Atmospheric Generation: the Technological Solution to the Lack of Drinking Water in the Military Sector

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ABSTRACT

Expeditionary missions largely depended on bottled water resupply and non-potable local water treatment that include purification systems, chemical tabs, or advanced filters. Atmospheric water generators (AWGs) can produce water from humidity in the air, being the best choice in locations with unreliable or inexistent access to drinking water.

Atmospheric water generation technology is based on cooling down the air below the dew point producing humidity to condense together with water treatment to ensure its quality. It has been available since the 1950s and combines several techniques including refrigeration by mechanical compression of a refrigerant gas, air and water filtration, ultraviolet disinfection, and mineralization.

GENAQ has been developing this technology since 2008 based on proprietary design and advanced thermodynamic systems. As a results of this, the main limitations of this solution have been solved, namely reliability, water generation uncertainty, energy consumption, and drinking-water quality. This has been validated in real field operation in 59 countries with several armies and multilateral organizations.

The adoption of this solution in a real environment can positively impact the water supply cost, casualties related to resupply, waste production, logistics, supply security, water quality, and water taste.

1.0 INTRODUCTION

1.1 Problem

Expeditionary forces operate in locations where indigenous water sources may contain microbial and chemical contamination and supply lines are unreliable or inexistent, i.e., a US DoD study in Afghanistan found that 65% of closed wells and 90% of open wells were contaminated with coliform bacteria. Also, man-made chemicals, i.e., PFAS from firefighting foams, have been found in water sources around many military bases.

As a result of this, armies expeditionary combat teams largely depend on bottled water as the primary source of resupply for forward operating units. The impact of this bottled water resupply is very important as, for example, more than 864,000 bottles of water are consumed each month at one FOB in Iraq.

The main impact of bottled water resupply is related to:

- Cost: Water transport makes up 51% of the logistical burden.
- Resupply risk: 1 casualty for every 29 water resupply convoys in Afghanistan
- Plastic waste generation: 27 million bottles recycled in 2012 in Camp Arifjan, Kuwait

The second alternative used when drinking water is not available is water purification. This includes combinations of water filtration and chemical treatments like Iodine and Chlor floc. Water treatment solutions face several challenges:

- Water source: Reliant on indigenous water supply. Water quality is location dependent and, thereby, water treatment system needs to be adapted to the local water quality.
- Toxics persistency: Some of the water treatments used do not remove all toxic chemicals or materials, microbiological threats, or salt.
- Inconvenient taste: The resulting taste of treated water is not broadly accepted by the warfighters and bottled water is preferred.

1.2. Company

Located in Spain, and since 2008, GENAQ has invested in researching, developing, and manufacturing of water from air solutions. As a result, a wide range of atmospheric water generators are already operational in 59 countries all over the world. The company's mission is to provide access to quality drinking water, at low cost, in a sustainable way and in situations without access to water or energy supply.

GENAQ has invested $3.5 million and over 100 engineer-years to develop its own technology, producing over 300 prototypes and functional systems, primarily targeting emergency response and industrial applications, thanks to a research and development team of 19 engineers and PhDs.

In 2020 GENAQ was awarded the "Seal of Excellence by the European Commission, and funded with $1.65 million, which allowed to increase the generators performance by 40%, reducing energetic cost to 0.18 kWh/liter.

GENAQ sales were over $1 million in 2021 and over $1.2 million in 2022 (until June 21). By 2026, total revenues are expected to reach $60 million, generating a net profit of $9.5 million and 162 new employees.

GENAQ belongs to KEYTER Group that is dedicated to the development and manufacturing of industrial air conditioning and refrigeration solutions with experience since 1986, with 28,000 sqm of manufacturing and laboratory facilities, with over 500 employees, and with a revenue of over $60 M in 2021.

Figure 1: KEYTER Group structure

1.3 Technology

First developed in the 1950s, atmospheric water generation technology (AWG) takes ambient air, cools it down below the dew point so water condenses, and treats that water to produce high quality drinking water.

Several subsystems are used including a refrigeration circuit with mechanical compression of a refrigerant gas, ventilation circuit including fans, heat exchangers, air filtration, water filtration, several water-treatment stages, water disinfection, water mineralization, electrical circuits, and electronic control.

AWGs are a promising solution for on-site water supply thanks to the following advantages:

- No water supply is required as water is harvested from air humidity
- No logistics or resupply related to drinking water is required
- Rapid deployment and, virtually, no installation is required
- Simple maintenance
- Drinking water quality in ensured (adjustable mineralization, free of any contamination)
- Drinking water supply in ensured

However, former AWG technology presented some limitations, namely:

- Water generation depends on climate (air temperature and relative humidity)
- Low water generation in harsh environments (with low air temperature and relative humidity)
- Uncertainty on the water generation in a specific location
- High energy consumption
- Product reliability
- Start-up current (with has an impact on oversizing gensets and solar PV installations)

These limitations have prevented a broader adoption of this technology so far. This paper addresses the developments performed by GENAQ to address these limitations thereby increasing the competitiveness of this solution and the interest of adopting it. The main outcomes of this development are the following:

- Performance increase to nominal 0.18 kWh/liter (from former 0.36 kWh/liter).
- Energy consumption reduction by 40%.
- Adaptation of AWG operating parameters to external air temperature and relative humidity conditions to increase performance in harsh conditions.
- Characterization in climate chamber of the generation (liters/day) and energy consumption (kWh/liter) as a function of air temperature and relative humidity.
- Integration of several features to ensure reliability and portability.
- Frequency variator to reduce the start-up current to 1.5 times the nominal (from 8 times previously).
- Remote monitoring and control through Internet of Things.
- Product certifications.

These improvements have been validated by laboratory tests as well as real-environment tests performed by customers in several locations internationally.

1.4 Implications

The main implications of the adoption of this technology, as compared to other solutions such as bottled water resupply or local-source water treatments, are related to:

- Cost: Drinking water cost reduced by 80% as compared to bottled water resupply.
- Performance-based planning for specific climate conditions.
- Portability, no installation, automated warnings, remote control, low maintenance.
- Safe water storage, no bacteriological proliferation in tanks.
- Best water taste, validated in blind water tasting events (preferred option against bottled and reverse osmosis water).
- Certified water quality analysis, compliant with US, EU and WHO drinking water standards
- Several models available ensure that supply meets demand (Marine Corps Survival Manual; at least 2.6 gallons of water per day in arid regions)
- Reduction of casualties related to resupply.
- Reduction of waste management.

2.0 ANALYTICAL METHODS

2.1 Technologies used

Atmospheric water generation relies on a thermodynamic cycle with mechanical compression refrigeration technology through three different circuits. The refrigerant circuit and heat exchangers are optimized to condense air humidity while reducing the energy consumption. The residual cold is used to pre-cool the inlet air without additional energy consumption. The resultant water is filtered, mineralized, and treated with UV tech to reach highest quality standards. Additionally, they incorporate IoT functionalities for remote control and monitoring and a SCADA system that enable the intelligent control and regulation of all the systems, guaranteeing maximum water production under different ambient conditions.

2.1.1 Refrigeration

The refrigeration circuit is responsible for enabling the heat transfer between ambient air and refrigerant gas. It controls the level of energy in the system's refrigerant: Some parts of the system have energy-packed refrigerant that is ready to release heat, whereas other parts have energy-depleted refrigerant that is ready to absorb heat. It is composed of the following parts:

The basic refrigeration circuit for water generation is composed of a compressor, condenser coil, expansion valve, evaporator coil. To increase the efficiency, a heat exchanger is used.

In addition, a plate exchanger is used to cool down the water generated to the temperature that is convenient for the user.

The high- and low-pressure side are protected by a high- and low-pressure switch, respectively.

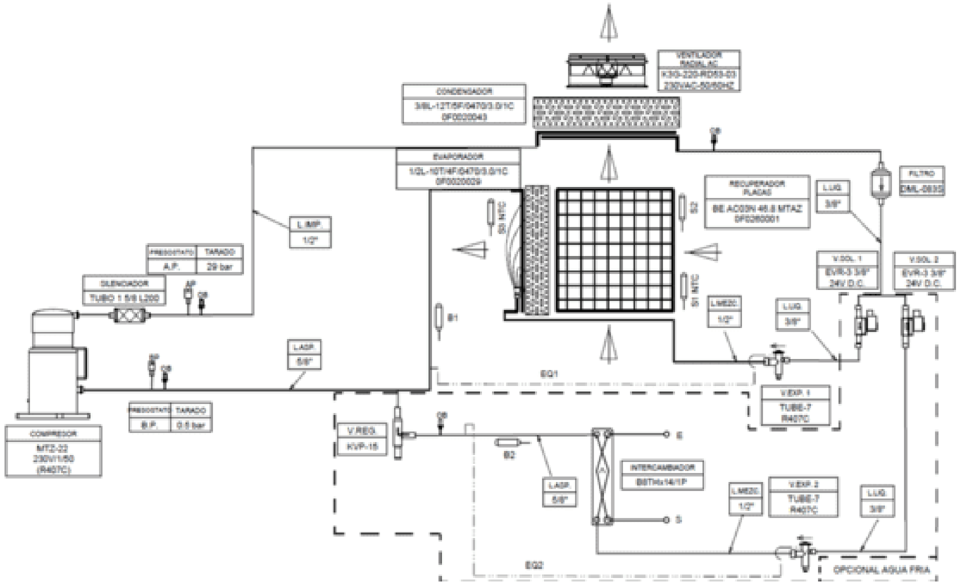


Figure 2: Refrigeration diagram

2.1.2 Ventilation and air treatment

In order to condense water from the humidity present in the air, it needs to enter the condensation chamber. All components of the condensation chamber in contact with water have food-grade certification and it includes a stainless steel casing, air filtration, evaporator and condenser coils, heat recovery unit, and fans.

