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Performance evaluation of atmospheric water generators under suboptimal humidity conditions in Orangeburg, SC

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Abstract

Two commercial atmospheric water generators (AWGs) were studied to compare their performance under varying environmental conditions. The efficiency of water harvesting depends on factors such as the instrument's design, power consumption, ambient temperature, and relative humidity (RH). AWGs operate optimally at humidity levels above 80% at room temperatures but also serve as efficient dehumidifiers in high-humidity regions. To ensure high-quality drinking water, AWGs use food-grade materials for condenser coatings and employ advanced filtration systems, including reverse osmosis and UV sterilization. This study presents the water harvesting performance of these devices during the summer in Orangeburg, SC, where the average laboratory temperature ranged from 25–29 °C, and RH was between 59–69%. Results highlight the potential and limitations of AWGs in moderate-humidity environments. Under these conditions, the AWG1, harvested 1.56 mLW^{-1}, which means \$0.077 per liter of water at the electricity rate of \$0.12kW^{-1}. The AWG2 harvested 0.42 mLW^{-1}, or \$0.29 per liter of water at the same electricity rate.

Keywords: Water scarcity mitigation; Renewable water resources; Water yield comparison; Energy efficiency in AWGs; Water collection rates; Condensation-based AWGs; Atmospheric water generators (AWGs); Water harvesting technologies

1. Introduction

Research data shows that freshwater scarcity poses a significant threat to communities worldwide; study on discovering innovative ways for supplemental freshwater sources is vital.[1–4] Atmospheric Water Generators (AWGs) have emerged as a promising technology, capable of extracting moisture from the air to produce supplemental clean drinking water and reduce its shortage.[5,6] The water harvested by an AWG must adequately be treated for human consumption. It means the collected water must pass through several filtering systems, and then, be enriched with minerals to generate alkaline water, rich in minerals and microelements essential for the human body. However, the reliance of AWGs on electricity has often posed a challenge, particularly in remote and off-grid areas. Integrating solar power with AWGs offers a sustainable and efficient solution. By utilizing electricity generated from solar panels, AWGs can operate independently of traditional power sources, making them more accessible and environmentally friendly. This combination not only ensures a consistent supply of high-quality freshwater but also aligns with global efforts to reduce carbon footprints and promote renewable energy. Our next work covers water harvesting in the natural environment of a farm powered by solar panels.

The filtration systems incorporated in the analyzed AWGs featured a pre-carbon filter designed to enhance water quality. This filter effectively removes residual chlorine, halogenated hydrocarbons, and various organic compounds that may be present as suspended particulates in the ambient air. By eliminating these contaminants, the pre-carbon

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filter plays a critical role in ensuring the safety and purity of the water produced by the AWG systems. [7] A post-carbon filter, which is specifically designed to eliminate odors and discoloration, thereby refining the overall quality and taste of the water. Additionally, a reverse osmosis (RO) membrane serves as a critical component, effectively removing microscopic impurities, colloidal particles, heavy metals, dissolved solids, bacteria, and a wide range of other harmful substances. Together, these advanced filtration processes enable AWGs to deliver a dependable and efficient solution for producing safe, high-quality drinking water, addressing the growing demand for freshwater in regions where it is scarce.

This article presents a comparative analysis of two electrically powered AWGs, focusing on their water harvesting capacity and energy consumption.

2. Experimental Procedure

2.1. Materials and Equipment

Two AWGs were tested. Figure 1 illustrates AWG1, purchased from Air Water Machine, a product manufactured by Shenzhen FND Air Water Technology Development Co., LTD, a subsidiary of Alibaba.com based in Florida (USA). AWG1 features a 4L storage capacity, with its condenser and water-exposed sections coated with food-grade materials to ensure safety and durability. It operates with a power consumption of 180 W and incorporates a comprehensive multi-stage filtration system, including pre- and post-carbon filters, a reverse osmosis membrane, UV sterilization unit, humidity and temperature sensors, and data logging capabilities for enhanced monitoring and performance.

