

Evaluation of Solar Thermal Collector Efficiency for Heat Transfer in Various Fluids: A Case Study Using a Parabolic Trough System

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Abstract - This research work examines the performance of a parabolic trough solar collector system that was installed and evaluated in Salah Uddin Governorate, Tikrit using several heat transfer fluids to collect and store thermal energy. The elements involved in the system are the cylindrical parabolic solar collector, hydraulic oil pump, insulated heat exchanger and the solar tracking means to optimize the collection of solar energy. Some experiments with water, mineral oil, synthetic oil, vegetable oil, hydraulic oil was performed at different times of the day to compare the temperature rise and the change in the flow rate depending on the variation of the solar radiation. Efficiency data show that the maximum thermal efficiency is achieved for midday solar irradiation while hydraulic and synthetic oils are identified as the best for thermal storage. Ultimately, the research identifies that the choice of heat transfer fluids and variable flow rate control depending on solar irradiance enhances the system's performance pointing out important indications for further solar thermal utilization.

Keywords: Solar thermal collector, Parabolic trough system, Heat transfer fluids, Thermal energy storage, Renewable energy, Solar energy efficiency, Heat exchanger, Solar tracking.

I. INTRODUCTION

Maintainable turn of events, which the Unified Countries has embraced by taking on 17 Economical Improvement Objectives (SDGs), has turned into a need in the cutting-edge world. With an accentuation on orientation correspondence, social consideration, the destruction of neediness, ecological security, and the advancement of harmony and thriving, these objectives try to address various worldwide issues[1]. Remarkably, representing practically 60% of ozone harming substance outflows, the energy business contributes fundamentally to environmental change. SDG-7 spotlights on giving networks from one side of the planet to the other admittance to modest, clean energy while advancing venture

and advancement in the different periods of energy creation and dissemination[2].

The level of individuals overall who approach power has expanded by 6.2% over the most recent decade, with rustic networks seeing a 13.2% expansion starting around 2010. The Global Environmentally friendly power Organization's (IREA) 2020 review, nonetheless, accentuates that 0.8 billion individuals actually need admittance to drive starting around 2018, despite headways[2]. Decentralized or conveyed energy frameworks are turning out to be more famous due to well established financial and administration issues with customary lattice-based energy frameworks. These frameworks present reasonable ways of expanding energy access as a result of their ability to deal with the energy trilemma, which comprises of expenses, discharges, and security[3].

Be that as it may, when appropriated energy sources become all the more broadly utilized, new issues for electrical dispersion networks emerge, similar to invert power stream. This calls for changes to customary power framework structures, highlighting the meaning of shrewd electrical frameworks in taking care of the changing organization conditions[4]. At various mechanical status levels (TRLs), there are currently around 400 innovation plans and parts focused on at bringing down CO₂ outflows. Among these choices are sun based energy advancements, for example, photovoltaics (PV) and sun oriented warm, which might give intensity and power both now and again the lattice[5].

Various causes, for example, the dropping expense of sustainable power, the need to cut fossil fuel byproducts, expanded energy security, all-inclusive energy access, the making of occupations, and monetary advantages, are pushing the worldwide create some distance from petroleum derivatives and towards sustainable power sources. As per reports, for sustainable power to represent 65% of the fundamental energy supply by 2050, a sum of USD 29 trillion in speculations should be made[6]. By 2050, as indicated by the Global Environmentally friendly power Organization

(IREA), 86% of power produced would come from inexhaustible sources, with 360 GW of sun-oriented PV expected to be introduced yearly. Three significant private PV development markets are Europe, the US, and China[7].

By 2030 and 2050, solar PV is predicted to provide 13% and 25% of the world's electricity needs, respectively, with distributed solar energy accounting for 40% of this total. Growth is anticipated in solar thermal, which now provides 7% of the world's heat needs, especially in space heating applications. In an effort to cut emissions, the European Union has set high goals for the percentage of renewable energy, increasing energy efficiency, and lowering greenhouse gas emissions[8].

Accelerating the adoption of clean energy technology through various interventions is the goal in order to meet power, heating, and cooling demands in a sustainable manner. Novel approaches to district heating and cooling networks are being investigated, including heat pumps, solar thermal, and geothermal. But there are obstacles, like limitations to social and aesthetic acceptance, especially in urban areas and historic sites[9]. It is imperative to support real-world demonstration projects that take techno-economic, legal, and social concerns into account. Initiatives like as the Interreg 2 Seas SOLARISE project are designed to showcase emerging technology and investigate their effects, encouraging the use of solar power in old structures and low-income homes[10].

Buildings account for 80% of the final energy consumption in the European Union, which is largely attributed to heating and cooling. Buildings' space heating and water heating systems account for 40% and 17% of total energy use, respectively. Even with this high demand for energy, only 22% of the energy needed for heating and cooling comes from renewable sources at the moment, with fossil fuels still providing 75% of the supply[11].

The EU is exploring digitization efforts in the building industry and energy systems in order to address this. Building digitalization offers a chance to increase energy efficiency and reach untapped markets. Some EU nations have witnessed notable increases in residential and commercial photovoltaic capacity, while others have prioritized utility-scale solar installations due to enticing feed-in tariff schemes[11].

Well-connected communities are fostered by the integration of distributed energy technologies and high-capacity renewables made possible by the development of smart grids and smart-ready buildings. The European Commission (EC) supports member states' decisions regarding their energy mix and is aware of the risks to energy security posed by the growing use of renewable energy sources. A few members have chosen to incorporate nuclear energy, which is

regarded as a clean and base load energy source, into their national energy plans[11].