The air filters are designed to prevent particles from a specific diameter to enter the condensation chamber.

A balance between air filtration effectivity and water filtration effectivity is required considering that increasing air filtration implies the following:

- It increases the lifespan of water filtration components.
- It decreases the maintenance frequency.
- It increases the power consumption (as the fan needs to be more powerful).

Vice versa, a decrease in air filtration would have the opposite effect.

Fans are used to enforce a defined air flow through the condensation chamber and heat exchangers.

The use of two fans, together with their ability to be controlled are a key aspect in the AWG ability to adapt its performance to the ambient air temperature and relative humidity.

2.1.3 Hydraulics

AWGs use an advanced water treatment system guaranteeing high water quality as well as additional functionalities such as water cooling, external tank preservation, or adjustable mineralization.

All components that are part of the hydraulic circuit have food-grade certification. It starts in the condensation chamber tray where condensed water is collected. Water is then pumped to the water treatment system that includes sediment filtration, activated carbon, zeolite, ultrafiltration, and mineralization. Water is dispensed through a tap and stored in an internal or external tank. By default, a ultraviolet (UV) light is used to ensure there is no bacteriological proliferation in the water that is preserved in tanks. Water in both internal and external tanks is recirculated though the UV in order to keep stored water safe.

Other antibiological treatments are used depending on the application as chlorine dosing, when water is to be stored without recirculation or is to be distributed in a network, or ozonation, when water is to be bottled.

Several solenoid valves are used to control the water flow and operating logic. These valves are managed from the main AWG control. They allow several functionalities:

- Water cooling through the plate exchanger.
- External tank preservation.
- Adjustable mineralization.

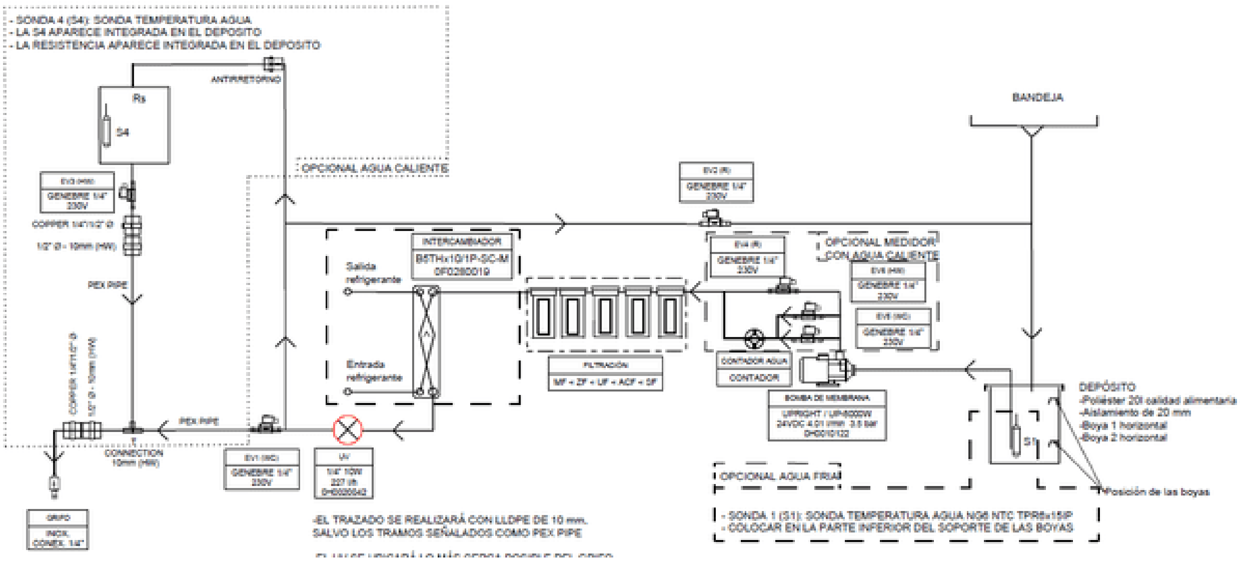


Figure 3: Hydraulic diagram

2.1.4 Electricity and control

AWGs incorporate advanced control features that enable several functionalities.

Electronic control unit and sensor network enabling the safety features, adaptation of the performance to ambient air conditions, no-frost technology, inverter technology, water treatment options, and user interface.

Internet of Things (IoT) is also used for remote control and monitoring and a SCADA system enables the intelligent control and regulation of all the sub-systems, guaranteeing maximum water production under different ambient conditions. It also notifies the user/maintenance responsible in case of a machine malfunctioning or alarm.

User friendly interface is used including a touchscreen to access all control functionalities and parameters.

2.2 Components

2.2.1 Refrigeration

Compressor

A refrigeration compressor takes low-pressure gas refrigerant coming into it, and turns it into high-pressure gas by the time the refrigerant leaves, increasing the chemical's temperature as well. The refrigeration system needs to be pressurized.

The selection of the compressor is done based on several simulation stages in combination with other components: fan, evaporator and condenser coils, expansion valve, and heat recovery unit.

They are defined by the pipes diameter, number of pipes expressed in rows and columns, and dimensions.

Computer calculations are used to define those parameters.

Condenser

Upon leaving the compressor, the high-pressure gas refrigerant enters the condenser, where the gas becomes a liquid. The condenser is a network of pipes that a hot, gas refrigerant passes through. By the time it leaves the condenser, the refrigerant has lost a lot of its heat and is now a liquid.

This component works due to the interaction between pressure and temperature. When the pressure increases, the temperature increases in response, and vice-versa.

So, the condenser decreases the pressure of the refrigerant, which then causes the temperature to decrease. Consequently, the air that crosses the condenser gets warmer.

The condenser coil is made of aluminum fins and copper pipes. No food-grade coating is needed as it is not in contact with water.

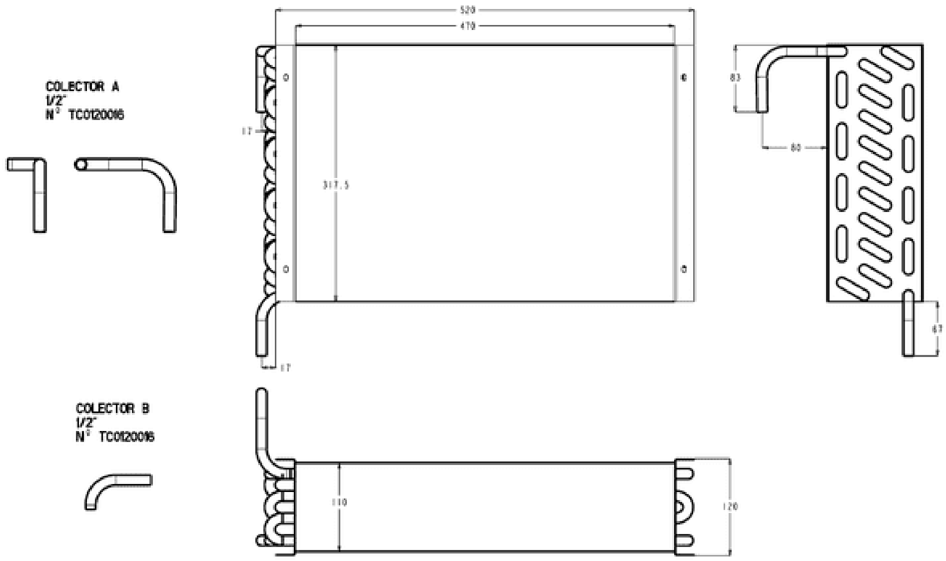


Figure 4: Coil dimensions

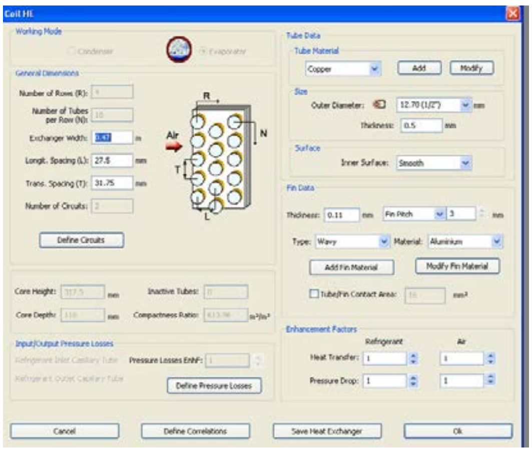


Figure 5: Coils simulation tool

Expansion Valve

The refrigerant has left the condenser as a high-pressure liquid. A high-pressure refrigerant, just like high-pressure water, wants to shoot through the pipes really fast. However, for the evaporator to do its job, the refrigerant has to move slower, and be lower pressure.

