

Development and Analysis of Atmospheric Water Harvesting Utilizing Peltier Module Thermoelectric Cooling

Muthuraman Subbiah^{1*}, Majid Saleem Al Aamri¹, Mohammed Yousuf Al Bulushi¹, Muhanad Mohamed Al Hinai¹, Mohamed Fahim Al Maqdasi¹

¹Department of Engineering, University of Technology and Applied Sciences, Muscat, Oman

DOI: <https://doi.org/10.36348/sjet.2025.v10i03.002>

| Received: 03.02.2025 | Accepted: 08.03.2025 | Published: 12.03.2025

*Corresponding author: Muthuraman Subbiah

Department of Engineering, University of Technology and Applied Sciences, Muscat, Oman

Abstract

This study examines the feasibility of utilizing atmospheric air as a clean water alternative to address water scarcity, considering Oman's normal humidity levels of 75% to 85%. The study utilizes a thermoelectric cooler (TEC 1-12706), augmented by a heatsink and fan on its hot side to improve heat dissipation. A copper cooling coil functions as both a heat absorber and a condenser for ambient air flowing through it. The coil, with a diameter of 7.9 mm and a length of 1000 mm, receives its cooling source from a water block affixed to the cold side of the cooler. Experiments were performed in three environmental conditions: laboratory, residential area, and coastal area, with variations in the airflow rate of the heatsink cooling fan. The data collection encompassed a humidity range of 72.27% to 83.01%. The findings indicated a clear association between the air mass flow rate of the heatsink cooling fan and the volume of water extractable from the air. During preliminary laboratory testing, a mass flow rate of 0.046 kg/s yielded 4.25 ml/hour, 0.069 kg/s resulted in 4.625 ml/hour, and 0.092 kg/s produced 5.5 ml/hour. Moreover, among the three environmental settings evaluated, a greater volume of water may be retrieved from coastal regions compared to labs and residential areas. In coastal regions, the air mass flow rate is 0.092 kg/s, with a potential water extraction of 7.75 ml/hour; in laboratory settings, it is 5.5 ml/hour, and in residential zones, it is 4.75 ml/hour. These encouraging results advocate additional research to enhance water extraction by optimizing the contact area between the air cooler and the coil surface, potentially providing a feasible solution for the scarcity of clean water.

Keywords: Thermoelectric Module, Heat sink, atmospheric water harvesting, air cooling and condensation.

Copyright © 2025 The Author(s): This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY-NC 4.0) which permits unrestricted use, distribution, and reproduction in any medium for non-commercial use provided the original author and source are credited.

1. INTRODUCTION

Water, an essential requirement for all living organisms, is obtained from diverse sources depending on local conditions and geographical areas. The significance intensifies when living situations change [2, 3]. Oman, although possessing enormous water resources of 15,500 cubic meters per capita annually, exceeding the global average of 8,000 cubic meters, faces a scarcity of potable water.

Approximately 19% of Oman's 27 million population lives in urban areas, with just 39% having access to clean, government-supplied piped water. Rural regions perform poorly, with merely 5% employing a piped system, 48% relying on non-piped systems, and the remaining 47% depending on dug wells and unprotected

water sources [6]. Oman's normal atmospheric humidity of 75% to 85% provides a substantial amount of water vapor, representing an innovative clean water resource. The average temperature of 27.2°C indicates a significant potential for atmospheric water vapor extraction [7]. Thus, investigating atmospheric water vapor condensation could provide a viable remedy for the worldwide water scarcity.

A thermoelectric cooler (TEC) is one method to condense atmospheric water vapor [8]. The operational mechanism of the thermoelectric cooler (TEC) as a water-cooling device has been investigated by Djafar *et al.*, [9, 10] and more recently by Kiran and Prakash [11]. Numerous studies concerning the application of thermoelectric cooler (TEC) elements have been

undertaken. For instance, Baharamsyah *et al.*, [8] researched a lifeboat by developing a device that generates fresh water from air using TEC technology, achieving a production rate of 53 ml/hour of potable water. Prasetyo and Wirenda [12] investigated the application of TEC elements in conjunction with a waterblock and heatsink as a dual-sided heat absorption and release mechanism for the TEC elements. Riahi *et al.*, [13] conducted intriguing research on the design and testing of freshwater condensation components from atmospheric air under tropical conditions at the University of Technology and Applied Science Muscat-Salalah campus.

