is 22.64 °C for mass flow rate 0.0085 kg/s. When compared to earlier air channel layouts, substantial turbulence is created, resulting in a large quantity of heat extraction.

The air cooled channel without fins, maximum outlet air temperature is 30.11 °C at 12 PM with mass flow rate 0.0137 kg/s. And the air cooled channel without fins, lowest outlet air temperature is 14.79 °C at 4 PM in evening for mass flow rate 0.0137 kg/s. The air cooled channel without fins, mean outlet air temperature is 21.06 °C for mass flow rate 0.0137 kg/s. However, this mean outlet air temperature is comparatively low as compare to air cooled channel without fins at 0.0085 kg/s. The main reason is higher mass flow rate than earlier air cooled channel without fins system. Uniform fins geometry of air cooled channel with fins system improves higher outlet air temperature as compare to without fins on the panel surface. The maximum, minimum and mean outlet air temperature is found 35.32 °C, 15.76 °C and 23.29 °C for mass flow rate 0.0137 kg/s.

4.3 Difference in Inlet and Outlet Air Temperatures

Inlet air temperature for both air cooled channels having fins and without fins channel are linearly followed by ambient air temperature. The difference in outlet and inlet air temperatures is incurred due to the varying physical geometry of the channels and mass flow rate of air. Fig. 4.5 presents the difference between outlet and inlet air temperature of air cooled channel with fins and air cooled channel without fins system for mass flow rate of 0.0085 kg/s. Each air channel has a unique geometry one having fins, therefore the temperature difference for the configuration without fins would be less.

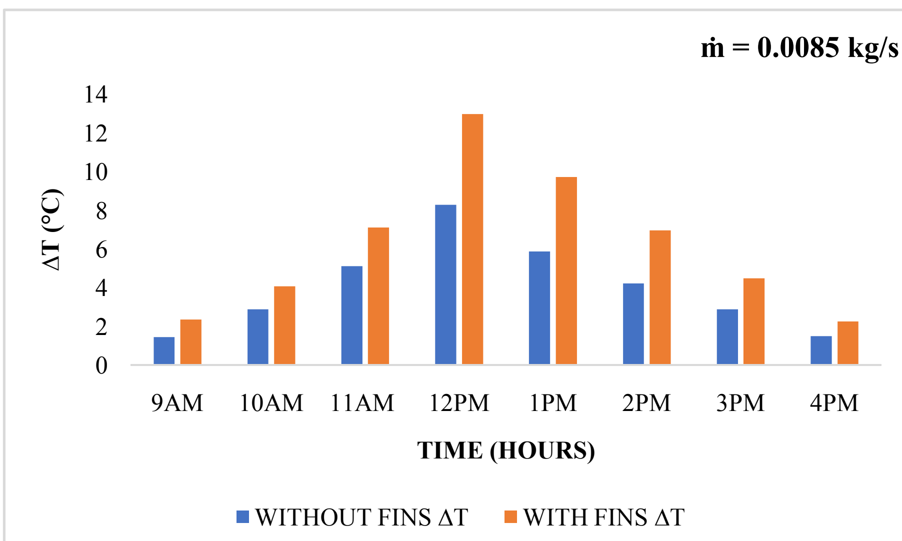

Fig. 4.5 Difference in Inlet and Outlet air temperature Vs Time for mass flow rate 0.0085 kg/s

The mean difference between inlet and outlet air temperature for air cooled channel without fins system is 4.034 °C for mass flow rate 0.0085 kg/s. Likewise, the air cooled channel with fins average difference between outlet and inlet air temperature is found to be 6.25 °C for mass flow rate 0.0085 kg/s. In air cooled channel with fins which has little better yield of temperature difference due to the turbulence effect of air flowing inside the configuration and its maximum difference between outlet and inlet air temperature is found to be 12.99 °C at 12 noon for mass flow rate 0.0085 kg/s. Similarly, the minimum temperature difference between inlet and outlet air of the air cooled channel for the fins less channel is observed 1.463 °C for the mass flow rate 0.0085 kg/s and 2.27 °C is observed for the air cooled channel with fins system at the mass flow 0.0085 kg/s.

The difference between outlet and inlet air temperature of air cooled channel with fins and air cooled channel without fins for mass flow rate of air 0.0137 kg/s is shown in Fig. 4.6. The average difference between outlet and inlet air temperature for air cooled channel without fins system is found 4.60 °C for mass flow rate 0.0137 kg/s. Likewise, the air cooled channel with fins average difference between outlet and inlet air temperature is found to be 6.79 °C for mass flow rate 0.0137 kg/s. With increase in mass flow rate, the turbulence gets increased due to the obstacles thus attaining higher heat transfer rate. In air cooled channel with fins which has little better yield of temperature difference due to the turbulence effect of air flowing inside the configuration and its maximum difference between outlet and inlet air temperature is found to be 14.49 °C at 12 PM for mass flow rate 0.0137 kg/s. Similarly, the minimum temperature difference between inlet and outlet air of the air cooled channel for the fins less channel is observed 1.7 °C for the mass flow rate 0.0137 kg/s and 2.67 °C is observed for the air cooled channel with fins system at the mass flow 0.0137 kg/s.

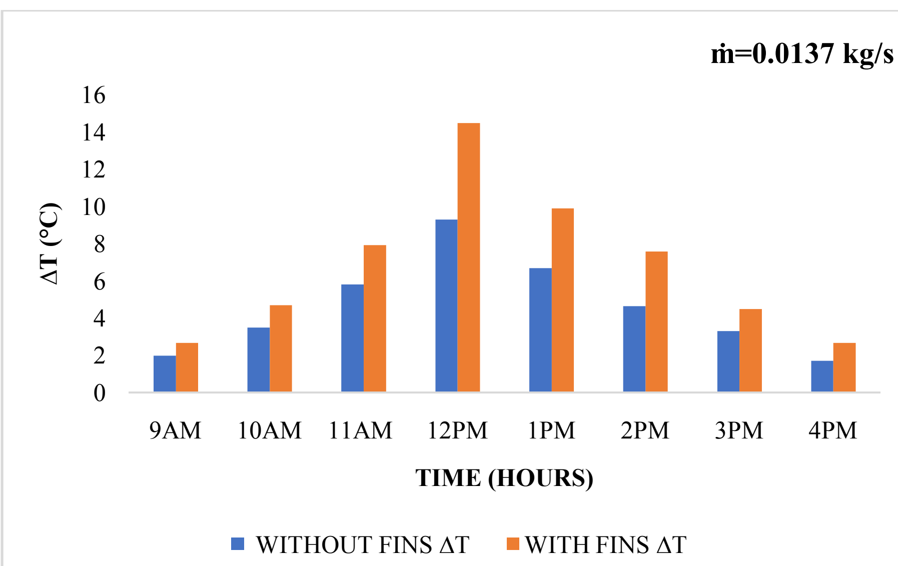

Fig. 4.6 Difference in Inlet and Outlet air temperature Vs Time for mass flow rate 0.0137 kg/s

4.4 Timely Variation on Panel Temperature

The hourly variation of the temperature of the solar panel with air cooled channel without fins and air cooled channel with fins for the mass flow rate 0.0085 kg/s and mass flow rate 0.0137 kg/s are shown in Fig. 4.7 and 4.8 respectively.

