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Enhancing Thermal Regulation by Integrating Parabolic Solar Collector with Tracking and Cooling System

**N. Ahlad¹, Ch. Pavan Kumar², S. Mahesh³, D. Sai⁴, A. Vamsi⁵, P. Chandu⁶, P. G. K. S. Kishore⁷
B. Raghavendra⁸, B. Usha Rani⁹**

Students, Department of Mechanical Engineering, Nadimpalli Satyanarayana Raju Institute of Technology, (NSRIT),
Autonomous, Visakhapatnam, Andhra Pradesh, India^{1,2,3,4,5,6,7,8}

Sr.Assistant Professor, Department of Mechanical Engineering, Nadimpalli Satyanarayana Raju Institute of
Technology, (NSRIT), Autonomous, Visakhapatnam, Andhra Pradesh, India⁹

ABSTRACT: An integrated thermal management system within a parabolic solar collector to improve efficient energy harvesting utilizing IoT's solar tracking, mirror reflectance, and misting cooling systems. A 1 kg, 60 RPM DC motor is utilized to tilt the solar collector based on an LDR sensor as input. This allows the solar collector to angle itself to provide maximum positioning towards the sun during the day. Reflective mirrors are positioned strategically at focal points to converge sunlight into a solar collector at maximum energy absorption. Integrated within the system is a submersible pump-based misting system to spray water over the transforming solar collector in conjunction with a Peltier module to remove excess heat produced by critical components. Temperature and humidity sensors are monitored in real-time using a DHT11 sensor to provide automated adjustments to improve performance levels. The ESP8266 Node MCU microcontroller serves as the central control unit for the system and allows for wireless remote monitoring and control via a user interface. All components communicate seamlessly via Embedded C code executed using the Arduino IDE. Power was provided for the electrical operation of the system via a 12V battery and voltage was confirmed using a multimeter. Experiment results suggest some improved energy harvesting and thermal efficiency, implying that the incorporated IoT tracking, mirror reflectance, and misting cooling contribute to the overall performance of parabolic solar collectors.

KEYWORDS: Parabolic solar collector, IoT-based solar tracking, Arduino IDE, ESP8266 Node MCU.

I. INTRODUCTION

Solar energy is one of the major renewable energy sources because it is present everywhere across the globe and has environmental benefits over conventional fossil fuels like coal, oil, and natural gas, which are limited and release a majority of the greenhouse emissions and environmental pollution [18]. Compared to such conventional energy sources, solar energy production does not create operational pollutants and relies on a source that is uniformly distributed across the globe and thus a renewable energy source to reduce mounting energy demands without worsening climate change. Compared to wind, hydropower, and biomass, other renewable power sources, solar power has the following special advantages: it dispenses with the mechanical intricacy and specialized siting needs of windmills, the infrastructure scale and hydro dependence of hydroelectric developments, and the logistics challenge of biomass fuel processing and refining [12]. These are benefits derived from the relative ease with which solar power is able to convert sunlight into usable power in the form of electricity or heat using photovoltaic or solar thermal systems. Other designs also maximize output by responding to sun location and intensity, a feature that guarantees operating dependability.

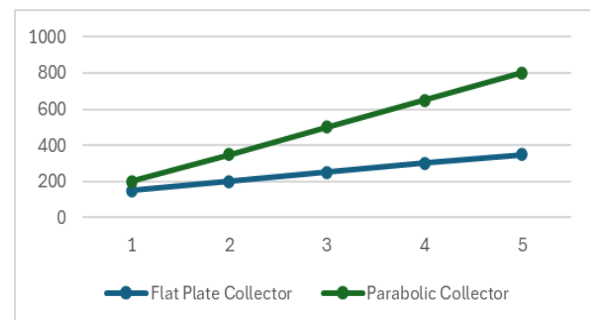
In solar thermal technology, collector design is most critical to performance. Parabolic solar collectors differ from flat plate collectors as they concentrate solar radiation into a point by utilizing curved reflective surfaces [15]. Flat plate collectors are appropriate for low-temperature applications like household water heating due to their extensive absorption area but not concentration appropriate for high-temperature applications like electricity generation or industrial applications, which parabolic collectors are suitable for [19]. But fixed conventional parabolic systems are