This study utilized 18 TEC modules, 18 heat sinks, and 18 cooling fan units, with observations recorded at 24 and 48 hours. The findings indicate that the value of clean water production is directly proportional to the relative humidity of the air, while being inversely proportional to the ambient temperature. Nocturnal circumstances are optimal for freshwater. The test findings yield roughly 3.5 liters of potable water over 24 hours and 7 liters over 48 hours, adhering to WHO quality criteria. This study seeks to assess the efficacy of the TEC element as the principal cooling component in the air condensation process, in order to ascertain the volume of clean water that can be harvested from a prototype situated in the tropical environment of Gowa Regency, Oman. This study differs from other studies [13] that collected data just on a campus, as it includes three locations: a university campus, residential neighborhoods, and coastal areas. This broadened breadth will yield a more thorough comprehension of many domains and atmospheric circumstances. The efficacy of a tool, characterized by its capacity to attain optimal outcomes, can be assessed by juxtaposing the results derived from empirical testing with theoretical computations. This study uses the following formulas to ascertain the model's effectiveness.

1.1 Efficacy

The efficacy of AWG is determined by contrasting theoretical water with actual water. Theoretical water refers to the anticipated volume of water derived from calculations, whereas actual water denotes the volume of water collected during the data acquisition procedure.

Theoretical water can be computed using the following equation:

$$\text{Theoretical Water} = \dot{m} (\text{win} - \text{wout}) \dots\dots\dots (1)$$

Where win represents the moisture ratio of incoming air and wout denotes the moisture ratio of exiting air.

Effectiveness can be determined using the formula:

$$\varepsilon = (\text{Actual Water} / \text{Theoretical Water}) \times 100\% \dots\dots (2)$$

Where Actual Water refers to the volume of water collected during data acquisition (ml/hour), Theoretical

Water denotes the volume of water derived from calculations (ml/hour), and ε represents Effectiveness (%).

1.2 Intake Air Mass Flow Rate

The incoming air mass flow rate quantifies the mass of air entering the AWG device per unit of time [14].

$$\dot{m} = vA/V \dots\dots\dots (3)$$

Where \dot{m} represents the inlet air mass flow rate (kg/s), V denotes the specific volume of air (m^3/kg), A signifies the inlet area (m^2), and v indicates the inlet air velocity (m/s).

1.3 Intake and exhaust air conditions

Critical parameters of the incoming and exiting air condition serve as indicators of the air's specifications and attributes, specifically the Partial Pressure of water vapor, Relative Humidity, and Humidity Ratio.

The partial pressure of water vapor is determined using the following equation [1].

$$P_s = P_{jwb} - 0.5 (T_{db} - T) P_t / 755 \dots\dots\dots (4)$$

Where, P_{jwb} is Wet bulb saturated vapor pressure (mmHg or kPa), P_s is Partial pressure of water vapor (mmHg or kPa), T_{db} is Dry bulb temperature ($^{\circ}\text{C}$), T_{wb} is Wet bulb temperature ($^{\circ}\text{C}$), and P_t is pressure atmospheric air (mmHg or kPa).

Relative Humidity is determined using the equation [16]

$$RH = P_s / P_{jdb} \dots\dots\dots (5)$$

Where, P_{jdb} is the dry bulb saturated water vapor pressure (mmHg or kPa), P_s is the partial pressure of water vapor (mmHg or kPa), RH is Relative Humidity (%).

The Humidity Ratio is calculated by:

$$w = 0.622 P_s / (P_t - P_s) \dots\dots\dots (6)$$

Where, P_s is Saturated vapor pressure (mmHg/kPa), P_t is air pressure (mmHg or kPa), w is Humidity Ratio.

2. EXPERIMENTAL METHODS

Figure 1 illustrates a prototype of the Atmospheric Water Generator. A thermoelectric cooler (TEC) functions as a cooling device, wherein the cold side cools the water block (WB) while the hot side is dissipated by a heatsink with an integrated fan. The TEC employed is of type TEC 1-12706, measuring $4\text{mm} \times 4\text{mm} \times 0.4\text{mm}$. The WB measures $120\text{mm} \times 40\text{mm} \times 12\text{mm}$ and is constructed from aluminum. The heatsink dimensions are $97\text{mm} \times 73\text{mm} \times 135\text{mm}$, featuring four rods with a heatpipe diameter of 6mm. The fan dimensions are $90\text{mm} \times 90\text{mm} \times 25\text{mm}$, with a maximum input voltage-current of 12V-0.18A. Cold water on the WB is circulated by a cooling coil (7.9 mm in diameter and 1000 mm in length) via a pump. The copper cooling coil serves to condense water vapor from

the air entering the AWG, with the resulting condensate collected in a reservoir. This investigation positioned the

Thermoelectric Cooler on both sides of the AWG, as illustrated in Figure 1.