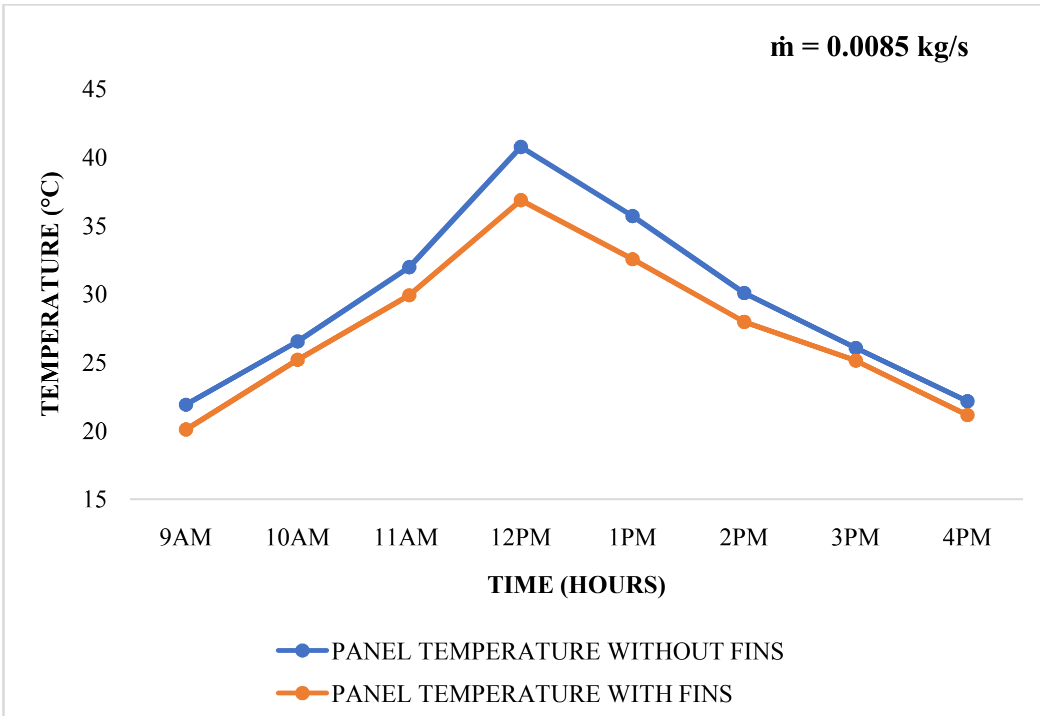

Fig. 4.7 Variation in Solar Panel Temperature Vs Time for mass flow rate 0.0085 kg/s

When sun rays fall on the solar panel, panel surface temperature will increase. Panel surface temperature is always higher than atmospheric temperature because panel surface is a closed body. Moreover, atmospheric air with higher temperature passes on panel surface side which collectively contributes to the increase in panel temperature. Due to low mass flow rate as well as free from obstacles on air cooled channel without fins which obtained high panel surface temperature. As a result, extreme panel temperature is attained to be 40.75 °C, at 12 PM with mass flow rate 0.0085 kg/s, and the mean panel temperature at mass flow rate 0.0085 kg/s is 29.398 °C. While in the air cooled channel with fins attained maximum panel temperature and average panel temperature 36.85 °C and 27.354 °C at the mass flow rate 0.0085 kg/s.

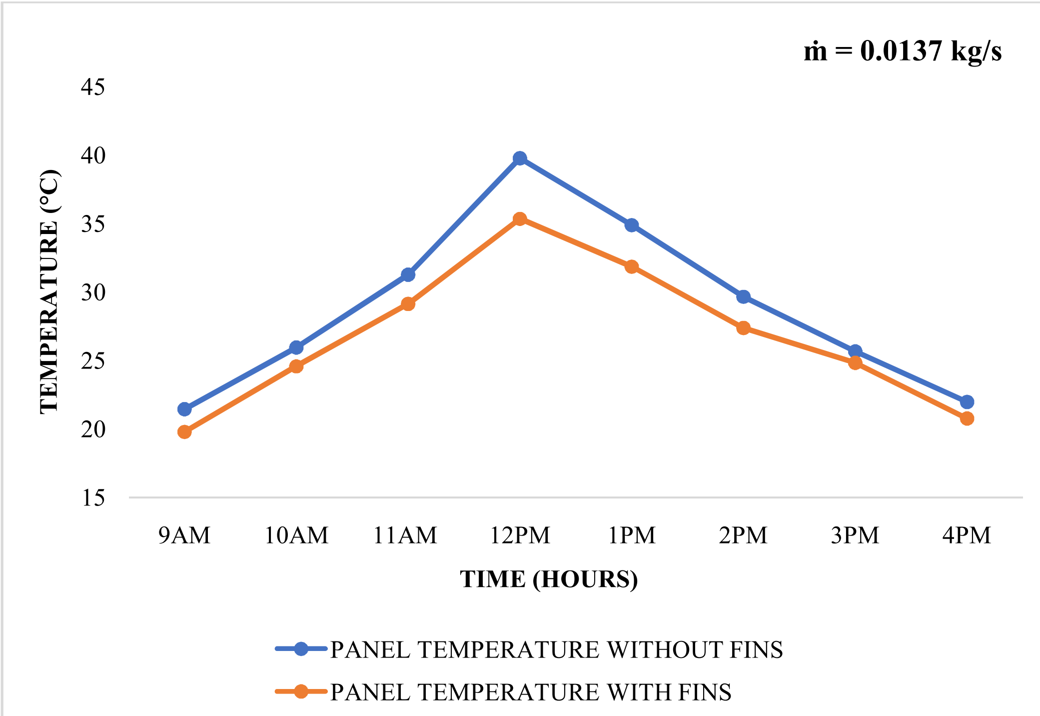

Fig. 4.8 Variation in Solar Panel Temperature Vs Time for mass flow rate 0.0137 kg/s

Similarly, maximum panel temperature is 39.76 °C at 12 noon with mass flow rate 0.0137 kg/s and the mean panel temperature at mass flow rate 0.0137 kg/s is 28.81 °C for the un finned air cooled channel. While in the air cooled channel with fins attained maximum panel temperature and average panel temperature 35.35 °C and 26.70 °C at the mass flow rate 0.0137 kg/s.

4.5 Heat Energy Gained

The difference in outlet and inlet air temperature of the air channel is directly proportional to heat generated (Qu). The heat energy generation is determined by the mass flow rate of air ($\dot{m}$), specific heat of air (C_p) and difference in outlet and inlet air temperature (ΔT). Timely variations on heat energy generated with respect to the time for both the air cooled channel with and without fins with mass flow rate 0.0085 kg/s is shown in Fig 4.9.