The electronic expansion valve slows the refrigerant down driven by the AWG control in order to adapt the pressure loss to the defined operating point.

The selection criteria are the power required by the thermodynamic circuit. This depends on the refrigerant gas mass flow, evaporation temperature and condensation temperature.

A simulation software was used to select the expansion valve for each generator.

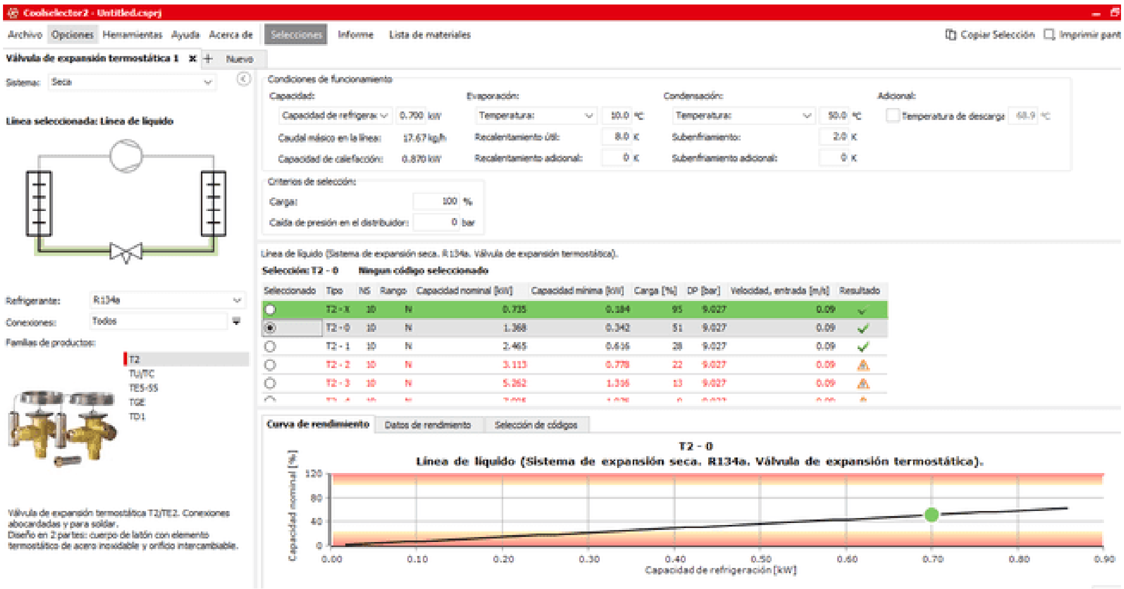


Figure 6: Expansion valves simulation tool

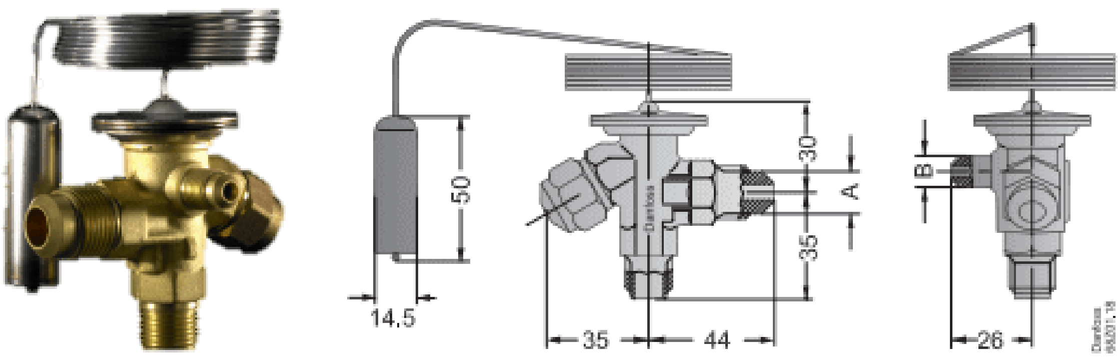


Figure 7: Expansion valve

Evaporator

The evaporator does the exact opposite of the condenser. Instead of turning the refrigerant from gas to liquid, it turns the refrigerant from liquid to gas. Instead of expelling heat, it absorbs heat and turns the air cold around it.

The evaporator and condenser work not by using a machine to heat/cool the refrigerant, but by changing the pressure of the refrigerant, which thus changes its temperature. In the evaporator, the refrigerant is evaporated into a gas, which forces it to absorb heat from the air around it, cooling the house where the system is placed.

The goal of the evaporator in an AWG is to reduce the ambient air temperature below the dew point so liquid water will start condensing.

The evaporator coil is made of aluminum fins and copper pipes with food-grade epoxy coating.

As for the condenser coil, the evaporator is defined by the pipes diameter, number of pipes expressed in rows and columns, and dimensions; and computer calculations are used to define those parameters.

Heat recovery unit

Heat recovery unit exchanges heat between cold air (from the evaporator) and inlet ambient air. It has the function of pre-cooling inlet air before it gets into de evaporator coil.

Performance of a heat recovery unit is measured in % as the inlet-outlet temperature difference of each flow.

Simulation tools have been used to select the most efficient heat recovery unit. A parallel counter-flow heat recovery unit is used with a performance of 94%. It has food-grade certification.

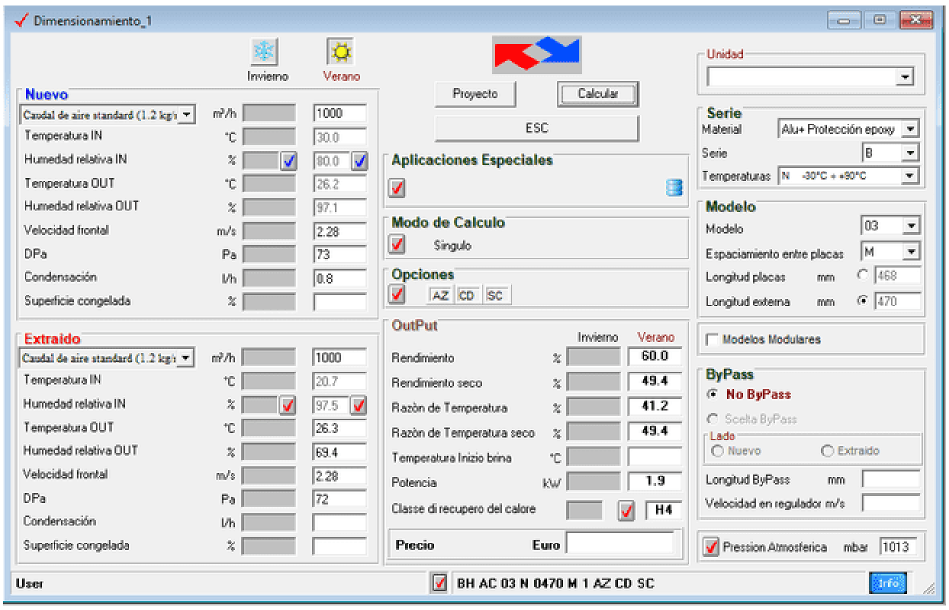


Figure 8: Heat recovery unit simulation tool

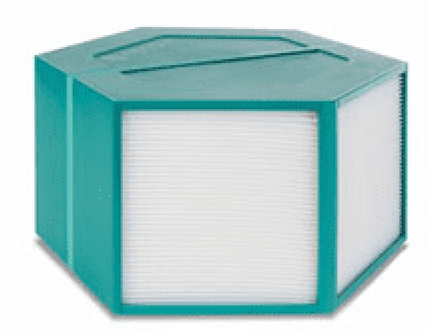


Figure 9: Heat recovery unit

Plate exchanger

Cold water was developed by using a plate exchanger solution. It allows the water in the tank to be kept at a temperature that is convenient for the user.

This method has the advantage of a quick cooling system and saving space by using the same compressor instead of an independent one, however it is necessary to highlight the complexity to control this system in order to avoid low pressure alarms, this can occur especially in same situation when the water tank is full, and no water is being generated, and only the compressor is running to cool the water tank. To protect the generator facing this situation, an additional electronic expansion valve is used that protects the compressor from low pressure and plate exchanger from too low temperature.

The following exchanger is used based on the power requirements for cooling down water to 10ºC. It has food-grade certification.