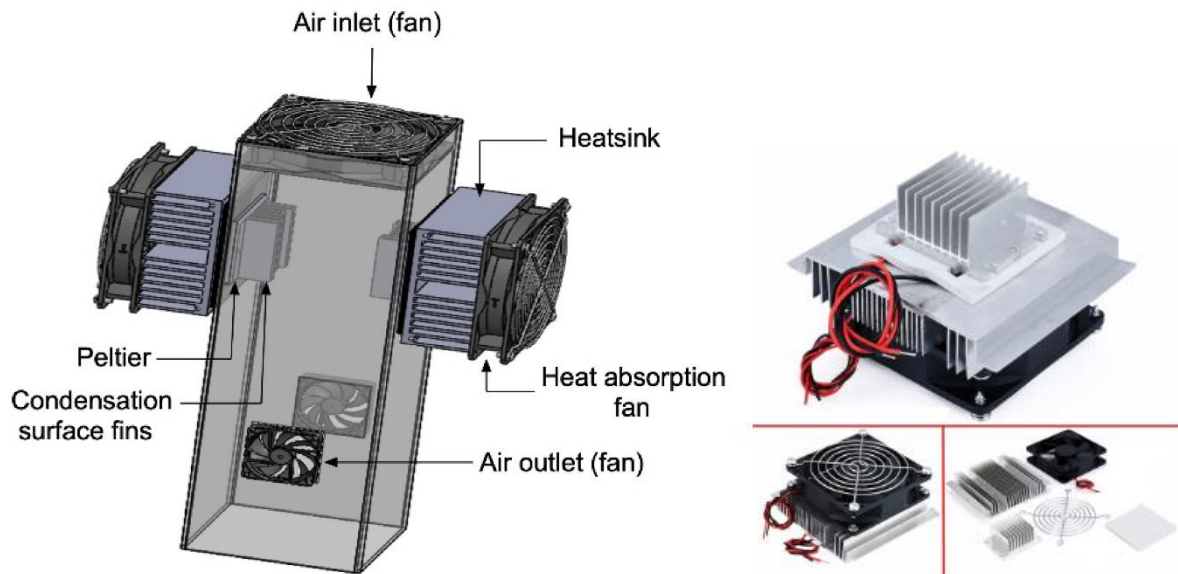


Figure 1: Schematic of the atmospheric water generator (AWG) -TEC module

The quantity of modules employed on either side is same. The quantity of modules on each side is modified as follows: Two single modules (SM), two stacked double modules (DM), and two stacked triple modules (TM). The fan air speed for the heatsink is varied to 12 m/s, corresponding to a mass flow rate of 0.092 kg/s; 9 m/s, with a mass flow rate of 0.069 kg/s; and 6 m/s, with a mass flow rate of 0.046 kg/s. Variations in air velocity are achieved by adjusting the input voltage to the fan and are quantified with an anemometer. The collected test data includes the temperature of the cold side of the TEC module, the temperature of the hot side of the TEC module, the temperature of the heatsink-fan, the inlet air temperature (both wet bulb temperature, TWB, and dry bulb temperature, TDB), the air temperature exiting the condensation chamber (TWB and TDB), the waterblock temperature, the water temperature leaving the waterblock, the temperature of the condensation room, the temperature of the cooling coil wall, the ambient air temperature (in laboratory, residential, and coastal environments), and the volume of condensate produced. Data collection was conducted by acquisition with the LabVIEW software package [17]. The data gathering lasted for 240 minutes. The exam was conducted thrice to obtain valid findings.

3. RESULTS AND DISCUSSION

The test findings and data analysis yielded many characteristics that serve as markers of the study's success: TEC Cold Side Temperature, Condensation

Chamber Temperature, Air Relative Humidity (RH), Condensed Water Volume, and AWG efficiency.

3.1 Temperature of the cold and hot sides of the Thermoelectric Cooler module

Figure 2 illustrates the temperatures of the cold and hot sides of the TEC module within the AWG system under laboratory conditions, with a test length of 240 minutes and a cooling fan air mass flow rate of 0.092 kg/s. The temperature graphs for the TEC's cold and hot sides have stayed stable since the 20th minute. The temperature disparity between the hot and cold sides for single and double modules is approximately 15°C, however for triple modules, it attains 31°C. The triple module necessitates a greater voltage to attain a minimum cold side temperature. Experiments indicate that each module necessitates approximately 4 Volts to achieve optimal cold side temperature. The optimal voltage for SM is 16V, for DM is 30V, and for TM is 50V.

The single module (SM) and dual module (DM) maintain cold side temperatures exceeding 25°C, making atmospheric air condensation unlikely, although the triple module (TM) can achieve a temperature of 10°C. This study identifies the optimal fan air speed at 12 m/s, corresponding to a mass flow rate of 0.092 kg/s. Enhancing the fan's airspeed will elevate the convection coefficient, hence augmenting the heat dissipation rate on the heatsink. Consequently, the results presented pertain exclusively to a mass flow rate of 0.092 kg/s.

