SMART SOLAR PANEL COOLING AND CLEANING SYSTEM

A Final Year Project Report

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In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

by

Muhammad Usama Khalid - 288661
Aleeza Waheed - 288015
Malak Khan - 304179
Abuzar Majid - 291210

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EXAMINATION COMMITTEE

We hereby recommend that the final year project report prepared under our supervision by:

Muhammad Usama Khalid	288661
Aleeza Waheed	288015
Malak Khan	304179
Abuzar Majid	291210

Titled: "SMART SOLAR PANEL COOLING AND CLEANING SYSTEM" be accepted in partial fulfillment of the requirements for the award of Mechanical Engineering degree with grade ___

Supervisor: Dr. Usman Bhutta, Title (faculty rank) Affiliation	______________ Dated:
Committee Member: Name, Title (faculty rank) Affiliation	______________ Dated:
Committee Member: Name, Title (faculty rank) Affiliation	______________ Dated:

______________________ ___________

(Head of Department) (Date)

COUNTERSIGNED

Dated: ________________ __________________________

(Dean / Principal

ABSTRACT

Solar power is a vital source of energy for all life on earth, but we lack resources to exploit its availability. Solar panels are a growingly popular renewable energy source; however, they can lose their efficiency significantly due to overheating. To address this issue, researchers have explored various methods for solar panel cooling, including passive and active cooling. In passive cooling, high thermal conductivity or reflecting materials are used, whereas fans or water-based cooling systems are used in active cooling techniques. This project involves the development of a smart water cooling system that monitors a panel's temperature and cools it using a heat exchanger made specifically for effectively cooling solar panels when it rises above its optimum working temperature. Also, due to its high cost, low efficiency and accumulation of dust on solar panels, people refrain from opting this very option. To address this problem, an automated smart solar panel cleaning system is proposed to maintain the optimum efficiency and power output. This approach is mindful of limited water availability in some regions. Moreover, it aims to reduce human involvement in the dangerous process of solar panel cleaning, specifically, in accessible regions. Overall, this project seeks to enhance solar power plant efficiency and promote a sustainable future.

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ABBREVIATIONS

ACH	Air change per hour
a-Si	Amorphous-silicon solar cell
CIS	copper indium gallium selenide solar cell
CdTe	Cadmium telluride solar cell

NOMENCLATURE

F_R	Collector heat removal factor
$F_R U_L$	Thermal losses of solar collector ((W/m^2)/°C)
$F_R(\tau\alpha)$	Conversion factor (optical efficiency of solar collector)

CHAPTER 1: INTRODUCTION

1.1 Motivation

1.1.1 Cooling System

It's becoming clear that the world is transitioning from fossil fuels to renewable energy for several reasons: environmental impact, depletion of resources, cost-effectiveness, and energy security. Environmental issues are a major driver, as fossil fuels are a major contributor to climate change through carbon emissions. Renewable energy sources, like solar, wind and hydroelectric power, produce little to no greenhouse gasses and are much safer for the environment. Fossil fuels are also finite resources that will eventually run out; conversely, renewable energy is virtually limitless and can provide reliable energy for generations. Additionally, the cost of renewable energy technologies has been decreasing in recent years, making them more competitive with fossil fuels in terms of cost and long-term maintenance. Lastly, investing in renewable sources can increase a country's energy security and reduce reliance on foreign sources of energy. All in all, the shift towards renewable energy is driven by environmental, economic and geopolitical factors – ultimately providing a pathway to a more sustainable future.

Solar panels are used that turn sunlight into power. However, solar panels are not very good in converting sunlight to electricity. Most solar panels are about 20% efficient. That means the rest 80% of the sunlight is trapped within the cells, causing them to heat up. Solar panels need to be kept cold in order to enhance their effectiveness and lifespan. This is due to the fact that solar cells become less efficient as they warm up, with the efficiency decreasing by at least 0.3% for every degree over 25°C.

Solar panels can be cooled in a number of ways. Air cooling, which includes moving air over the solar panels to remove heat, is one of the most popular techniques. You can accomplish this by installing. Installing fans or vents in the panels will do this. Water cooling is an additional technique that includes moving water through the panels to dissipate heat. While this cooling technique is more efficient than air cooling, it is also more expensive and maintenance-intensive. Phase change materials and thermoelectric devices are two examples of innovative cooling technologies that some researchers are investigating. Phase change materials may collect and release heat as they change phase, whereas thermoelectric devices can generate power from the temperature difference between the solar panel and the surrounding air.

Overall, solar panel cooling is a crucial consideration for increasing the efficiency and durability of solar panels. Many elements, including cost and upkeep, will determine the type of cooling that is used. The method of cooling chosen will be determined by a number of elements, including cost, maintenance needs, and the climate where the solar panels will be installed. For this an extensive literature review was carried out.

1.1.2 Cleaning System

From stone tools to automotive vehicles to human robots, the world has evolved significant enough and so have humans themselves. From the Stone Age to living a lavish lifestyle, humans have left no stone unturned to keep up with the modern world and adapt to the situations they encounter every day. Although they have achieved success in literally everything, they are still working on some of their creations to make them eco-friendly and sustainable to eliminate the threat they pose significantly to the survival of human race.

Undoubtedly, we have succeeded in making a living in this world, but we are now facing the consequences of our negligence in the form of energy crisis. To overcome this difficulty people have now started installing solar panels in homes, hotels, and at their institutions and work places. Their duty just do not end here. With every installation of solar panel, there comes a ton of responsibility: a responsibility of keeping solar panels alive and treating them as important part of their lives; i.e. by proper cleaning and maintenance.

Solar panel cleaning plays an important role in its working. The sole purpose of a solar panel is the conversion of solar energy radiant on its surface into useful form of energy may it be electricity or heat energy etc. if the surface of the solar panel is not cleaned thoroughly, the intensity of light reaching the photovoltaic cells will decrease which can affect the output power. Hence, decreasing the overall efficiency of the solar panels. Therefore, it is necessary to clean solar panels to ensure efficient working maximum work output.

The frequency with which the solar panel must be cleansed depends upon the several factors including climate, location and the amount of dirt and debris that accumulates on the panels. In general, it is advised to clean the solar panel at least twice a year. However, in places with arid planes, where there is heavy air/land pollution, dust, or other environmental factors that cause the buildup on the panels, it may be necessary to clean them more frequently, perhaps once every two months.

Noticeable changes in working of solar panels i.e.: decreased efficiency or power output, may be an indication that solar panels need cleaning. Areas with frequent rainfall, it may not be necessary to wash solar panels as often since the rain can help to rinse off some of the dust and debris.

Moreover, other than reduced efficiency, filthy solar panel tend to decrease the life of a solar panel. The dirt and debris accumulated on the surface can harm the cells reducing its ability to produce useful form of energy mainly electricity. Also, the build-up of dust on the surface will require extensive cleaning, increasing the maintenance cost. With the installation of solar panels in inaccessible regions comes the hazard of safety for the maintenance workers who may need to climb on the roof for cleaning and regular maintenance.

However, it is necessary to inspect the solar panels and clean them as needed to ensure their efficient working.

1.2 Project Definition

Abundant amount of solar radiation enters the earth atmosphere that can meet the demand for solar power systems. The amount of sunlight available is sufficient enough to fulfill global energy consumption 10, 000 times over. On average, every square meter of land is exposed to enough sunlight to generate 1, 700 kWh of power annually. While solar panels have a positive impact on the environment by reducing the use of harmful power generation plants, they require frequent cleaning. The frequency of cleaning varies depending on the country, with daily cleaning required in Southern Asia, which can be expensive sometimes. There are several methods available for cleaning solar panels, but our proposal is to develop a smart solar panel cleaner that can clean the panel automatically and remotely to maintain optimal efficiency without any human intervention or external assistance.

1.3 Problem statement

Many cleaning systems are expensive, some are not commercially feasible and other are inefficient. Additionally, the majority of solutions are not adaptable to various solar array sizes, and no one has developed a dust sensor that can do instantaneous cleaning in the event of a sandstorm.

Hence, we need a smart cleaning system which should be reliable, applicable for all array sizes, can perform instant cleaning, affordable and commercially viable.

On the other hand, the existing cooling methods for solar panels, including air cooling, clay pot evaporative cooling, water cooling with geothermal systems, nano-plated heat pipe plates, and thermoelectric cooling, suffer from various limitations. Air cooling is inefficient due to the low coefficient of air and high-power consumption. Clay pot evaporative cooling is not feasible on a large scale. Water cooling systems with geothermal systems are also not suitable for large-scale implementation. Nano-plated heat pipe plates offer efficiency but are expensive. Thermoelectric cooling is also costly. Moreover, the current U-tube type heat exchanger fails to effectively maintain optimal panel efficiency. The temperature of the PV cells located between the U-tubes does not decrease adequately, resulting in reduced overall efficiency of the solar panels. Therefore, there is a pressing need to develop a smart, efficient, and cost-effective device or system that can efficiently cool solar panels when the panel temperature surpasses a predefined threshold. This solution should overcome the limitations of the U-tube heat exchanger and deliver enhanced cooling capabilities to prevent performance degradation of the solar panels. The ideal smart cooling system should be efficient, inexpensive, and intelligent, ensuring that the solar panels operate at their peak efficiency.

1.4 Objectives

The objective of first module of the project is to devise a system which could sense the desirable layer of dust on the solar panel surface and immediately clean it so that neither the working nor efficiency is affected by it. We plan to achieve it by making a smart automated solar panel cleaning system which does not involve any labor work and does cleaning itself; which is environment friendly and does not require consumption of harmful material; a system that does not affect the quality of the solar panel.

The objective of second module of the project is to develop a smart solar panel cooling system that addresses the limitations of existing cooling methods and the inefficiencies of the U-tube type heat exchanger. The smart solar panel cooling system has specific objectives aimed at improving the efficiency, sustainability, and performance of solar panels. Firstly, the system focuses on enhancing panel efficiency by effectively reducing panel temperature when it exceeds a predefined threshold. By maintaining optimal temperature levels, the system ensures maximum power generation and overall panel efficiency.

Secondly, the system aims to be cost-effective by utilizing affordable components and technologies, making it accessible for large-scale implementation. This cost-efficiency enables widespread adoption and facilitates the integration of the cooling system into various solar panel installations.

Energy efficiency is another key objective of the system. It is designed to minimize power consumption while efficiently dissipating heat, ensuring overall energy efficiency within the solar panel system. This optimization contributes to the reduction of operational costs and promotes sustainable energy practices.

The system is also scalable, accommodating different sizes and types of solar panel installations. Whether it is a small residential system or a large commercial or industrial array, the cooling system can be easily integrated to enhance cooling performance and panel longevity.

Intelligent control mechanisms are integrated into the system to continuously monitor panel temperature and activate the cooling process when necessary. By utilizing smart and automated controls, energy usage is optimized, and human intervention is minimized.

Reliability and durability are essential considerations, as the system must withstand the challenging environmental conditions encountered in solar panel installations. By ensuring reliability and minimizing maintenance requirements, the system is designed for long-term operation and reduced downtime.

Compatibility and integration are prioritized, enabling the cooling system to work seamlessly with various solar panel technologies and easily integrate into existing and future installations. This versatility promotes widespread adoption and facilitates the transition to sustainable energy solutions.

In summary, the smart solar panel cooling system aims to enhance efficiency, sustainability, and performance, contributing to the broader adoption of solar energy as a renewable and environmentally friendly power source.

1.5 Project Specifications

Cooling system module specifications are given below:

- Cooling Efficiency: Develop a cooling system that effectively reduces solar panel temperature to maintain optimal efficiency and maximize power generation.
- Cost-Effectiveness: Design a system that utilizes affordable materials and components without compromising performance, ensuring cost-effective implementation on a large scale.