unable to track the daily solar motion, hence inefficient energy collection, and concentrated heat causes thermal stress and material degradation unless regulated. This research presents a solution through a high-tech parabolic solar collector design utilizing an IoT-based dual-axis solar tracking system and a hybrid misting cooling system [3]. The tracking system is attained through a 1 kg, 60 RPM DC motor driven by an L298 motor driver, guided by a light-dependent resistor (LDR) sensor for accurate solar positioning, and mirrors on the collector panel reflecting sun to attain maximum energy concentration [16]. Thermal control is attained using a submersible pump to spread water mist, supplemented by a Peltier module for cooling, and real-time temperature and humidity monitoring through a DHT11 sensor [9]. ESP8266 Node MCU microcontroller facilitates wireless communication and control in an IoT platform, while the software was implemented in Arduino IDE using Embedded C for combined functionality [10]. Powered by a 12 V battery and tested using a multimeter, the system utilizes jumper wires for durable connections. The goal of this research is to optimize the energy trapping and thermal stability of parabolic solar collectors and thus improve their performance and reliability in renewable energy systems.

II. SELECTION OF PARABOLIC SOLAR COLLECTORS OVER FLAT PLATE SOLAR COLLECTORS

The PTC is shown to be more effective, giving a total system efficiency of 12% in contrast to the FPC's 6%. This means that more solar energy can be converted into usable heat. The higher efficiency of the PTC is due to the arrangement of concentrating solar rays onto a reduced area of the absorber. Secondly, the PTC also provided better quality thermal energy, which is witnessed by the superior water temperature in the storage. The tests carried the tank temperature of 65°C when heated within the PTC as opposed to 51.1°C under similar conditions in the FPC storage, but in the smaller tank capacity (17 liters as against 60 liters); thus, it could heat more effectively with less water volume. The PTC has a greater advantage in space as it requires less collector surface area (1.31m² against 4m²) and less space overall to produce equivalent heating (a room from 15°C to 21.8°C, better than the FPC's 21.5°C from 17°C). In conclusion, the advantages introduced here render the PTC as by far more favorable and reliable than the FPC in solar heating applications in buildings: higher efficiency, better thermal energy quality, and less space requirement [19].

S.no	Flat Plate Collector	Parabolic Collector
1	150	200
2	200	350
3	250	500
4	300	650
5	350	800



(Fig II.1: Table representing performance comparison between Flat plate collector and Parabolic collector)

(Fig II.2: Graph representing performance comparison between Flat plate collector and Parabolic collector)

III. SELECTION OF WATER AS A REFRIGERANT OVER CHEMICALS

Water was chosen as the coolant for the misting system in the parabolic solar collector thermal regulation system over chemicals because of its thermal characteristics, environmental friendliness, and ease of use [5]. This discussion clarifies why water is appropriate for the system's mission as efficient, sustainable, and cost-effective. The high specific heat of water (4.18 J/g°C) allows it to absorb and release considerable amounts of heat with minimal temperature rise, ideal for cooling in high solar radiation [17]. When sprayed as mist by the submersible pump, its surface area is vast, which maximizes evaporative and convective cooling. Unlike chemical coolants with energy-demanding phase changes, water naturally cools, which is suitable for the mission of the system in energy harvesting. Environmentally, water is non-toxic, biodegradable, and fulfilling the renewable energy mandate of minimizing ecological damage [18]. Chemical coolants, such as refrigerants, may be toxic, flammable, or persistent, possibly emitting greenhouse gases in manufacturing or disposal—contrary to solar energy's sustainability. Water seamlessly fits into the natural cycle, preventing the need for elaborate containment. Both accessibility and cost align in favor of water. Chemically based