Figure 10: Plate exchanger

Refrigerant gas

The use of refrigerants is critical to the success of an air refrigeration system. Refrigerants work because of their ability to reach high and low temperatures, having an important impact on the ability of the system to exchange heat with external air.

Refrigerant selection criteria include performance, safety, global-warming potential, cost and availability in the market.

R134a is used due to its lower cost, high performance, low Global Warming Potential (GWP), non-flammable characteristics, and availability internationally.2.2.2 Ventilation and air treatment

Air filtration

The air filtration is affected by several regulations, namely:

- EN 779: Performance of a filter with a particle size: 0.4 µm. Suspended particles (PM) are not uniform in size or shape, so exposing a filter to a single particle size in tests does not reflect the conditions you will face when in operation.
- ISO 16890: Standardized process for the classification of air filters used in ventilation.

Tests were performed internally to select the optimum balance between air filtration and fan energy consumption. Thereby, two filtration stages were defined with G3 and F7 filtration level correspondingly.

Figure 11: Air pre-filter

Figure 12: Air filter

Fans

The criteria defined for fan selection is the following:

- Air flow for the circuit pressure drop
- Electronic control
- Noise below 50 dB
- Low energy consumption
- Dimensions

The selection of fans has been done with electronic fans that meet the required air flow. This has been calculated from the pressure drop – flow curve of all components present in the circuit:

- Pre-filter (G3)
- Filter (F7)
- Heat recovery unit (1/2)
- Evaporator coil
- Heat recovery unit (2/2)
- Condenser coil

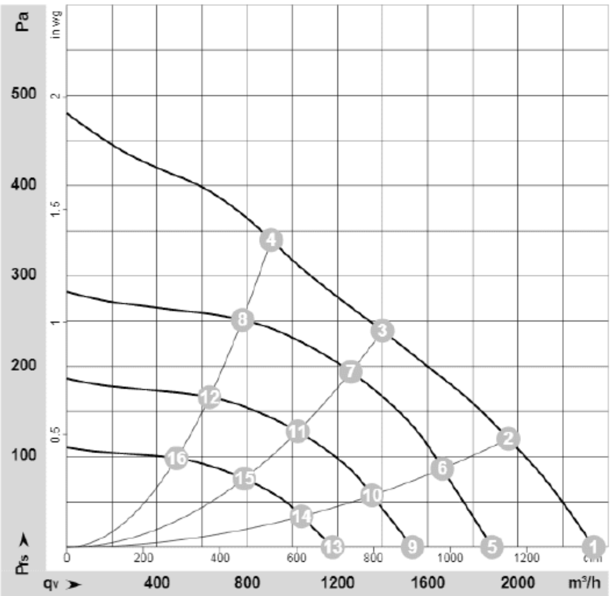


Figure 13: Fan curves

	U	f	n	P_{ed}	I	LpA_{in}	LwA_{in}	qv	p_{fs}	qv	p_{fs}
	V	Hz	min^{-1}	W	A	dB(A)	dB(A)	m^3/h	Pa	CFM	inH2O
1	230	50	3540	168	1.40	70	78	1290	0	760	0.00
2	230	50	3370	168	1.40	65	73	1065	200	625	0.80
3	230	50	3230	168	1.40	62	70	750	400	440	1.61
4	230	50	3310	168	1.40	66	74	435	550	255	2.21
5	230	50	3000	99	0.82	66	73	1090	0	645	0.00
6	230	50	3000	115	0.96	62	70	950	159	560	0.64
7	230	50	3000	135	1.12	61	68	700	350	415	1.41
8	230	50	3000	121	1.01	63	70	395	451	230	1.81
9	230	50	2400	51	0.42	60	68	875	0	515	0.00
10	230	50	2400	59	0.49	57	64	760	102	445	0.41
11	230	50	2400	69	0.57	55	63	560	224	330	0.90
12	230	50	2400	62	0.51	57	65	315	289	185	1.16
13	230	50	1800	21	0.18	53	61	655	0	385	0.00
14	230	50	1800	25	0.21	50	57	570	57	335	0.23
15	230	50	1800	29	0.24	48	55	420	126	250	0.51
16	230	50	1800	26	0.22	50	58	235	162	140	0.65

Figure 14: Fan tables

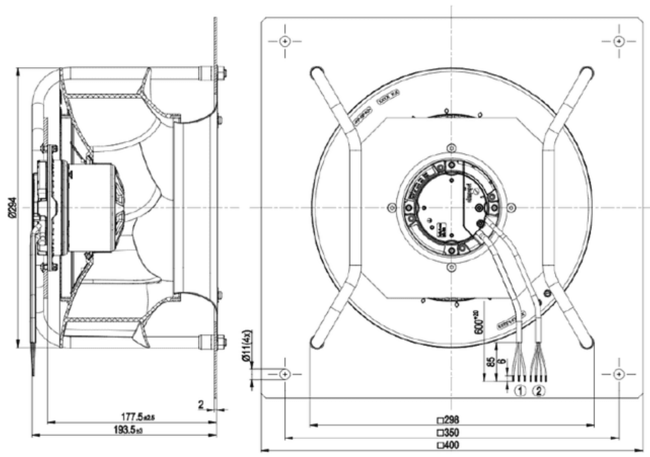


Figure 15: Fan dimensions

2.2.3 Hydraulics

Tray

The tray collecting the water is made from stainless steel material (1mm) with an inclination of 2º to ensure water circulation to the sink.

Figure 16: Condensation tray

Water tank

The tank is where the water is stored. The tank is insulated and has food-grade quality. It contains two buoys indicating the upper and lower level of water. Its size is defined based on the generation capacity of each AWG model.

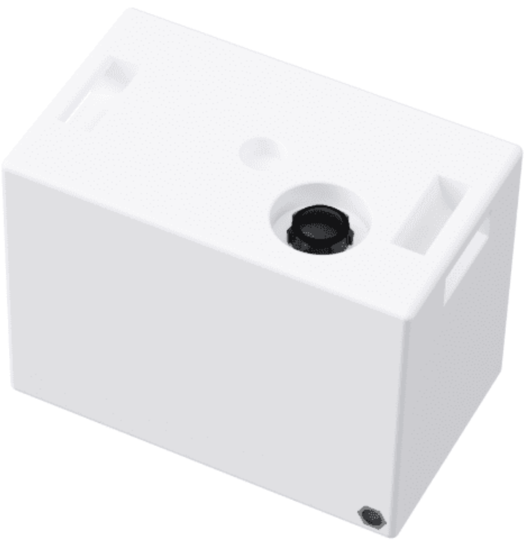


Figure 17: Water tank

Water pump

The criteria that has been used to select the water pump is pressure and flow. The flow rate is conditioned by the filters, that imply a maximum flow rate, and the pressure drop is created by the filters and pipes.

The design conditions are the following (example of a 200 liters-per-day generator):

- Maximum Pressure: 4 bar
- Maximum Flow: 2 liters/min

The pump used provides with the maximum flow below the limit of 2 l/min for the circuit pressure drop.

The pump is used for three functions:

- Water service though tap.
- Filling an external tank.
- Recirculation of stored water though UV light.

Figure 18: Water pump

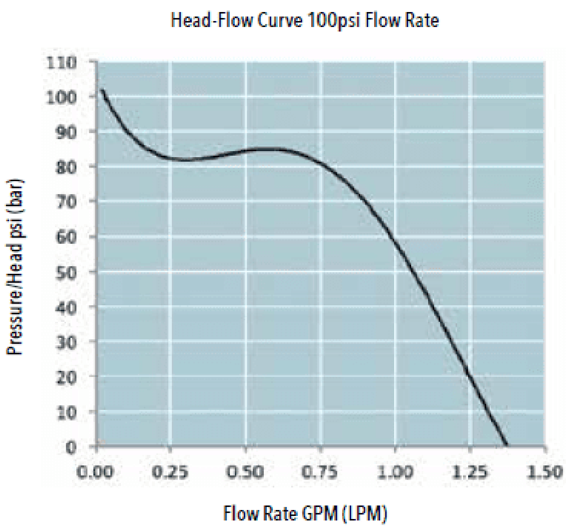


Figure 19: Pump curve

Sediment filter

Sediment filters are designed to remove suspended solids, which are also known as sediment, turbidity, or particulate. A sediment filter essentially functions like a net that catches unwanted dirt particles as our water flows through the system. In general, sediment filters are rated by a "micron" number. The sediment filter is rated 5 microns.

Figure 20: Sediment filter

Activated carbon filter

Activated carbon filters remove sediment, but they also remove chlorine, volatile organic compounds, odors, and unpleasant tastes from water. They contain activated carbon, which is made through a special manufacturing process that creates more bonding sites.

Figure 21: Activated carbon filter

Ultrafiltration

Ultrafiltration retains minerals in the water, while filtering out bacteria, viruses, and parasites. The filter used retains particles with a diameter over 0.1 microns.