- Power Consumption: Minimize power consumption of the cooling system while efficiently dissipating excess heat from solar panels, promoting overall energy efficiency.
- Intelligent Control: Incorporate intelligent control mechanisms to monitor panel temperature and automatically activate and adjust cooling processes in real-time.
- Reliability and Durability: Design the system to withstand harsh environmental conditions encountered in solar panel installations and minimize maintenance requirements.
- Compatibility and Integration: Ensure compatibility with different solar panel technologies and easy integration into existing and future installations.
- Safety Considerations: Comply with safety standards, implement necessary insulation, grounding, and protection mechanisms.
- Data Monitoring and Reporting: Optional inclusion of data monitoring and reporting features for real-time information on panel temperature, cooling efficiency, and energy consumption.
- Environmental Impact: Minimize environmental impact through the use of eco-friendly materials, reduced energy consumption, and proper disposal or recycling practices.

These project specifications aim to deliver an efficient, cost-effective, scalable, and intelligent solar panel cooling system that maintains optimal panel performance and maximizes the benefits of solar energy.

Project specification of cleaning system are given below:

- Dust Sensing Capability: Develop a system with the ability to sense the desirable layer of dust on the solar panel surface accurately. The sensing mechanism should be capable of detecting the optimal threshold of dust accumulation that negatively impacts panel efficiency.
- Automated Cleaning System: Design an automated solar panel cleaning system that can effectively remove dust from the panel surface without the need for manual labor. The cleaning process should be efficient, thorough, and tailored to remove dust without causing damage to the solar panels.
- Environmentally Friendly: Ensure that the cleaning system is environmentally friendly by using methods and materials that are safe and sustainable. Avoid the use of harmful chemicals or substances that could negatively impact the environment during the cleaning process.

- Non-Destructive Cleaning: Implement cleaning techniques and mechanisms that do not affect the quality, structural integrity, or performance of the solar panels. The cleaning process should not cause scratches, marks, or any damage to the panel surface.
- Smart and Automated Operation: Incorporate intelligent control and automation features into the cleaning system. The system should be capable of autonomously initiating the cleaning process based on the detected dust accumulation and perform the cleaning operation efficiently without human intervention.
- Energy Efficiency: Design the cleaning system to minimize energy consumption during the cleaning process. Utilize energy-efficient components and optimize the cleaning process to reduce overall energy requirements.
- Adaptability: Ensure that the cleaning system can be easily adapted and integrated into different types of solar panel installations, accommodating varying sizes, configurations, and technologies.
- Monitoring and Reporting: Include monitoring capabilities to track the cleaning system's performance, including cleaning cycles, dust accumulation levels, and cleaning efficiency. Provide real-time reporting and notifications to alert users of any issues or maintenance requirements.
- Longevity and Durability: Design the cleaning system to be durable and reliable, capable of withstanding environmental conditions typically encountered in solar panel installations. The system should have a long operational lifespan and require minimal maintenance.
- Cost-Effectiveness: Develop a cost-effective cleaning system that offers a good return on investment. Consider the affordability of the system, including the initial setup cost, maintenance requirements, and operational expenses.

By strictly adhering to these project specifications, the primary goal of the smart automated solar panel cleaning system is to proficiently detect and eliminate dust particles from the surfaces of solar panels. This system aims to achieve optimal operational efficiency, prioritize environmental friendliness, and uphold the overall quality and performance of the solar panels.

CHAPTER 2: LITERATURE REVIEW

2.1 Cooling System

Many methods have been proposed to alleviate this issue of solar panels overheating, ranging from passive cooling to active cooling. This literature review seeks to discuss and assess recent research in the subject of solar panel cooling.

Passive cooling approaches: Passive cooling techniques such as reflecting coatings, thermally conductive materials, and radiative cooling have been researched in recent years. A study conducted by Hossain et al. (2020) indicated that reflecting coatings can reduce the temperature of solar panels by up to 10 °C. Additionally, thermally conductive materials such as grapheme and carbon nanotubes have been demonstrated to boost the heat dissipation of solar cells (Suresh et al., 2020).

(M. Kesavan et al., 2016) shows that clay pot evaporative cooling water that employs thin film of water to cool the panel can decrease reflection loss and temperature, therefore boosting the electrical efficiency of the combined system. The temperature of the panel can be controlled by water cooling, and the water that is collected can be heated. In the investigation, a pot water cooled PV/T panel obtained an overall efficiency of 62%, which is greater than water cooled PV/T and simple PV panels. The pot water cooling method keeps the temperature of the panel 5-8°C cooler than the surrounding air through the evaporative impact of cooling water in a clay pot. In comparison to the other two panels, the pot water cooled PV/T panel performed better in terms of electrical efficiency, thermal efficiency, overall efficiency, power output, and sensible heat recovery. Unfortunately, because of the unavoidable water losses in this process, it cannot be used on a large scale.

(Nam Cao Hoai Le et al., 2016) discovered that nano-plated heat pipe plate lowers the temperature variation within the panel to 1.0-2.5°C and reduces the temperature rise of the panel by 47-50%, leading to a recovery of efficiency loss of about 50% and an extended lifetime of solar cells. Analyzing the variation of thermal resistance or comparing temperatures at various sections of the heat pipe plate can be used to determine the heat pipe plate's effective working mode. The current heat pipe plate can deliver a cooling flux of 380 W/m2, which is adequate for the majority of real-world scenarios. However, additional cooling techniques at the condenser section are needed to further improve heat removal ability to 600 W/m2, enabling solar cells to be cooled down to be close to ambient temperature. Also, coating life of the plate is only a few years and this process is pricey.

Active cooling techniques: Active cooling techniques such as water cooling, air cooling, and thermoelectric cooling have also been researched. A study found that water cooling can reduce the temperature of solar panels by up to 25°C, resulting in a 3.5% improvement in power output. Similar to this, air cooling has been proven to be a successful cooling technique; a study by Amin et al. (2020) found that using air cooling increased power output by 5.5%.

Thermoelectric cooling has also been researched as a potential cooling solution for solar panels. A study by Feng et al. (2020) revealed that thermoelectric cooling may reduce the temperature of solar cells by up to 17°C, resulting in a 3.6% improvement in power output. However, thermoelectric cooling has higher costs and energy consumption than other cooling methods.

Active cooling techniques: Active cooling techniques such as water cooling, air cooling, and thermoelectric cooling have also been investigated. A study showed that water cooling can reduce the temperature of solar panels by up to 25°C, resulting in a 3.5% increase in power output. Similarly, air cooling has been shown to be an effective cooling method, with a study by Amin et al. (2020) demonstrating a 5.5% increase in power output with the use of air cooling.

Thermoelectric cooling has also been investigated as a potential cooling method for solar panels. A study by Feng et al. (2020) showed that thermoelectric cooling can reduce the temperature of solar cells by up to 17°C, resulting in a 3.6% increase in power output. However, thermoelectric cooling has higher costs and energy consumption than other cooling methods.

(Abdelgalil Eltayesh et al., 2023) utilized forced convection to cool PV panels. Two different cooling methods were examined: PV panels with forced air-cooling using a lower duct and supplying air using the blower, and PV panels with forced air-cooling using small fans arranged symmetrically on the backside of the PV panels. The temperatures determined by the CFD calculations are compared to the experimentally measured temperatures and it was found to be in good agreement. The results showed that cooling PV using small backside fans can enhance the performance and achieve a maximum total increase of 2.1% in PV panel efficiency with 7.9% saving energy. Using the blower cooling technique achieves a maximum total increase of 1.34% in PV panel efficiency with 4.2% saving energy. This isn’t as efficient as the previous methods and has greater power consumption.

Forced convection was used by (Abdelgalil Eltayesh et al., 2023) to cool PV panels. Two different cooling techniques were looked at: forced air cooling of PV panels using a lower duct and a blower to deliver air, and forced air cooling of PV panels using small fans mounted symmetrically on the backside of the PV panels. When the temperatures determined by the CFD calculations are compared to the temperatures that were recorded experimentally, a good agreement is discovered. The results revealed that cooling PV employing small backside fans can boost the performance and achieve a maximum total increase of 2.1% in PV panel efficiency with 7.9% saving energy. Utilizing the blower cooling technology produces a maximum total increase of 1.34% in PV panel efficiency with 4.2% saving energy.

The usage of a phase change material (PCM) based cooling tower with nano-fluids to increase the electrical efficiency of a solar panel was studied (Masoud Rahimi et al., 2020). The results showed that the flow rate and concentration of nano-fluid had a substantial effect on the temperature reduction of the solar panel, with the largest temperature decrease achieved at a flow rate of 18.91 mL/s and a nano-fluid concentration of 0.1 wt.%. The highest electrical power and efficiency of the solar panel were achieved at the maximum flow rate and concentration of nano-fluid.

(K. Morad et al., 2019) employed geothermal pre-cooled air flow across the back surface of a PV module at an ideal rate of 0.0288 m3/s. Due to the reduction in PV module temperature at this ideal flow rate, improvements in PV module output power and electrical efficiency of approximately 18.90% and 22.98%, respectively, were made on average. According to economic analysis, the suggested cooling system reduces summertime CO2 emissions by roughly 13896 g, which helps to improve the relative levelized cost of energy by 12%. Geothermal cooling through water system has the maximum attainable electricity generation increase of 11.6%. (Jafari, 2021). Overall, geothermal cooling is not a feasible solution as it is costly, requires a lot of space, and isn’t that efficient comparatively.

(Maciej Sułowicz et al., 2022) proposes an innovative thermal collector for photovoltaic-thermal (PV/T) systems. The thermal behaviour of the photovoltaic module and the designed cooling box flow are coupled to achieve the thermal and electrical conversion efficiencies of the water-based PV/T system. Different inlet mass flow rates and temperatures are simulated under normal operating cell temperature conditions (NOCT) (NOCT). Investigated are the layers of the photovoltaic module's temperature distribution and average temperature. The results demonstrate that the PV module achieves an electrical conversion efficiency of 17.79% with a thermal efficiency of 76.13% at a mass flow rate of 0.014 kg/s and an inlet flow temperature of 15 °C. The designed cooling system exhibits better performance with a significant increase in thermal and electrical conversion efficiency compared to current solutions. The research presented in this paper emphasizes the value of PV/T systems and their enormous potential to spread awareness of solar energy while simultaneously harvesting thermal and electrical energy. These panels are however, not available locally and as it's an integrated solution, the existing panels cannot be utilized.

2.2 Cleaning System:

2.2.1 Water spray Cleaning

Water spray cleaners are a common yet not so effective method for cleaning solar panels. They work in a similar way as water sprinklers, a fine mist of water is sprayed on the surface of the solar panel, which loosens and removes any dirt, dust or debris that may be present. Water spray cleaners are also environmentally friendly, as they do not require the use of harsh chemicals or detergents that can be harmful to the environment. However, it's important to note that water spray cleaning may not be suitable for areas with hard water, as mineral deposits can build up on the surface of the solar panel over time and reduce its efficiency.

The limitation of this method is that this method is particularly useful in areas where there is plenty of access to water or where the solar panels are difficult to access. This method is effective only when there is loose dust on solar panels. Bird droppings would be hard to remove if not timely washed from the solar panels. The major drawback of this method is the loss of water in evaporation.

2.2.2 Carbon fiber brush Dry cleaning

Carbon fiber brush cleaning is a gentle and effective method of cleaning solar panels. In this a soft, lightweight and durable brush is used to clean the surface of the solar panels. As the name suggests, no water is used in this process, making it suitable for the regions where the water is scarce or where the solar panels are difficult to access. In this process, brush attached to a telescopic pole allows the operator to reach and clean the solar panels from the ground without the need for ladder or other equipment.