With an emphasis on energy efficiency, the EU hopes to establish itself as a leader in renewable energy. By 2050, electricity is expected to account for 53% of total energy consumption; nevertheless, in order to attain net zero greenhouse gas emissions, there will need to be a major increase in the production of renewable electricity[8]. According to a recent report (Figure 1), the power generation mix would consist of 86% renewable energy by 2050, with solar photovoltaics (PV) emerging as the dominant source of installed power capacity[12].

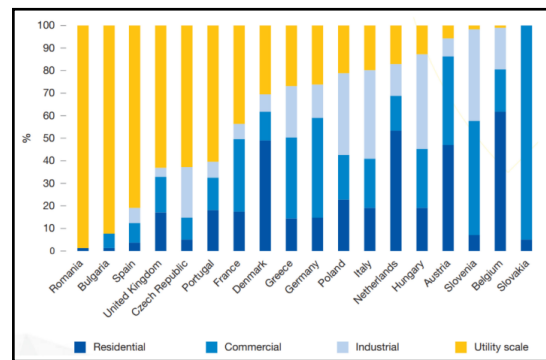


Figure 1: Part of each category in the overall solar PV capacity of the EU's chosen nations [13]

A number of roadmap studies and projection studies show how the energy system will change from being heavily dependent on traditional fuels with high operating costs to one with larger initial capital investments and lower fuel costs over time. Infrastructural upgrades are required to enable greater integration of renewable energy sources to meet the demands for power, heating, and cooling. The decarbonization goals of the transportation sector, especially with regard to the use of electric vehicles, are anticipated to increase the share of electricity in final energy demand [14].

Despite a slowdown in China, the global solar PV market experienced significant growth in 2019, with PV generation increasing by 22%. This growth was partially offset by China's decision to discontinue feed-in tariffs, focusing instead on cost control and grid integration challenges. In contrast, stable solar PV growth was observed in the United States, supported by federal tax incentives and state-level policies [15].

II. USING PV FOR COOLING SYSTEMS

Table (1) summarizes key studies focused on various solar-powered cooling systems, highlighting their methodologies, findings, and benefits. These studies explore a range of technologies, including photovoltaic (PV) systems without batteries, DC air conditioning, concentrated

photovoltaic (CPV) cooling and evaporative air-cooling systems. Different approaches are examined, from integrating phase change materials (PCM) and desiccant air-cooling to combining radiative and thermoelectric cooling. Many of these systems aim to enhance energy efficiency, reduce CO₂

emissions, and improve cooling performance in buildings, vehicles, and agricultural applications. The findings indicate significant gains in energy efficiency, reductions in environmental impact, and advances toward achieving net-zero energy goals in various contexts.

Table 1: Research's for Using PV for Cooling Systems

Authors	Study Focus	Method/Approach	Main Findings	Key Benefits
Han et al. (2019)[16]	Integrated control technique for a solar cooling system powered by PV without a battery.	PV system without battery, coupled with air conditioning.	Increased photoelectric conversion efficiency by 83.7% (average efficiency of 0.129), COP solar increased by 60.4%, compressor operation at irradiance > 143 W/m ² .	Improved energy efficiency and reduced reliance on batteries.
Pang et al. (2019)[17]	Solar-powered DC air conditioning system using R134a refrigerant.	Solar-powered DC system with refrigerant.	Minimum refrigerating capacity of 1500 W; system maintained comfortable temperatures in vehicles, with positive environmental impact.	Achieved comfortable cooling in vehicles with reduced environmental footprint.
Zuhur et al. (2019)[18]	Prototype concentrated photovoltaic cooling system for building cooling and power.	Concentrators on photovoltaic panels.	Using concentrators raised panel temperatures, reducing electrical output. CO ₂ emissions reduced by 0.07 kg/hour; environmental savings of around 0.1/hour.	Reduced CO ₂ emissions and energy consumption.
Kiyania et al. (2019)[19]	Exergoeconomic study of a direct evaporative air-cooling system powered by solar PVs.	Evaporative cooling integrated with PV.	Max efficiency ~20% for 30°C input air and 30% humidity. Exergoeconomic factor shift of 60% depending on water temp (15–27°C) and air flow (300–1500 m ³ /h).	Significant energy savings based on optimized temperature and airflow conditions.
Lin et al. (2020)[20]	Solar system integrating concentrating PV, thermal collectors, and a variable effect absorption chiller.	Integration of concentrating PV and absorption chiller.	Exergy efficiency between 32%-33%. Variable chiller provided higher cooling power with less frequent on/off cycling. Cooling-electricity ratio between 1.4–2.0.	Higher energy efficiency and optimized cooling power.
Song & Sobhani (2020)[21]	Solar desiccant air-cooling system enhanced by phase change material (PCM) and Maisotsenko cooler.	PCM-enhanced solar desiccant system.	Seasonal COP _{th} = 0.415, COP _{el} = 16.27, COP _{tot} = 0.404. Highest PV module power output ~0.77 kW in October, lowest efficiency 13.6% in September.	Improved seasonal energy efficiency and power output.
Bilardo et al. (2020)[22]	Optimization of solar cooling system for Mediterranean buildings using TRNSYS.	TRNSYS software for system optimization.	Increased renewable energy ratio from 48% to 83% of total energy consumption. Solar cooling helps reach the nZEB goal for energy efficiency in future buildings.	Contributed to net-zero energy building (nZEB) goals.
Wu et al. (2020)[23]	Solar façade cooling systems for technical and economic performance comparison.	Façade solar cooling systems with economic performance review.	Solar fraction increased by 40-50%, unit cooling cost decreased by 10% with the ORC-VCC system compared to adsorption and absorption chillers in specific climates.	Reduced cooling costs and increased energy efficiency.
Lorenzo et al. (2020)[24]	PV-HP system with MPPT control and inverter for	PV system with heat pumps (HP) and MPPT control.	Key performance indicators (PR, EER, SPF) ranged from 2.51–3.06. System utilization	Achieved higher efficiency and autonomy in operation.