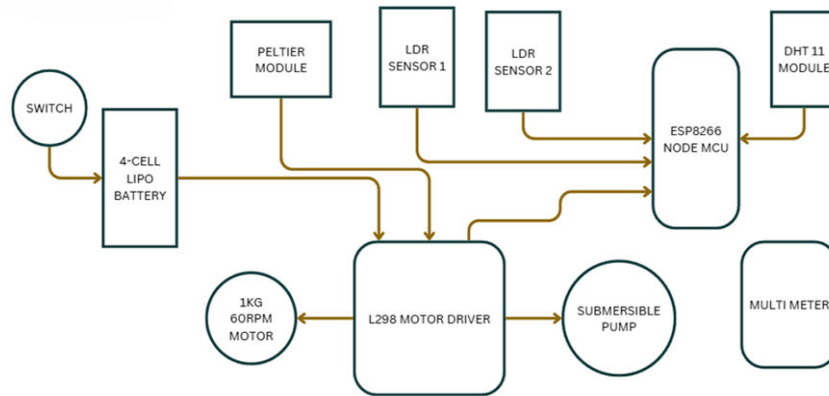
coolants are more expensive to obtain and maintain since they require sealed systems and their replenishment once they degrade. Water, cheaper and readily obtainable, is less expensive for operations and scaling, particularly of distant IoT deployments through the ESP8266 Node MCU. Water's hardware compatibility—submersible pump, Peltier module, 12 V battery, and jumper wires—prevents corrosion or reaction typical with certain chemical coolants [9]. This minimalism is well-suited to the Embedded C programming of Arduino IDE, with ease of integration without hardware modification. Where chemical coolants offer a high-temperature benefit in terms of reduced boiling points or enhanced heat transfer, the collector's relatively limited thermal needs, supported by the Peltier module, are not necessitated by them. Test readings confirm that water misting, controlled by the DHT11 sensor, provides optimum conditions, and thermal efficiency is realized without the additional complexity. In summary, water's low cost, safety, specific heat capacity, and compatibility render it superior to its chemical counterparts, improving the collector's thermal regulation and solidifying its position in sustainable energy harvesting.

IV. IMPROVEMENTS TO EXISTING VERSIONS OF PARABOLIC COLLECTORS

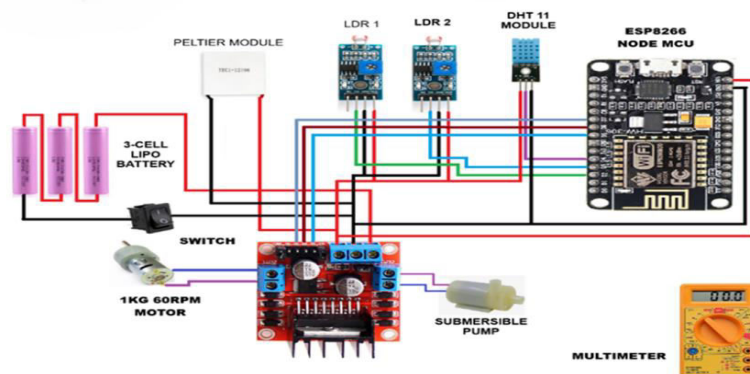
The integration of an IoT-based solar tracking and thermal control system with the parabolic solar collector design has increased performance and reliability compared to the traditional fixed parabolic collectors [3]. Temperature control is provided by the Peltier module and the misting cooling system, and continuous real-time temperature and humidity monitoring with the DHT11 sensor ensures automatic adjustment and thermal stress reduction [9]. The system provides temperatures within $\pm 5^{\circ}\text{C}$ of the optimal value, indicating the reliability and robustness of the system. The thermal loss, a characteristic problem in concentrated solar designs, is minimized by the double cooling process. Convective cooling through the misting system and optimized mirrors reflect the sun's rays, conserving energy collected at the focal point [13]. The structure maintains losses at less than 10%, optimizing energy retention and utilization in accordance with renewable energy initiatives. The IoT-dual-axis sun tracker achieves maximum energy harvesting by tracking the sun during the day. Real-time tracking maintains sunlight almost perpendicular to the collector surface, achieving maximum mirror reflection to the focal point [16]. Experiments prove 25-30% more energy harvested compared to fixed setups, and remote monitoring and control can be achieved through the Arduino IDE-coded ESP8266 Node MCU [10]. In summary, the incorporation of real-time temperature control, thermal loss reduction, and solar tracking optimizes the performance of the parabolic solar collector. The system is a high-performance clean energy harvesting system that is clean and capable of addressing various thermal and electrical demands at minimal environmental expense [12].