Figure 1 Views and information about FND AWG 1 system

Figure 2 Shape and information about airiver, AWG2 system

Figure 2 shows AWG2, purchased from Amazon.com and made by airver (USA). It has built-in humidity and temperature sensors along with a food-grade coating condenser and water-exposed parts to enhance water safety and product durability. It also has a multi-stage filtration system (pre-carbon filter, post-carbon filter, reverse osmosis membrane), along with a UV sterilization unit. Moreover it AGW2 offers water cooling and heating resources, data logging for performance tracking, a 12.5 L storage capacity, and operates with a nominal power consumption of 500 W. The water collected from the instrument before passing through the filtration and sanitization system, to ensure the water harvested is not trapped in the system, as shown in Figure 2.

2.1.1. Power Source

Figure *3* shows the EcoFlow DELTA 2 Max Portable Power Station (Δ2M). The Δ2M stores around 2,048W in LFP batteries, holding an estimated 3,000 cycles to 80% of capacity. It can power AWG1 for about 10 hours, and AWG2 for about 4 hours. Its recharging time is 90 minutes under optimal conditions, however, when simultaneously powering one of the AWGs, the full charge duration was longer.

Figure 3 Shape and information about the Power Station Δ2M, power storage, and supply

The AWGs were placed in an open area to maximize air intake for effective water harvesting. Each AGW, separately, was connected to Δ2M power storage when it was fully charged at 100%. The readings from the built-in humidity and temperature sensors agreed with those from standalone measurement instruments. This ensures accurate and consistent data.

2.1.2. Initial Testing

Each AWG was unpacked according to the manufacturer's instructions. Once assembled, the AWG was powered on and allowed to run for several days under controlled laboratory conditions to ensure stability. During this period, the humidity and temperature readings from the sensors installed in the AWG were consistently compared with readings from stand-alone instruments, demonstrating good agreement.

2.1.3. Data Collection Process

To ensure the AWGs were properly conditioned, they were operated continuously for several weeks before data collection began. Throughout the data collection period, all instruments were maintained in continuous operation. Key parameters, including the volume of water generated, relative humidity (RH%), laboratory temperature, and power consumption, were recorded at regular intervals. These values are documented in the data tables presented within the text for detailed analysis.

2.1.4. Performance Analysis

From the experimental data, the efficiency of the AWGs on the volume of water harvested to the power consumed was evaluated. There was no analysis of the impact of varying humidity and temperature conditions on water production since the climate of the laboratory, temperature and RH, were relatively constant.

2.1.5. Maintenance and Troubleshooting

Periodically checked and maintained the AWG components, according to their user manuals. The condensers were cleaned and replaced filters as needed. Documented any issues encountered during the operation and the steps taken to resolve them.

2.1.6. Reporting

This work summarizes the collected data and provides a detailed analysis of the results, focusing on the performance, efficiency, and amount of water harvested by the AWGs. The data collected spans key metrics such as volume of water generated, relative humidity (RH%), laboratory temperature, and power consumption, which are analyzed to evaluate the overall functionality and effectiveness of the AWGs.

2.1.7. Safety Considerations

Safety gloves and goggles were worn at all times when handling electrical components and water samples to ensure personal protection and high-quality data. All electrical connections were carefully insulated and protected from moisture to prevent potential hazards. Additionally, all manufacturer guidelines, and safety instructions for operating the AWGs and associated equipment were followed meticulously to maintain a safe and controlled environment.

3. Results and Discussions

The AWG1 was connected to the fully charged Δ2M (2048 W), and the water harvested was monitored and collected every hour.

Figure 4 shows the amount of water produced under the indicated laboratory conditions.