Figure 22: Ultrafiltration

Mineralization

It adds minerals to the water, affecting its pH and its organoleptic properties. By default, it contains calcite, KDF and carbon. An adjustable mineralization is developed to tune these properties to the user preferences.

Figure 23: Mineralization

Zeolite

Zeolite cartridge forces an ionic exchange on water that prevents the proliferation of ammonia. Natural zeolite is used for that purpose.

Figure 24: Zeolite

Ultraviolet light

In order to preserve the water inside the internal or external tank UV treatment technique is used. UV disinfects water containing bacteria and viruses and can be effective against protozoans like Giardia lamblia cysts or Cryptosporidium oocysts, among others.

Figure 25: UV light

2.2.4 Electricity and control

Control

A control software has been developed based on a refrigeration control platform that includes the following features:

- Control of compressors with regulating capacity 0-33-66-100%
- Control of start-up process to reduce current peak.
- Management of refrigeration circuits
- Various types of defrost: Air, hot gas or adaptive gas
- Management of hydraulic programs
- Water cooling and heating
- Operating modes configuration
- Detailed alarm information
- Management of fans power as a function of inlet air temperature and relative humidity.

Display

A touchscreen display has been developed for the user and a keyboard display has been developed for the maintenance supplier. It gives access to all functions and parameters defined in the control depending on the user level.

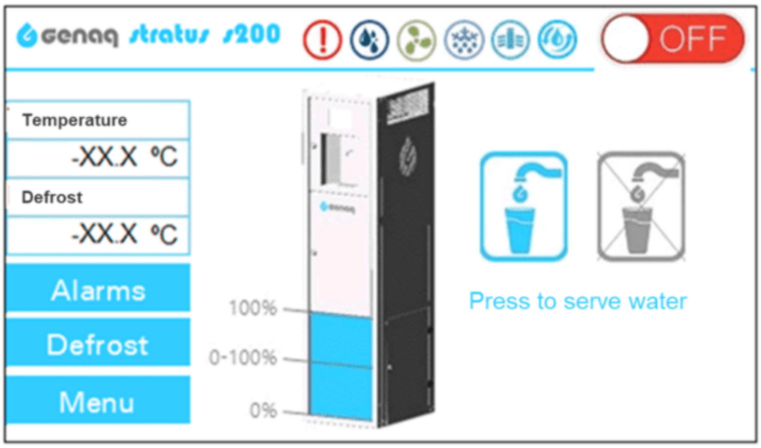


Figure 26: Touchscreen display

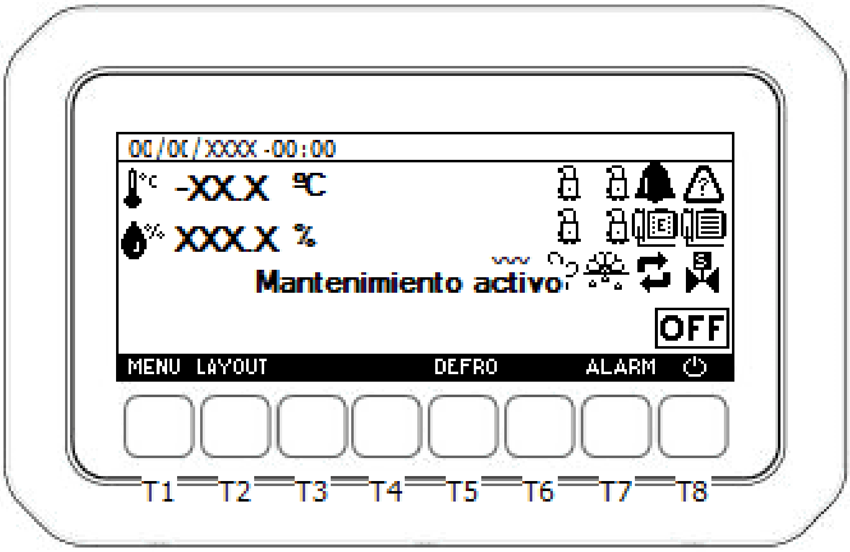


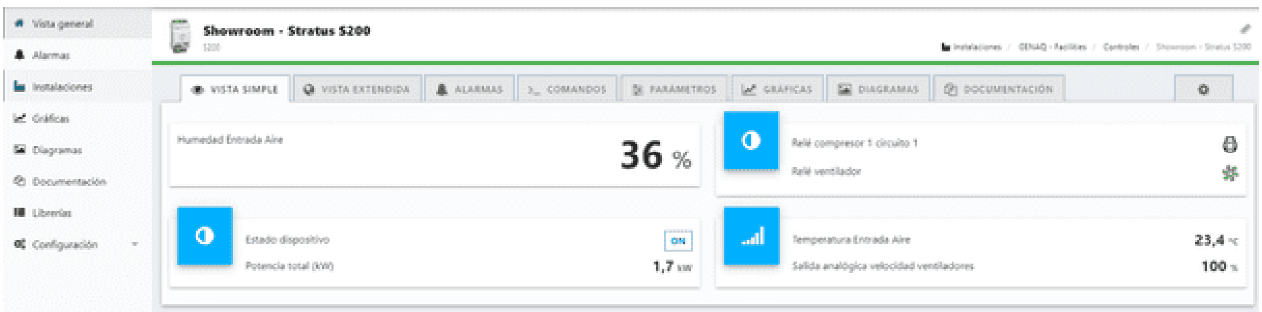
Figure 27: Keyboard display

Internet of Things

An Internet of Things remote control and monitoring has been developed to let the user operate the generator from a computer and mobile phone as well as to give access to it to the maintenance company and manufacturer. It also notifies the user in case of appearance of an alarm.

It contains the following sections:

- Simple view
- Extended view
- Alarms
- Commands
- Parameters
- Graphs
- Diagrams
- Documentation



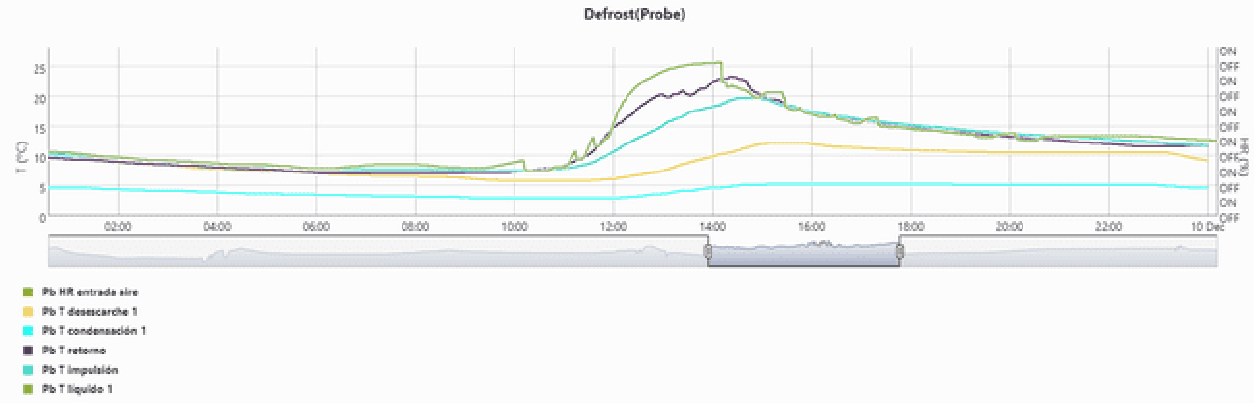


Figure 28: Internet of Things interface

Electrical circuit

The electrical circuit has been developed to complement the control software in terms of functionalities, communications, and protections.