The efficiency achieved with this process is only 2.77% which limits its use for long arrays of solar panels where output and efficiency are main concern.

2.2.3 Microfiber Dry Cleaning

Microfiber dry solar panel cleaning is the most efficient method of all. It uses extremely fine synthetic fibers that are woven together to create a soft, non-abrasive material that is gentle on the surface of solar panels. These cloths are also highly absorbent, which allows them to pick up dirt and debris without leaving any streaks or scratches on the surface.

It is a popular choice for industries which have installed arrays of solar panels in their organizations because it is quick and easy way to keep solar panels clean and functioning at their best without using any water or chemicals. It is also an environmental friendly option as it does not require any additional resource or leave behind any harmful waste.

The only drawback of this method is that the system developed is only applicable to one configuration.

2.2.4 Surface Vibration Cleaning

Surface vibration cleaning is a method of cleaning of solar panels using high-frequency vibrations to dislodge dirt and debris from the surface of the panels. This method uses a specialized cleaning tool, which can be handheld or mounted on a robotic arm, to create rapid vibrations that shake lose any dirt or debris on the solar panel surface.

It is a dry-cleaning method, which means that it does not require the use of water or cleaning solutions. This makes it more environmentally friendly option than traditional cleaning methods, which often require the use of large amounts of water and cleaning chemicals.

The use of graphite-epoxy composite sheet for pasting solar cells makes it uneconomical and not feasible and hence, limits its use on large scale.

2.2.5 Anti-Soiling cleaning

It prevents dirt, dust and other debris from accumulating on the surface of the panels in the first place. This method typically involves the use of specialized coating or treatments that are applied to the surface of the solar panels to repel dirt and debris and make them easier to clean surfaces and reducing the frequency of cleaning required.

The coatings include hydrophobic coatings to glass or ceramic surfaces, which repel water and prevent the accumulation of dirt and other contaminants. Other methods may involve the use of chemical treatments, such as those that create a self-cleaning effect on surfaces, or physical methods such as the use of air or water to remove dirt and debris from the surfaces.

This method is highly expensive due to the use of hydrophobics and high installation cost. The use of hydrophobics also reduces the life which limits its use for even a single array of solar panel.

2.2.6 Electrostatic Repulsion Cleaning

One of the hot topics right now among all the solar panel users is the electrostatic cleaning. MIT is currently doing research on its applicability and workability.

Electrostatic repulsion cleaning is a method that uses electrostatic charge to attract and remove dirt and debris from the surface of solar panels. This method uses a special tool called an electrostatic cleaning device, which generates a static charge that attracts and remove dirt and debris form the surface of the solar panels.

It is highly effective cleaning method, as it is able to remove even the smallest particles of dirt and debris that may not be visible to the naked eye. This method is also very efficient, as it can clean large areas of solar panels quickly and effectively.

One of its benefit is that it does not require the use of water or cleaning solutions, making it an environmental friendly option. Additionally, this method does not require any physical contact with the solar panels, which reduced the risk of damage or scratching.

Overall, electrostatic cleaning of solar panels is an effective and efficient cleaning method that can help to ensure that solar panels are working at their best by removing dirt and debris that can impact their performance.

This concept seems quite fascinating but this idea comes with some drawbacks of its own. This technique is indeed innovative: however, cost competitiveness is still a key issue for their feasibility and commercialization.

CHAPTER 3: METHODOLOGY

3.1 Cooling System

Now that the research part is done so we are heading towards narrowing down the approaches. The two major techniques that we have tried to perform cleaning are:

- Cooling of solar panel through U-Tube heat exchanger
- Flat Plate heat exchanger with V-shaped pattern installed behind the plate of solar panel.

3.1.1 U-Tube Heat Exchanger

A U-tube heat exchanger is a type of heat exchanger that is designed in a U-shaped configuration. It consists of two parallel tubes that are bent in a U-shape, with the ends of the tubes located at opposite ends of the heat exchanger. The U-tube heat exchanger is typically used for heat transfer applications, where one fluid flows through the tubes while another fluid flows over the tubes.

3.1.1.1 Operation

In operation, one fluid flows through the tubes of the U-tube heat exchanger while the other fluid flows over the tubes. Heat is transferred from one fluid to the other through the walls of the tubes. The U-shape of the tubes allows for a more efficient transfer of heat, as it creates a longer path for the fluids to flow, increasing the amount of heat transfer that occurs.

3.1.1.2 Application in Solar Panels

When a U-tube heat exchanger is installed at the back of a solar panel, it can be used to transfer heat from the solar panel to a fluid, such as water or air. The U-tube heat exchanger is typically connected to the solar panel using a series of pipes or hoses.

The main function of a U-tube heat exchanger installed at the back of a solar panel is to increase the efficiency of the solar panel. This is achieved by transferring excess heat away from the panel, which prevents the solar panel from overheating and losing efficiency. When a solar panel becomes too hot, its efficiency decreases as the temperature of the solar cells increases. This is because solar cells are most efficient at converting sunlight into electricity when they are kept cool.

By installing a U-tube heat exchanger at the back of a solar panel, excess heat can be transferred away from the solar cells, which can maintain the efficiency of the panel. The heat is transferred to a fluid flowing through the U-tube heat exchanger, which can then be used for heating or other applications.

One of the most common applications of a U-tube heat exchanger installed at the back of a solar panel is to provide hot water or space heating in a building. The heat generated by the solar panel is transferred to the fluid flowing through the U-tube heat exchanger, which can then be used for these purposes. This can be an efficient way to heat a building, as it uses the heat generated by the solar panel, which is a renewable source of energy.

3.1.1.3 Contribution:

Experiment was designed to analyze the potential of increase in efficiency. The objectives of the experiment were to investigate.

1. How much the solar panel surface is cooled if piping is used with a fluid inside it?
2. How much the fluid inside the piping is heated so that it can be used for other purposes such as internal heating in radiators?

For this a simple analysis was performed to check how much it needs to be cooled to function in an optimized way. The results of the test showed that the panel was not functioning optimally without a cooler.

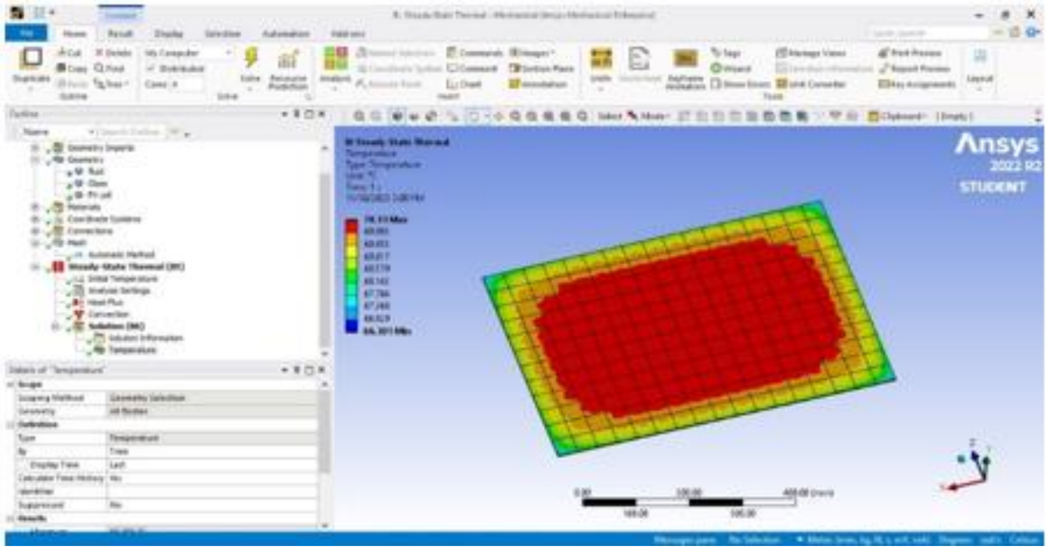


Figure 1: Temperature contours (Ansys) of Uncooled Solar Panel

3.1.1.4 Design

To remedy this, a 3D model of a U-tube heat exchanger was created using SolidWorks. The material of the piping was Copper, and it was designed in such a way that it is enclosed between backside of the panel and a Polymer sheet. There were 2 functions of polymer sheet as follows.

1. It was enclosing the area by providing the support to the piping.
2. It acts as a thermal insulator to not waste any heat which was crucial if that fluid in piping is used for internal heating purposes.

All the assumptions were made as per the original panel as follows,

3.1.1.5 Material Properties

After that we have started analysis on ANSYS. All the material properties are assumed as per the quality of material used in solar panels. The material properties are as follows.

Table 1. Properties of the layers of photovoltaic panel [17]

Layer	Thickness (m)	Thermal conductivity (W/m K)	Density (kg/m^3)	Specific heat capacity J/kg K)
1. Glass	0.003	1.8	3000	500
2. ARC	100×10^{-9}	32	2400	691
3. PV Cells	225×10^{-6}	148	2330	677
4. EVA	500×10^{-6}	0.35	960	2090
5. Rear contact	10×10^{-6}	237	2700	900
6. PVF	0.0001	0.2	1200	1250

Figure 2: Properties of material used in a solar panel

3.1.1.6 Meshing

The next step was meshing that was very challenging. For this step the body was divided into different parts in order to simplify such as

1. Solar Panel part which includes all the layers with it
2. Piping part at the back side of panel
3. Fluid part inside the pipe
4. Air part which is the area at the back.

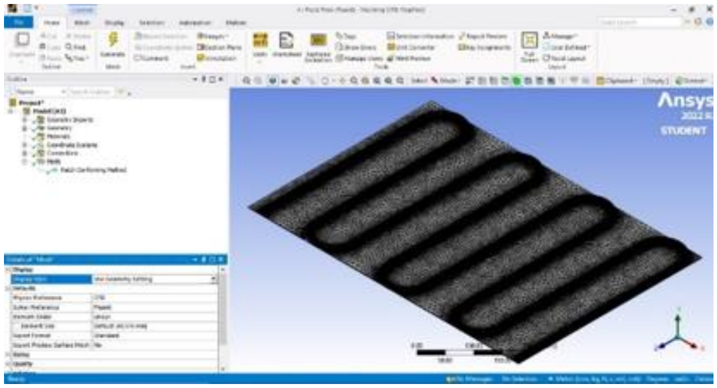


Figure 3: Meshing of U-Tube Heat exchanger in Ansys

3.1.3.4 Analysis

After the meshing part, we moved on to analysis part which we have done with the following assumptions:

- Turbulent Flow
- K-w Model
- Mass Flow Rate = 0.018kg/s

3.1.2 Plate Type Heat Exchanger

Plate type heat exchangers are a type of heat exchanger that use a series of thin, corrugated plates to transfer heat. Normally, there are two fluids i.e. Hot and Cold fluid. But we have designed a novel parallel plate heat exchanger in which heat is transported by only one fluid and it works on the principal of Conduction and Convection.