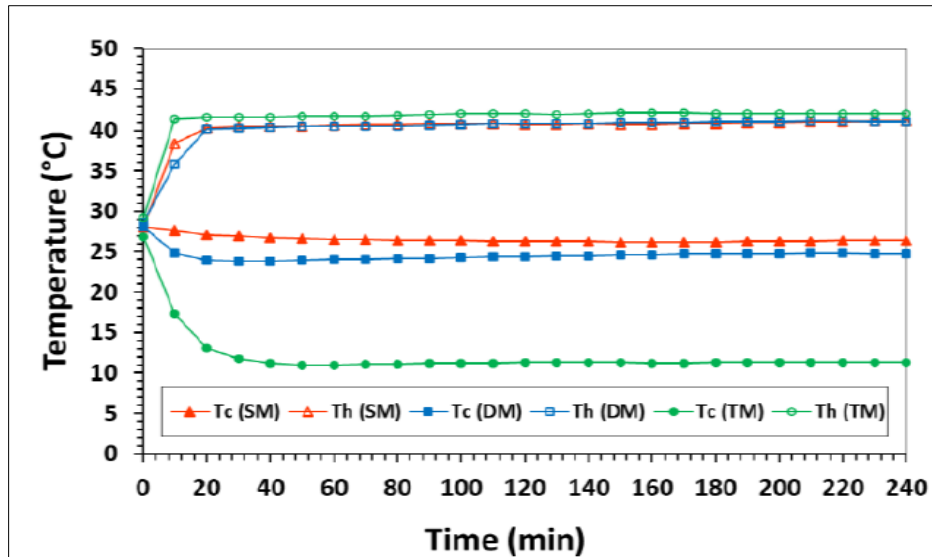


Figure 2: History cold side and hot side temperatures for three variations of the TEC module series with a duration of 240 minutes in laboratory environment conditions

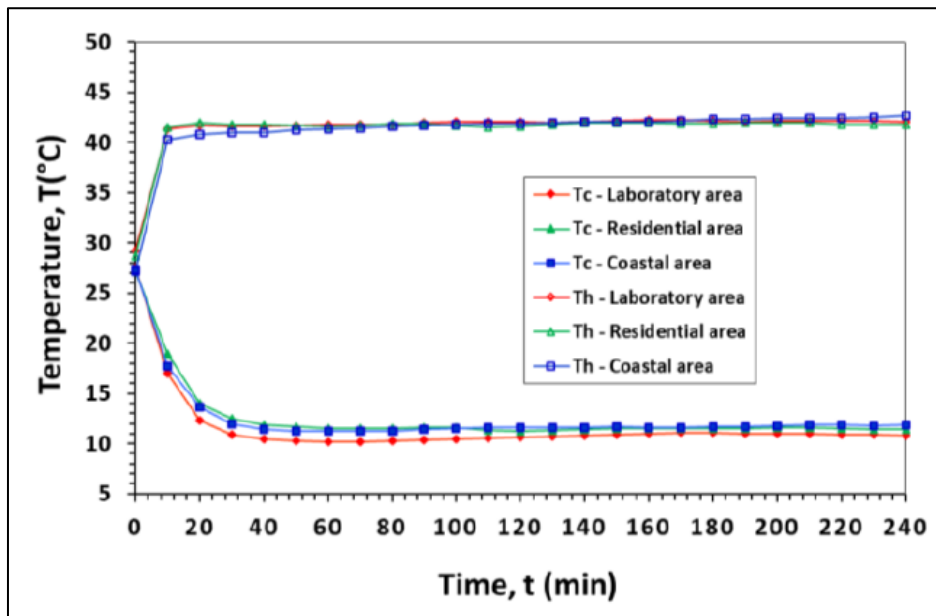


Figure 3: History of temperature on the cold side and hot side of the triple TEC module with three different environmental conditions

Figure 3 illustrates the disparity in temperature values between the cold and hot sides of the thermoelectric cooler (TEC) for the triple module at a mass flow rate of 0.092 kg/s across three environmental conditions: laboratory, residential, and coastal regions. The minimum temperature of the cold-side thermoelectric cooler and the maximum temperature of the hot-side thermoelectric cooler were recorded in the laboratory setting. The cold-side TEC temperatures in the laboratory, residential areas, and coastal areas are 10.693°C, 11.674°C, and 11.690°C, respectively, while the hot-side TEC temperatures are 41.988°C, 41.815°C, and 41.865°C. The temperature on the cold side is sufficiently low to cool the water block.

3.2 Temperature within the water block and cooling coils of the AWG system under three environmental situations

In addition to the temperature on the cold side of the TEC module, it is imperative to monitor the temperature of the copper coil cooling water exiting the water block (WB). Figure 4 illustrates the temperature of the water block (WB) and the cooling coil for a duration of 240 minutes across three environmental conditions: laboratory, residential area, and coastal region, utilizing a triple module (TM) and a heatsink cooling fan with a fluid flow rate of 0.092 kg/s. The graph indicates that the temperatures of the WB and the cooling coil have remained steady since the 20th minute, with each environment exhibiting relatively similar temperatures. The temperatures in the water block (WB) are 14.871°C

for labs, 14.912°C for residential regions, and 14.986°C for coastal areas, while in the cooling coil, they are 15.393°C, 15.313°C, and 15.321°C, respectively. This indicates that the fluid temperature from the water bath to the cooling coil has only marginally changed, and the cooling coil temperature remains sufficiently low to facilitate the condensation of ambient air.