Table 1 Environmental conditions, power consumed, and the amounts of water harvested by AWG1 on July 16, 2024, in Hodge Hall

Time (h)	Total AWH (mL)	The power of battery pack (%)	T (°C) Lab	RH% Lab
0.00	0	100	25	67
1.03	362	90	26	68
2.00	725	81	27	67
3.32	1100	68	29	64
4.72	1450	52	29	64
6.00	1800	41	29	64
7.08	2155	30	28	63
8.33	2510	18	27	64

Error! Reference source not found. shows that 2510 mL of water was harvested by AWG1 on July 10, 2024, in Hodge Hall, for 8 hours and 33 minutes at temperatures range 26-28 °C, and RH 60-69%. By extrapolation, under similar conditions, the instrument can generate 7500 mL (2 gallons) of water per day under the same conditions. During the first 60 minutes, AWG1 harvested 360 mL of water at room temperature of 26 °C, and 68% RH; consuming about 10% of Δ2M power (about 204 ±40 W). Its consumption is slightly higher than 180 W indicated by the manufacturer on the back label of the instrument. As the room temperature increased the amount of water collected decreased, as was expected. The average amount of water collected during the day was 295±10 mLh^{-1} meanwhile the temperature ranged 26-28 °C, and humidity varied by 64 - 68%, as shown by the data in Table 1, Figure 5, Figure 4.

Figure 4 Volume of water collected from AWG1 including date, time, temperature, and RH values in Hodge Hall Lab 312 on July 16, 2024

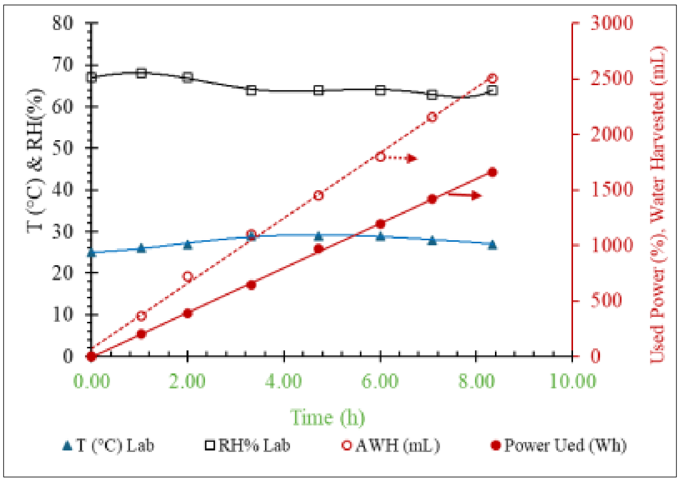

Figure 5 Illustration of the variation of temperature, and humidity in the laboratory with the amount of water obtained and power consumed over time by AWG1

Figure 5 shows the variation in temperature and humidity within the laboratory alongside the amount of water harvested and power consumed by AWG1 over time. The average value of power consumption by AWG1 was estimated as 201 ± 40 determined from the slope of variation of the power consumption curve over time in the graph. The rate of water harvested was also obtained from the slope of water-harvested versus time graph, as 295 ±10 mLh^{-1}.

In this experiment, the AWG1 successfully produced 2,510 mL of water under temperatures ranging from 25 °C to 28 °C and relative humidity levels between 63% and 68%. This operation consumed 81% of the Δ2M's capacity, demonstrating the system's efficiency and capability to generate a substantial amount of water within these environmental parameters. The performance highlights the potential of the AWG1 and Δ2M combination for effective water production under indicated conditions.

Table 2 shows the result of water generation by AWG2 on July 3, 2024 in our lab at Hodge Hall (Experiment 1). A 1000 mL beaker was inserted under the water delivery port of the AWG2 to collect and measure directly the amount of water generated without passing through the filtering and sanitizing system. The AWG2 harvested 725 mL of water under laboratory conditions (T = 23 to 26 °C, %RH = 54-58), and consumed a fully charged Δ2M (2040 W). The rate of water harvesting was 161 mLh^{-1}, and the estimated cost was 0.355 mLW^{-1} or $0.34 per L.

