Advanced International Journal of Multidisciplinary Research
E-ISSN: 2584-0487
editor@aijmr.com
Volume 4, Issue 4, July-August 2026
CrossRef DOI: 10.62127/aijmr.2026.v04i04.1421

Solar Water Condensation Using Thermoelectric Coolers

P. Paul Joshua[1], C.Raghunath Reddy, M. Tech[2]

[1,2]Department of Mechanical Engineering (CAD/CAM)
Tadipatri College of Engineering, Tadipatri

Abstract:
Fresh water scarcity is a major challenge in many regions, particularly in arid and remote areas where access to conventional water sources is limited. Atmospheric water generation offers a practical solution by extracting moisture directly from the air. This project presents the design and development of a solar-powered water condensation system using thermoelectric coolers (TECs). The system operates on the Peltier effect, where a temperature difference is created across the thermoelectric module when electric current is supplied. The cold surface of the TEC cools the surrounding air below its dew point, causing moisture present in the air to condense into water droplets. The condensed water is collected and stored for further use. Solar photovoltaic panels provide the electrical energy required to operate the thermoelectric modules, making the system suitable for locations with limited or no access to grid electricity. Heat generated on the hot side of the TEC is dissipated through a heat sink and fan arrangement to maintain efficient operation. The proposed system is compact, environmentally friendly, and economical, utilizing renewable solar energy for water production. The study demonstrates the feasibility of producing potable water from atmospheric humidity while reducing dependence on conventional water resources.

Keywords: Solar Water Condensation, Thermoelectric Cooler (TEC), Atmospheric Water Generation, Peltier Effect, Solar Photovoltaic System, Renewable Energy, Water Harvesting.