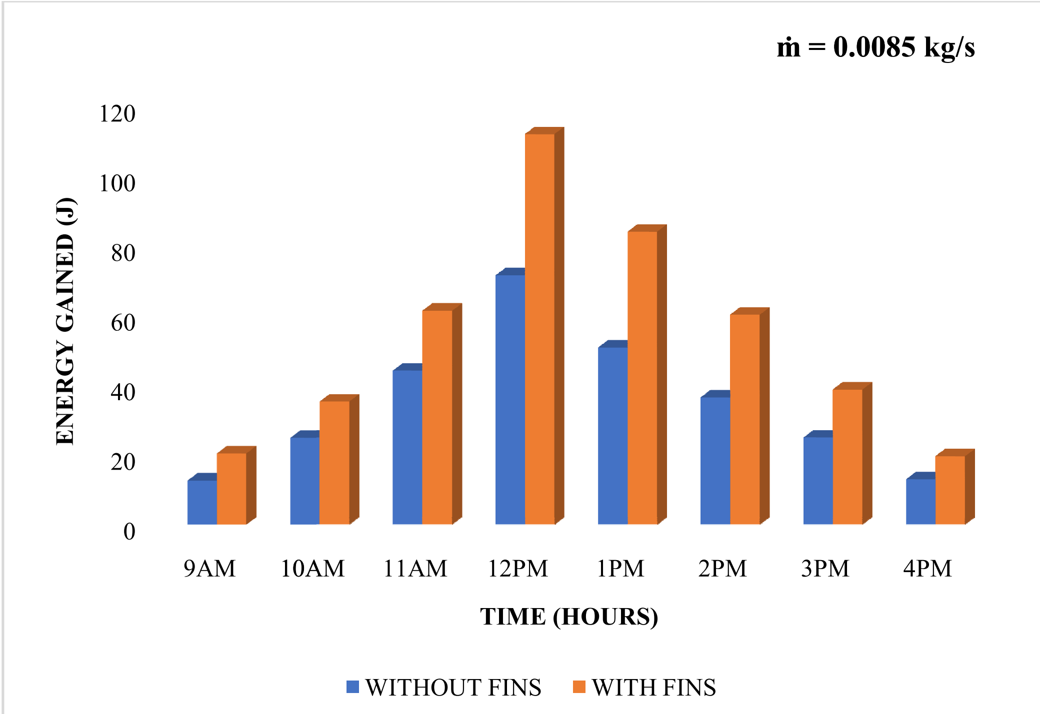

Fig. 4.9 Timely variation Vs Energy gained for mass flow rate 0.0085 kg/s

To evaluate the heat energy gained for both the air cooled channels with mass flow rate of 0.0085 kg/s and mass flow rate of 0.0137 kg/s respectively equation 3.10 is used. There are no barriers in the air cooled channel without fins system hence which generated less quantity of heat energy. As a result, the maximum heat energy generation of air cooled channel without fins is found to be 71.51 J for mass flow rate 0.0085 kg/s. Likewise, the air cooled channel with fins system maximum heat energy gained is 112.05 J with mass flow rate 0.0085 kg/s. In air cooled channel with fins there are barriers on the absorber surface that produced comparatively better heat energy than air cooled channel without fins for both the mass flow rate of air. Therefore, the air cooled channel with fins has maximum heat energy gained is found to be 199.99 J at 12 noon for mass flow rate 0.0137 kg/s. Similarly, the air cooled channel without fins has supreme heat energy gained is 128.08 J at 12 noon for mass flow rate 0.0137 kg/s shown in Fig. 4.10.

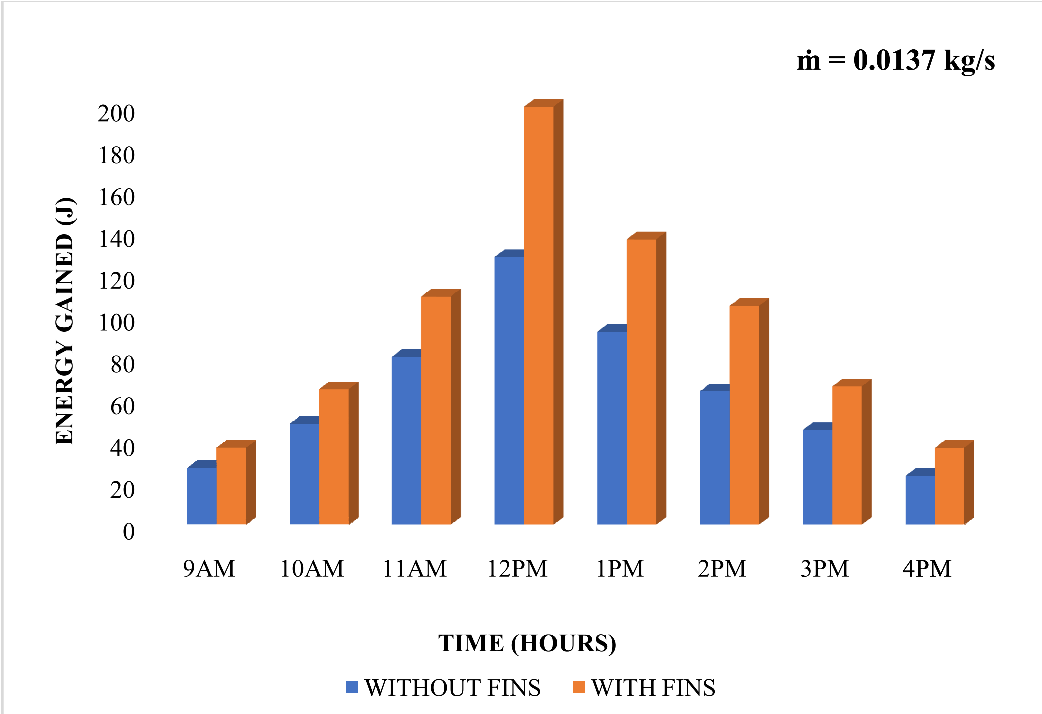

Fig. 4.10 Timely variation Vs Energy gained for mass flow rate 0.0137 kg/s

4.6 Thermal Efficiency Analysis

Thermal efficiency is evaluated on the basis of parameters such as difference in entry and exit air temperature of air cooled channel, mass flow rate of air ($\dot{m}$), specific heat of air (C_p), solar radiation (G) and area of the solar panel (A_{pv}). By increasing in mass flow rate of air gives improved thermal performance. The thermal performance of air channel with fins is better than without fins. The turbulence which is created with the use of fins resulted in distribution of air at all the corners of the air duct. This extracted more heat energy from the panel surface which generated better performance of the system. Hourly variations of thermal efficiency for air cooled channel with fins and air cooled channel without fins for mass flow rate 0.0085 kg/s and mass flow rate of air 0.0137 kg/s are shown in Fig. 4.11 and 4.12 respectively. The air cooled channel with fins contained obstacles of equal shape at an equal distance on its panel surface. Hence, its performance is little better than air cooled channel without fins configuration. Physical geometry form (size, measurements, etc.) the layout and orientation of the impediments influenced improved thermal efficiency. As a result, the maximum efficiency of air cooled channel without fins is 5.45 % for mass flow rate 0.0085 kg/s. Similarly, the air cooled channel with fins system maximum efficiency is 8.54 % with mass flow rate 0.0085 kg/s.