Table 2 Environmental parameters (T, %RH), the volume of water harvested, power consumed during the process by AWG2, on *July 3, 2024,* in *Hodge H*all

Time	Time (h)	AWG (mL)	Temp (°C)	RH%	Battery pack (Δ2M)
Experiment 1					
8:05 AM	0	0	23	54	Full
12:30	4:30	725	26	58	Empty
Experiment 2					
12:47	0	0	26	58	Connected
2:	1:30	175	26	58	Connected
2:41	2	230	24.5	56	Connected
3:50	3	330	24.5	55	Connected
4:30	3:40	400	25	55	Connected

In experiment 2, AWG2 harvested 400 mL of water at temperatures ranging 25-26 °C, and %RH range from 55 to 58, for 3 hours and 43 minutes, while it was consuming the power grid. The rate of water harvesting under these conditions was 109 mLh^{-1}, smaller than the previous one due to higher temperature which has an inverse relationship with air vapor content.

Table 3 summarizes the volume of water harvesting and the recharging time of Δ2M on July 8, 2024. Experiment 3 showed that the AWG2 harvested about 650 mL of water with a rate of 178 mLh^{-1}. The laboratory condition was relatively stable, the variation of temperature ranged within one degree Celsius (25-26 °C), and the humidity variation range was 65 - 68%. The experiment concluded by the consumption of a full pack of Δ2M power within 3 hours and 50 min. The estimated cost of water is 0.32 mLW^{-1}, or $0.38 per L.

Table 3 Result of water harvesting by AWG2, on July 8, 2024, in Hodge Hall**.**

Time	Time (h)	AWG (mL)	Temp (°C)	RH%	Battery pack
Experiment 3					
8:45 Am	0	0	25	68	Full
9:25	.75	25	25	68	
10:43	2	275	25	65	
11:45	3	490	26	66	
12:35	4	650	26	65	Discharged batteries
Experiment 4: Charging					
12:45					Charging
12:55					16%

13:13					36%
13:48					72%
14:02					82%
14:13	0	0	26	67	97%
Experiment 5					
14:55	¾	200	28	65	100% connected
15:55	1 ¾	400	28	65	100%
16:55	2 ¾	575	28	64	100%

Experiment 4 shows the charging time for Δ2M power supply pack. It took one hour and 28 minutes to recover its power, and the rate of recovery was 66% per hour.

Experiment 5 shows that the AWG2 harvested 575 mL of water within 3 hours and 45 min while it was powered by Δ2M, and at the same time, the Δ2M was powered by the city grid. Therefore, there was no change in the amount of power stored in the Δ2M pack. The rate of water harvesting was 178 mLh^{-1}. The environmental temperature was slightly higher than the experiment 3, ranging 26-28 °C, and the humidity level was slightly lower than the previous experiment, ranging 64 - 65% as shown by data in Figure 6 and *Table 3*. Also, it is worth mentioning that there is an inverse relationship between humidity level and the temperature of air. Therefore, it is within expectation when the temperature rises, the humidity level decreases to reduce the rate of water harvesting, as it was observed by the data in Table 3.

Figure 6 Date, time, temperature, and RH values during the water collection on July 8, 2024

Table 4 and *Figure* 7 show the result of water generation by AWG2 on July 10, 2024 in Hodge Hall. The AWG2 harvested 748 mL of water for 3 hours and 34 minutes, then it stopped when the power of ∆2M was consumed. The rate of water harvesting was 226 $\mathrm{mLh^{-1}}$, it was obtained from the slope of the adjusted line to the variation of the volume of water harvested versus time. The rate of power consumption was 555 $\mathrm{Wh^{-1}}$obtained from the slope of the line adjusted to the variation of power consumed over water harvested time, in Fig. 8. The environmental temperatures range 26-28 °C, and RH 60-69%. The price of harvest water was 0.46 $\mathrm{mLW^{-1}}$, or $0.34 per liter of water at the rate of $0.12 per W.

