# Harvesting Water from Air Using Renewable Energy

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Water scarcity remains a critical issue worldwide, especially in dry and isolated areas with limited conventional water sources. In this paper, the concept of an eco-friendly, solar-powered atmospheric water generator (AWG) using a Peltier thermoelectric cooler as the moisture extraction component is developed and realized. The system is optimized for efficient off-grid operation with renewable energy, thus being extremely viable for regions with water scarcity. The essential components of the system encompass the DHT11 sensor for the measurement of temperature and humidity, an ultrasonic sensor for water level measurement, a TDS sensor for water quality testing, and UV LED for sterilization. Real-time monitoring and control based on the internet of things (IoT) is facilitated by the ESP32 microcontroller. The proposed system is a low-power and decentralized solution with high potential for water generation with a focus on sustainability and independence. Experimental results ensure the efficacy of the Peltier based condensation process as well as the power management with smart features of the integrated system and show the potential of the system in solving water problems all over the world with renewable power.

## I. INTRODUCTION

Scarcity of water is a continued concern of the 21st century, more so in far-flung and dry areas with restricted access to safe and clean drinking water. Conventional water sources such as ground water, river water, and rain collection systems become less reliable as a result of climatic changes, pollution, and seasonal variations. With the increased population and demand for water in the world, alternative sources of water and renewable sources become a pressing necessity.

One such water source is atmospheric moisture. Even in arid regions, the air holds some amount of water vapor that is able to get trapped and condensed into potable water. Atmospheric Water Generation (AWG) technology harnesses this water vapor, with Peltier modules—solid-state coolers that generate the temperature differences necessary to enable condensation—being a highly efficient and lights solution.
The project aims to implement low-cost AWS that harvest atmospheric moisture with the assistance of a Peltier module. The system is run mainly with renewable solar energy and is thus sustainable and ideal for off-grid, rural, or disaster zones. The system further accommodates sensors that monitor environmental conditions as well as water quality to determine its safety for drinking.

By interfacing renewable energy with thermoelectric cooling, this paper offers a green and viable option for water scarcity that presents a method, design, preliminary findings, and prospects for extended applicability in resolving water issues around the world.

## II. LITERATURE REVIEW

As access to clean drinking water becomes more limited with its decreasing supply in rural and arid regions, scientists continue researching new technologies such as atmospheric water generation (AWG). The most promising of these is based on the application of thermoelectric cooling with Peltier modules that have the capacity of drawing water directly from the air.

The TEC1-12703 Peltier module is widely employed in such systems because of its high energy efficiency combined with its small size and compatibility with low-power supplies such as solar panels. Efficiency is largely a function of heat management along with ambient humidity. To improve its efficiency and as an added benefit of low-humidity conditions, most systems make use of fans and heat sinks. Forced air directed over the cooling surface has been shown by Radhika and Kumar to significantly enhance condensation output even with low-humidity conditions.

The natural choice for AWG systems in the case of limited access to the conventional infrastructure is solar power. The incorporation of the ESP32 microcontroller technology, with the system having the ability to monitor the environment for factors like temperature, humidity, as well as water quality in real-time, ensures the system delivers optimum performance as well as safe drinking water. UV LED sterilization is usually build in in an effort to eliminate infectious agents ensuring the water received is safe for consumption. The inclusion of MPPT (Maximum Power Point Tracking) controllers is also used to ensure increased solar energy efficiency such that the system operates effectively even with alteration sunlight conditions.

In short, AWG systems are observing massive growth with innovations in solar energy, water sterilization, IOT monitoring, and thermoelectric cooling that offer a sustainable and efficient water scarcity solution for off-grid locations.

## III. BACKGROUND THEORY

Even in the most arid climates, the air carries trace amounts of moisture in the form of vapor. Atmospheric Water Generation (AWG) systems are developed to utilize this often-overlooked resource by condensing it into drinkable water. The process involves cooling the air below its dew point so that water vapour condenses into liquid form. Main component to this mechanism is a Peltier module, a thermoelectric device that generates a temperature differential producing a cold surface on one side and heat on the other. The cooled side gets the temperature to low of the surrounding air, activating the condensation of atmospheric moisture into extractable water drops.