I.INTRODUCTION

Fresh water is one of the most critical natural resources required for human survival, agricultural activities, industrial operations, and economic development. Despite the abundance of water on Earth, only a small fraction is available as accessible fresh water suitable for human consumption. Rapid population growth, urbanization, industrial expansion, and climate change have placed increasing pressure on existing freshwater resources, resulting in water scarcity in many regions around the world. According to global water resource assessments, billions of people experience seasonal or chronic water shortages, particularly in arid and semi-arid regions where conventional water sources are either insufficient or unreliable. These challenges have created an urgent need for sustainable and alternative methods of freshwater generation that can supplement traditional water supply systems. Conventional sources of fresh water, including rivers, lakes, reservoirs, and groundwater aquifers, are facing significant depletion due to excessive extraction and environmental degradation. In many rural and remote areas, access to potable water remains limited because of inadequate infrastructure and high transportation costs. Furthermore, the increasing contamination of surface and groundwater resources by industrial effluents, agricultural runoff, and domestic waste has further reduced the availability of safe drinking water. Although desalination technologies provide a potential solution for coastal regions, they are often associated with high energy consumption, expensive infrastructure, and environmental concerns related to brine disposal. Consequently, researchers have been exploring alternative approaches capable of producing fresh water with lower environmental impact and improved accessibility. One promising approach is atmospheric water harvesting, which utilizes the moisture naturally present in the atmosphere as a source of fresh water. The Earth's atmosphere contains a considerable quantity of water vapour distributed across different climatic regions. This atmospheric moisture is continuously replenished through natural processes such as evaporation and transpiration, making it a renewable water resource. Atmospheric water harvesting technologies are designed to capture and condense this water vapour into liquid form for collection and utilization. Unlike groundwater extraction or surface water utilization, atmospheric water generation does not depend on geographical proximity to water bodies and can be implemented in locations where traditional water resources are scarce. This characteristic makes atmospheric water harvesting particularly attractive for remote, drought-prone, and off-grid regions. The principle of atmospheric water generation is based on the condensation of water vapour when humid air is cooled below its dew point temperature. When the air temperature decreases sufficiently, the moisture content exceeds the saturation limit, causing water droplets to form on a cold surface. Various technologies have been developed to achieve this cooling process, including vapor-compression refrigeration systems, desiccant-based moisture extraction systems, and thermoelectric cooling devices. Among these technologies, thermoelectric cooling has gained considerable attention due to its compact structure, reliability, environmental compatibility, and ease of integration with renewable energy sources. Thermoelectric cooling operates on the basis of the Peltier effect, a thermoelectric phenomenon discovered by Jean Charles Athanase Peltier in 1834. When a direct electric current passes through the junction of two dissimilar semiconductor materials, heat is absorbed on one side and released on the opposite side, creating a temperature difference across the device. Thermoelectric modules, commonly known as Peltier modules, exploit this effect to generate cooling without the use of refrigerants or moving mechanical components. The cold side of the module can be used as a condensation surface, while the hot side requires effective heat dissipation to maintain system efficiency. The absence of compressors, pumps, and refrigerants makes thermoelectric cooling systems environmentally friendly, compact, lightweight, and suitable for small-scale water harvesting applications. The efficiency of a thermoelectric water condensation system depends on several environmental and operational parameters. Ambient temperature and relative humidity directly influence the amount of moisture available in the air and the rate of condensation. Higher humidity levels generally result in increased water production, while elevated ambient temperatures may require greater cooling capacity to achieve the desired dew point conditions. Airflow rate is another critical factor, as adequate circulation of humid air over the cooling surface enhances moisture transfer and improves condensation efficiency. In addition, the thermal performance of heat sinks and cooling fans attached to the hot side of the thermoelectric module significantly affects the temperature gradient across the device. Efficient heat dissipation enables the cold side to maintain lower temperatures, thereby increasing water collection rates. Recent research efforts have focused on improving the performance of thermoelectric atmospheric water generators through design optimization and advanced thermal management techniques. The incorporation of high-conductivity heat sinks, forced convection cooling systems, and optimized condensation chambers has been shown to enhance moisture extraction efficiency. Researchers have also investigated the influence of module configuration, surface area enhancement, and airflow control mechanisms on water production capacity. These studies indicate that proper system design plays a crucial role in maximizing condensation efficiency while minimizing energy consumption. Energy availability remains a major consideration in the practical implementation of atmospheric water harvesting systems. Conventional electricity-based systems may not be suitable for remote or off-grid locations where power infrastructure is limited. To address this challenge, renewable energy sources have been increasingly integrated with atmospheric water generation technologies. Among the available renewable energy options, solar energy has emerged as one of the most attractive choices due to its abundance, sustainability, and widespread availability. Solar photovoltaic (PV) systems convert sunlight directly into electrical energy and can provide the power required for thermoelectric modules, cooling fans, and auxiliary control systems. The integration of solar energy with thermoelectric cooling technology offers several advantages. First, it enables completely independent operation without reliance on conventional electrical grids. Second, the peak availability of solar energy often coincides with periods of higher atmospheric temperatures, when moisture extraction systems are actively required. Third, solar-powered systems contribute to the reduction of greenhouse gas emissions and operational costs associated with fossil fuel-based electricity generation. The combination of renewable energy and atmospheric water harvesting therefore represents an environmentally sustainable solution for decentralized fresh water production. In recent years, advancements in photovoltaic technology, energy storage systems, and thermoelectric materials have further improved the feasibility of solar-powered atmospheric water generators. Enhanced photovoltaic conversion efficiencies, improved battery storage capabilities, and the development of high-performance thermoelectric modules have contributed to increased system reliability and productivity. Furthermore, the incorporation of intelligent control systems and environmental monitoring sensors has enabled adaptive operation based on changing weather conditions, thereby improving overall energy utilization and water production efficiency. The present research focuses on the design, development, and performance evaluation of a solar-powered water condensation system utilizing thermoelectric cooling technology. The proposed system consists of solar photovoltaic panels, thermoelectric modules, heat sinks, cooling fans, a condensation chamber, and a water collection unit. The thermoelectric modules are employed to create a cold surface for moisture condensation, while solar energy serves as the primary power source for system operation. The objective of the study is to investigate the feasibility of utilizing atmospheric moisture as an alternative source of fresh water through a compact, energy-efficient, and environmentally sustainable system.