	autonomous operation.		rates varied from 0.27–0.77.	
Lv et al. (2021)[25]	PVRC-TE system integrating radiative cooling and thermoelectric cooling for improved sky cooling.	PV with radiative and thermoelectric cooling integration.	System daily cooling energy gain of 285.57 MJ/m ² . Worked best in dry, sunny climates. Geometric ratio maximized PV and radiant cooling performance.	Improved cooling efficiency in specific climate conditions.
Omar et al. (2021)[26]	Solar-assisted evaporative cooling system for greenhouse cucumber production.	Solar-powered evaporative cooling for greenhouses.	Evaporative cooling used 8.32 MJ/day of solar power, reduced temperature by 10°C, efficiency of evaporation 74%. Increased cucumber production.	Enhanced agricultural productivity with efficient energy usage.
Zapaowicz & Zenczak (2021)[27]	PV module cooling for ships using the ship’s power plant cooling system.	Ship-integrated PV cooling system.	Cooling increased PV output by 13%. PV system generated 1177 kWh of electric energy during a 6-hour port stay in May, with an additional 148 kWh due to cooling.	Increased PV energy output for maritime applications.
Al-Naemi & Al-Otoom (2023)[28]	Smart sustainable greenhouse powered by solar PV with water recycling.	IoT-based control system for greenhouse.	Reduced water needs by 40%. Microcontrollers managed greenhouse climate. The greenhouse met energy needs with PV storage and IoT-based controls.	Enhanced sustainability with IoT and efficient water and energy management.
Li et al. (2021)[29]	Solar direct-drive air conditioning system with ice thermal storage and adaptive control.	Solar direct-drive with ice thermal storage.	Improved ice-making performance, system stability with MPPT control. Variable speed compressor allowed efficient energy use and increased solar energy availability.	Energy-efficient cooling with storage for later use.
Ozcan et al. (2021)[30]	Energy and economic analysis of solar PV-powered air conditioning system with battery storage (PBAS).	Battery-backed solar PV system for air conditioning.	Environmental and operational factors significantly impacted performance metrics. Economic analysis correlated net present value with energy consumption patterns.	Demonstrated energy and economic benefits of solar with battery storage.
Haffaf et al. (2021)[31]	Viability study of solar PV air conditioning system for office buildings.	Solar PV integrated with office AC systems.	80.5% of energy needs met by PV, total daily energy generation of 2875 kWh. Renewable fraction 79.2%, with significant reductions in energy purchases and CO ₂ output.	Reduced carbon emissions and dependence on grid electricity.

III. METHODOLOGY

This research presents the design and fabrication of a parabolic trough collector with a detailed explanation of how each part of the system works in Figure (2), which consists of a two-parabolic trough solar collector, a manual solar tracking system, a heating fluid tank, connection pipes, an oil pump, an insulated heat exchanger, an insulated boiler, a burner, a turbine, a generator, and an absorption system. It includes the practical tests that were carried out for the system parts and the relationship of the system to the variables specific to the weather conditions of the test area. The system was designed, implemented, and tested in Salah Uddin Governorate - Tikrit.

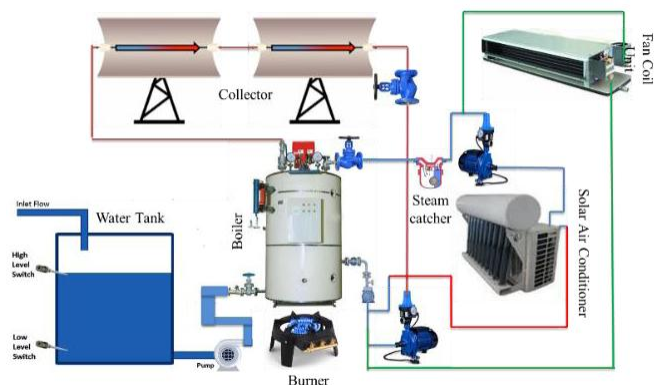


Figure 2: Model Block Diagram

The principle of operation of the cylindrical solar collector is to collect the sunlight falling on the reflective surface, condense it, convert it into high thermal energy, and focus it on the receiving tube installed at the focus of the cylindrical collector, through which the oil passes, which leads to a gradual increase in its temperature. There are several factors that affect the increase in the amount of thermal energy transferred by oil, namely:

1. The surface area of the solar collector, as the larger the surface area, the greater the concentration of solar radiation on the receiving tube, thus increasing the thermal efficiency of the liquid, which leads to increasing the efficiency of the system.
2. The amount of heat gained by the liquid depends on the type of material the receiving tube is made of and the surface area of the receiving tube used in the solar collector.
3. The process of tracking the movement of the sun.