For the system to operate efficiently, it's necessary to manage the heat produced by the Peltier module. This is gained through a combination of a heat sink and a fan, which dissipate excess thermal energy from the hot side. The system is particularly effective at night, when lower ambient temperatures and reduced evaporation rates enhance water more. Cooler night time air allows more efficient condensation, heading to better water extraction rates.

To ensure the safety of the harvested water, it passes through a UV LED sterilization unit that counter balances bacteria and viruses without the use of chemicals. The quality of the purified water is tracked using a Total Dissolved Solids (TDS) sensor. An ultrasonic sensor is also used to keep track of the water level in the storage tank. At the core of the system's operation is an ESP32 microcontroller, which collects sensor data, displays real-time readings on an LCD, and works on system functions.

Power is supplied with via a 12V SMPS or a solar-powered battery system governed by an MPPT (Maximum Power Point Tracking) charge controller. These two power sources setup enables the system to operate independently of the grid, making it especially valuable in remote or needy regions. By integrating renewable energy with intelligent water purification, this AWG solution offers a sustainable and good approach to addressing water scarcity in areas lacking dependable access to clean drinking water.

Fig 1: Peltier Module (Heart of the system)

## IV. ARCHITECTURE

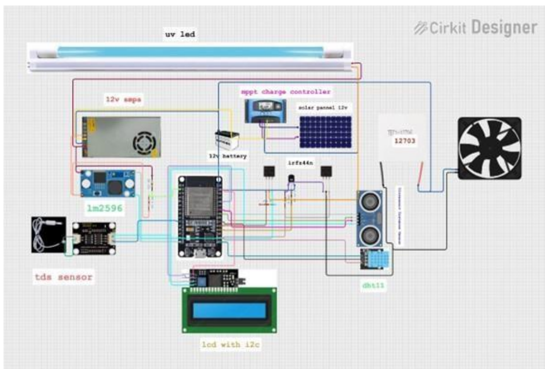


Fig 2: Circuit Diagram

This system withdraw moisture from the atmosphere by using a Peltier module, which cools the air below its dew point, activating condensation. To keep the module running efficiently, heat generated on the hot side is dissipated with the help of a heat sink and cooling fan. Once water droplets form, they pass through a UV LED sterilization unit that get rid of bacteria and viruses without the use of chemicals. A Total Dissolved Solids (TDS) sensor is used to judge water quality, while an ultrasonic sensor monitors the water level in the storage tank. The entire operation is run by an ESP32 microcontroller, and the system is powered either by a 12V SMPS or a solar battery setup, which is balanced through an MPPT charge controller—making it ideal for remote or off-grid environments.

## V. METHODOLOGY & IMPLEMENTATION

### 5.1 METHODOLOGY

The EcoWaterGen prototype follows a stepwise procedure to extract drinkable water from air. This design uses thermoelectric condensation via the Peltier effect, automatic control based on environmental sensors, sustainable solar energy management, and a real-time data monitoring system over IoT. The entire system is premeditated by an ESP32 microcontroller.

5.1.1. Environmental Monitoring

The DHT11 sensor is used for an in-passive recording of humidity and temperature levels in the atmosphere. If the humidity crosses a certain set threshold believable to favor condensation, the ESP32 initiates water production.

5.1.2. Thermoelectric Condensation Methods

When conditions allow, the ESP32 activates the TEC1-12703 Peltier module to begin condensation. Per this thermoelectric device, the electrical energy results in heat transfer between two junctions of different conductors according to the Peltier effect. In this case:

The cold side of the module is exposed to the air and cools down very quickly when powered. The hot side is mounted on a heatsink and actively cooled by the fan for better heat dissipation. Moist air contacting the cold surface results in vapor condensing into water droplets, much as dew forms on a chilled surface. The droplets are then collected in a reservoir placed at the base of the cooling surface.

To further improve performance:

Thermal paste or pads are used between the Peltier and the heatsink for increased thermal A cold-side metallic extension plate is attached to enhance the surface area. This may be made of aluminium or copper. Insulation shall be provided around the cold side to prevent heat ingress from ambient air; this enhances cooling. Thermoelectric cooling ensures the compact, noiseless sort of orientation conceivable, with the entire setup running on solar energy with a 12V battery as a backup arrangement, as shown in the schematic below.