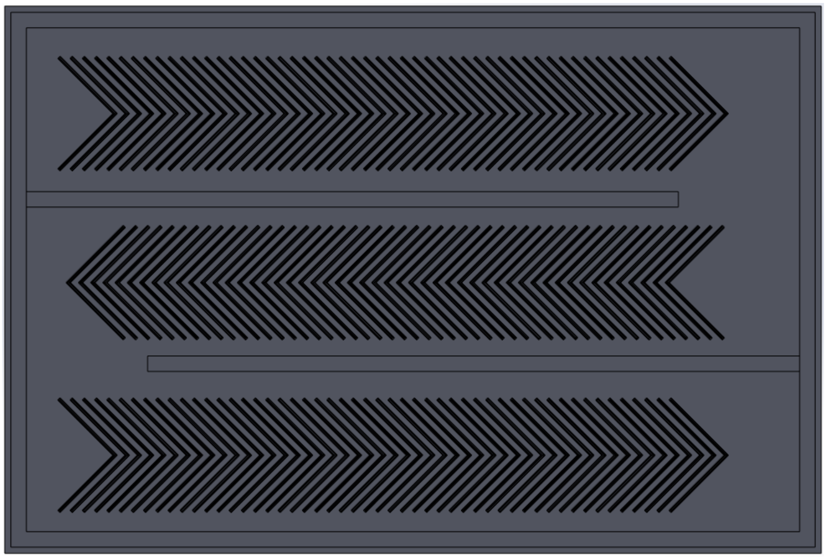


Figure 4: Aluminum Sheet with V shaped pattern engrooved on it

3.1.2.1 Operation:

This parallel plate heat exchanger works in a way that heat is first transported through conduction to the fluid which is continuously moving on the other side. That heat is then transferred to the working fluid and can be used for other purposes such as swimming pool water, geyser water etc.

3.1.2.2 Applications in Solar Panels

Parallel plate heat exchangers are particularly effective in solar panel applications because they can provide high heat transfer rates in a relatively compact design. They are also easy to maintain and can be easily cleaned to prevent buildup of sediment or other contaminants.

The main reason that plate type heat exchangers should be used is that they provide the maximum heat transfer from solar panel to the fluid because the surface of heat exchanger is fully in contact with the back side of solar panel. There is no air entrapped to lower the heat transfer. Plus, the fluid is always in contact with the plates of exchanger transferring maximum heat. These two advantages increase the efficiency of solar panel drastically unlike the U-Tube heat exchanger.

3.1.2.3 Calculations

Assuming the laminar flow without any turbulator or pattern

$$Length\ of\ Exchanger = 26.3\ in = 0.66802m$$

$$Width\ of\ Exchanger = 17.6\ in = 0.4445m$$

$$thickness\ of\ plate = 0.0254\ m$$

$$Surface\ area = 066802 * 0.4445 = 0.029693m^2$$

$$Area\ of\ Cross\ Section = 0.4445 * 0.0254 = 0.01129m^2$$

Prandtl Number is calculated as

$$Prandtl\ number = \frac{4A_c}{P} = \frac{4(0.01129)}{0.0254 + 0.4445} = 0.048108$$

Assuming mass flow rate

$$Q = \frac{1000L}{h} = \frac{0.00027m^3}{s}$$

$$Q = v *\ A_c$$

$$v = \frac{0.02459m}{s}$$

Kinematic viscosity of water is 0.6617 x 10^{-6} m^2/s

$$Re = \frac{v * D}{viscousity} = 1964.9 < 10000$$

That is showing that the flow would be laminar.

Now for the Nusselt number

$$Nu = 7.54 + \frac{0.03\left(\frac{D_h}{L}\right) * Re * Pr}{1 + 0.016(\left(\frac{D_h}{L}\right) * Re * Pr)^{2/3}}$$

Putting the values from above we got

$$Nu = 16.0536$$

Using formula

$$Nu = \frac{h * D_h}{k}$$

Now applying the values

$$h = 99.608 W/m^2C$$

$Q = h * A_s * (Del\ T) = \dot{m} * C_p * \Delta T$

Assuming that the temperature of solar panel plate at the inlet side is 65 Degrees and inlet fluid temperature is 25 Degrees

Now by putting values in the above equation and equating them afterword gives us

$$T_e = 62.52\ Degrees$$

So, considering the above calculation we can see that plate is cooled only 2.5 Degrees

3.1.2.4 Role of turbulators:

Turbulators are devices that can be installed in plate type heat exchangers to increase the turbulence of the fluid flow and enhance heat transfer. In plate type heat exchangers, the fluid flows through channels between the plates, and the presence of turbulators can disrupt the flow and create vortices, which increase the convective heat transfer coefficient.

The use of turbulators can improve the performance of plate type heat exchangers, particularly in applications where high heat transfer rates are required. They can also be effective in reducing the fouling of the heat exchanger surfaces by preventing the accumulation of deposits on the plates. However, the use of turbulators can also increase the pressure drop across the heat exchanger, which can impact the overall efficiency of the system. Therefore, it is important to consider the trade-offs and select the appropriate type of turbulator for the specific application.

Figure 5: Twisted Turbulator

3.1.2.5 Contribution

We have considered 2 main types of turbulators that are twisted tape and square Patterned.

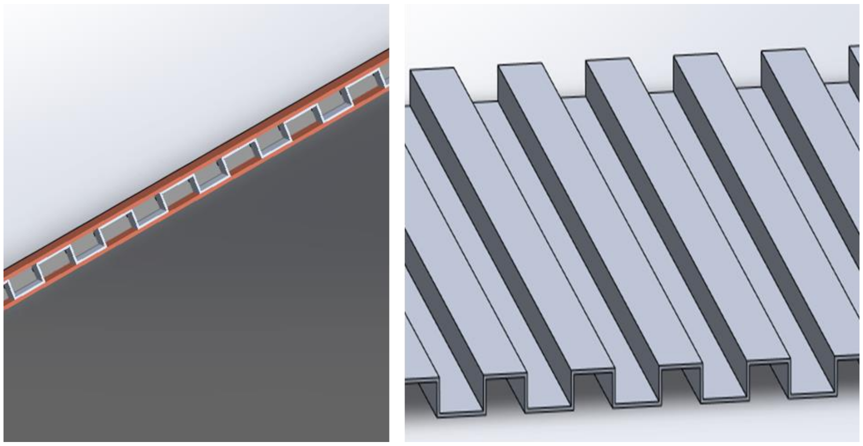


Figure 6: Square Patterned Turbulator

But the issue with them was that they were just making point or line contact with the plate of heat exchanger, but we needed the one which make surface contact with the surface so that there will be uniform heat transfer.

So, there are 2 major challenges while designing a turbulator.

1. Maximize the turbulence so that heat transfer will be maximum because in a turbulent flow the momentum transfer between the layers of fluid is maximum.
2. Minimize the pressure drop so that very less energy is wasted in pumping of fluid.

Keeping in view the above discussion, the only option is to intimate the turbulator shape on one side of the exchanger such that there would be engravings on the plate and they will be acting like the turbulator providing the desired heat transfer along with the minimum pressure drop. So, we designed a pattern shown in the figure below

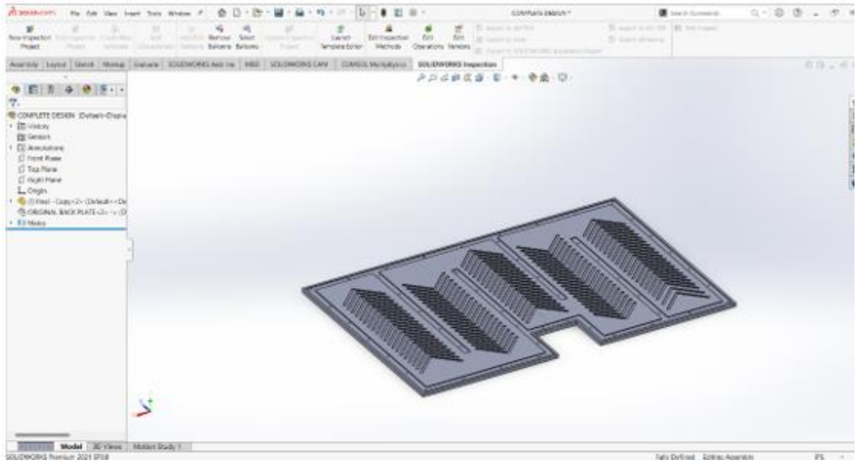


Figure 7: Plate type Heat exchanger solar plate with V shaped patterned engraved on it

The pattern shown in the above figure shows arrow like pattern with 2 lined perpendicular to each other as they provide the maximum heat transfer. [REFERENCE]. This pattern also directs the flow of water from inlet to outlet.

3.1.2.6 Design:

We have designed the overall exchanger with pattern in the plate of it. Fluid is passed over it. The opposite side of exchanger id of polymer sheet to entrap the fluid inside it. Along with it, there is a pattern of gaskets all over the plate

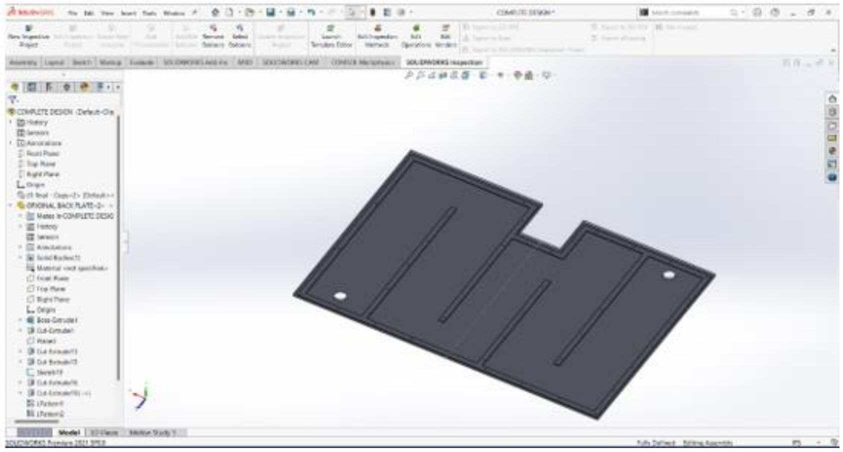


Figure 8: Back plate with inlet, outlet and slots for gaskets

These gaskets direct the flow of the fluid and increase the contact time of the fluid with exchanger so that fluid has enough time to exchange heat. Along with it, there are 2 holes on the polymer plate one for the inlet and one for outlet.

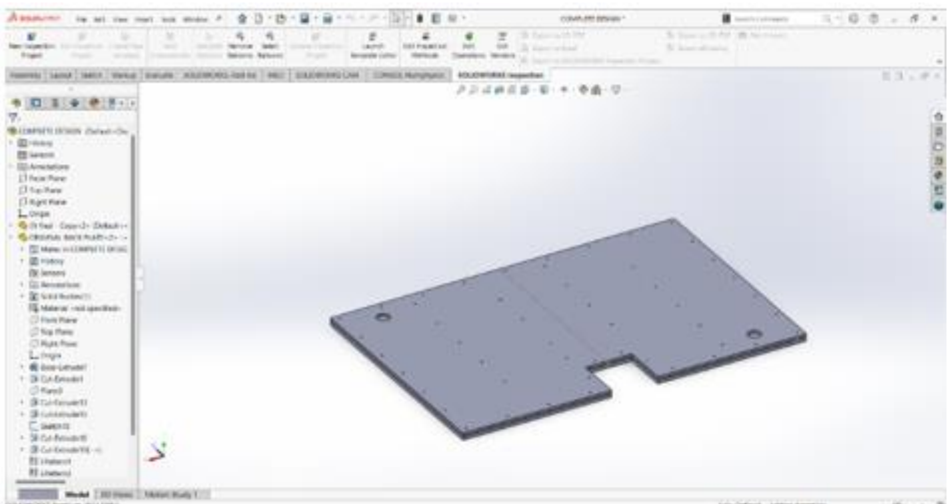


Figure 9: Back plate of heat exchanger

3.2.4.2 Material Properties

After that we have started analysis on ANSYS. All the material properties are assumed as per the quality of material used in solar panels. The material properties are as follows.