Parts of a Parabolic Solar Collector

A model of a solar collector was constructed and tested. This model consists of the mechanical unit. The following are the parts of the solar collector:

1. Cylindrical solar collector: This receiver collects solar radiation, which is an electromagnetic ray that reaches the receiver in parallel and focuses them on the focus. A cylindrical receiver with a parabola with a length of (2.5) meters and a perimeter of (2) meters was used, with a visual area of (7.5) square meters. The receiver was installed on a rectangular iron metal frame with the following dimensions (3x2) meters as shown in Figure (3). The metal frame was installed to facilitate the process of moving up and down, as it is perpendicular to the sun to obtain perpendicular rays on the solar center, to ensure high efficiency for the system. The solar receiver was designed and constructed according to the following specifications according to Table (2).

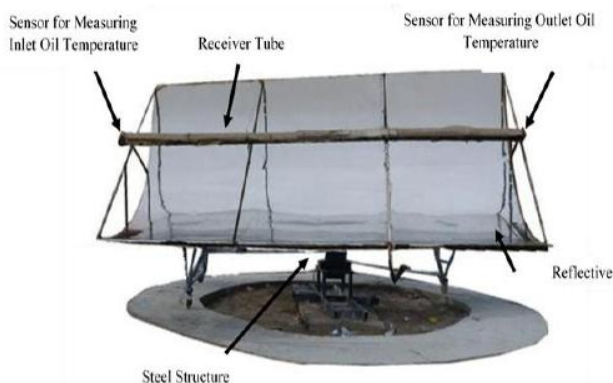


Figure 3: Cylindrical and parabolic solar collector

Table 2: Dimensions of the pickup

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retem	0.5	<i>f</i>	eht fo htgnel lacof snel
erauqs retem	7.5	<i>A</i>	fo aera lacitpO rotcelloc ralos
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2. Heat receiving system: The heat receiving system represents the focus located in the center of the solar collector. It was designed in the form of a copper coil with a length of (6) meters. The copper tube was wound in a spiral manner on a galvanized iron tube with a diameter of (2.5) inches and a length of (6) meters, with a number of turns of (561) turns in order to increase the surface area of the focus exposed to reflected solar radiation. It was painted in thermal black to increase heat absorption and raise the efficiency of the system, as shown in Figure (4).



Figure 4: The threaded copper tube used in the pickup

3. Metal structure of cylindrical solar collector: A square iron metal base with a thickness of (0.5) meters was made in the shape of a cylindrical arch using the rolling process to manufacture the parabolic arch, and iron plates with a thickness of (0.6) millimeters were fixed as shown in Figure (4) on the metal structure. Then, reflective silver aluminum strips were glued on the iron plates that act as a reflector mirror, i.e. they reflect the sun's rays and focus them on the focus. The reflectivity of these plates is (90%) according to what is fixed on these strips.

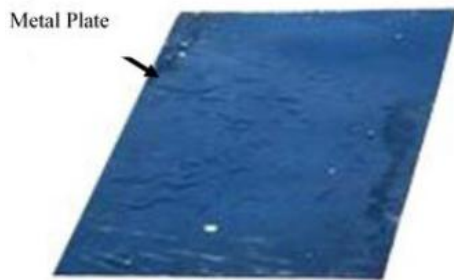


Figure 5: Metal Panels

- Hydraulic oil pump: The hydraulic pump is one of the important parts in the solar collector system. It pumps oil from the oil tank to the parabolic focus. This type of pump deals with light liquids with Viscosity Low. Where we used the electrical transformer oil available in the local markets, which is characterized by high thermal capacity. As shown in the Figure (6).

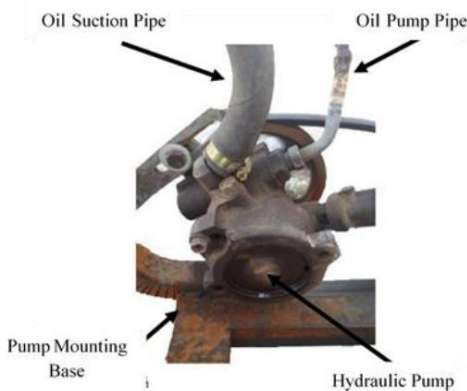


Figure 6: Oil Pump Used in the Pickup

- Flow Meter: It is the tool through which the amount of liquid passing through a specific medium can be measured during a unit of time. The process of controlling the amount of liquid flowing is done by manual control valves as shown in Figure (7).

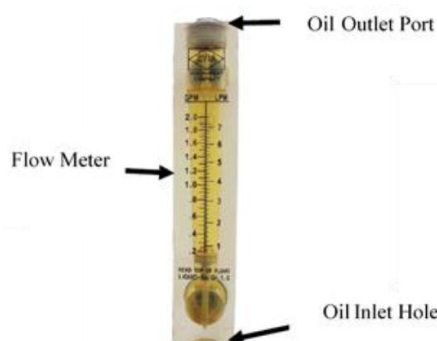


Figure 7: Flow meter

- Cylindrical oil tank: cylindrical iron tank with a capacity of (12) liters and a thickness of (0.3) millimeters,

containing oil that acts as a means of transferring thermal energy extracted from solar energy reflected from the solar collector. The cylindrical tank was used because it is designed to withstand high pressures, as shown in Figure (8).