5.1.3. Water Level Detection and Quality Assessment

An ultrasonic sensor (HC-SR04) determines the current water level in the storage chamber. If the water stored is adequate enough, the subsequent testing of TDS levels of the water is carried out; any water with a TDS value less than 500 ppm is considered suitable for drinking.

5.1.4. Ultraviolet Sterilization

Once the quantity is verified and water check passes, the UV LED sterilizes the water. It is controlled with an IRFZ44N MOSFET, serving as a switching device to safely and efficiently manage high-power loads.

5.1.5. Power Supply and Management

Primarily, the system gets power from a solar panel of 12V. This panel charges a 12V battery with the help of an MPPT (Maximum Power Point Tracking) charge controller. The distribution of energy happens over an:

- LM2596 buck converter used to step down from 12V to 5V for devices like ESP32 and sensors.
- The 12V SMPS will be the backup power source if solar charging is insufficient.
- Relays or MOSFETs are selectively used to activate/deactivate power-hungry loads such as the Peltier module, UV LED, and the fan to conserve energy.

5.1.6. IoT Integration and Local Display

The ESP32 collects and processes data from all sensors and uploads this information to cloud platforms, such as Thing speak or Firebase, for remote access and monitoring. On the local front, an LCD with an I2C interface displays current readings for temperature, humidity, TDS levels, and water volume.

### 5.2 IMPLEMENTATION

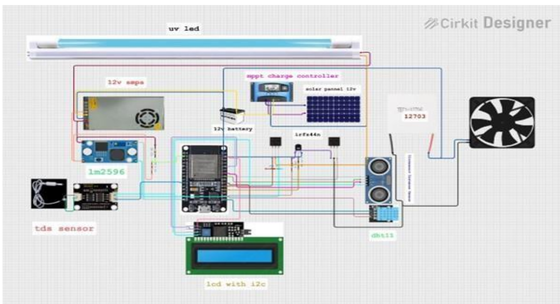


Fig 3: Components Image

The EcoWaterGen is a solar-powered unit set up to autonomously produce potable water out of atmospheric moisture by integrating several subsystems, such as thermal condensation, solar harvesting, environmental sensing, water purification, and IoT communication, into a compact design. Coordinating the operations of sensors, actuators, display modules, and communication systems is the ESP32 microcontroller.

Acting as the system's brain, the ESP32 reads data from environmental sensors and controls the cooling module's power supply while uploading the operational data of the system onto the cloud platform such as ThingSpeak or Firebase. Using the received real-time data on temperature, humidity, water level, and water quality, the ESP32 takes decisions on when to switch on or off individual subsystems.

TEC1-12703 Peltier module is the main watermaker. Enabled when humidity reaches a particular level (for example, 60%), it forms a cold surface from heat transfer between two sides of the module through electric current. The cold side is kept exposed for atmosphere touch and serves as a condensation surface. When air touches it, moisture condenses into liquid water, thus parallel to the dewcollecting process. The hot side is thermally managed with a heatsink and DC fan, which ensures that steady temperature differentials are maintained for condensation.

Water droplets on the Peltier surface fall into a reservoir chamber. The water level is continuously monitored by the ultrasonic sensor (HC-SR04).

Once enough water to be measurable is present, water purity is tested using the TDS sensor. If the Total Dissolved Solids (TDS) value falls under 500 ppm, the water is labelled fit for consumption. LED sterilizes the water collected for biological safety by switching it with an IRFZ44N MOSFET.

Preparation of UV sterilized water ensures that microbial contaminants are neutralized, and that the water produced is potable.

A solar panel of 12V powers the plant and charges the 12V lead-acid battery via an MPPT charge controller. For the 5V output required to power the ESP32 and sensors, the voltage is stepped down by an LM2596 Buck converter. A 12V SMPS is kept as the secondary backup power supply. Using MOSFETs or relay modules, power-intensive loads such as Peltier, UV LED, and fans are switched in a power-saving manner to enhance power efficiency and system runtime. An IoT dashboard is connected to the ESP32 for these parameters related to environmental and system data, all logged in realtime. In front of the LCD locally made with I2C, multiple users able to see it immediately can view humidity, temperature, TDS, and water volume.

This hardware-software integration then results in solar-powered autonomous water harvesting machinery: useful in off-grids, drought-stricken, or rural areas deprived of potable water.