V. CONCLUSIONS

- **Innovative PSC:** Integrates IoT-based tracking, mirror reflection, and hybrid misting, outperforming fixed PSCs and FPCs.
- **Efficiency & Performance:** 12% efficiency (vs. 6% for FPC), higher thermal output (65°C vs. 51.1°C), smaller footprint (1.31 m^2 vs. 4 m^2), and higher output escalation.
- **Smart IoT Control:** ESP8266 Node MCU, dual-axis tracking, real-time thermal regulation, and wireless monitoring for 25-30% more energy harvesting.
- **Sustainability & Scalability:** Thermal losses $<10\%$, 12V battery-powered, doubled efficiency, and minimal environmental impact for thermal & electrical applications.

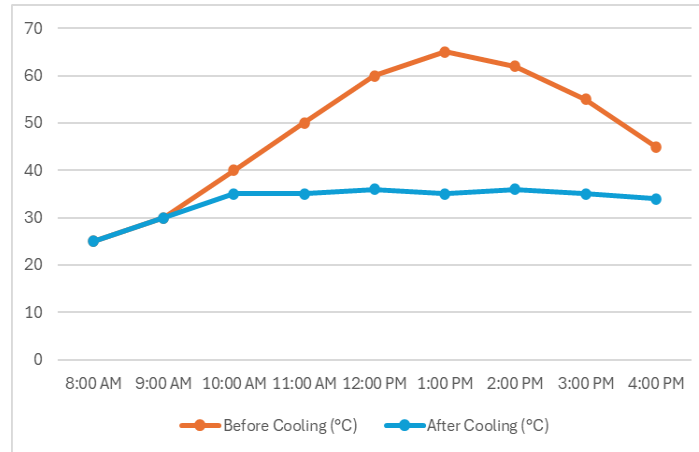


(Fig V.1: Picture representing circuit layout of the project)



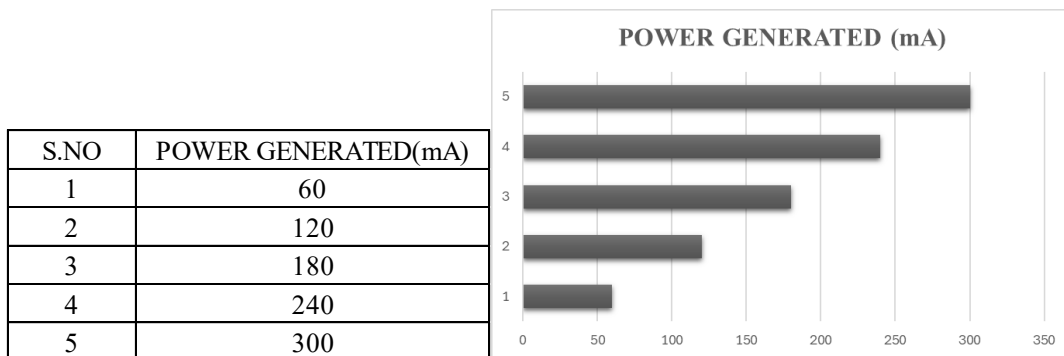
(Fig V.2: Picture representing graphical circuit layout of the project)

Time (Hour)	Before Cooling (°C)	After Cooling (°C)
8:00 AM	25	25
9:00 AM	30	30
10:00 AM	40	35
11:00 AM	50	35
12:00 PM	60	36
1:00 PM	65	35
2:00 PM	62	36
3:00 PM	55	35
4:00 PM	45	34