Table 1. Properties of the layers of photovoltaic panel [17]

Layer	Thickness (m)	Thermal conductivity (W/m·K)	Density (kg/m^3)	Specific heat capacity J/kg·K)
1. Glass	0.003	1.8	3000	500
2. ARC	100 x 10^{-9}	32	2400	691
3. PV Cells	225 x 10^{-6}	148	2330	677
4. EVA	500 x 10^{-6}	0.35	960	2090
5. Rear contact	10 x 10^{-6}	237	2700	900
6. PVF	0.0001	0.2	1200	1250

Figure 10: Properties of materials used in solar panel

We have taken the material of the exchanger plate as aluminum due to its weight and cost- effective nature as compared to the copper. Along with that the gasket is assumed to be made of cork sheet.

3.2.4.3 Meshing

The next step was meshing that was very challenging. For this step the body was divided into different parts in order to simplify such as

1. Solar Panel part which includes all the layers with it
2. Exchanger plate
3. Fluid part over the plate

3.2.4.4 Analysis

After the meshing part, we moved on to analysis part which we have done with the following assumptions:

- Turbulent Flow
- K-w Model
- Mass Flow Rate = 0.018kg/s

3.1.3 Condenser Design

Another major part of the design is the design of the condenser. Condenser consists of a piping in a helical manner which is placed in a tank.

Now there are 2 paths for the hot fluid from exchanger.

1. Open circuit in consisting of only one fluid and it is continuously moving.
2. Closed circuit in which there are 2 fluids. Hot fluid containing heat from the solar panel exchanges its heat to the fluid present in the tank.

3.1.4 Automation and Control:

We have designed a smart system where the sensors are there to sense any type of temperature and pressure change. As long as the plate is below a certain temperature, the pump will not be started. As soon as the temperature crosses the threshold temperature which is 25 degrees the pump will start and fluid will be started to flow and cooling action will start. The fluid will then be used to heat the other fluid which is present in tank. The tank is attached with valve which will be only opened if the fluid in tank is heated to a certain temperature.

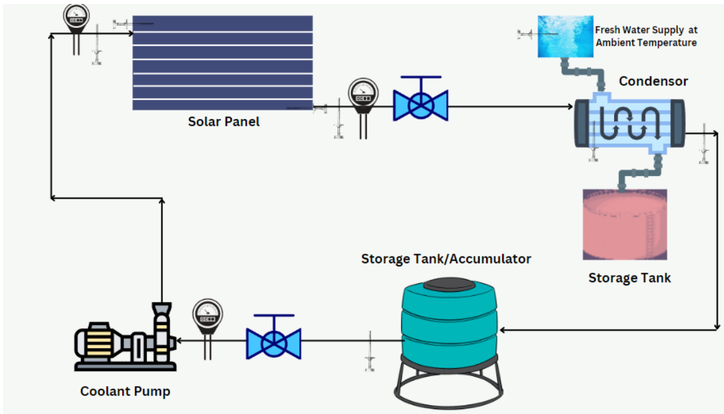
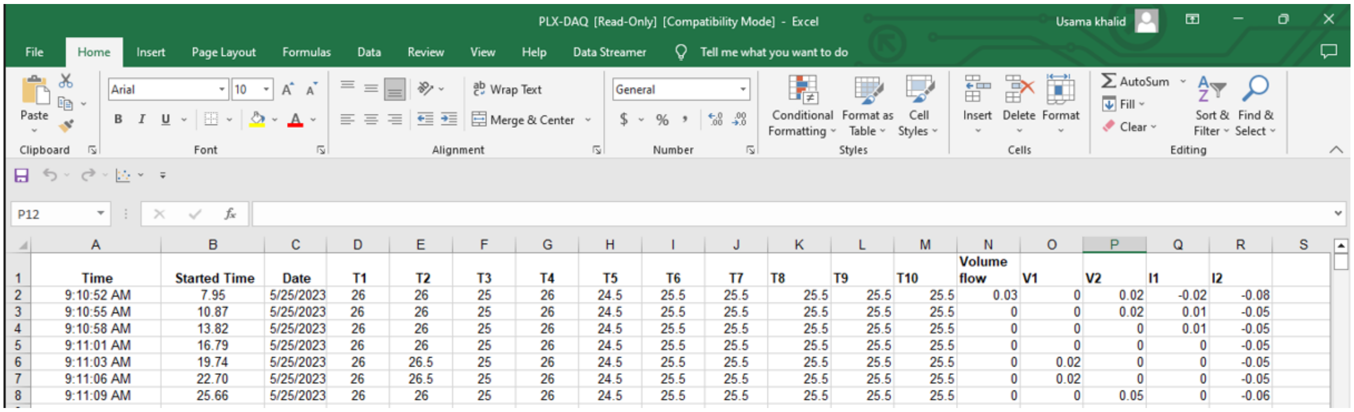


Figure 11: Schematic diagram of Cooling system

Cooling system control system works on Arduino Microcontroller and its code is given in Appendix I. Data Acquisition system transfer data from Arduino to Excel Sheet using PLX-DAQ software. Given below is the screenshot of data recorded from various sensors installed in the test rig of Solar Panel Cooling System,



Time	Started Time	Date	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	Volume flow	V1	V2	I1	I2
9:10:52 AM	7.95	5/25/2023	26	26	25	26	24.5	25.5	25.5	25.5	25.5	25.5	0.03	0	0.02	-0.02	-0.08
9:10:55 AM	10.87	5/25/2023	26	26	25	26	24.5	25.5	25.5	25.5	25.5	25.5	0	0	0.02	0.01	-0.05
9:10:58 AM	13.82	5/25/2023	26	26	25	26	24.5	25.5	25.5	25.5	25.5	25.5	0	0	0	0.01	-0.05
9:11:01 AM	16.79	5/25/2023	26	26	25	26	24.5	25.5	25.5	25.5	25.5	25.5	0	0	0	0	-0.05
9:11:03 AM	19.74	5/25/2023	26	26.5	25	26	24.5	25.5	25.5	25.5	25.5	25.5	0	0.02	0	0	-0.05
9:11:06 AM	22.70	5/25/2023	26	26.5	25	26	24.5	25.5	25.5	25.5	25.5	25.5	0	0.02	0	0	-0.05
9:11:09 AM	25.66	5/25/2023	26	26	25	26	24.5	25.5	25.5	25.5	25.5	25.5	0	0	0.05	0	-0.06

3.2 Cleaning System

3.2.1 Design of cleaning system:

Figure 12: Smart Solar Panel Cleaning System

After conducting a comprehensive literature review, it has been determined that there is a clear need for a solar panel cleaning system that can effectively clean solar panels of any array length and angle, particularly when solar tracking technology is implemented. Furthermore, the cleaning system should be capable of performing immediate cleaning in the event of sandstorms, as well as utilizing a single robot to clean an entire solar park rather than requiring multiple robots to clean each individual array.

In addition, the weight distribution of the cleaning system or robot on the panel surface should be optimized to significantly reduce the risk of micro-cracks on the panel surface. By incorporating these key features into a solar panel cleaning system, it is possible to enhance the overall efficiency and performance of solar energy systems while reducing maintenance costs and efforts.

- The proposed system encompasses several noteworthy features, which are outlined as follows:
- The device is capable of automatically detecting dust accumulation on the solar panel surface and subsequently initiating the cleaning process to restore optimal panel efficiency.
- It can be easily installed on solar panel arrays of any rectangular configuration, allowing it to be precisely calibrated for optimal performance regardless of the number of panels in a vertical direction.
- The cleaning mechanism is executed by the movement of nylon wheels along the edges of the array, enabling it to clean large lengths of the solar panel efficiently.
- The cleaning process is gentle and free from any potential harm or scratches, as it utilizes specialized brushes designed specifically for solar panel cleaning.
- The system is versatile and can perform waterless cleaning, as well as water cleaning, by replacing the cleaning assembly with the appropriate technology.
- The device can detect dust on the panel surface and initiate a rapid cleaning process, providing swift and efficient cleaning capabilities.
- The device is particularly useful for regions frequently affected by sandstorms, such as the Middle East and North Africa, due to its advanced dust sensing capability.
- The system can communicate with a mobile app via WIFI to keep the user informed about cleaning status, current panel efficiency, and cleaning schedules.
- The system's uniform weight distribution and use of nylon wheels can significantly reduce the risk of micro-cracking on the panel surface.

Overall, the combination of these features in the proposed solar panel cleaning system can provide a cost-effective, efficient, and user-friendly solution to ensure optimal solar panel performance while minimizing maintenance costs and efforts.

3.2.2 Cleaning and Drive Mechanism

The proposed cleaning system utilizes a sophisticated mechanism to ensure thorough cleaning of the solar panel array. The cleaning assembly moves along the width of the solar array, while the entire robot moves along the length of the array in increments equivalent to the width of the robot or cleaning brush.

This movement is facilitated by a Lead Screw equipped with stepper motors, which allows the cleaning system to move up and down along the width of the rectangular solar panel array. Additionally, two stepper motors are employed to move the system along the length of the array, with one step of the device in the direction of the array's length corresponding to the width of the device, thereby ensuring comprehensive coverage of the entire solar panel surface.

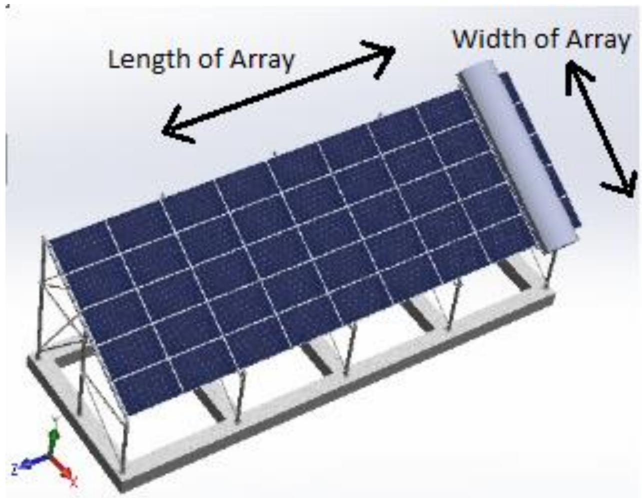


Figure 13: Smart Cleaning System on a rectangular array

Through the utilization of this intricate movement system, the proposed cleaning system can effectively clean solar panel arrays of any configuration, offering an adaptable and versatile solution for maintaining optimal solar panel efficiency.

3.2.3 Adaptable Array Cleaning:

The proposed cleaning system has been designed with adaptability in mind, and to cater to varying array sizes, aluminum profiles/extrusion have been utilized to ensure that the length of the cleaning system can be adjusted according to specific requirements.

The incorporation of aluminum profiles/extrusion in the design of the cleaning system allows for the seamless customization of the system's length to meet the demands of diverse solar panel array configurations.

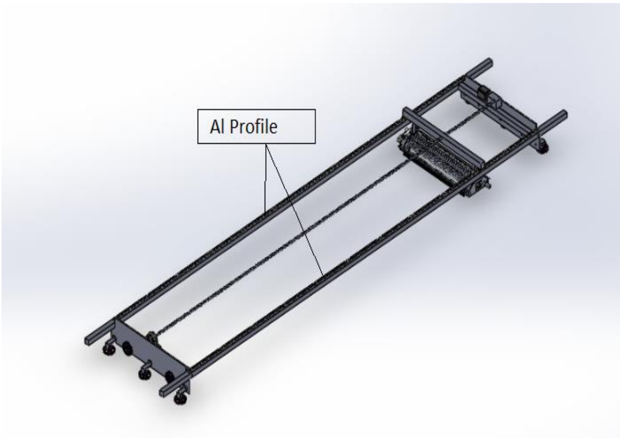


Figure 14a

Figure 14b

Figure 14: : Aluminum Profile/Extrusion

3.2.4 Drive of Cleaning Assembly:

The drive of the proposed cleaning system has been engineered to ensure optimal performance, with T8 Lead Screw supported by nut support and KFL08 bearings serving as key components of the drive system.