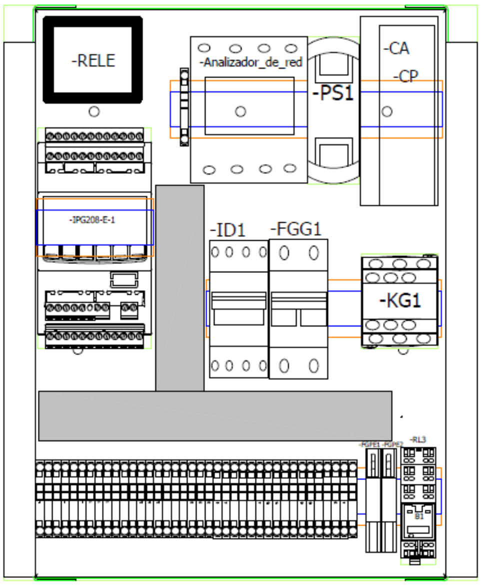


Figure 29: Electrical board

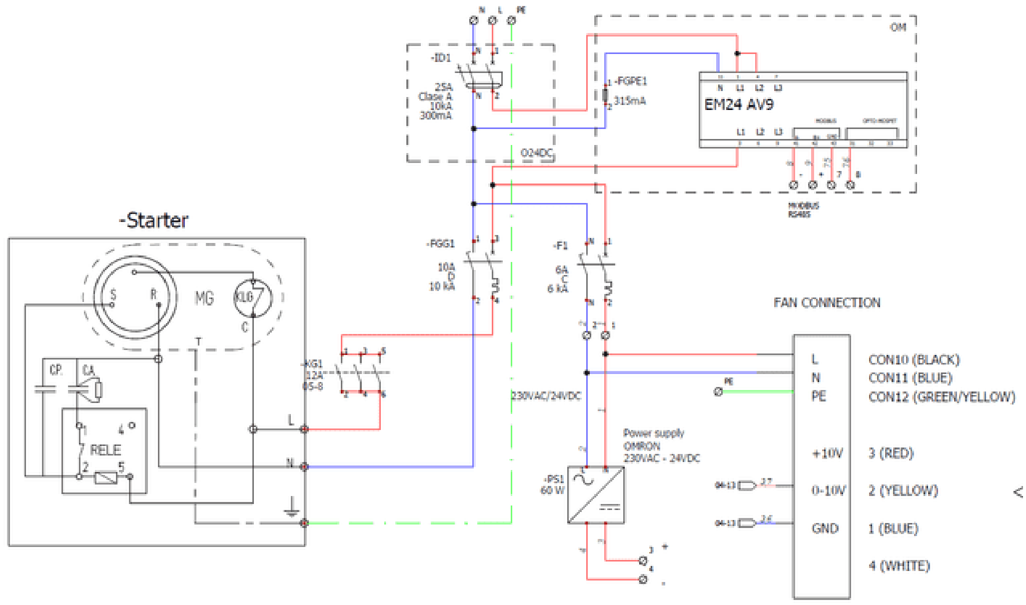


Figure 30: Electrical diagram

2.3 Calculations and tests

The development of GENAQ AWGs includes the definition of circuits; thermal, fluid dynamics, structural mechanics, and electrical calculations; dimensioning and selection of components; 3D and diagrams design; manufacturing documentation production; laboratory testing and quality control; creation of specifications, product and user documentation; and obtention of certification.

Besides the selection of components, the main conclusions of calculations are:

- Operating parameters of each controlled component (compressor, fans, pumps).
- Operating physical variables (refrigerant pressure, air temperature and flow, water quality parameters, electrical power).
- Water generation as a function of air temperature and relative humidity.
- Energy consumption as a function of air temperature and relative humidity.

To make a comparison between the theoretical data obtained during the development and the real behaviour of an AWG, it is essential to carry out several tests.

2.3.1 Laboratory tests

The fact that the climatic conditions in the area where GENAQ is located are quite limited in terms of variability, and the difficulty that exists when transporting an AWG to other areas with different climatic conditions, made us design and manufacture a Climate Chamber. This chamber allows us to replicate any climate condition for which we consider it important to know the behaviour of our AWGs.

The climate chamber is made of several subsystems:

An inverter and reversible heat able to control the temperature of, at least, 2000 m3/h of air, capable of having enough power to be able to change the setpoint easily, and with a regulation to allow the testing of AWGs from 20 liters per day to 5000 liters per day.

Air is conducted through insulated ducts with the ability of air recirculation or renovation thanks to automatic gates, and designed to distribute the air temperature and humidity evenly inside the chamber.

Humidifiers are used to control the humidity with addition of water vapor between 0.5 and 20 l/h, and with regulation capacity to maintain a constant value of relative humidity.

All components of the Climate Chamber are integrated into a single control with internet of things functionality.

The error band of the Climate Chambre is small enough in order to ensure the accuracy of the measurements:

- Humidity error band under steady state conditions: +-5%
- Temperature error band at steady state conditions: +-0.8ºC

Figure 31: Climate Chamber

Figure 32: Heat pump and dehumidifiers

Figure 33: Climate Chamber

The summary of AWG tests is the following:

- Refrigeration circuit pressure safety: Once the refrigeration circuit is welded, it is filled with nitrogen at a high pressure and with the help of pressure gauges it is verified that it can maintain said pressure over a long period of time. With this test we know that there are no leaks and that it is a safe circuit.
- Electrical circuit safety: It is checked that all the electrical connections are made as specified in the manufacturing documentation, and that all the protections work correctly.
- Hydraulic circuit leaks: The correct location and connection of all the elements that are integrated in the circuit are checked, ensuring that there is no water leakage.
- Quality Control: The different subsystems that make up the AWG are inspected following the steps described in the QC Document. Once the document is completed, it produces a series of actions to be carried out based on the non-conformities found, when these actions are 0 or the non-conformities have been corrected, the QC is complete.
- Behaviour test: The AWG is introduced into the climate chamber, and it is tested under different outdoor conditions with the idea of comparing the theoretical values with the real ones. The test is passed if the difference between the two does not exceed a defined percentage, and the result obtained helps us to properly characterize each generator.
- Custom tests: Specific tests are proposed on components, configurations, behaviour in specific cases, etc.
- Noise tests.
- Hydraulic tests: They include components characterization (performance, reliability, ease of operation, and maintenance frequency), and effect of components selected and working mode on water quality parameters. These tests are performed in the hydraulic laboratory.

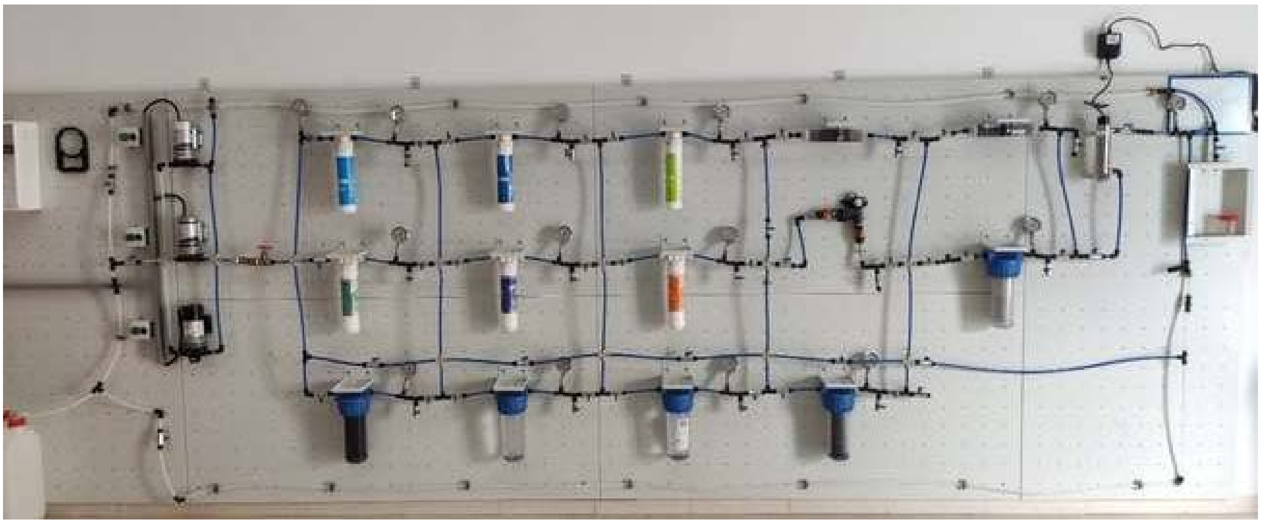


Figure 34: Hydraulic laboratory

- Water quality parameters tested:
  - Full analysis:
    - Escherichia coli
    - Enterococci
    - Sulfite-reducing anaerobic bacteria including spores
    - Pseudomonas aeruginosa
    - Total coliforms
    - Count of revivable aerobic germs at 22°C
    - Count of revivable aerobic germs at 37°C
    - Pathogenic microorganisms: Cryptosporidium, Giardia, Legionella species and Legionella pneumophila
    - Acrylamide
    - Antimony
    - Arsenic
    - Benzene, #toluene, #ethylbenzene, #xylenes
    - Benzo[a]pyrene
    - Boron
    - Bromates
    - Cadmium
    - Vinyl chloride
    - Chromium
    - Copper
    - Total cyanides
    - 1,2-dichloroethane
    - Epichlorohydrin
    - Fluorides
    - Polycyclic aromatic hydrocarbons (PAHs)
    - Mercury
    - Total Microcystins
    - Nickel
    - Nitrates ($NO3^–$)
    - Nitrites ($NO2^–$)
    - Pesticides (per individual substance)
    - Aldrin, Dieldrin, Heptachlor, Heptachlorepoxide (per substance
    - individual)

- Total pesticides
- Lead
- Selenium
- Tetrachlorethylene
- and trichlorethylene
- Total trihalomethanes (THMs)
- Aluminum
- Ammonium
- Barium
- Total Organic Carbon (TOC)
- Chlorites
- Chlorides
- Conductivity
- Color
- Copper
- Total iron
- Manganese
- Odour
- pH (concentration of hydrogen ions)
- Sodium
- Flavor
- Sulphates
- Turbidity
- Overall alpha activity
- Residual global beta activity
- tritium
- Indicative dose (ID)
- Radon

- Simplified analysis:
  - Flavour
  - Odour
  - Color
  - E.C.
  - Free Chlorine
  - pH

- Turbidity
- Ammonium
- Chromium
- Copper
- Iron
- Lead
- Nickel
- Escherichia coli
- Total coliform count

- Fan performance: Fan speed is modified, and air flow is monitored in order to characterize the fan performance.