Figure 8: Oil tank

- Oil: Transformer oil available in local markets was used, which has high thermal capacity, is cheap and available in local markets.
- Cylindrical heat exchanger: A heat exchanger was manufactured to transfer thermal energy from a high temperature fluid to another low temperature fluid without mixing the fluids with each other or vice versa for the purpose of evaporating water. The heat exchanger was manufactured from a cylindrical iron tank with a thickness of (0.3) m per meter containing a safety valve that adjusts the pressure when it exceeds the critical limit at (10). Bar, and the exchanger is characterized by the ability to withstand pressure of about (15) bars. It includes inside it a copper tube wrapped inside, through which hot oil flows and works to exchange this heat with the water inside the tank, which leads to the evaporation of the water, as shown in Figure (9).

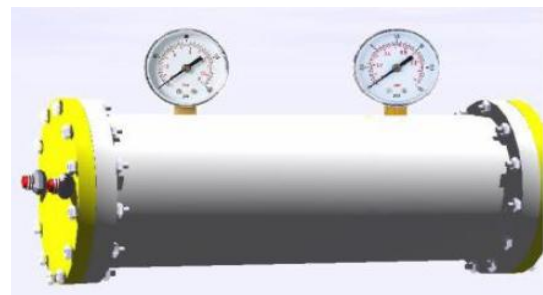


Figure 9: Heat exchanger

- Water pump: alternating current (220) volts was used to pump water to the heat exchanger as shown in Figure (9)

and that this pump is designed to pump the liquid at a rate of (2000) liters/hour and at a height of (10) meters and that this quantity is greater than the required quantity, so the control system was used to return the excess water to the tank and control it through the valve system.



Figure 10: Water Pump

10. Water tank: It is a tank made of galvanized iron with a thickness of (1) mm, square in shape with a length of (0.5) meters, a width of (0.5) meters and a height of (0.7) meters. This tank was insulated with insulating fiberglass material covered with aluminum with a thickness of (0.055) meters, and an opening was made to draw water and an opening to circulate water, and it was painted with a rust-proof paint.
11. Manual control valves: It is one of the important parts of the system through which the flow of fluids is controlled and their quantities are controlled during the circulation of fluids in the system. It also ensures that the water does not return in the opposite direction in the case of high pressure.
12. Copper tube: It is a tube made of pure copper. It is characterized by connectivity. It is good for heat and electricity and is considered the strongest conductor of electricity after silver. However, it is affected by moist air, as its surface is covered with a green film. A copper tube with a diameter of (0.008) meters, a thickness of (1) millimeters, and a length of (160) meters was used.

Kettle 14

It is a type of heat exchange systems that all consist of a room in which water is heated to boiling, producing steam under pressure by burning fuel with a capacity ranging from a quarter of a ton to 50 tons. It is used in bad weather (clouds or rain).

1. Burner: It is a device that works on waste car engine oil to produce a blue flame with high heat content. It is used to heat water inside the boiler and thus obtain steam.

2. Turbine: It is a device that receives steam either from the heat exchanger or through the boiler to convert it into kinetic energy and thus rotate the generator and obtain electric current.
3. Generator: It is a device connected to the steam turbine and receives movement from the turbine to generate electricity.
4. Absorption system: The absorption system works on the steam coming out of the turbine, which is used for cooling in the summer or heating in the winter.

Calibration of measuring devices

The thermometer and thermocouple were calibrated by testing them with a mercury thermometer. The thermocouple and mercury thermometer were placed in a container containing distilled water heated to boiling point (100 ° C) and then the thermocouple and mercury thermometer were placed in a container containing frozen water (0 ° C) where the difference between the temperature of the mercury thermometer and the thermocouple did not exceed (0.5 %). As for the flow meter, it was calibrated using a flask containing graduations to know the amount of oil flowing at different temperatures and the largest error percentage obtained for the measuring device was (5.2%).

IV. RESULTS AND DISCUSSIONS

The effectiveness of a solar thermal system in advancing several heat transfer fluids for the absorption and distribution of solar heat during the day. Using simple oil-water model, the research compares how different types of fluids include water, mineral oil, synthetic oil, vegetable oil, hydraulic oil responds to various levels of solar radiation different with the early morning at 300W/m² and the peak at 900W/m² in the afternoon.

The analysis actually takes into account standards such as the inlet and outlet temperatures of the oil and the oil flow rates, which are controllable quantities that depend on the solar intensity. By means of these parameters, the current research seeks to determine which heat transfer fluid provides the highest thermal energy storage capacity and convection heat transfer coefficient. The study has important effects for solar thermal applications based on the identified relationships between certain fluid parameters and thermal necessities in solar heating systems.

Water Fill

The analysis of results in Table (3) shows the efficiency of the system in using solar radiation for heating of the fluid at various time intervals of the day. Solar radiation starts at 300 W/m² at 8: It starts from 00 AM with intensity of 100 W/m²,

rises to 900 W/m² at midday and then decreases to 500 W/m² at 4:00 PM. Similarly, the inlet temperature increases from 25°C in the morning to 45°C at midday, while the outlet temperature increases from 40°C to a high of 70°C in the afternoon before reducing to 58°C in the evening. This pattern shows that the system heats the water at the highest efficiency in the presence of abundant sunlight during the day. The oil (water) flow rate also adjusts throughout the day, beginning at 10 L/min in the morning, reaching 15 L/min at noon, and slightly reducing to 11 L/min by 4:02:00 PM, probably due to changes in solar irradiation.