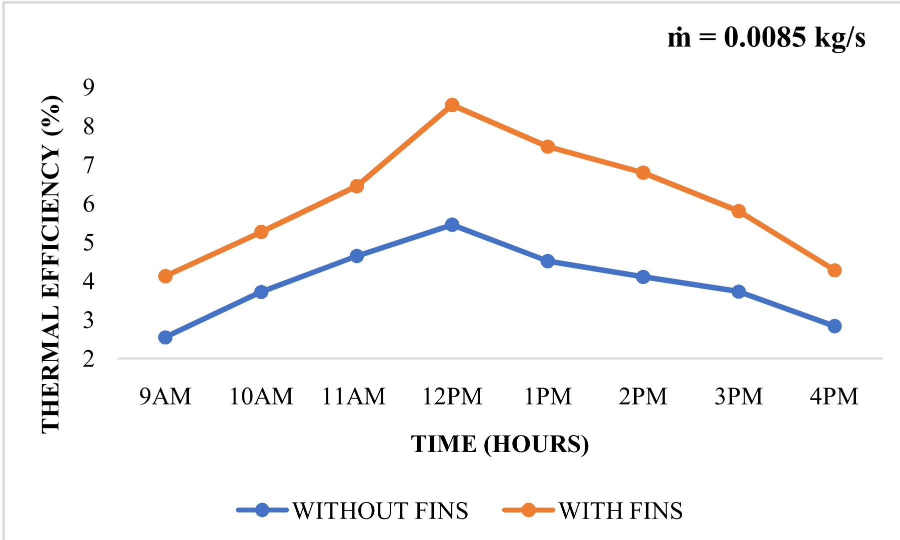

Fig. 4.11 Thermal efficiency Vs Time for mass flow rate 0.0085 kg/s

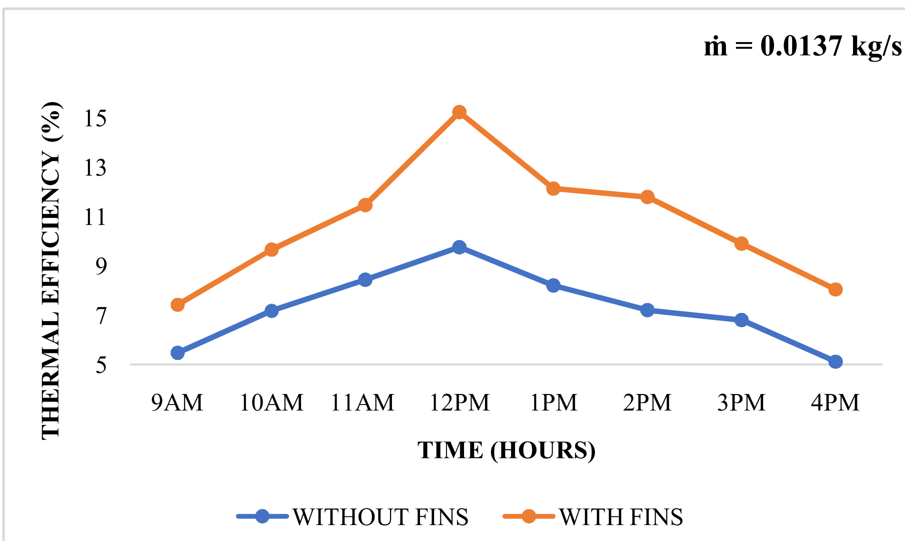

Fig. 4.12 Thermal efficiency Vs Time for mass flow rate 0.0137 kg/s

Similarly, the highest thermal efficiency of the air cooled channel without fins is 9.76 % at 12 noon for the 0.0137 kg/s air mass flow rate and the lowest thermal efficiency is found to be 5.13 % at 4 PM in the evening for the 0.0137 kg/s mass flow rate of air. Similarly, at 12 noon the maximum thermal efficiency is found to be 15.24% and the minimum thermal efficiency is 7.34 % at 9 AM in the morning for 0.0137 kg/s mass flow rate of air. The air cooled channel with fins, mean thermal efficiency is 6.09 % for mass flow rate 0.0085 kg/s and mean thermal efficiency is 10.71 % for mass flow rate of air 0.0137 kg/s.

4.7 Exergy Efficiency Analysis

The second law efficiency performance analysis is analyzed using parameters such as the day's solar radiation (G), the transmittance of the glass cover (τ), the absorption of the solar cell (α), the region of the solar panel (A_{PV}), the air mass flow rate ($\dot{m}$), specific heat of air (C_p), the atmospheric temperature (T_a), the temperature of the PV panel (T_s) and the inlet temperature (T_i) and outlet temperature(T_o) As the atmospheric temperature increases then outlet air temperature increases due to increase in heat transfer rate.

Thermodynamics' second law deals with the loss of energy quality, which states that it is difficult to fully transform low-grade energy into high-grade energy. Energy quality is expressed in terms of energy usage. The peak solar radiation on any day is observed at 12 noon that resulted in high exergy efficiencies of both mass flow rate 0.0085 kg/s and 0.0137 kg/s. On the increment in mass flow rate of air, the thermal and exergy performance also increased. Hence, thermal and exergy efficiency increased as turbulence increased from laminar to turbulent flow with increase in mass flow rate.

Hourly variations of exergy efficiency for air cooled channel without fins and air cooled channel with fins for mass flow rate 0.0085 kg/s is assessed in Fig. 4.13.