2.3.2 Offsite tests

Several clients and proxy clients have tested the generators in several countries.

A pilot project guide document has been used to document the feedback.

The main conclusion of their feedback is that the water generation and energy consumption per litre is close to the expected value:

- Maximum absolute variation: 22%
- Average variation: 1%

Qualitative feedback has also been received by clients including:

- Documentation
- Generator reception and unpacking
- Generator start-up
- Generator usability
- Generator maintenance
- Technical support

The full list of documented offsite testing is the following:

Test number	Location	Company	Model	Start	End	Duration (days)
1	Panama	IEA	S50	12-07-21	22-07-21	11
2	Qatar	Al-Wajba	S50	18-10-21	22-10-21	5
3	Ecuador	CODEMET	S200	14-12-20	18-12-20	5
4	Malaysia	RIVIL	S200	02-08-21	06-08-21	5
5	Pakistan	Khattak Sons	S200	11-05-20	15-05-20	5
6	Chile	Inversiones Kuvasz	S50 and S200	01-06-20	08-06-20	8
7	Philippines	GEOSFER	S50	22-09-20	30-09-20	9
8	Jordan	GFM	S200	18-08-21	26-08-21	9
9	Colombia	AQUASOLEM	S50	05-04-21	15-04-21	11
10	Argentina	Mateo Martínez	S50	20-01-21	29-01-21	10
11	France	Watshep	S50	25-11-20	03-12-20	9
12	Guatemala	MAYAQWA	S200	08-03-21	19-03-21	12
13	Peru	IEA Peru	S200	19-04-21	30-04-21	12
14	Spain	GENAQ	S50	08-02-21	18-02-21	11
15	Oman	NTWinternational	S50	20-06-21	24-06-21	5
16	France	Home Atmospheric Water	S50	02-08-21	13-08-21	12
17	Greece	Brunel University	S200	04-10-21	14-10-21	11
18	Costa Rica	Gicorp	S50	05-07-21	23-07-21	19
19	Germany	BNG Trading	S50	21-08-21	30-08-21	10
20	Morocco	GENAQ	S50	28-01-20	30-01-20	3
21	Indonesia	BATS	S50	04-10-21	12-10-21	9
22	Mexico	Eco Ambientales	S50	21-01-20	23-01-20	3
23	United Arab Emirates	Galleria Trading	S50	16-02-20	27-02-20	12
24	Honduras	Invetgroup	S200	11-05-20	22-05-20	12
25	Spain	Aldebaran Energía	S50	04-10-21	08-10-21	5
26	Benin	Rotary Club	S200	18-10-21	22-10-21	5

Table 1: Offsite tests

In the following pages there are pictures of some of these demonstrations:

Figure 35: Chile

Figure 36: Colombia

Figure 37: Malaysia

Figure 38: Panama

Figure 39: Oman

Figure 40: Spain

Figure 41: Honduras

Figure 42: Chile

Figure 43: Pakistan

Figure 44: Benin

Figure 45: Jordan

Figure 46: Malaysia

Figure 47: Greece

Figure 48: Colombia

Figure 49: Spain

Figure 50: Spain

Figure 51: Portugal

Figure 52: Spain

Figure 53: Qatar

Figure 54: France

Figure 55: Colombia

Figure 56: Spain

Figure 57: Pakistan

Figure 58: Germany

Figure 59: France

Figure 60: Spain

The reported generation and energy consumption is shown in the following table:

Site	Generator	Temperature (ºC)	Relative Humidity (%)	Generation (l/day)	Var	Consumption (kWh/l)	Var
1	S50	27	83	49	4%	0.4	-7%
2	S50	31	65	44	-2%	0.44	-4%
4	S200	27	85	167	-2%	0.42	5%
5	S200	24	61	95	6%	0.61	0%
6	S50	23	41	12	0%	0.98	-3%
8	S200	26	41	57	6%	0.88	1%
9	S50	27	81	47	0%	0.45	5%
11	S50	21	74	29	-6%	0.6	15%
12	S200	26	89	162	1%	0.45	10%
15	S50	21	68	25	-4%	0.56	-5%
18	S50	27	91	52	6%	0.41	-2%
19	S50	22	76	33	-3%	0.5	0%
22	S50	24	58	24	-4%	0.65	5%
23	S50	27	68	37	-8%	0.46	-2%
26	S200	29	73	167	-5%	0.39	0%

Table 2: Offsite tests results

The previous data shows some variation as compared to the theoretical data:

- Generation:
  - Minimum variation: -8%
  - Maximum variation: 6%
  - Average variation: -1%
- Consumption:
  - Minimum variation: -7%
  - Maximum variation: 15%
  - Average variation: 1%

Note: Altitude and atmospheric pressure were not considered in this data and may negatively affect the generation as compared to the expected value.

2.4 Validation

GENAQ AWGs have obtained both mandatory and optional certification to ensure their reliability and performance. This includes:

- ISO 9001.
- European Commission Machinery Directive.
- European Commission Pressure Equipment Directive.
- European Commission ERP directive (ecodesign).
- European Commission Low Voltage Directive.
- European Commission RoHS.
- European Commission Electromagnetic Compatibility Directive.
- UNE 149101:2015 Water conditioning equipment inside buildings. Validation of equipment used in the treatment of drinking water in the interior of buildings.
- European Commission 1935/2004 Applicable to materials and articles intended to come into contact with food.
- Climate Chamber accuracy certification.
- Certification of AWGs generation in liters per day and consumption in kWh per liter results measured in Climate Chamber as a function of air temperature and relative humidity.
- Water quality directives (World Health Organization, United States, European Commission).

3.0 RESULTS

3.1 Performance

GENAQ AWGs have enhanced the performance of the AWG technology thanks to the optimization of the refrigeration circuit, heat exchangers, air flow, and fan control.

The following tables show the generation in gallons per day and consumption in kWh per gallon as a function of air temperature and relative humidity for one of the models:

Generation [gal/day]

Relative Humidity [%]	Temperature [°C] 55	50	45	40	35	30	25	20	15	10
100	-	-	194	185	168	140	126	99	72	30
90	-	-	194	185	167	139	124	97	70	26
80	-	199	194	184	163	133	117	91	58	22
70	200	197	190	178	152	119	103	73	30	18
60	196	191	182	161	132	113	79	58	20	13
50	186	178	160	135	105	86	59	42	11	7
40	156	145	123	92	70	62	50	30	12	4
30	99	90	75	58	52	37	28	12	4	2
20	55	50	40	43	21	11	8	3	-	-
10	13	18	14	11	6	3	-	-	-	-

Consumption [kWh/gal]

Relative Humidity [%]	Temperature [°C] 55	50	45	40	35	30	25	20	15	10
100	-	-	0.45	0.45	0.49	0.61	0.64	0.76	0.98	1.85
90	-	-	0.49	0.49	0.53	0.64	0.68	0.83	1.06	2.35
80	-	0.57	0.57	0.57	0.61	0.68	0.76	0.91	1.36	2.91
70	0.68	0.64	0.64	0.64	0.68	0.79	0.87	1.14	2.57	3.52
60	0.76	0.76	0.72	0.76	0.87	0.87	1.21	1.59	3.63	4.43
50	0.87	0.87	0.91	1.02	1.10	1.14	1.63	2.31	6.06	8.14
40	1.17	1.17	1.29	1.44	1.63	1.40	2.01	3.07	6.62	11.47
30	1.82	1.78	1.93	2.04	2.01	2.16	2.95	5.83	11.81	16.96
20	2.76	2.84	3.48	2.65	4.28	5.94	7.31	15.44	-	-
10	7.08	7.49	8.59	9.61	12.38	18.58	-	-	-	-

Table 3: Generation **Table 4: Consumption**

This data allows the calculation of performance and selection of the required AWG model for any location. For example:

- Location: Dubai, UAE
- Average Temperature: 28ºC
- Average Relative Humidity: 56%
- Electricity Cost: 0.08 USD per kWh
- Need: 400 liters per day
- Current solution: Bottled water (0.20 USD per liter)
- Results:
  - AWG: GENAQ Cumulus C500
  - Generation: 401 liters per day
  - Consumption: 0.24 kWh per liter
  - Investment: 30k USD
  - Operating cost: 0.02 USD per liter
  - Return on investment: 1.1 years
  - Monthly savings: 2,160 USD

3.2 Water quality

Water quality analysis results, certified by external laboratories prove that water generated by GENAQ AWGs respects the limits of all drinking water regulations internationally.