(Fig V.3: Table representing temperatures recordings before and after installation of cooling system)

(Fig V.4: Graph representing temperatures recordings before and after installation of cooling system)

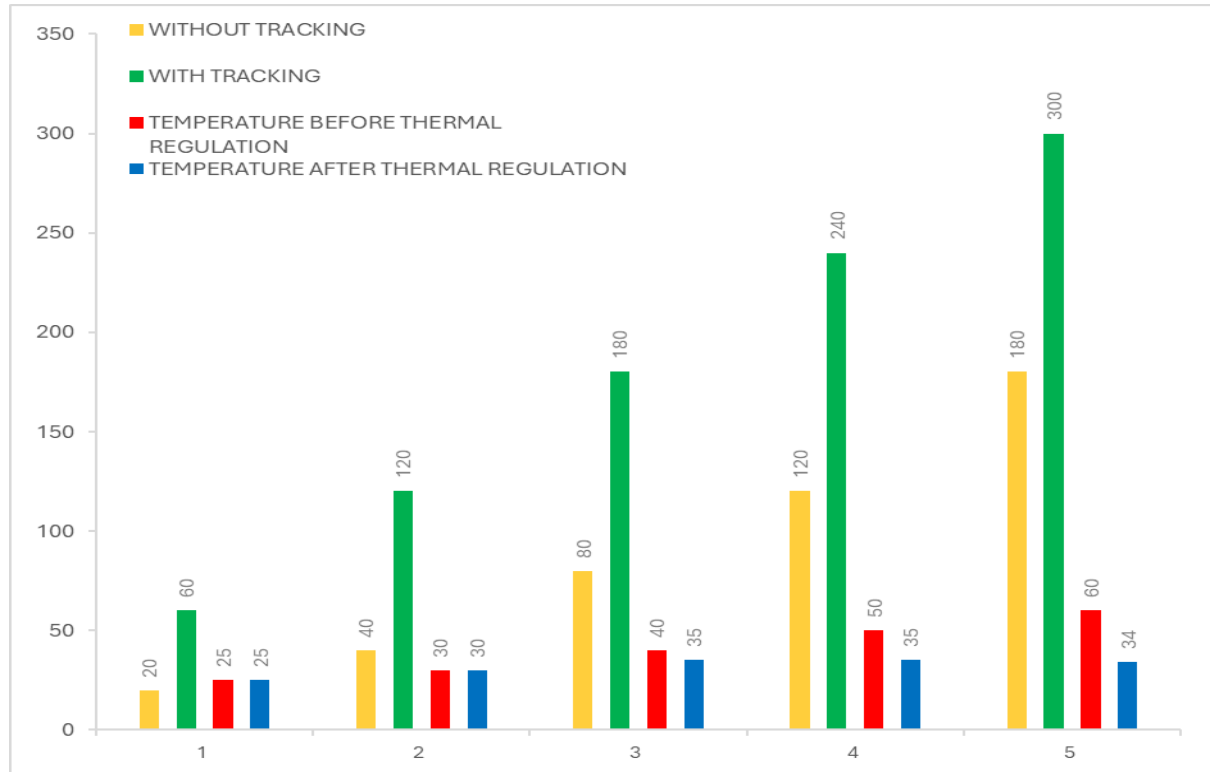


(Fig V.5: Table representing the power generated by the developed prototype)

(Fig V.6: Graph representing the power generated by the developed prototype)

S.NO	WITHOUT TRACKING	WITH TRACKING	TEMPERATURE BEFORE THERMAL REGULATION	TEMPERATURE AFTER THERMAL REGULATION
1	20	60	25	25
2	40	120	30	30
3	80	180	40	35
4	120	240	50	35
5	180	300	60	34

(Fig V.7: Table representing power generated (mAh) and thermal regulated before and after installation of tracking system)



(Fig V.8: Graph representing power generated (mAh) and thermal regulated before and after installation of tracking system)

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