II.LITERATURE SURVEY

[1] (2024) presented a numerical analysis of a multi-effect diffusion solar still using measured solar radiation data. The study demonstrated that the use of multiple diffusion stages improved heat transfers and enhanced freshwater productivity. The results showed that proper utilization of solar energy could significantly increase the efficiency of water distillation systems. [2] (2025) investigated the application of solar vacuum membrane distillation for desalination in arid regions. The study highlighted the potential of membrane-based technologies powered by solar energy to provide sustainable freshwater production with reduced dependence on conventional energy resources. The findings indicated that solar-assisted membrane systems could be a viable solution for addressing water scarcity in dry climates. [3] (2026) conducted an experimental comparison of different solar still configurations, including double slope, double absorber with capillary wicks, and double condensation arrangements. The investigation revealed that design modifications have a considerable impact on evaporation and condensation processes, leading to variations in freshwater output. The enhanced configurations achieved better performance than traditional solar still designs. [4] (2024) developed a hybrid solar still system utilizing photovoltaic energy for wastewater distillation. The integration of solar PV technology improved system reliability and reduced operational costs while maintaining effective water purification performance. [5] (2024) proposed a method for seawater desalination using a solar collector. The research demonstrated that solar thermal energy could be effectively utilized for converting saline water into freshwater without requiring complex equipment. The system provided a cost-effective and environmentally friendly approach to desalination. [6] **(**2024) examined the performance improvement of solar stills through the integration of condensers, cooling fans, and reflectors. The study reported enhanced condensation rates, increased water collection efficiency, and higher freshwater yield due to improved heat transfer characteristics within the system. [7] **(**2025) carried out an exergy analysis of a tubular solar still incorporating sensible heat storage material. The results showed that thermal energy storage improved system stability and maintained water production during periods of reduced solar intensity. The use of predictive techniques further assisted in evaluating system behaviour under different operating conditions. [8] (2025) introduced an Iota-based atmospheric water generator designed for portable water harvesting applications. The developed system employed sensors and monitoring technologies to improve operational control and optimize water collection from atmospheric humidity. [9] (2025) developed an autonomous solar-powered atmospheric water generation system equipped with real-time monitoring and water quality assessment features. The study demonstrated that atmospheric moisture could serve as a reliable source of potable water, particularly in remote and off-grid locations. The reviewed literature shows considerable progress in solar desalination, atmospheric water harvesting, and renewable-energy-driven water production systems. However, limited research has focused on combining solar photovoltaic technology with thermoelectric cooling modules for direct atmospheric water condensation. Therefore, the present work aims to develop a solar water condensation system using thermoelectric coolers to harvest moisture from the atmosphere efficiently and provide a sustainable source of fresh water with minimal energy consumption. [10] (2025) developed an autonomous solar-powered atmospheric water generation system equipped with real-time monitoring and water quality assessment features. The study demonstrated that atmospheric moisture

could serve as a reliable source of potable water, particularly in remote and off-grid locations. The reviewed literature shows considerable progress in solar desalination, atmospheric water harvesting, and renewable-energy-driven water production systems. However, limited research has focused on combining solar photovoltaic technology with thermoelectric cooling modules for direct atmospheric water condensation. Therefore, the present work aims to develop a solar water condensation system using thermoelectric coolers to harvest moisture from the atmosphere efficiently and provide a sustainable source of fresh water with minimal energy consumption.

III.SYSTEM MODULE

EXISTING SYSTEM

Existing water harvesting systems commonly use solar stills, desalination units, and conventional refrigeration-based cooling systems to produce fresh water. These systems depend on either thermal energy or compressor-based cooling for the condensation process. Most of them require continuous power supply and involve complex components, resulting in higher installation and maintenance costs. Their performance is often affected by environmental conditions and energy availability. As a result, their suitability for remote and off-grid locations is limited.

Disadvantages

- High power consumption in refrigeration-based systems.
- Increased installation and maintenance costs.
- Dependence on continuous electricity supply.
- Complex system configuration and operation.
- Reduced suitability for remote and rural areas.
- Lower efficiency under unfavourable environmental conditions.

PROPOSED SYSTEM

The proposed system utilizes solar energy and thermoelectric cooling technology to provide air conditioning and atmospheric water condensation in areas with limited access to electricity. The system operates based on the Peltier effect, where a thermoelectric module creates a temperature difference between its hot and cold sides. The cold side is used to cool the surrounding air and facilitate moisture condensation, while the heat generated on the hot side is dissipated into the environment through a heat exchange unit. The system consists of a thermoelectric cooling module, heat sink, air circulation unit, condensation chamber, and a solar photovoltaic panel with a control circuit to supply power. By using solar energy as the primary power source, the system can function independently of the electrical grid and provide a sustainable solution for cooling and water generation.