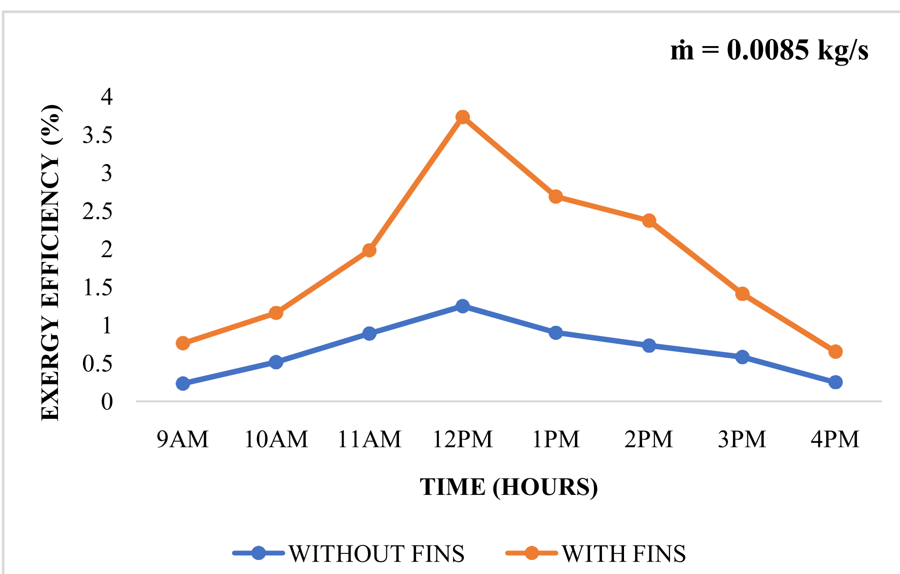

Fig. 4.13 Exergy efficiency Vs Time for mass flow rate 0.0085 kg/s

Due to physical geometrical nature of the air channel and various mass flow rate the exergy efficiency also varies. Though too many factors affect the exergy performance, solar radiation and ambient temperature are the prime factors. When the solar radiation is 987 W/m^2 and ambient temperature is 20.83°C, the air cooled channel without fins configuration maximum exergy efficiency is found to be 1.25 % at 12 PM for mass flow rate 0.0085 kg/s. Subsequently, maximum exergy efficiency is found to be 2.62 % at 12 PM for mass flow rate 0.0137 kg/s. Therefore, an increase in exergy efficiency can be identified with increase in mass flow rate of air. Hourly variations of exergy efficiency with mass flow rate 0.0137 kg/s is assessed in Figure 4.14.

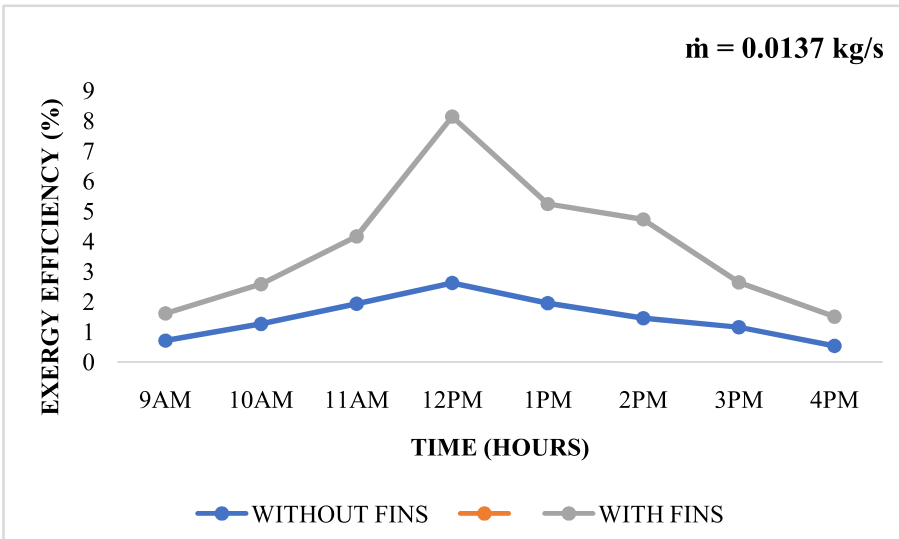

Fig. 4.14 Exergy efficiency Vs Time for mass flow rate 0.0137 kg/s

As mentioned earlier, the geometry of air cooled channel plays an important role in exergy efficiency of the PVT system. When solar radiation is 987 W/m^2 and the ambient temperature is 20.83°C, the exergy performance is high for air cooled channel with fin. Further, the air cooled channel with fins maximum exergy efficiency is 3.73 % at 12 noon for mass flow rate 0.0085 kg/s. Similarly, maximum exergy efficiency is 8.14 % at 12 noon for mass flow rate 0.0137 kg/s.

4.8 Effect of Duct Depth

Three ducts depths viz. 100 mm, 125 mm and 150 mm are considered for the analyses of panel temperature, thermal efficiency and exergy of solar PV/T system without fins for mass flow rate 0.0085 kg/s. During day hours, atmospheric temperature and solar radiation are maintained the same for three different duct depths. Fig. 4.15, 4.16 and 4.17 display the effect of duct depth on the panel temperature, thermal performance and energy of the solar PVT system.

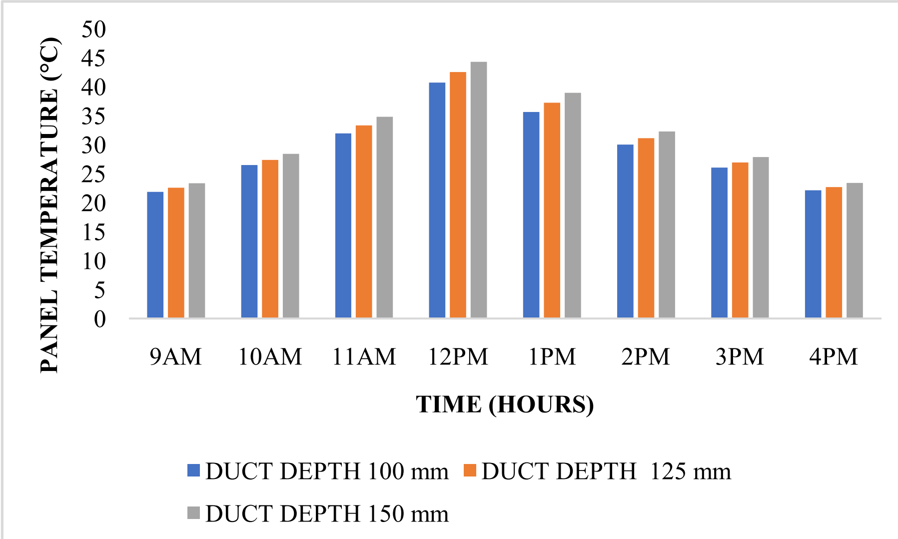

Fig 4.15 PV Panel temperature Vs Duct depth

From the Fig. 4.15, it is observed that the temperature of the PV panel increases with an increase in the depth of the duct. This is due to the increase in the depth of the duct at a constant air mass flow rate decreases the velocity of air in duct, leading to an increase in panel temperature. It can be observed that when the mass flow rate increases at the same duct depth, the PV panel temperature decreases. At a mass flow rate of 0.0085 kg/s, the maximum panel temperature of 44.35 °C exceeds 150 mm duct depth at 12 noon. The minimum panel temperature of 21.923 °C attains at mass flow rate for 100 mm duct depth at 9 AM in the morning.