3.3 Temperature within the condensing chamber of the AWG system under three distinct environmental circumstances

The cooling coil effectively cools the air, facilitating condensation. Figure 5 illustrates the ambient

temperature and the condensing chamber during a duration of 240 minutes across three environmental contexts: laboratory, residential area, and coastal region, for the triple module (TM) with a heatsink cooling fan mass flow rate of 0.092 kg/s. The graph indicates that the temperature of the condensing chamber has been consistent since the 20th minute. The temperatures of the condensing chamber are 21.077°C, 21.225°C, and 21.434°C. The average ambient temperatures are 29.168°C, 30.009°C, and 29.953°C. The addition of a cooling coil results in a reduction of ambient air temperature by approximately 9°C upon entering the condensation chamber.

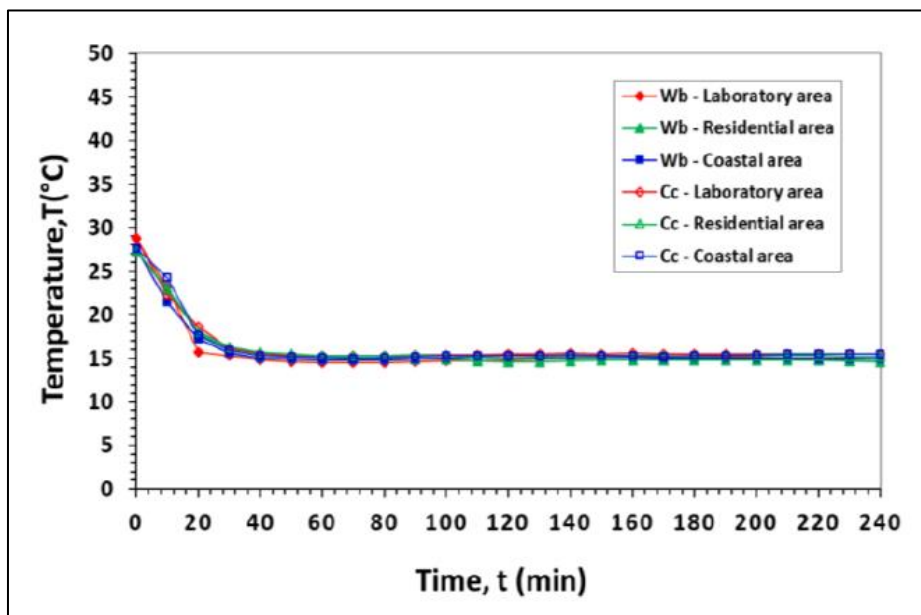


Figure 4: History of water block and cooling coil temperatures on the three environmental conditions: Laboratory, residential area & coastal areas

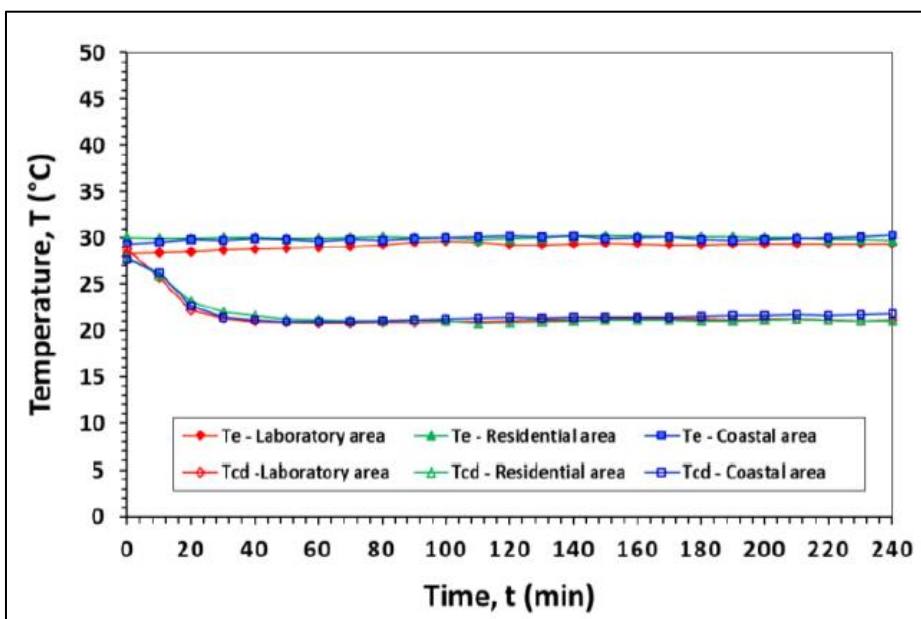


Figure 5: Temperature of the environment and condensation room on the three environmental conditions: Laboratory, residential area & coastal areas

Figure 5 illustrates the environmental temperature and the condensing chamber during a duration of 240 minutes across three environmental variations: laboratory, residential area, and coastal region, for the triple module (TM) with a heatsink cooling fan fluid flow rate of 0.092 kg/s. The graph indicates that the temperature of the condensing chamber has been consistent since the 20th minute. The temperatures of the condensing chamber are 21.077°C, 21.225°C, and 21.434°C. The average ambient temperatures are 29.168°C, 30.009°C, and 29.953°C. The reduction in ambient air temperature upon entering the condensation chamber is around 9°C.