Experiment 8 demonstrates that the ∆2M required 2 hours and 5 minutes to fully recharge to 100% while simultaneously supplying power to the AWG2. This recharge time is slightly longer than the time required when the ∆2M was recharged in stand-alone mode. This observation suggests that the concurrent load imposed by the AWG2 has a modest impact on the recharging efficiency of the ∆2M system.

Table 4 Result of water harvesting by AWG2 on July 10, 2024 in Hodge Hall

Time	Time (h)	AWG (mL)	Temp (°C)	RH% around the AWG	RH% in Lab	Battery pack
Experiment 7						
8:24	0	0	26	69	69	100
9:24	1	235	26	64	69	75
10:24	2	438	27	62	68	49
11:26	3	638	28	60	66	24
12:02	3:34	748	28	60	66	0.0
Experiment 8						
12:46	4.75	930	28	60	64	35
1:46	5.75	1080	29	59	64	82
2:07	6					100
2:30	6.5	1340	29	61	64	100
4:24	8	1880	29	66	64	100
Total	8	1,880	26-29	69-61	69-64	2 pack

Figure 7 Volume, date, time, temperature, and RH values during the water collection on July 10, 2024

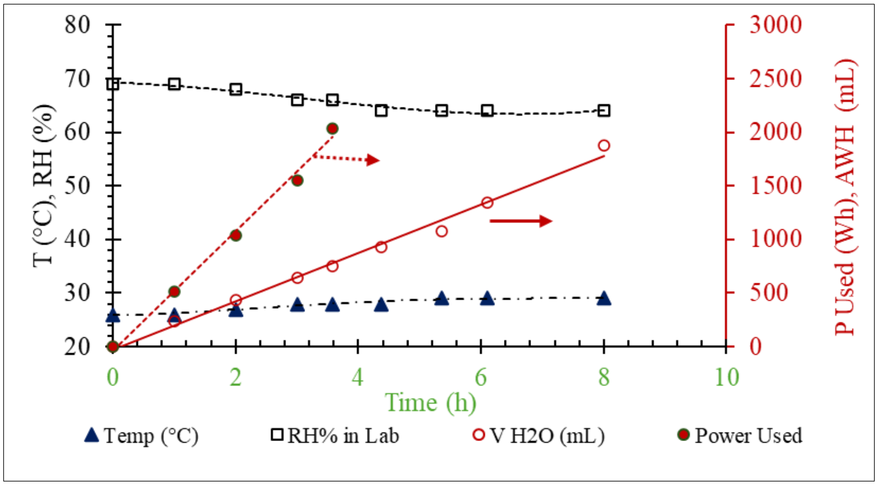

Figure 8 Variation of temperature, and humidity in the laboratory with the amount of water obtained and power consumed over time by AWG2

4. Conclusions

The performance of two commercially obtained atmospheric water generators was studied and compared. AWG1 showed a rate of AWH of 295 mL h^{-1} and power usage, of 201 Wh^{-1} under the environmental temperatures of 25–28 °C and 59–66% RH. Its performance was close to the manufacturer's specifications. Testing AWG2, was within the temperature range of 25–29 °C and 60–69% RH. The water harvesting rate of 226 mL h^{-1} was obtained from the slope of the variation of harvest water versus time in Fig. 8. The power usage of 555 Wh^{-1} also was obtained from the slope of the variation of water harvest over power consumed in Fig 8. Its power usage exceeds the manufacturer's specification of 500 Wh^{-1}.

The choice between AWG1 and AWG2 should be guided by specific operational needs. AWG1 is better suited for energy-conscious environments and AWG2 offers broader functionality for diverse applications. AWG1 demonstrated a higher rate of water harvesting and lower power usage. Its compact size, higher efficiency, and lower energy consumption make it an ideal choice for tabletop or bench installations, particularly in smaller spaces or where energy efficiency is prioritized. Conversely, AWG2, exceeds its manufacturer's specified power consumption. While less efficient in water production and energy usage, AWG2's standalone design and additional capability to provide cold and hot water make it a versatile solution for larger setups or applications requiring multifunctionality.

Compliance with ethical standards

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Disclosure of conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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