Table 3: Collector Heat - Water Oil Results

Time of Day	Solar Radiation (Watts/m ²)	Inlet Temperature (°C)	Outlet Temperature (°C)	Oil Flow Rate (L/min)
8:00 AM	300	25	40	10
10:00 AM	600	35	55	12
12:00 PM	900	45	70	15
2:00 PM	850	42	65	14
4:00 PM	500	38	58	11

These adjustments enable the system to capture more energy by increasing flow during high radiation situations while reducing it during low radiation conditions. For the system, it is most efficient at midday when the radiation is highest as seen from the highest outlet temperatures and flow rates, and then the efficiency decreases as the input decreases in the afternoon. This steady rise in outlet temperature over inlet temperature, from 15°C to 25°C, is an indication of the efficiency of the heat transfer and adaptability of the system to the amount of availability of solar energy.

Mineral Oil Fill

The results in Table (4) reveal how the system is effective in heating the mineral oil at various times of the day through the exploitation of the solar radiation. Solar radiation begins at 300 W/m² at 8: from 0 to 600 W/m² at 12:00 PM and then reduces to 300 W/m² at 4:00 PM. This pattern affects the inlet and outlet temperatures which in the morning are 30°C and 45°C respectively, in the afternoon 50°C and 75°C respectively and in the evening 44°C and 65°C respectively. The oil flow rate also adjusts in response to changing solar radiation, starting at 8 L/min at 8: From midnight to 6:00 AM is at 5 L/min, it increases to 13 L/min at midday, and drops down to 9 L/min at 4:00 PM.

Table 4: Collector Heat - Mineral Oil Results

Time of Day	Solar Radiation (Watts/m ²)	Inlet Temperature (°C)	Outlet Temperature (°C)	Oil Flow Rate (L/min)
8:00 AM	300	30	45	8
10:00 AM	600	40	60	10
12:00 PM	900	50	75	13
2:00 PM	850	48	70	12
4:00 PM	500	44	65	9

These changes are reflective of the system’s ability to control factors such as flow rate and temperature variation across the system during periods of high solar radiation. In summary, the system reasonably intercepts and transmits the solar heat; gets maximum heating during the midday when the solar input is greatest; and sustains good heat rise over the inlet temperature during the entire day.

Synthetic Oil Fill

The data in Table (5) presents how the system performs in heating with synthetic oil as the heat transfer fluid under different levels of solar radiation in a day. Solar radiation starts at 300 W/m² at 8: Rises from 00 AM to 900 W/m² at 12 PM and drops to 500 W/m² at 4:00 PM. This solar input is proportional to the inlet and outlet temperatures which are 28°C and 42°C in the morning, 48°C and 68°C at midday and 40°C and 60°C at evening. The oil flow rate also adjusts based on solar intensity, starting at 6 L/min at 8: From 12:00 am to 8:00 am it is 5 L/min, from 8:00 am to 12:00 pm it is 11 L/min and from 12:00 pm to 4:00 pm the rate is 7 L/min. These variations show that the system is sensitive to changes, with a higher flow rate and greater temperature difference at periods of maximum solar radiation, which creates a good heat transfer.

Table 5: Collector Heat - Synthetic Oil Results

Time of Day	Solar Radiation (Watts/m ²)	Inlet Temperature (°C)	Outlet Temperature (°C)	Oil Flow Rate (L/min)
8:00 AM	300	28	42	6
10:00 AM	600	38	55	8
12:00 PM	900	48	68	11
2:00 PM	850	46	65	10
4:00 PM	500	40	60	7

In general, the best heating performance of the system is observed at midday when the intensity of solar radiation is highest and the outlet temperature increase in comparison with the inlet temperature is observed throughout the day.

Vegetable Oil Fill

The data in Table (6) the ability of the system in heating vegetable oil during the day with solar radiation as the energy input. Solar radiation begins at 300 W/m² at 8: rises from 00 AM to a maximum of 900 W/m² at 12:00 PM and drops down to 500 W/m² at 4:00 PM. These temporal variations are observed on the inlet and outlet temperatures of the vegetable oil: 34°C inlet and 50°C outlet in the morning; 54°C inlet and 72°C outlet at midday; 46°C inlet and 65°C outlet in the evening. The oil flow rate also varies in response to solar intensity, beginning at 7 L/min at 8: Rising from 12 L/min at 12:00 PM, it lowers down to 8 L/min at 4:00 PM.

Table 6: Collector Heat - Vegetable Oil Results

Time of Day	Solar Radiation (Watts/m ²)	Inlet Temperature e (°C)	Outlet Temperature e (°C)	Oil Flow Rate (L/min)
8:00 AM	300	34	50	7
10:00 AM	600	44	60	9
12:00 PM	900	54	72	12
2:00 PM	850	50	70	11
4:00 PM	500	46	65	8

This change in the flow rate enables the improvement of heat collection since high flow rates occur during high radiation in solar energy. In general, the system gets the highest heat gain at midday, and it produces substantial rise in temperature from inlet to outlet throughout the day indicating efficient use of solar energy for heat applications.

Hydraulic Oil Fill

The data in Table (7) focuses on the performance of heat transfer in hydraulic oil within the system with respect to time depending on the intensity of radiation from the sun. Solar radiation starts at 300 W/m² at 8: It is the highest 900 W/m² at midday and drops to 500 W/m² at 4:00 PM. The inlet and outlet temperatures of the hydraulic oil respond to this solar input: 32/47°C in the morning, 52/77°C at noon, and 46/67°C in the afternoon. The oil flow rate also varies with solar radiation, starting at 7 L/min at 8: At 12:00 AM, the rate was 10 L/min and in the midday, it was 13 L/min, while in the evening it was 9 L/min.