3.4 Volume of produced condensate

The condensation process generates water droplets from the atmosphere. Figure 6 illustrates the volume of water collected over 240 minutes under laboratory conditions for three configurations of thermoelectric cooler (TEC) modules: single module (SM), double modules (DM), and triple modules (TM), with three distinct mass flow rates of the heatsink cooling fan: 0.046 kg/s, 0.069 kg/s, and 0.092 kg/s.

Figure 6 illustrates that the SM and DM circuits do not generate water. Additionally, in the TM circuit with three modifications of the cooling fan mass flow rates of 0.046 kg/s, 0.069 kg/s, and 0.092 kg/s, it generated 17 ml, 18.5 ml, and 22 ml of water, respectively. The rise in water production corresponds with the rise in cooling rate.

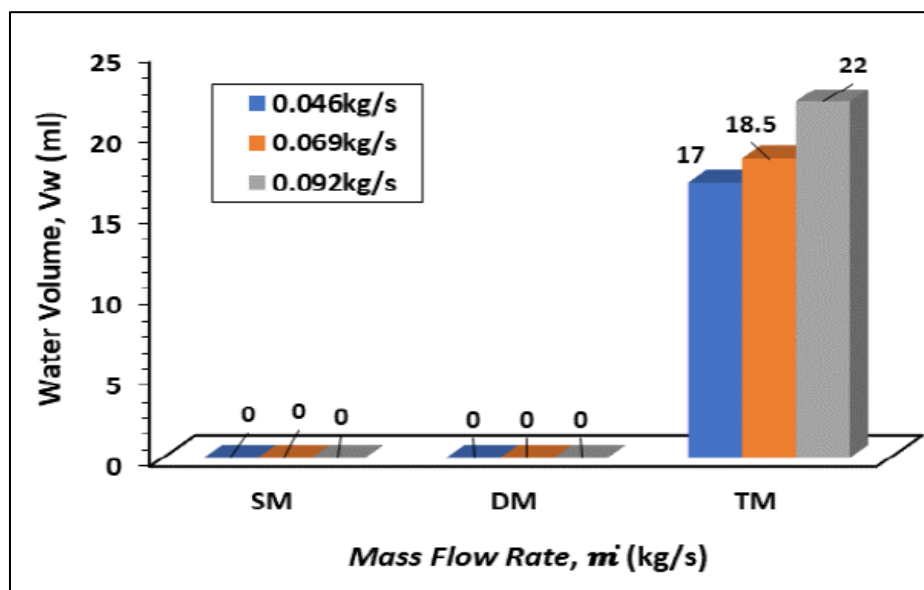


Figure 6: Water volume for a test duration of 240 minutes in the laboratory as initial data collection

In the single module (SM) and double module (DM) series, the temperature of the cooling coil remains elevated, above 25°C (refer to Figure 2), thus preventing any condensation in the air. If the air temperature remains above the dew point, condensation has not transpired. Additionally, in the triple modules (TM), it is evident that the maximum amount of water is derived from the mass flow rate of the heatsink cooling fan at 0.092 kg/s, equating to 2 ml.

3.5 Comparative Analysis of Water Volume, Relative Humidity, and Equipment Efficacy Over a Test Duration of 240 Minutes

Figure 7 presents a comparison of water volume under three distinct climatic circumstances throughout a test length of 240 minutes, utilizing a series of TEC triple modules with an optimal air mass flow rate of 0.092 kg/s. As illustrated in Figure 7, the volume of water collected in a laboratory setting is 22 ml, exhibiting an effectiveness of 4.24% and a relative humidity (RH) of 77.27%. In a residential neighborhood, the volume is 19

ml, with an effectiveness of 4.78% and a RH of 75.39%. In a coastal environment, the level reaches 31 ml, demonstrating an efficacy of 5.035% and a RH of 82.62%. The peak water production value is observed at the coast due to its elevated relative humidity (RH) levels. In other terms, it possesses a higher water content. Figure 7 illustrates that the maximum volume of water is acquired in the coastal environment characterized by the highest relative humidity and optimal efficacy. The test findings indicated that the maximum volume of water (condensate) was generated using a configuration of three stacking modules (TM) at a mass flow rate of 0.092 kg/s, with a cooling fan output of 31 ml and a relative humidity (RH) of 82.619%, located in the coastal region. Enhancing water recovery can be achieved by enlarging the cooling area, now measuring 0.0064 m². Furthermore, this can be accomplished by augmenting the contact area of the cooling coil with the airflow. Despite employing just 12 TEC modules, the volume of condensate water generated in this investigation (31 ml in 2 hours) exceeded the ideal measurement of 9.335 ml

in 24 hours reported by Riahi *et al.*, [13] utilizing 18 TEC modules. The 31ml of water produced in this study contributed to fulfilling WHO guidelines for freshwater

supplies [18] and benefitted numerous places worldwide [19-22], through the utilization of TEC modules advantageous to humanity [23-26].