## VI. TESTING & RESULT

### 6.1 RESULT

The system that has been developed utilizes atmospheric air to condense water with the help of a Peltier-based condenser unit. The system works continuously but is more efficient at night time because there is less evaporation and greater condensation. The Peltier module condenses moisture when the humidity is suitable, and the gathered water is exposed to UV radiation for simple sterilization. A sensor of TDS makes the quality checkup and, in case the TDS level is found to be less than 300 ppm, the water is deemed fit for common human consumption but not proved safe to drink.

The device shows live temperature, humidity, and TDS values on the LCD screen. It operates on both the 12V SMPS and on the sun-charged battery through an MPPT controller, which ensures operation in off-grid conditions as well. The prototype has successfully shown sustained production of water, basic purification, and quality testing of the water, and the produced water is safe to use for non-potable applications including cleaning and irrigation.

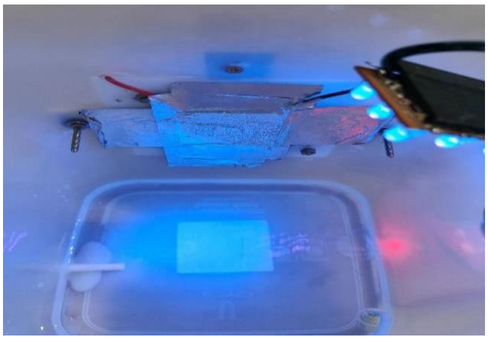

Fig 4: Water Generation

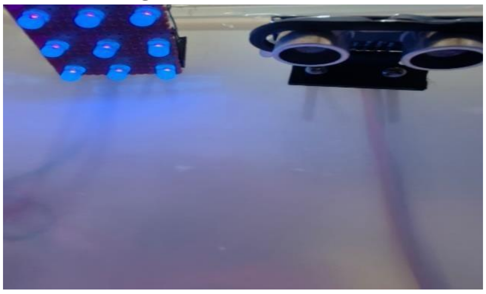

Fig 5: UV light Output

6.2 ULTRA SONIC SENSOR & UV

The ultrasonic sensor continuously tracks the level of the water in the container through measuring the distance from the water level. It informs the ESP32 microcontroller when the level reaches or is at 10% of the capacity of the container. Upon receiving the alert, the ESP32 turns on the UV LED to commence the sterilization. The UV light produces ultraviolet light to kill the bacteria, viruses, and other pathogens and render the water safe to drink. The UV LED is active as long as the level of the water is maintained at greater than 10%, continuously purifying and adding to the dependability of the system of water production.


Fig 6: TDS value Output

6.3 TDS SENSOR OUTPUT

The TDS (Total Dissolved Solids) sensor is a main component in assessing the quality of the water generated by the system. It recognizes the level of dissolved elements like minerals, salts, and trace metals that may be present in the condensed water. To avoid inaccurate readings caused by sudden fluctuations, the system calculates an average from ten back-to-back measurements. This approach ensures the results are more consistent and reliable of the actual water purity.

Once this average is calculated, its evaluated against set benchmarks to identify if the water is suitable for use. If the TDS level is under 300 ppm, the water is considered as clean and safe. A range between 301 and 330 ppm the water is still usable, though approaching the upper safety limit. Any reading over 330 ppm indicates a higher level of impurities, meaning the water might not be safe to drink without further treatment.

To help users stay informed, the system shows both the TDS value and a simple safety status on an LCD screen in real time. This makes it easy to understand water quality and decide if extra filtration is needed. The combination of accurate sensing and clear communication helps it to make the system both dependable and convenient for everyday water monitoring.

## VII. CONCLUSION

The "Harvesting Water from Air" system is designed to draw moisture from the air using a Peltier-based cooling mechanism, with its performance optimized for cooler nighttime conditions. To ensure the water collected is safe for practical use, the setup includes UV light for disinfection and a TDS sensor to monitor water quality. An ESP32 microcontroller oversees the system's operations, displaying environmental data such as humidity, temperature, and water purity on an LCD screen, while an ultrasonic sensor keeps track of water levels in the tank. Power is supplied either through a 12V SMPS or a solar-powered battery setup managed by an MPPT controller, making the system suitable for off-grid environments. The working prototype has proven its ability to consistently generate and purify water, offering promising potential for future upgrades aimed at producing drinking-quality water.