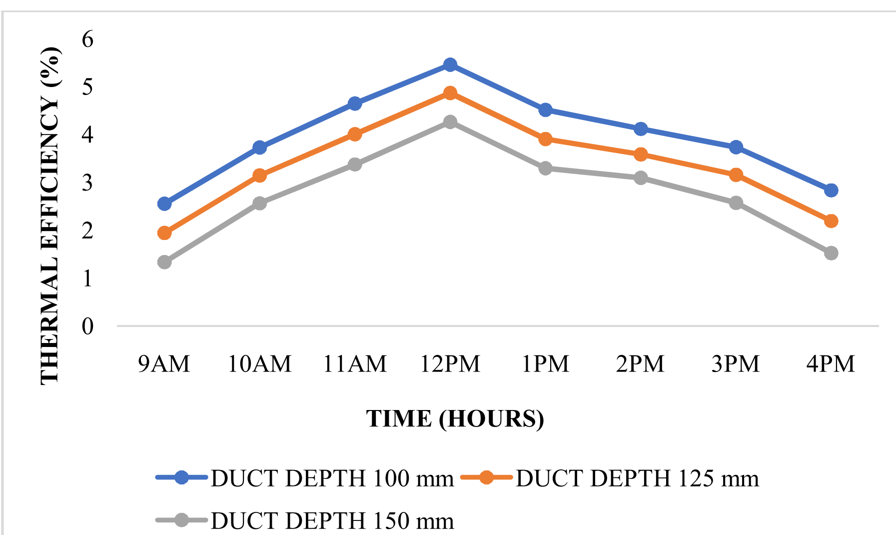

Fig 4.16 Thermal efficiency Vs Duct depth

The variance of thermal efficiency with duct depth for a constant mass flow rate of air with different solar radiation is shown in Fig 4.16. The findings show that, at constant mass flow rate, the thermal efficiency of the PV module decreases with an increase in duct width. This is because the rise in duct depth from Fig. 4.15 raises the temperature of the panel, which contributes to a decrease in thermal efficiency. Thermal efficiency is maximum at a minimum duct depth and vice versa. The maximum thermal efficiency of 5.45 % attains at mass flow rate 0.0085 kg/s for 100 mm duct depth at 12PM. The minimum thermal efficiency of 1.33 % attains at mass flow rate 0.0085 kg/s for 150 mm duct depth at 9 AM in the morning.

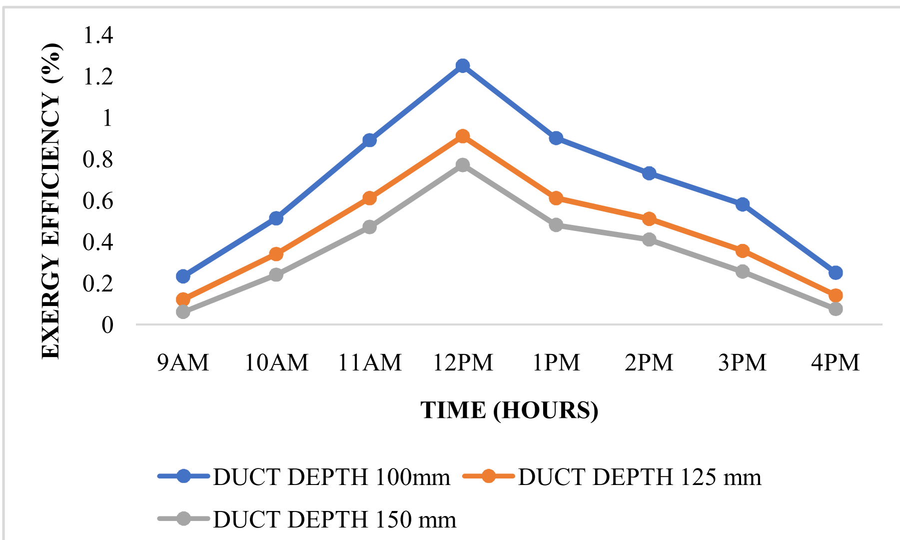

Fig 4.17 Exergy efficiency Vs Duct depth

In addition, the effect of the duct depth on the efficiency of the exergy for a constant air mass flow rate is shown in Fig. 4.17. Exergy efficiency is found to be inversely proportional to the depth of the duct. It is evident from Fig. 4.12 that the rise in duct depth contributes to a degradation in the PV/T system's energy efficiency. Results, the maximum exergy efficiency is obtained 1.25 % for 100 mm duct depth for mass flow rate 0.0085 kg/s. And the minimum exergy efficiency is found 0.06 % for 150 mm at 9 AM at 0.0085 kg/s. The exergy efficiency of 125 mm duct depth is in between 100 mm and 150 mm duct depth. The maximum exergy efficiency for 125 mm duct is 0.91% at 12 PM and minimum exergy efficiency is 0.12 at 9 AM for mass flow rate 0.0085 kg/s.

4.9 Effect of Roughness

Roughness of duct surface and fins surface also play a vital role in the solar PVT system. Roughness of duct surface and fins surface directly affect the temperature of panel, thermal efficiency of solar PVT and exergy efficiency of the solar PVT system.

Panel temperature decreased by increasing the roughness from 0.5 mm to 0.7 mm as depicted in Fig. 4.18 PVT system with fin also divulged the same results, it is due to turbulency created by roughness. Fig. 4.18 clearly divulged that combine effect of fin and roughness of surface decreased the temperature of PVT cooling system. At noon 12 PM maximum temperature of panel was 40.45 °C and due to roughness, it has been drawdown to 38.95 °C for air cooled channel without fins.

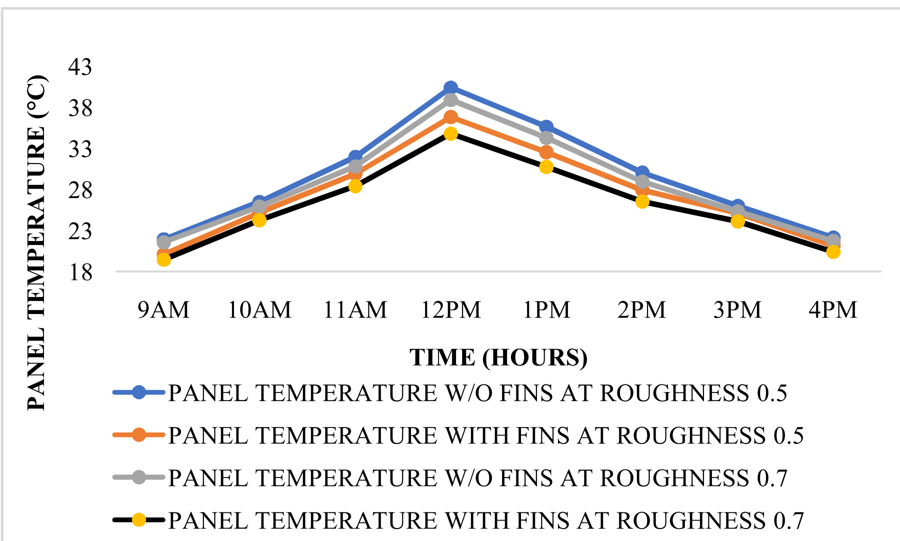

Fig. 4.18 Roughness effect Vs Panel temperature

Figure 4.19 represent the effect of roughness on thermal efficiency of PVT system. As depicted in Fig. 4.16 thermal efficiency increased with roughness of ducts and fins. Maximum thermal efficiency of PVT system achieved at noon 12 PM i.e., 9.78%. Thermal efficiency of PVT system was increased from 8.544% to 9.78% by providing roughness. Increasing the roughness from 0.5 to 0.7 in PVT fin system, 1.25% of thermal efficiency increased at noon 12 PM.