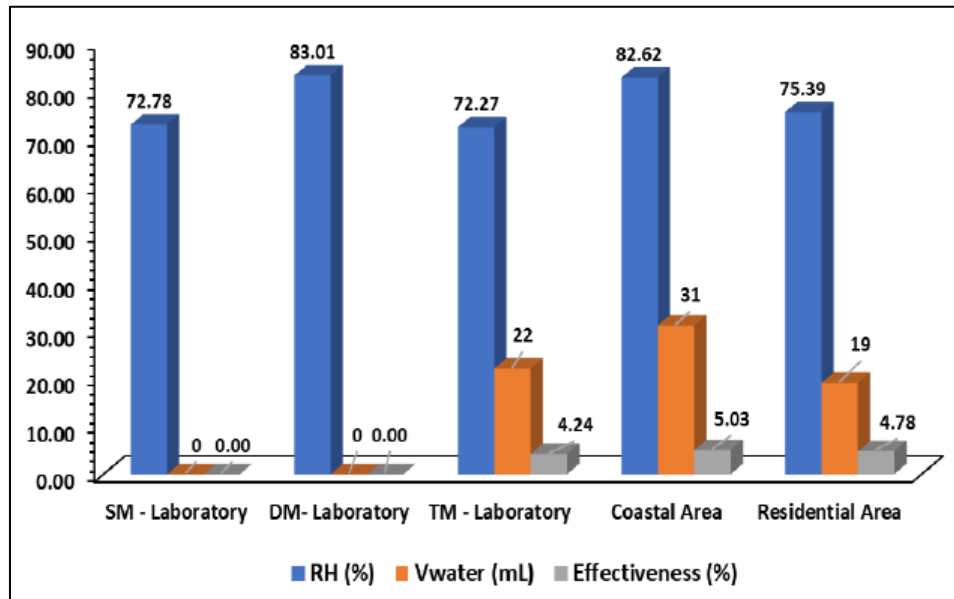


Figure 7: The volume of water for testing for 240 minutes in three environmental conditions: laboratory area, residential area and coastal area

4. CONCLUSIONS

The tests conducted indicate that the mass flow rate in the heatsink cooling fan on the hot side of the thermoelectric cooler (TEC) is directly proportional to water production. Laboratory tests for three speed variations yielded mass flow rates of 0.046 kg/s, 0.069 kg/s, and 0.092 kg/s, resulting in water production rates of 4.25 ml/hour, 4.625 ml/hour, and 5.5 ml/hour, respectively. Additionally, for three distinct locations: laboratory, residential area, and coastal area, the water consumption rates are 5.5 ml/hour, 4.75 ml/hour, and 7.75 ml/hour, respectively. The maximum water production occurs around the coast. Opportunities remain to enhance water acquisition by optimizing the contact factor between air and the cooling coil surface.

Subscripts

AWG	Atmospheric Water Generator
SM	Single Module
DM	Double Module
TM	Triple Module
TEC	Thermoelectric Cooler
WB	Water Block

REFERENCES

- Mashuri, M., Fauzi, M., & Sandhyavetri, A. (2015). Study of the availability and demand of raw water with Ithacres modeling in the Tapung Kiri River Basin. *Jurnal Online Mahasiswa (JOM) Bidang Teknik dan Sains*, 2(1), 1-1.
- Kilic, Z. (2020). The importance of water and conscious use of water. *International Journal of*

- Hydrology*, 4(5), 239-241. DOI: <https://doi.org/10.15406/ijh.2020.04.00250>
- UNICEF. (2008). *Unicef Handbook on Water Quality*. United Nations Children's Fund (UNICEF), New York.
- Kardono, K. 2007. Condition of water resource in Oman and its environmental technology. *Jurnal Air Oman (JAI)*, 3(2), 2331. doi: <https://doi.org/10.29122/jai.v3i2.2331>
- Tortajada, C., & Biswas, A. K. (2018). Achieving universal access to clean water and sanitation in an era of water scarcity: Strengthening contributions from academia. *Current Opinion in Environmental Sustainability*, 34, 21-25. doi: <https://doi.org/10.1016/j.cosust.2018.08.001>
- World Data. 2023. The climate in Oman. Accessed on Aug. 9, 2023.
- Joshi, V. P., Joshi, V. S., Kothari, H. A., Mahajan, M. D., Chaudhari, M. B., & Sant, K. D. (2017). Experimental investigations on a portable fresh water generator using a thermoelectric cooler. *Energy Procedia*, 109, 161-166. doi: <https://doi.org/10.1016/j.egypro.2017.03.085>
- Baheramsyah, A., Prananda, J., & Setiyawan, D. (2019). The experiment of producing freshwater from the air using thermoelectric cooler for the need of drinking water in a lifeboat. *International Journal of Marine Engineering Innovation and Research*, 4(1), 68-73.
- Djafar, Z., Amrullah, A., Wahyu, H. P., & Sukri, H. (2014). Experimental test of thermoelectric performance on the dispenser cooler. In *Proceeding of the 1st International Symposium on Smart*