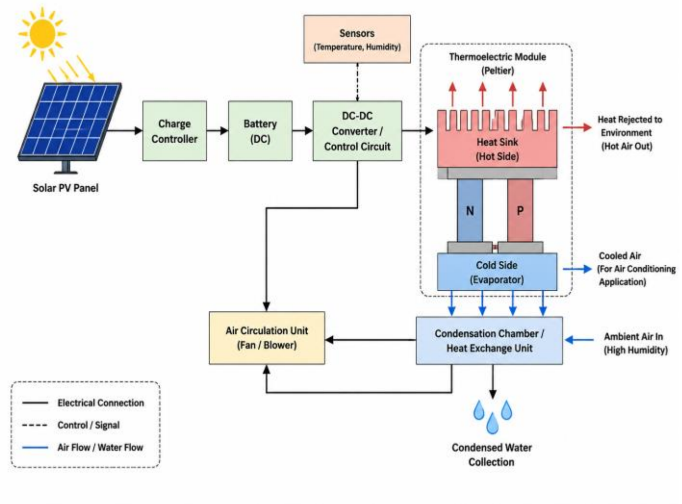

Figure: Block Diagram of Solar-Powered Thermoelectric

Advantages of Proposed System

- Operates using renewable solar energy.
- Suitable for remote and off-grid locations.
- Low operating and maintenance costs.
- Environmentally friendly with no refrigerants required.
- Compact and simple system design.
- Provides both cooling and water condensation functions.
- Reduces dependence on conventional electricity sources.
- Quiet operation due to the absence of mechanical compressors.

IV.MATERIALS AND METHODS

The solar water condensation system was developed using a solar photovoltaic panel, thermoelectric cooler (Peltier module), heat sinks, DC cooling fans, battery, charge controller, condensation chamber, water collection container, connecting wires, and a supporting frame. The solar panel converts sunlight into electrical energy, which is supplied to the thermoelectric module through the control circuit. When electric current passes through the Peltier module, a temperature difference is created between its two surfaces. The cold side of the module cools the surrounding humid air below its dew point temperature, causing water vapour present in the atmosphere to condense into liquid droplets. These droplets are collected in a storage container through the condensation chamber. The heat generated on the hot side of the module is removed using heat sinks and cooling fans to maintain efficient operation. The system was assembled and tested under ambient atmospheric conditions to evaluate its ability to produce fresh water using solar energy. Data related to temperature, humidity, and water output were observed and recorded for performance analysis.

EXPERIMENTAL PROCEDURE

The experimental setup was assembled by connecting the solar photovoltaic panel, charge controller, battery, thermoelectric cooler, heat sinks, cooling fans, and condensation chamber. The solar panel was placed in an open area to receive maximum sunlight and provide electrical power to the system. When power was supplied to the thermoelectric module, a temperature difference was created between its hot and cold surfaces. The cold surface was exposed to humid atmospheric air, causing the moisture present in the air to condense into water droplets. Heat sinks and cooling fans were used to dissipate the heat generated on the hot side of the module and maintain efficient cooling performance. The condensed water droplets were collected through the condensation chamber and stored in a collection container. Temperature, humidity, and the quantity of water collected were monitored and recorded at regular intervals. The performance of the system was evaluated under different environmental conditions to determine its effectiveness in producing fresh water from atmospheric moisture using solar energy.

V.RESULTS

The solar-powered thermoelectric water condensation system was successfully developed and tested under ambient environmental conditions. The thermoelectric module generated a temperature difference between its hot and cold surfaces, enabling the condensation of atmospheric moisture on the cold side. Water droplets formed continuously and were collected through the condensation chamber. The heat sink and cooling fan effectively removed heat from the hot side, maintaining stable system performance. The amount of water collected was observed to increase with higher humidity levels and favourable weather conditions. The solar photovoltaic panel provided sufficient power for system operation during daylight hours. The experimental results demonstrated that atmospheric moisture can be converted into usable water using renewable energy. The system operated reliably and showed the potential of thermoelectric cooling technology for small-scale freshwater generation in remote and water-scarce regions.

VI.CONCLUSION

The proposed solar-powered thermoelectric water condensation system successfully demonstrated the ability to harvest water from atmospheric humidity using renewable energy. The thermoelectric module provided the required cooling effect for condensation, while the solar panel supplied clean and sustainable power. The system operated without conventional refrigeration equipment and produced freshwater through a simple and compact design. Experimental observations confirmed the feasibility of using thermoelectric cooling for atmospheric water generation. The low maintenance requirement, eco-friendly operation, and suitability for remote locations make the system a practical solution for small-scale water production where access to freshwater and electricity is limited.