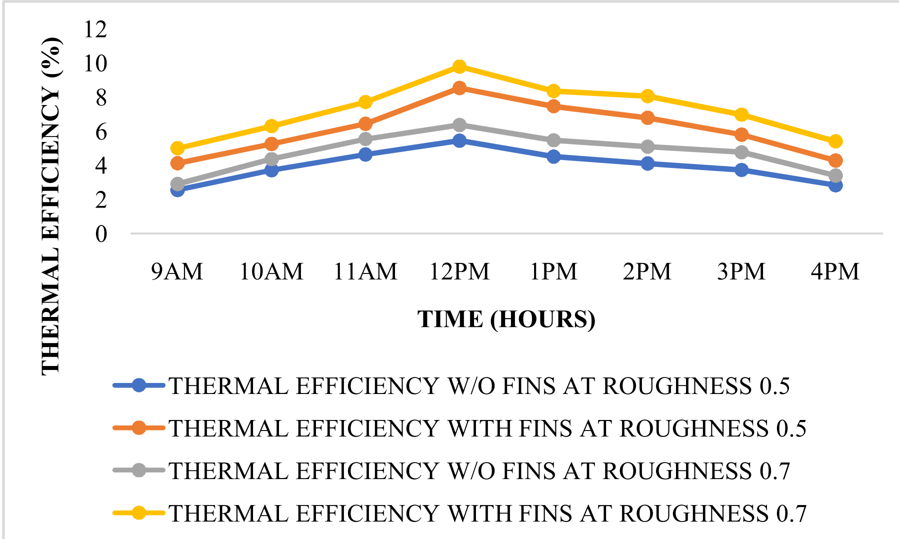

Fig. 4.19 Roughness effect Vs Thermal efficiency

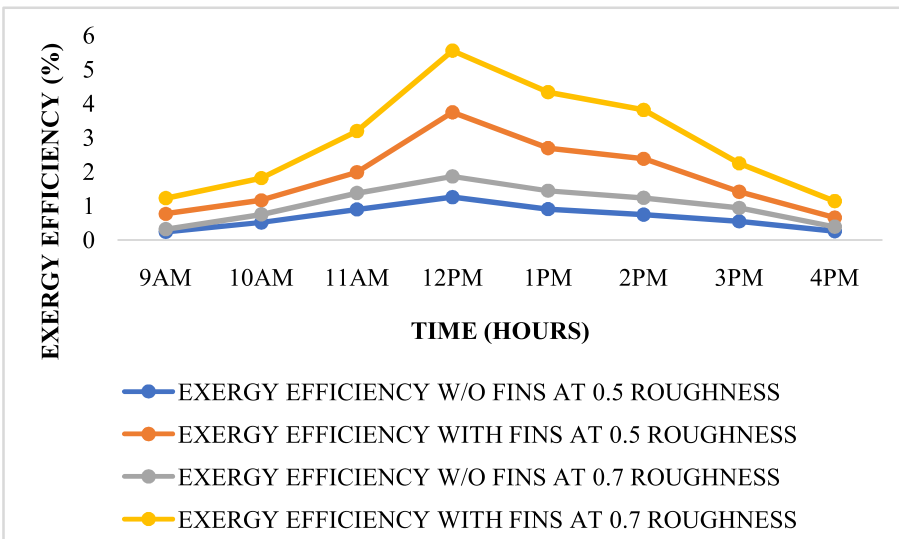

Fig. 4.20 Roughness effect Vs Exergy efficiency

Figure 4.20 divulged the effect of roughness on exergy efficiency of PVT system. As depicted in Fig. 4.17 exergy efficiency increased with roughness of ducts and fins. Maximum exergy efficiency of PVT system achieved at noon 12 PM i.e., 5.55% with fin and 0.7 mm roughness. Thermal efficiency of PVT system was increased from 1.25% to 5.55% by providing fins with roughness.

Hence, the thermal efficiency and quality of energy in PVT system was increased by proving the adequate roughness of ducts and fins surfaces.

Closure

The simulation results of computational model of solar PVT system are presented and compared by using different mass flow rate of air in air cooled channel having fins and without fins. The air cooled channel with fins is more effective and efficient than the air cooled channel without fins. At higher mass flow rate of air, it shows more thermal efficiency and exergy in both air cooled channels.

Summary and Conclusion

Chapter 5 SUMMARY AND CONCLUSION

5.1 Summary and Conclusions

The present study proposes an approach for the simulation of a solar PVT system. Solar PVT is the system that produces heat and electricity simultaneously. Overheating of the solar panel is an important factor for the system's efficiency. For this purpose, the fins cooling technique has been applied. A uniform low-temperature distribution on the panel surface can be achieved by cooing, and the cell temperature can be held under optimal operating conditions. Thus e□ciency and lifespan of the PV panels increases. The numerical models for the cooling of the solar PVT by fins and without fins are developed. The models are developed using ANSYS software in which a computational fluid dynamic (CFD) program is used to simulate all the conditions. The solution of the system gives the temperature effect on the efficiency and exergy of the solar PVT system. To check this effect very fine mesh is used. The solution of the system with computational fluid dynamic (CFD) program uses uniform mesh across the whole length of the air cooled channel including with fins and without fins. The simulation is performed under steady-state conditions.

In the current study, two kinds of air cooled channels are considered for the inspection of performance and energy efficiency of solar PVT systems. According to the findings, it is observed that the performance of PVT systems is based on mainly three parameters: solar radiation, the geometry of the air cooling channels, and the mass flow rate of air. Increment in mass flow rates overall performance of solar PVT systems improved. This is due to turbulence of the air in the air cooled channel.

Besides, the findings also showed that heat transfer rate played an important role in the air cooled channel. From the study, the obtained results give the thermal efficiency in the range between 5 – 16 % for both air cooled channels. Furthermore, for both air cooled channels exergy efficiency is about 1 – 9 %. Fins air cooled channel shows considerably higher performance because of its geometry. Considerably low thermal performance is observed in the air cooled channel without fins due to its poor artificial roughness. The fins provide a strong turbulent airflow in the air cooled channel that improved that help in better system's performance. Using fins there is an enhancement in heat transfer was observed in the photovoltaic module. By increasing the duct depth, it was observed that the performance of the system decreases. Maximum efficiency was observed for 100 mm duct depth and minimum efficiency for 150 mm duct depth. Similarly, by increasing the roughness performance of the system is also increases.