- Material and Mechatronics, Gowa, Sulawesi Selatan, Oman.
10. Djafar, Z., Wahyu, H. P., & Alwi. (2016). Heat pipe application in cool boxes based on non-branded Peltier elements. In Proceedings of the 8th AVOER National Seminar, Palembang, Oman.
 11. Kiran, P. S., & Prakash, S. B. (2022). Performance evaluation of thermoelectric cooler. Lecture Notes in Mechanical Engineering book series (LNME).
 12. Prasetyo, B. Y., & Wirenda, S. A. (2021). Thermoelectric experimental study as a cooling system alternative. In Proceedings of the 12th Industrial Research Workshop and National Seminar (IRWNS), Bandung State Polytechnic.
 13. Riahi, A., Zakaria, N. A., Noh, N. M., Amin, M. Z. M., Ideris, M. M., Zainol, M. R. M. A., Shaharuddin, S., & Yusof, M. F. (2021). Performance investigation of 18 thermoelectric cooler (TEC) units to supply continuous daily fresh water from Muscat-Salalah's atmosphere. *Sustainability*, 13(3), 1-16.
 14. Cengel, Y. A. (2004). Heat Transfer: A Practical Approach. McGraw-Hill, New York.
 15. Arismunandar, W., & Saito, H. (2005). Air Conditioning. Pradnya Paramita, Jakarta.
 16. Stoecker, W. F., & Jones, J. W. (1982). Refrigeration and Air Conditioning. McGraw-Hill, New York.
 17. Djafar, Z., Salsabilah, A. Z., & Piarah, W. H. (2021). Performance comparison between hot mirror and cold mirror as a beam splitter on photovoltaic-thermoelectric generator hybrid using LabVIEW simulator. *International Journal of Heat and Technology*, 39(5), 1609-1617.
 18. World Health Organization. (2012). Global Costs and Benefits of Drinking-Water Supply and Sanitation Interventions to Reach the MDG Target and Universal Coverage. WHO Press, Geneva, Switzerland.
 19. Pál, L., Jenei, T., McKee, M., Kovács, N., Vargha, M., Bufa-Dórr, Z., Muhollari, T., Bujdosó, M.O., Sándor, J., & Szűcs, S. (2022). Health and economic gain attributable to the introduction of the World Health Organization's drinking water standard on arsenic level in Hungary: A nationwide retrospective study on cancer occurrence and ischemic heart disease mortality. *Science of The Total Environment*, 851, 158305.
 20. Venkatesan, A.K., Lee, C., & Gobler, C. J. (2022). Hydroxyl-radical based advanced oxidation processes can increase perfluoroalkyl substances beyond drinking water standards: Results from a pilot study. *Science of the Total Environment*, 847, 157577.
 21. de Oliveira, D. M., Agostinotto, L., & Sieglöch, A. E. (2023). Comparison of the drinking water standard for pesticides of Brazil with other countries. *Heliyon*, 9(3), e13783.
 22. He, W., Yu, P., Hu, Z., Lv, S., Qin, M., & Yu, C. (2019). Experimental study and performance analysis of a portable atmospheric water generator. *Energies*, 13(1), 73.
 23. Tan, F. L., & Fok, S. C. (2013). Experimental testing and evaluation of parameters on the extraction of water from air using thermoelectric coolers. *Journal of Testing and Evaluation*, 41(1), 96-103.
 24. Muñoz-García, M., Moreda, G., Raga-Arroyo, M., & Marín-González, O. (2013). Water harvesting for young trees using Peltier modules powered by photovoltaic solar energy. *Computers and Electronics in Agriculture*, 93, 60-67.
 25. Liu, S., He, W., Hu, D., Chen, D., Wu, X., Xu, F., & Li, S. (2017). Experimental analysis of a portable atmospheric water generator by thermoelectric cooling method. *Energy Procedia*, 142, 1609-1614.
 26. Su, C., Wang, Z., Liu, X., Xiong, X., Jiang, T., & Wang, Y. (2022). Research on thermal comfort of commercial vehicle and economy of localized air conditioning system with thermoelectric coolers. *Energy Reports*, 8, 795-803.