The incorporation of the T8 Lead Screw enables the cleaning assembly to be moved at any angle of the array, offering flexibility and versatility in the cleaning process. This is in contrast to pulley systems employed in some of the systems reviewed in the literature, which encounter limitations in movement when the array angle changes beyond 90 degrees. This is due to the gravity pull being in the direction of the pulley pull, making it difficult to move the assembly against gravity. As a result, the assembly system remains close to the pulley and cannot be moved in the opposite direction.

By utilizing the T8 Lead Screw, the proposed cleaning system overcomes these limitations, enabling the cleaning assembly to move smoothly and effectively at any angle of the array, ensuring comprehensive coverage of the entire solar panel surface. This drive system design feature enhances the practicality and efficiency of the cleaning system, providing an adaptable and effective solution for maintaining optimal solar panel efficiency.

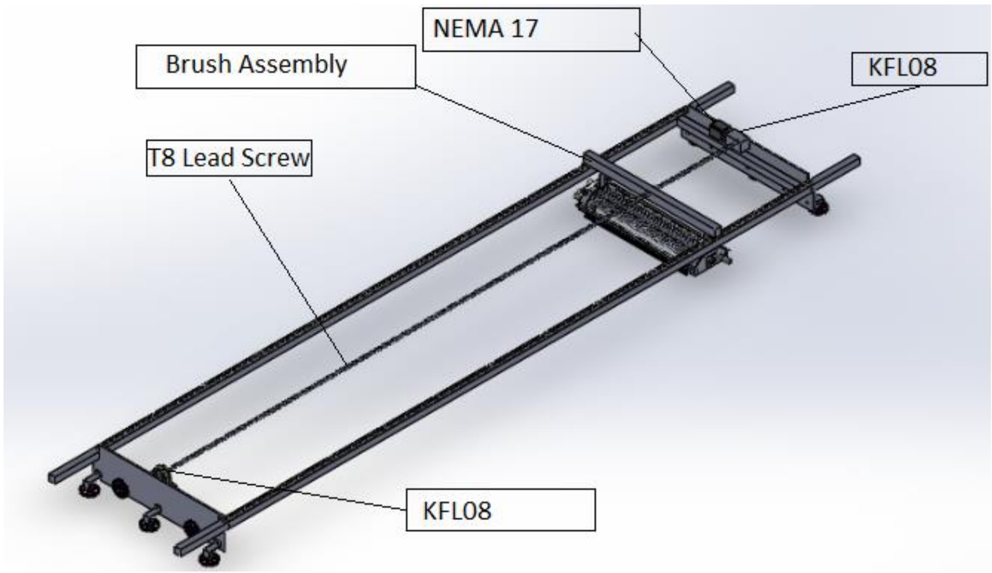


Figure 15: Key components of Cleaning system

3.2.5 Dust Sensor:

Despite the availability of several sensors in the market, none currently exist which can accurately measure the amount of dust on a flat surface. As such, a novel dust sensor has been developed for this purpose, specifically designed to measure the amount of dust on the surface of a solar panel.

The dust sensor utilizes a Light Dependent Resistor (LDR) as its primary sensing component. It has been engineered to detect the presence of dust particles on the solar panel surface, even during daytime and nighttime conditions.

To validate the efficacy of the dust sensor, experimental testing has been conducted. The sensor's performance has been evaluated under varying conditions, with its accuracy and reliability thoroughly assessed. This novel dust sensor design represents a significant advancement in the field of solar panel cleaning, providing a reliable means of detecting dust accumulation and ensuring the optimal performance of solar panels.

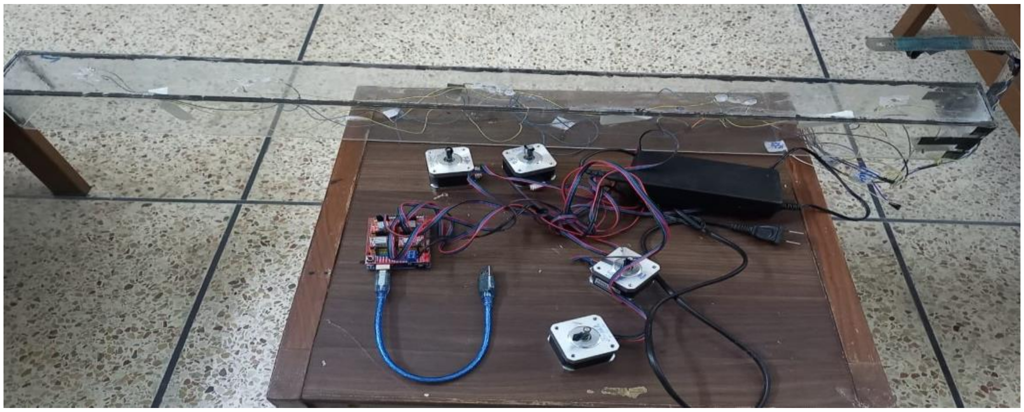


Figure 16: Dust Sensor and internal circuit with stepper motor

3.2.6 Working of Dust Sensor:

In the dust sensor, a constant laser light is pointed at the Light Dependent Resistor (LDR) placed behind a transparent acrylic sheet. The resistance of the LDR changes as the dust accumulates on the surface of the acrylic sheet, which indicates the presence of dust on the solar panel. Standard thresholds have been set to determine the level of dust accumulation on the panel surface, such as slight, mild, or too much dust. To ensure the accuracy of the readings, multiple sensors have been installed to detect changes in LDR resistance caused solely by dust accumulation, as opposed to other factors such as the presence of birds. A control system has been put in place to check the output of the dust sensors periodically, and if the readings indicate the presence of dust, the system will instruct the cleaning robot to start the cleaning process.

3.2.7 Internal Circuitry

To design the control system of the Smart Cleaning system, we utilized Arduino Mega UNO, CNC shield, and NEMA 17 Stepper motors equipped with A4988. We opted for this setup as it provides precise and accurate control over the movement of the cleaning system. To enable wireless communication between the dust sensor and the control system, we plan to incorporate a Wi-Fi shield. This additional component will enhance the system's overall functionality and enable it to transmit data wirelessly to the user.

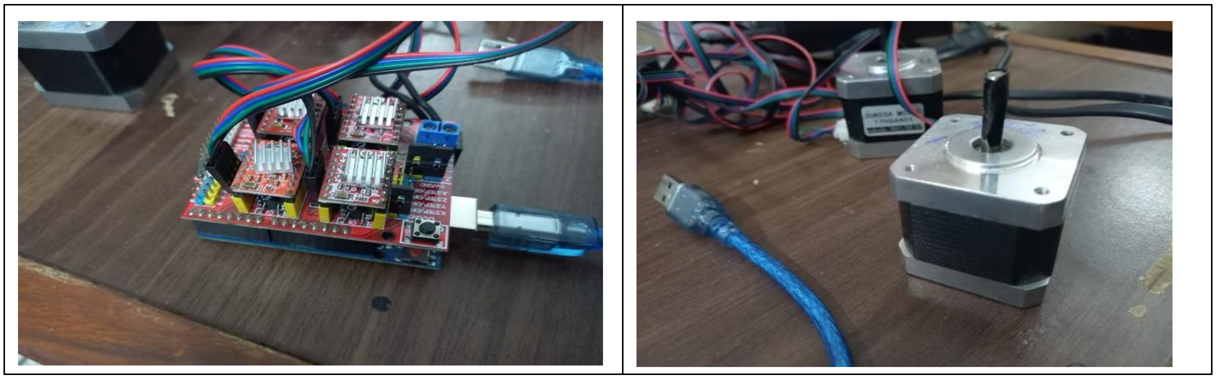


Figure 17: Circuitry

3.2.8 Calculations

$$\text{Weight approximately} = 25kg$$
$$\text{Velocity of cleaner required} = v = 9mms^{-1}$$
$$F = ma = m\left(\frac{v_f - v_i}{t}\right)$$
$$w = 180rpm \quad \text{(Stepper selected)}$$
$$\text{Lead of pitch screw selected is 3mm per revolution}$$
$$\text{It means that } w = \frac{180}{60} = 3 \text{ revolution per second}$$

Hence 9mm per seconds speed is attained in one second as lead is 3mm and stepper completes 3 revolutions in a second (If cleaner starts at the rest)

$$F = (25)\left(\frac{9mms^{-1} - 0mms^{-1}}{1}\right)$$
$$\boxed{F = 0.225N} \text{ Force required at initial start}$$

Now $P = Fv$ which is the power required to move brush assembly at constant speed of 9mm per second from initial start

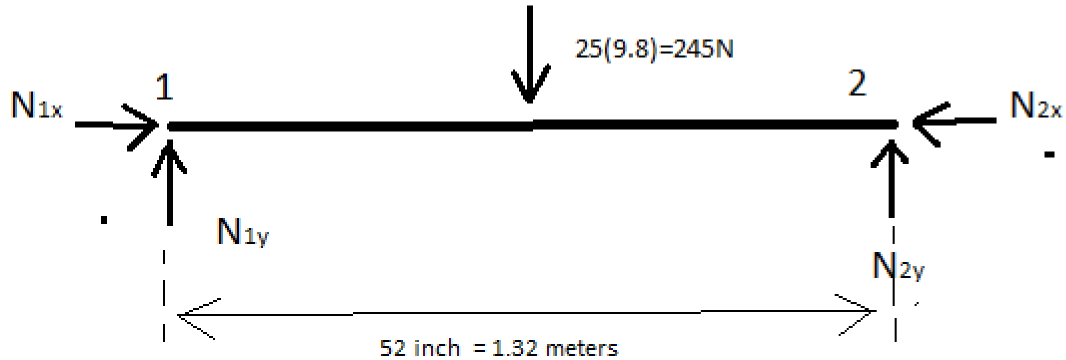
$$P = (0.225)(9mms^{-1})$$
$$\boxed{P = 2.025mW}$$

Now Power consumed by motors to provide constant 180 rpm is 11.25W

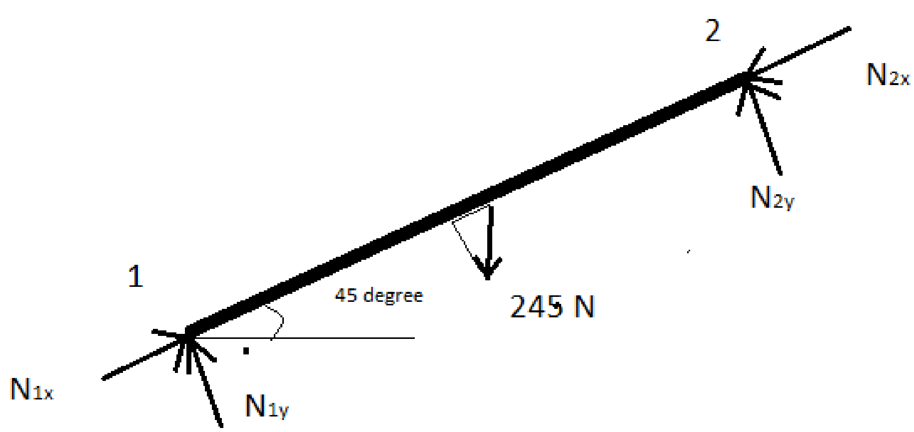
So 4 stepper motor used means that electric power consumed is:

$$4(11.25) = 45W$$
$$N_1x = \text{Horizontal reaction force of wheel on panel plate}$$
$$N_1y = \text{Vertical reaction force of wheel on panel plate}$$

Similarly same reaction forces at point 2



$$\sum F_x = 0$$
$$N_1x + (-N_2x) = 0$$
$$\boxed{N_1x = N_2x}$$
$$\sum F_y = 0$$
$$N_1y + N_2y = 25(9.8)$$
$$\sum M_1 = 0$$
$$(N_2y)(1.32) - (25)(9.8)(0.66) = 0$$
$$\boxed{N_2y = 122.5N}$$
$$\sum M_2 = 0$$
$$-(N_1y)(1.32) + (25)(9.8)(0.66) = 0$$
$$\boxed{N_1y = 122.5N}$$



$$\sum F_x = 0$$
$$N_1x + N_2x = W\cos 45$$
$$N_1x + N_2x = (25)(9.8)(\cos 45) = 173.24N$$
$$\sum F_y = 0$$
$$N_1y + N_2y = W\sin 45$$
$$\sum M_1 = 0$$
$$(N_2y)(1.32) - (W\sin 45)(0.66) = 0$$
$$N_2y = \frac{(25)(9.8)(0.66)(\sin 45)}{1.32}$$
$$\boxed{N_2y = 86.6N}$$
$$\sum M_2 = 0$$
$$-(N_1y)(1.32) + W\sin 45(0.66) = 0$$
$$\boxed{N_1y = 86.6N}$$

Notice that all the reaction forces of wheel are not sufficient to cause micro-cracks on the panel surface. According to research solar panels can sustain up to 900 newton force. Hence, all the reaction force at horizontal condition or 45-degree angle are less than 900 Newton.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Results of Cooling System:

We have performed an experiment on both the exchangers and here are the results.