The major irreversibility is found in the air cooled channel without fins where PVT system efficiency is low and lowest irreversibility found in air cooling channel with fins where system efficiency is high. It is evident from the CFD study that the presence of fins leads to an increase in the rate of heat transfer from the surface of the panel to air. However, it is found that with a change in ambient temperature and solar radiation, the exit temperature of the air cooled channel varies.

Following conclusions can be achieved from the present study:

1. By using fins in the air cooled channel the performance and exergy efficiency is improved as compared to the air cooled channel without fins.
2. By using fins reduction in panel temperature is observed which improves its performance.
3. Increase in mass flow rate leads to achieving the better performance of solar PVT systems.
4. Exergy efficiency is the maximum at noon due to high radiation and ambient temperature.
5. Increase in duct depth cause the reduction in the overall performance of solar PVT systems.
6. Surface roughness also affected the performance of the solar PVT system positively as the roughness increases.

5.2 Future Scope

In current research tapered fins are used to evaluate the performance and exergy efficiency of the solar PVT systems. The differently shaped fins can be used for the comparative investigation on the performance of solar PVT systems due to the shape of fins. Variations in fins height in the air cooled channel can affect the performance of solar PVT systems. Arrangement of the fins in the air cooled channel can be helpful to improve the overall performance of solar PVT systems. Change in mass flow rate can be used for further improvements in solar PVT systems. Materials of fins may be a key factor to improve exergy efficiency and performance of solar PVT systems.

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ABSTRACT

Photovoltaic thermal (PVT) systems are systems are used to generate electrical energy and remaining energy lost as heat. One of the most critical parameters influencing the performance and life of PV panels is the temperature of photovoltaic (PV) cells. Higher cell temperature increases the waste heat that is not extracted, thus cell voltage/power decreases with an increase in cell temperature. By cooling the solar cell with a fluid stream like air/water/nano fluids, the electricity conversion can be increased. In addition to this, heat energy can be used for other applications such as space heating, drying of agricultural products, paint spraying and related processes.

In present work, exergy analysis is done for a solar PVT system having fins in an air-cooled channel attached at the back of the PVT system. For this a 3-D numerical model is developed. Numerical simulations are achieved using ANSYS-Fluent software. The comparative study of air cooled channels with fins and without fins are performed considering two mass flow rates of air of 0.0085 kg/s and 0.0137 kg/s. The parameters such as panel temperature, inlet and outlet air flow temperatures in the air cooling channels are analyzed. Effect of duct depth on the panel temperature, thermal efficiency and exergy efficiency is analyzed. Also, roughness of the duct and fins surfaces on the panel temperature, thermal efficiency and exergy efficiency is analyzed.

The results of the PVT system showed considerable improvement in thermal performance with using fin in air cooled channel. The maximum thermal performance observed 8.54 % at a mass flow rate of 0.0085 kg/s and 15.24 % at a mass flow rate of 0.0137 kg/s for the air cooled channel with fins. Subsequently, the maximum exergy efficiency was attained as 3.73 % at a mass flow rate of 0.0085 kg/s and 8.14 % at a mass flow rate of 0.0137 kg/s in air cooled channel with fins. However, the increment in duct depth decreases the thermal efficiency decreased by 0.6 % and exergy efficiency decreased by 0.5 %.

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सारांश

फोटोवोल्टिक थर्मल (PVT) सिस्टम विद्युत ऊर्जा उत्पन्न करने के लिए उपयोग किया जाता है और शेष आपतित ऊर्जा, ऊष्मा के रूप में खो जाती है । पीवी पैनल के प्रदर्शन और जीवन को प्रभावित करने वाले सबसे महत्वपूर्ण मापदंडों में से एक फोटोवोल्टिक (पीवी) सेल का तापमान है। उच्च सेल तापमान अपशिष्ट ऊष्मा को बढ़ाता है जिसे निकाला नहीं जाता है, इस प्रकार सेल वोल्टेज / शक्ति सेल तापमान में वृद्धि के साथ घट जाती है। सौर सेल को हवा / पानी / नैनो तरल पदार्थ की तरह एक तरल पदार्थ की धारा के साथ ठंडा करके, विद्युत् के रूपांतरण को बढ़ाया जा सकता है। इसके अलावा ऊष्मा ऊर्जा का उपयोग अन्य अनुप्रयोगों जैसे कि अंतरिक्ष हीटिंग, कृषि उत्पादों के सुखाने, पेंट छिड़काव और संबंधित प्रक्रियाओं के लिए किया जा सकता है।

वर्तमान कार्य में, पीवीटी प्रणाली के पीछे लगे एयर-कूल्ड चैनल में फिन रखने वाले सौर पीवीटी सिस्टम के लिए एक्सर्जी विश्लेषण किया गया है। इसके लिए 3-डी संख्यात्मक मॉडल विकसित किया गया है। ANSYS-Fluent सॉफ़्टवेयर में संख्यात्मक सिमुलेशन प्राप्त किए गए हैं। फिन और फिन रहित वाले एयर कूल्ड चैनलों का तुलनात्मक अध्ययन 0.0085 किग्रा / सेकंड और 0.0137 किग्रा / सेकंड की हवा के दो द्रव्यमान प्रवाह दर पर विचार करके किया गया है। एयर कूलिंग चैनलों में पैनल तापमान, इनलेट और आउटलेट एयर फ्लो तापमान जैसे मापदंडों का विश्लेषण किया गया है। पैनल के तापमान, थर्मल दक्षता और बाहरी दक्षता पर वाहिनी की गहराई के प्रभाव का विश्लेषण किया गया है। इसके अलावा, पैनल के तापमान पर नलिका और फिन की सतह की खुरदरापन, थर्मल दक्षता और एक्सर्जी दक्षता का विश्लेषण किया गया है।

पीवीटी प्रणाली के परिणामों में ,एयर कूल्ड चैनल में फिन का उपयोग करने के साथ तापीय प्रदर्शन में काफी सुधार दिखा । फिन के साथ एयर कूल्ड चैनल के लिए अधिकतम तापीय प्रदर्शन 8.54% और 15.24% क्रमशः 0.0085 किग्रा / सेकंड तथा 0.0137 किग्रा / सेकंड के द्रव्यमान प्रवाह दर बड़े पर था। तथा फिन के साथ एयर कूल्ड चैनल में 0.0085 किग्रा / सेकंड तथा 0.0137 किग्रा / सेकंड के द्रव्यमान प्रवाह दर अधिकतम एक्सर्जी प्रदर्शन 3.73% तथा 8.14% का अध्ययन क्रमशः प्राप्त किया गया था। हालांकि, वाहिनी की गहराई में वृद्धि से तापीय दक्षता में 0.6% की कमी आई है और एक्सर्जी दक्षता में 0.5% की कमी आई है।

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