This variation of the flow rate is useful in enhancing heat transfer, the maximum rates being applied during the highest rates of solar radiation to capture and utilize more thermal heat.

Table 7: Collector Heat - Hydraulic Oil Results

Time of Day	Solar Radiation (Watts/m ²)	Inlet Temperature e (°C)	Outlet Temperature e (°C)	Oil Flow Rate (L/min)
8:00 AM	300	32	47	7
10:00 AM	600	42	62	10
12:00 PM	900	52	77	13
2:00 PM	850	50	72	12
4:00 PM	500	46	67	9

In total, the system provides good heat absorption and transfer during the middle of the day when solar irradiation is at its apex and experiences a significant temperature rise from the inlet to the outlet during the day indicating the utility of hydraulic oil for thermal energy storage.

V. CONCLUSION

The parabolic trough collector system displayed high thermal efficiency especially during midday solar radiation test period with significant temperature rise from inlet to outlet of all fluids investigated. These results demonstrate that solar thermal systems have the capability of harnessing large amounts of thermal energy if the solar thermal system is used in combination with a solar tracking system as well as properly regulated flow rates. Of all the fluids investigated in the study, hydraulic oil and synthetic oil performed well, with high TES and heat transfer coefficients that are ideal for high-efficiency systems. The versatility of this system in connection to heat transfer fluids makes it possible to be employed in many industrial and agricultural heating sectors.

Also, the study concludes that there is need to vary the flow rate since higher rates when radiation is high result in better heat absorption. This modulation in flow rate improves energy capture and reduces thermal losses especially during low solar radiation. Therefore, the practical contribution of this work is that when tracking mechanism, heat transfer fluids and flow control are properly incorporated into the solar thermal systems, tremendous efficiency can be achieved off-grid and remote regions for heating requirements to minimize the use of fossil fuels.

Further research should be directed towards search for materials with high thermal conductivity, designing improved flow control mechanisms, and application of combined PV/T systems. This approach could still extend the use of solar technologies in meeting residential, commercial, and agricultural energy demands which are in line with sustainable energy practices all over the world.

REFERENCES

- [1] António Guterres, "The Sustainable Development Goals Report 2019," *United Nations Publ. issued by Dep. Econ. Soc. Aff.*, vol. 10, pp. 1–64, 2019.
- [2] A. G. Olabi *et al.*, "Wind Energy Contribution to the Sustainable Development Goals: Case Study on London Array," *Sustain.*, vol. 15, no. 5, 2023, doi: 10.3390/su15054641.
- [3] M. J. Barasa Kabeyi, "Decentralized and Distributed Power Generation," *Proc. 5th African Int. Conf. Ind. Eng. Oper. Manag. Decentralized*, no. December, 2023, doi: 10.46254/ap04.20230268.
- [4] K. A. Makinde, D. O. Akinyele, and A. O. Amole, "Voltage rise problem in distribution networks with distributed generation: A review of technologies, impact and mitigation approaches," *Indones. J. Electr. Eng. Informatics*, vol. 9, no. 3, pp. 575–600, 2021, doi: 10.52549/V9I3.2971.
- [5] A. Boretti, "Technology Readiness Level of Solar Thermochemical Splitting Cycles," *ACS Energy Lett.*, vol. 6, pp. 1170–1174, Mar. 2021, doi: 10.1021/acsenerylett.1c00181.
- [6] W. Strielkowski, E. Tarkhanova, M. Tvaronavič, and Y. Petrenko, "Renewable Energy in the Sustainable Development of Electrical," *Energies*, vol. 14, pp. 1–24, 2021.
- [7] M. Larsson, *Global energy transformation: Four necessary steps to make clean energy the next success story*. 2009. doi: 10.1057/9780230244092.
- [8] I. Tsiropoulos, W. Nijs, D. Tarvydas, and P. Ruiz Castello, *Towards net-zero emissions in the EU energy system by 2050*. 2020. doi: 10.2760/081488.
- [9] L. Chen *et al.*, *Green building practices to integrate renewable energy in the construction sector: a review*, vol. 22, no. 2. Springer International Publishing, 2024. doi: 10.1007/s10311-023-01675-2.
- [10] N. Bertelsen *et al.*, *Integrating low-temperature renewables in district energy systems: Guidelines for policy makers*. 2021.
- [11] Federal Ministry for Economic Affairs and Energy (BMWi), "Comprehensive assessment of the potential for efficient heating and cooling for Germany," *IREES*, vol. 14, no. 1, 2020.
- [12] Singapore Energy Market Authority, "Charting the Energy Transition to 2050: Energy 2050 Committee Report," no. March, 2022.
- [13] A. Alazazmeh, A. Ahmed, M. Siddiqui, and M. Asif, "Real-time data-based performance analysis of a large-scale building applied PV system," *Energy Reports*, vol. 8, pp. 15408–15420, 2022, doi: 10.1016/j.egy.2022.11.057.
- [14] K. Handayani, Y. Krozer, and T. Filatova, "From fossil fuels to renewables: An analysis of long-term scenarios considering technological learning," *Energy Policy*, vol. 127, no. January 2018, pp. 134–146, 2019, doi: 10.1016/j.enpol.2018.11.045.
- [15] C. Dong, R. Zhou, and J. Li, "Rushing for subsidies: The impact of feed-in tariffs on solar photovoltaic capacity development in China," *Appl. Energy*, vol. 281, p. 116007, Jan. 2021, doi: 10.1016/j.apenergy.2020.116007.
- [16] Y. Han *et al.*, "Impedance matching control strategy for a solar cooling system directly driven by distributed photovoltaics," *Energy*, vol. 168, pp. 953–965, 2019, doi: <https://doi.org/10.1016/j.energy.2018.11.148>.
- [17] W. Pang, H. Yu, Y. Zhang, and H. Yan, "Solar photovoltaic based air cooling system for vehicles," *Renew. Energy*, vol. 130, pp. 25–31, 2019, doi: <https://doi.org/10.1016/j.renene.2018.06.048>.
- [18] S. Zuhur, İ. Ceylan, and A. Ergün, "Energy, exergy and environmental impact analysis of concentrated PV/cooling system in Turkey," *Sol. Energy*, vol. 180, pp. 567–574, 2019, doi: <https://doi.org/10.1016/j.solener.2019.01.060>.
- [19] A. Kiyani, H. Karimi, and V. Madadi Avargani, "Exergoeconomic analysis of a solar photovoltaic-based direct evaporative air-cooling system," *Sol. Energy*, vol. 193, pp. 253–266, 2019, doi: <https://doi.org/10.1016/j.solener.2019.09.068>.
- [20] L. Lin, Y. Tian, Y. Luo, C. Chen, and L. Jiang, "A novel solar system integrating concentrating photovoltaic thermal collectors and variable effect absorption chiller for flexible co-generation of electricity and cooling," *Energy Convers. Manag.*, vol. 206, p. 112506, 2020, doi: <https://doi.org/10.1016/j.enconman.2020.112506>.
- [21] J. Song and B. Sobhani, "Energy and exergy performance of an integrated desiccant cooling system with photovoltaic/thermal using phase change material and maisotsenko cooler," *J. Energy Storage*, vol. 32, p. 101698, 2020, doi: <https://doi.org/10.1016/j.est.2020.101698>.
- [22] M. Bilardo, M. Ferrara, and E. Fabrizio, "Performance assessment and optimization of a solar cooling system to satisfy renewable energy ratio (RER) requirements in multi-family buildings," *Renew. Energy*, vol. 155,