4.1.1 U-Tube Heat Exchanger

The results for the U-Tube Heat exchanger are as follows.

The following figure shows the uncooled solar panel plate.

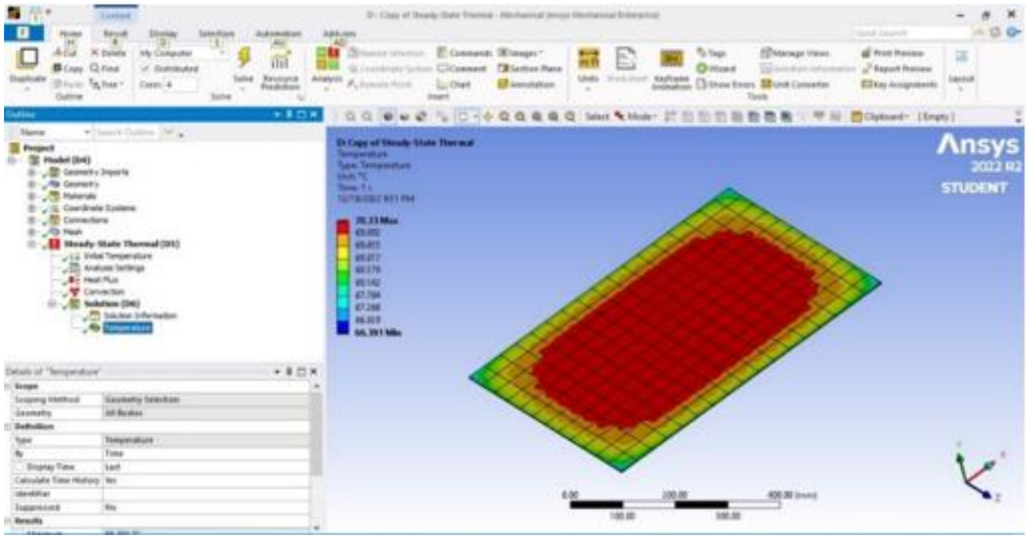


Figure 18: : Temperature contours of Uncooled solar panel

The following figure shows the contours of the exchanger plate with the U-Tube heat exchanger at the back of the plate. The temperature is changing along the plate because fluid is entered at the ambient temperature and till reaching the outlet absorbs heat.

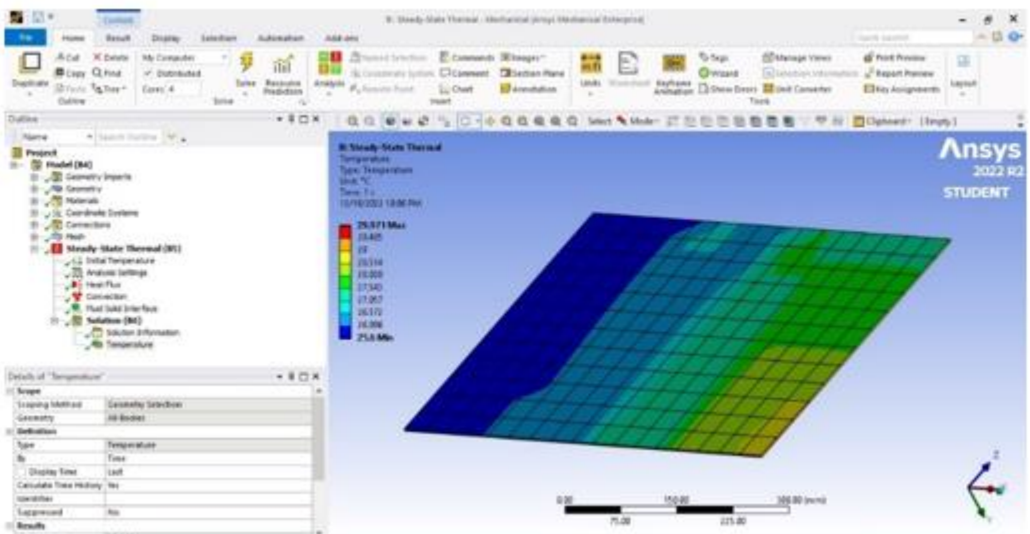


Figure 19: Temperature contours of U tube Heat exchanger cooled plate

Below is the figure showing the contour of the fluid.

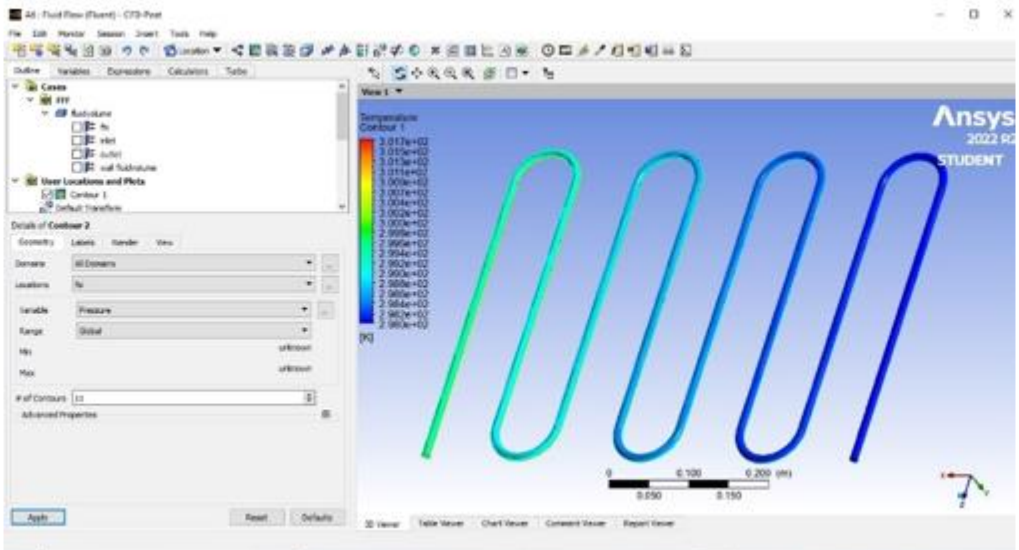


Figure 20: Temperature contours of U tube pipe

4.1.2 Parallel Plate heat exchanger

The results for the Parallel plate Heat exchanger are as follows.

Below is the contour of the solar panel plate when fluid is passed through the parallel exchanger plates. Water enters at the ambient temperature and exits at temperature 3-4 Degree more than inlet. Following points needs to be discussed.

1. There are gaskets at the in between the pattern which are providing sealing along with directing the flow.
2. Pressure drop of the fluid is minimum as there are no wake regions to trap the fluid.
3. Demineralized water is a good option but not necessarily required as in the case of U Tube exchanger. That is because the grooves in the plate are cleaned with fluid flowing due to turbulence.
4. The Efficiency of the plate is limited to the maximum temperature which is at the outlet of the fluid.
5. Pumping losses are minimum as water just needs to be input and it will then be flowed directed by pattern and gaskets paths.
6. The threshold temperature is 25 degrees. At any point if temperature of the plate increases from 25 degrees Celsius the pumping will start.

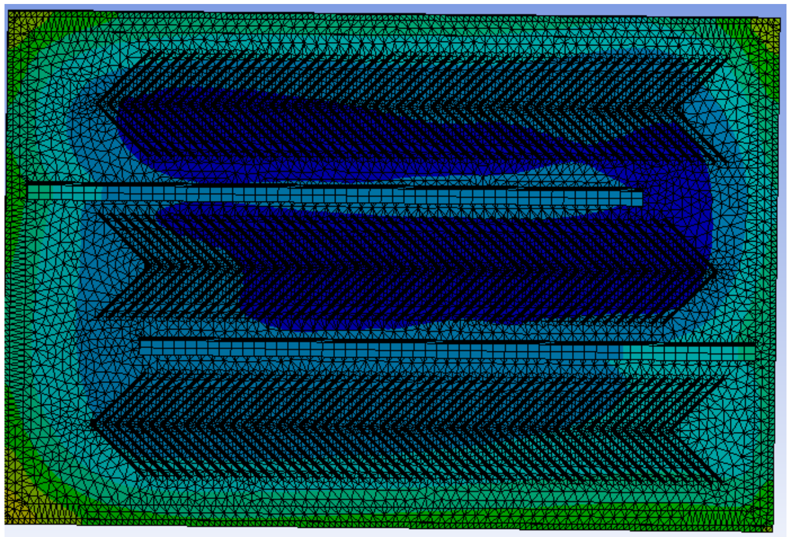


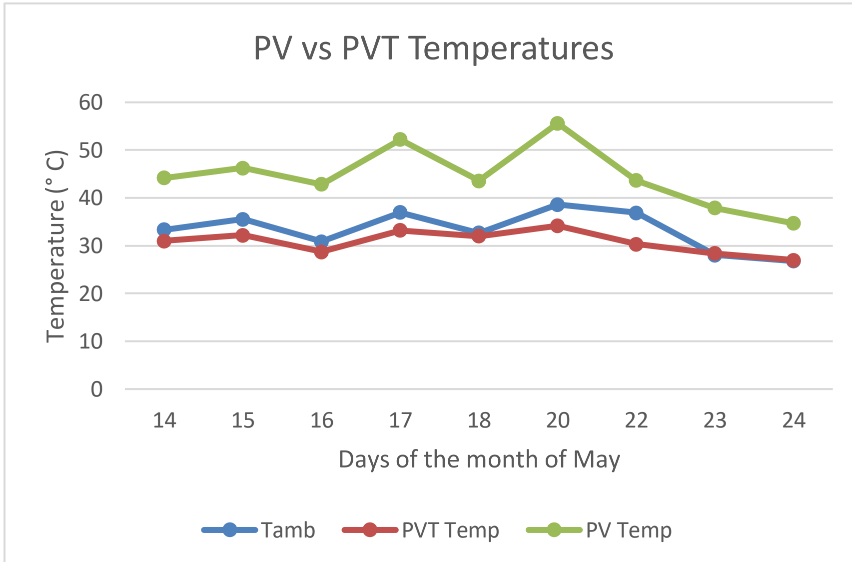
Figure 21: Temperature contours of plate type heat exchanger with V patterns