FUTURE SCOPE

The performance of the system can be improved by increasing the number of thermoelectric modules and optimizing the condensation chamber design. Advanced heat dissipation methods can be incorporated to enhance cooling efficiency and water production. Larger solar panels and improved battery storage can support longer operating hours and continuous operation during low sunlight conditions. Automatic monitoring systems with temperature and humidity sensors may be integrated for better control and energy management. Future research can focus on testing the system under different climatic conditions and scaling the design for larger water production applications in rural, coastal, and water-deficient regions.

REFERENCES:

1. G. Ibrahim and H. M. Had, "Numerical Analysis of Multi Effect Diffusion Solar Still with Measured Solar Radiation," *2024 IEEE 9th International Conference on Engineering Technologies and Applied Sciences (ICETAS)*, Bahrain, Bahrain, 2024, pp. 1-6, doi:10.1109/ICETAS62372.2024.11119899.
2. Khaliah, M. Kolb and M. Elboghdadi, "Solar Vacuum Membrane Distillation for Desalination in Arid Regions," *2025 14th International Conference on Renewable Energy Research and Applications (ICRERA)*, Vienna, Austria, 2025, pp. 638-643,doi:10.1109/ICRERA66237.2025.11283940.
3. S. Mankai, F. O. Saad, J. Madiouli, H. Cherif, S. Chemkhi and J. Sghaier, "Experimental Comparative Study of Three Solar Still Configurations: Double Slope, Double Absorber with Capillary Wicks, and Double Condensation with Asymmetric Cover," *2026 International Symposium of Systems, Advanced Technologies and Knowledge (ISSATK)*, Hammamet, Tunisia, 2026, pp. 1-5, doi: 10.1109/ISSATK69667.2026.11566694.
4. R. H. Putra, Fajri, P. O. Hadi and S. Hidayat, "Design and Implementation of a Hybrid Solar Still Sistem Utilizing Solar PV for Waswater Distillation," *2024 6th International Conference on Power Engineering and Renewable Energy (ICPERE)*, Bandung, Indonesia, 2024, pp. 1-6, doi: 10.1109/ICPERE63447.2024.10845395.
5. M. Lemeshko and A. Lemeshko, "Method of Desalination of Seawater in a Solar Collector," *2024 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM)*, Sochi, Russian Federation, 2024, pp. 235-239, doi: 10.1109/ICIEAM60818.2024.10553664.
6. H. M. Ahmed, "Boosting Solar Still Performance Through Condenser, Fan, and Reflectors Integration," *2024 IEEE 9th International Conference on Engineering Technologies and Applied Sciences (ICETAS)*, Bahrain, Bahrain, 2024, pp. 1-6, doi: 10.1109/ICETAS62372.2024.11120101.
7. B. K. Ahirwar, A. Kumar, S. Nagpure, A. K. Mandal, V. Shrivastava and A. K. Shrivastava, "Artificial Neural Networks (ANNs)-Exergy Analysis of Tubular Solar Still with Sensible Heat Material," *2025 IEEE 1st International Conference on Smart Innovations in Systems, Infrastructure, Mechanical, Power, AI and Computing Technologies (SISIMPACT)*, Bhopal, India, 2025, pp. 1542-1547, doi: 10.1109/SISIMPACT67725.2025.11439269.
8. S. C. Das *et al.*, "A Sustainable IoT-Based Atmospheric Water Generator for Portable Clean Water Harvesting," *2025 IEEE 7th International Conference on Sustainable Technologies For Industry 5.0 (STI)*, Dhaka, Bangladesh, 2025, pp. 1-5, doi: 10.1109/STI69347.2025.11367589.
9. J. G. M. Castro, D. I. A. Mora, H. M. Dávila and N. C. Sánchez, "Development of an Autonomous Solar-Powered Atmospheric Water Generator with Real-Time Monitoring and Potability

Assessment," *2025 IEEE Central America and Panama Student Conference (CONESCAPAN)*, Tegucigalpa, Honduras, 2025, pp. 1-6, doi: 10.1109/CONESCAPAN67936.2025.1122966

10. O. Haris, A. Darmawan, I. L. Adi Saputra and A. Firmansyah, "Design and Analysis Utilizing Water in the Air (Condensation Process) Using a Thermoelectric Cooler with a Solar Power Plant," 2021 IEEE 7th International Conference on Computing, Engineering and Design (ICCED), Sukabumi, Indonesia, 2021, pp. 1-6, doi: 10.1109/ICCED53389.2021.9664870.