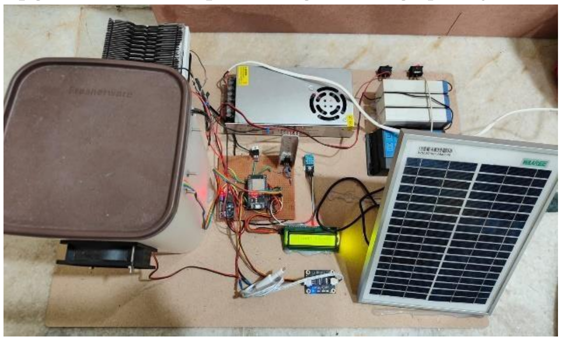

Fig 7: Overall System

## VIII. FUTURE SCOPE

The Harvesting Water from Air system exhibits high potential for further development and application. Future work can include the incorporation of sophisticated multi-stage filtrations (for example, activated carbon or reverse osmosis) to render the water completely potable and meet drinking standards. Optimization of energy usage through improved thermal management of the Peltier modules or the use of higher-efficiency cooling technologies can greatly enhance the amount of output. The inclusion of IoT-based distant monitoring and data recording can facilitate smarter management and real-time diagnostic monitoring. Scaling the system to community or agricultural scale and optimizations for different climatic conditions can render the system more flexible. Properly developed, the system can be an assured source of clean drinking water in desert areas, disaster areas, or non-traditional areas without traditional water supply infrastructure.

## REFERENCES

[1] Humphrey, J. H., Brown, J., Cumming, O., Evans, B., Howard, G., Kulabako, R. N., ... & Wang, E. N. (2020). The potential for atmospheric water harvesting to accelerate household access to safe water. *The Lancet Planetary Health*, *4*(3), e91-e92.

[2] Lord, J., Thomas, A., Treat, N., Forkin, M., Bain, R., Dulac, P., ... & Schmaelzle, P. H. (2021). Global potential for harvesting drinking water from air using solar energy. *Nature*, *598*(7882), 611-617.

[3] Jarimi, H., Powell, R., & Riffat, S. (2020). Review of sustainable methods for atmospheric water harvesting. *International Journal of Low-Carbon Technologies*, *15*(2), 253-276.

[4] Tashtoush, B., & Alshoubaki, A. (2023). Atmospheric water harvesting: A review of techniques, performance, renewable energy solutions, and feasibility. *Energy*, *280*, 128186.

[5] Ezeani, E. U., David, D., Orji, C., & Ekeocha, N. E. A REVIEW OF RAINWATER HARVESTING AS A TOOL FOR ACTUALIZATION OF SUSTAINABLE DEVELOPMENT GOALS.

[6] Kandeal, A. W., Joseph, A., Elsharkawy, M., Elkadeem, M. R., Hamada, M. A., Khalil, A., ... & Sharshir, S. W. (2022). Research progress on recent technologies of water harvesting from atmospheric air: A detailed review. *Sustainable Energy Technologies and Assessments*, *52*, 102000.

[7] Uddin, M. N., Rab, M. F., Islam, A. N., Asmatulu, E., Rahman, M. M., & Asmatulu, R. (2022). Nanostructured hybrid hydrogels for solar-driven clean water harvesting from the atmosphere. *Materials*, *15*(21), 7538.

[8] Alsyouf, L., Alsyouf, I., & Obaideen, K. (2024). Advancing Water Security in Arid Regions: A Technological and Bibliometric Study on Integrating Hydro Panels in Buildings for Sustainable Development Goals. *Energy Nexus*, 100312.

[9] Al-Khasawneh, Y., Alshawabkeh, M., Khwaileh, M., Almalahi, R., & Alshawabkeh, Q. (2025). Sustainable Atmospheric Water Generation Systems as a Solution to Alleviate Clean Water Scarcity in Jordan's Arid and Semiarid Terrain. *Journal of Environmental Engineering*, *151*(5), 05025002.

[10] Tu, Y., Wang, R., Zhang, Y., & Wang, J. (2018). Progress and expectation of atmospheric water harvesting. *Joule*, *2*(8), 1452-1475.

[11] Poredoš, P., Shan, H., Wang, C., Deng, F., & Wang, R. (2022). Sustainable water generation: grand challenges in continuous atmospheric water harvesting. *Energy & Environmental Science*, *15*(8), 3223-3235.