4.1.3 Calculations and Observations

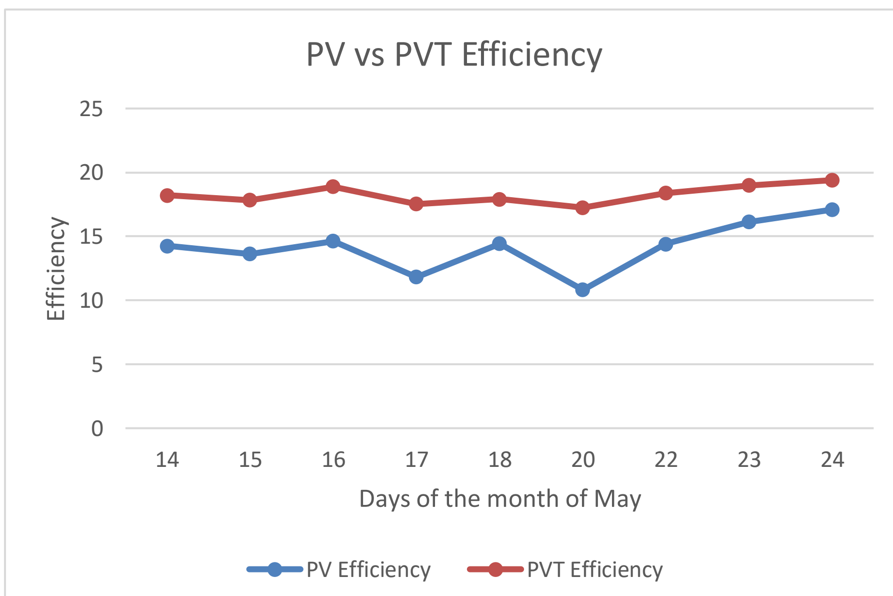
Table 1: Observations

Day	*Tamb* C	$Temp_{PV}$ C	$Temp_{PV}$ C	Efficiency of PV	Efficiency of PVT
14/5/2023	33.31	44.16	30.97	14.252	18.209
15/5/2023	35.57	46.26	32.21	13.622	17.837
16/5/2023	30.86	42.87	28.69	14.639	18.893
17/5/2023	36.94	52.22	33.19	11.834	17.543
18/5/23	32.67	43.6	31.98	14.42	17.906
20/5/2023	38.62	55.62	34.17	10.814	17.249
22/5/2023	36.88	43.65	30.33	14.405	18.401
23/5/2023	28.08	37.87	28.38	16.139	18.986
24/5/2023	26.79	34.69	27.01	17.093	19.397

4.1.4 Graphical Analysis



Graph 1 Temperature plot for PV and PVT



Graph 2 Efficiency plot for PV and PVT

4.1.3 Comparison

The two types (plate type and U tube heat exchanger) are both smart and efficient enough to optimally cool the solar panel pate along with effectively increasing the efficiency of solar panel, but the thing is that

1. With U Tube exchanger temperature falls down to approximately 30 C but with plate type it falls to almost 30 Degrees. But the main reason to choose plate type is the pressure loss and turbulence.
2. To design a cost-effective exchanger which saves energy, the pumping loss should be minimum and that can only be achieved with plate type exchanger.
3. The cost to make U tube exchanger is very high as it includes a lot of processes like pipe bending, welding and joining and life of these pipes is also a matter of concern, but the plate type exchanger does not use piping inside the plates and less expensive to fabricate then the U Tube type.
4. Maintenance is rarely needed with the plate type while pipe type needs preventive maintenance because there is always the risk of scaling and choking of the piping that ultimately increases the pressure drop.

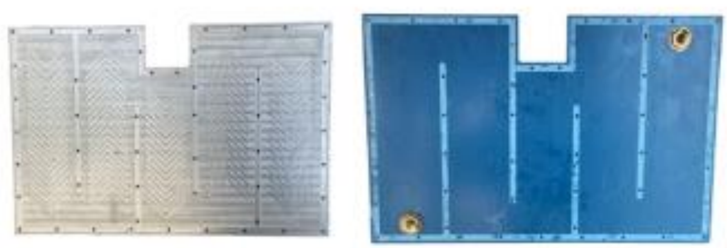


Figure 22: Heat exchanger prototype

4.2 Cleaning System

4.2.1 Results

The proposed solar panel cleaning system addresses several key challenges that have been identified in the literature regarding solar panel maintenance. One of the most notable features of the system is its ability to automatically detect dust accumulation on solar panel surfaces and initiate the cleaning process. This feature not only ensures optimal panel efficiency but also reduces maintenance costs and efforts. The system's versatility allows it to be installed on solar panel arrays of any rectangular configuration and calibrate it for optimal performance regardless of the number of panels in a vertical direction.

The cleaning mechanism of the proposed system is executed by the movement of nylon wheels along the edges of the array, enabling it to clean large lengths of the solar panel efficiently. The system's cleaning process is gentle and free from any potential harm or scratches, as it utilizes specialized brushes designed specifically for solar panel cleaning. This feature further reduces the risk of maintenance costs and panel damage.

Another noteworthy feature of the system is its versatility in cleaning methods. The system can perform both waterless and water cleaning by replacing the cleaning assembly with the appropriate technology. The device can detect dust on the panel surface and initiate a rapid cleaning process, providing swift and efficient cleaning capabilities. This feature is particularly useful for regions frequently affected by sandstorms, such as the Middle East and North Africa, due to its advanced dust sensing capability.

The system's uniform weight distribution and use of nylon wheels can significantly reduce the risk of micro-cracking on the panel surface, which is a common issue in solar panel maintenance. This feature further ensures the system's effectiveness and cost-effectiveness.

Overall, the combination of these features in the proposed solar panel cleaning system provides a cost-effective, efficient, and user-friendly solution to ensure optimal solar panel performance while minimizing maintenance costs and efforts.

Cleaning system control system works on Arduino Microcontroller and it’s code is given in Appendix II.

Figure 23: Smart Solar Panel Cooling and Cleaning system

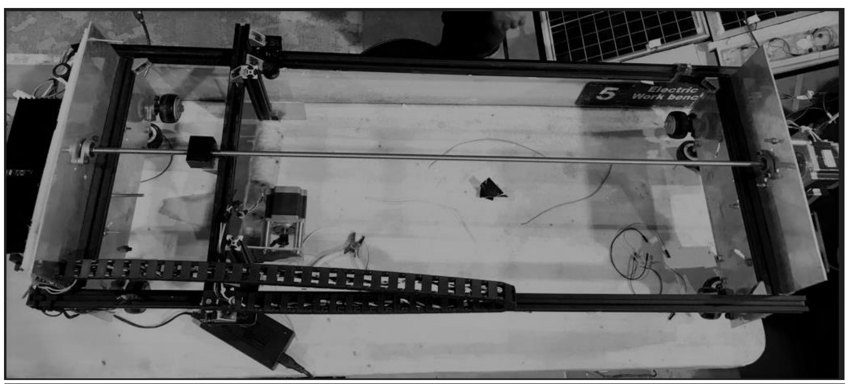


Figure 24: Cleaning robot

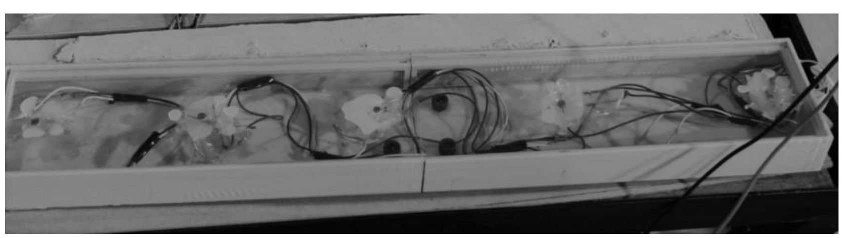


Figure 25: 3D printed Dust sensor (LDR based)

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Smart Solar Panel Cooling System:

The development of a smart solar panel cooling system is essential for maximizing the efficiency and performance of solar panels. By effectively reducing panel temperature when it exceeds a predefined threshold, the system ensures optimal power generation and overall panel efficiency. The system's objectives of cost-effectiveness, energy efficiency, scalability, intelligent control, reliability, durability, compatibility, and integration work together to create a solution that is accessible, sustainable, and adaptable. With the implementation of this smart cooling system, solar panels can operate at their peak efficiency, contributing to the wider adoption of solar energy as a sustainable and renewable power source.

Smart Automated Solar Panel Cleaning System:

The introduction of a smart automated solar panel cleaning system addresses the issue of dust accumulation on solar panel surfaces, which can negatively impact their efficiency and performance. By effectively sensing and removing dust particles without the need for manual labor, this system ensures the continuous optimal operation of solar panels. With objectives focused on enhancing panel efficiency, environmental friendliness, non-destructive cleaning, adaptability, intelligent control, reliability, durability, compatibility, and cost-effectiveness, the smart automated cleaning system provides an efficient and sustainable solution. By maintaining the cleanliness and quality of solar panels, this system supports the widespread adoption of solar energy as a reliable and clean power source.

In conclusion, both the smart solar panel cooling system and the smart automated solar panel cleaning system contribute to the improvement and optimization of solar panel performance. By addressing critical factors such as temperature control and dust accumulation, these systems enable solar panels to operate at their highest efficiency levels, leading to increased power generation and enhanced sustainability. The combination of intelligent control, cost-effectiveness, scalability, reliability, and compatibility ensures that these systems offer practical and efficient solutions for the maintenance and optimal performance of solar panels. Through the implementation of these technologies, solar energy continues to be a viable and environmentally friendly solution for meeting our energy needs.

5.2 Recommendation

Following are the recommendations for the room of improvement in cooling system:

- The incorporation of Artificial Intelligence (AI) within the control system of the cooling system offers the potential to establish temperature thresholds at which the efficiency of the solar panels begins to decrease, based on factors such as light intensity and ambient conditions. By integrating AI algorithms into the control system, it becomes possible to dynamically adjust the cooling mechanisms in response to real-time data and optimize the panel's performance. This intelligent approach allows for more precise and efficient cooling, ensuring that the panels operate within the optimal temperature range and maintain their highest level of efficiency.
- The Junction box is fitted at the back of the panel and that was the place where fluid cannot be flowed. And we know that the efficiency is limited at the maximum temperature of the solar panel plate. So, it can be fixed at the frame in such a way that space optimality satisfied along with the cooling.

The following recommendations are proposed for the cleaning system:

The integration of Artificial Intelligence (AI) into the control system of the dust sensor enables automatic calibration and the establishment of a dust amount threshold. This threshold is crucial as it determines the point at which the efficiency of the solar panels begins to decrease. By leveraging AI algorithms, the control system can dynamically adjust the dust sensing parameters based on factors such as the type of dust, environmental conditions, and humidity levels. This intelligent approach ensures accurate and adaptive monitoring of dust accumulation on the panels, allowing for timely cleaning or maintenance actions to be taken. Ultimately, the AI-powered control system optimizes the efficiency and performance of the solar panels by effectively managing the impact of dust on their operation.

The main purpose of this project is to bring innovation in the existing idea and make it smart and free from human intervention with a solution of maintaining solar efficiency as a by project.

Designing and fabricating this project has given us access to various machineries to carry out numerous machining processes. This project involves the use of engineering concepts including fluid mechanics, mechanics of machines, electrical and electronics engineering, instrumentation and measurements etc. We were able to get a know-how of arduino and C++ programming language. We were able to use SolidWorks knowledge and saw its real life application and implementation of engineering drawing in fabrication of parts.

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APPENDIX I: CODE OF COOLING SYSTEM

Arduino file for the code of cooling system can be accessed from the following link:

final code for cooling system

APPENDIX II: (CODE OF CLEANING SYSTEM)

Arduino file for the code of cleaning system can be accessed from the following link:

nema23.ino