- pp. 990–1008, 2020, doi: <https://doi.org/10.1016/j.renene.2020.03.044>.
- [23] D. Wu, L. Aye, Y. Yuan, P. Mendis, and T. Ngo, “Comparison of optimal oriented façade integrated solar cooling systems in Australian climate zones,” *Sol. Energy*, vol. 198, pp. 385–398, Mar. 2020, doi: [10.1016/j.solener.2020.01.003](https://doi.org/10.1016/j.solener.2020.01.003).
- [24] C. Lorenzo, L. Narvarte, R. H. Almeida, and A. B. Cristóbal, “Technical evaluation of a stand-alone photovoltaic heat pump system without batteries for cooling applications,” *Sol. Energy*, vol. 206, pp. 92–105, 2020, doi: <https://doi.org/10.1016/j.solener.2020.05.097>.
- [25] S. Lv, Z. Qian, B. Zhao, Z. Hu, and M. Liu, “A novel strategy of enhancing sky radiative cooling by solar photovoltaic-thermoelectric cooler,” *Energy*, vol. 219, p. 119625, Mar. 2021, doi: [10.1016/j.energy.2020.119625](https://doi.org/10.1016/j.energy.2020.119625).
- [26] M. N. Omar, A. T. Taha, A. A. Samak, M. H. Keshek, E. M. Gomaa, and S. F. Elsis, “Simulation and validation model of cooling greenhouse by solar energy (P V) integrated with painting its cover and its effect on the cucumber production,” *Renew. Energy*, vol. 172, pp. 1154–1173, 2021, doi: <https://doi.org/10.1016/j.renene.2021.03.092>.
- [27] Z. Zapałowicz and W. Zeńczak, “The possibilities to improve ship’s energy efficiency through the application of PV installation including cooled modules,” *Renew. Sustain. Energy Rev.*, vol. 143, p. 110964, 2021, doi: <https://doi.org/10.1016/j.rser.2021.110964>.
- [28] S. Al-Naemi and A. Al-Otoom, “Smart sustainable greenhouses utilizing microcontroller and IOT in the GCC countries; energy requirements & economical analyses study for a concept model in the state of Qatar,” *Results Eng.*, vol. 17, p. 100889, 2023, doi: <https://doi.org/10.1016/j.rineng.2023.100889>.
- [29] G. Li *et al.*, “Study on matching characteristics of photovoltaic disturbance and refrigeration compressor in solar photovoltaic direct-drive air conditioning system,” *Renew. Energy*, vol. 172, pp. 1145–1153, 2021, doi: <https://doi.org/10.1016/j.renene.2021.03.110>.
- [30] H. G. Ozcan, S. Varga, H. Gunerhan, and A. Hepbasli, “Numerical simulation and parametric study of various operational factors affecting a PV-battery-air conditioner system under prevailing European weather conditions,” *Sustain. Cities Soc.*, vol. 67, p. 102754, 2021, doi: <https://doi.org/10.1016/j.scs.2021.102754>.
- [31] A. Haffaf, F. Lakdja, D. Ould Abdeslam, and R. Meziane, “Solar energy for air conditioning of an office building in a case study: Techno-economic feasibility assessment,” *Renew. Energy Focus*, vol. 39, pp. 148–162, 2021, doi: <https://doi.org/10.1016/j.ref.2021.09.002>.

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