A water analysis is shown as follows:

ANALYTICAL RESULTS				
Parameter	Result	Uncert	Units	ML
Parámetros Organolépticos				
Flavour	1.00	-	Ind. Dilución a 25° C	3.00
Odour	1.00	-	Ind. Dilución a 25° C	3.00
Physicochemical Properties				
Color	< 1.00	-	mg/L Pt/Co	15.0
E.C.	< 70.0	-	µS/cm a 25°C	2,500
Free Chlorine water	< 0.10	-	mg/L	1.00
pH	7.56	-		6.50 - 9.50
Turbid	< 0.20	-	NTU	5.00
Cations				
Ammonium	0.40	-	mg/L	0.50
Metals Soluble in Acid				
Chromium	< 1.25	-	µg/L	50.0
Copper	< 0.0013	-	mg/L	2.0000
Iron	< 25.0	-	µg/L	200
Lead	< 0.50	-	µg/L	10.0
Nickel	< 2.50	-	µg/L	20.0
Microbiology				
Escherichia coli	< 1.0	-	u.f.c./100 ml	0.0
total coliform count	< 1.0	-	u.f.c./100 ml	0.0

Table 5: Water analysis

3.3 Features

GENAQ AWGs include the following features:

- High quality water.
- Good taste as proven by blind water tasting events.
- Water cooling/heating.
- Low energy consumption per liter (nominal 0.18 kWh per liter).
- Predictable performance based on location.
- Adaptation of air flow to inlet air conditions.
- Portability.
- No installation.
- Automated warnings.
- Low maintenance.
- Reliability as proven by offsite tests by clients.
- Usability as proven by offsite tests by clients.
- Internet of Things.
- 1-week autonomy with genset.
- Compatibility with solar PV.
- Marine Environment.
- 7 models available from 50 to 5,000 liters per day.
- Certification.

3.4 Products

There are several models available arranged in four ranges for four different markets/applications:

Figure 61: Markets

The four ranges available are:

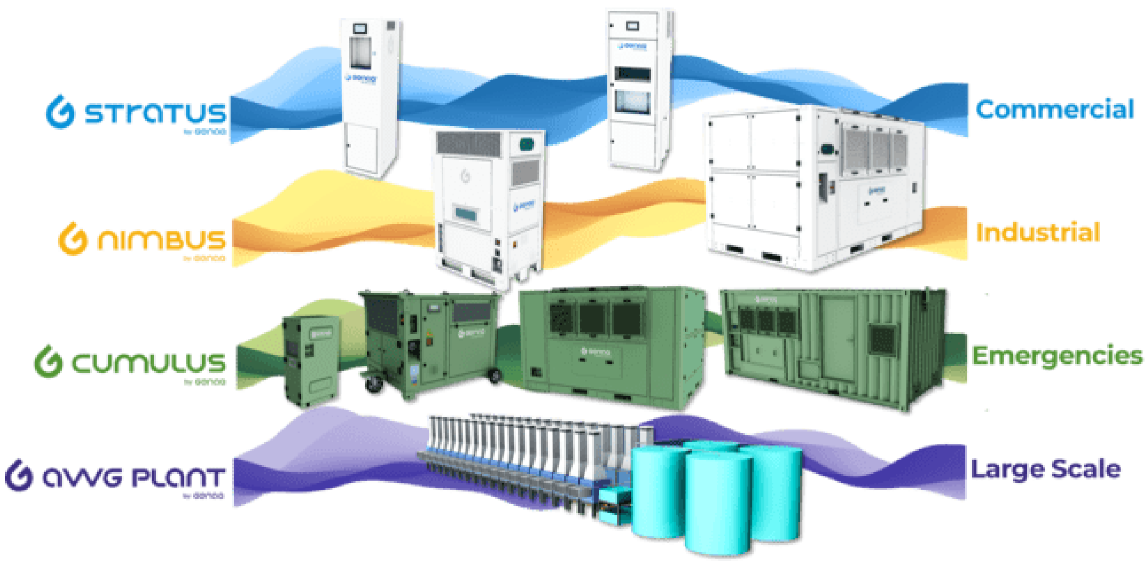


Figure 62: Product ranges

3.4.1 Stratus

GENAQ Stratus are designed as water dispensers that supply the purest drinking water avoiding plastic waste and storage space, compared with bottled water dispensers. They can be used at homes, offices, hotels, hospitals, public buildings, etc.

Two models are available:

- Stratus S50: Nominal generation of 50 liters per day.
- Stratus S200: Nominal generation of 200 liters per day.

3.4.2 Nimbus

GENAQ Nimbus brings an affordable and excellent quality water source when water network is not available or it has a high cost of connection. GENAQ Nimbus are an ideal solution for remote locations such as construction sites, mines, oil rigs, remote facilities, etc. Also as an alternative water supply for Industres like Agriculture, Food Industry or Livestock. It is free of biologic contamination with excellent physical and chemical properties. GENAQ technology is a 61ustainable source of water and it is also compatible with renewable power sources such as photovoltaic panels.

Two models are available:

- Nimbus N500: Nominal generation of 500 liters per day.
- Nimbus N4500: Nominal generation of 4500 liters per day.

3.4.3 Cumulus

GENAQ Cumulus are a quick deployment water supply in case of emergencies, natural disasters, humanitarian aid, civilian and military camps, etc. With a reinforced and easy-to-carry structure designed to overcome any logistical challenge, they supply safe water wherever they are located.

Three models are available:

- Cumulus C50: Nominal generation of 50 liters per day.
- Cumulus C500: Nominal generation of 500 liters per day.
- Cumulus C5000: Nominal generation of 5000 liters per day.

3.4.4 AWGplant

AWGplants are tailored projects to offer a solution for larger high-quality water needs for residential water supply, bottling plants, industrial processes, etc. This solution has been optimized for both low investment and operating cost per liter.

Solution dimensioning is defined for each specific need.

3.5 References

AWGs are currently being used by the following organizations, among others:

Spanish Army

Figure 63: Spain

Madagascar Government

Figure 64: Madagascar

Portuguese Army

Figure 65: Portugal

Nigerian Navy

Figure 66: Nigeria

US Army

Figure 67: US Army

Figure 68: US Army

Malaysian Army

Figure 69: Malaysia

Pakistani Police

Figure 70: Pakistan

Puerto Rico Government

Figure 71: Puerto Rico

UAE Government

Figure 72: UAE

Qatar Government

Figure 73: Qatar

Red Cross

Figure 74: Red Cross

United Nations

Figure 75: United Nations

3.6 Comparison with other alternatives

The following table shows a comparison with other drinking water solutions:

	Bottled water	Filtered water (dispensers)	Filtered water (jugs)	Water tanks	GENAQ
Cost per litre	**High:** €0.34 per l average in Europe	**Low:** <€0.01 (tap water)	**Low:** <€0.01 (tap water)	**Variable:** <€0.01-0.03	**Medium:** €0.03
Requires a water supply	No	Yes	Yes	No	No
Heavy metal contents	Low	**Variable** (depends on the source)	**Variable** (depends on the source)	**Variable** (depends on the source)	Low
In situ sanitation	No	No	No	Optional	Yes
Water taste	Good	Variable	Variable	Variable	Good
Need for installation	No	Yes	No	Yes	No
Environmental performance	**Low:** plastic waste and transportation impacts	**High:** no residues or transportation impacts	**High:** no residues or transportation impacts	**Low:** transportation impacts	**High:** no residues or transportation impacts

Table 6: Comparison

4.0 CONCLUSION

AWG technology has some advantages as compared to existing drinking water solutions (bottled water and local water treatment):

- No water supply is required as water is harvested from air humidity
- No logistics or resupply related to drinking water is required
- Rapid deployment and, virtually, no installation is required
- Simple maintenance
- Drinking water quality in ensured (adjustable mineralization, free of any contamination)
- Drinking water supply in ensured

However, former AWG technology presented some limitations, namely:

- Water generation depends on climate (air temperature and relative humidity)
- Low water generation in harsh environments (with low air temperature and relative humidity)
- Uncertainty on the water generation in a specific location
- High energy consumption
- Product reliability
- Start-up current (with has an impact on oversizing gensets and solar PV installations)

These limitations have limited the broad adoption of AWG technology so far.

However, thanks to the advancements achieved in recent years, AWGs have eliminated or reduced these limitations as a result of several developments that include refrigeration circuit optimization, adaptable performance, characterization in climate chamber and real environment, water treatment techniques, or adoption of frequency variation.

The current maturity and performance of this solution allows a extension of the applications where it is preferred over traditional drinking water solutions.

The main implications of the adoption of this technology, as compared to other solutions such as bottled water resupply or local-source water treatments, are related to:

- Cost: Drinking water cost reduced by 80% as compared to bottled water resupply.
- Performance-based planning for specific climate conditions.
- Portability, no installation, automated warnings, remote control, low maintenance.
- Safe water storage, no bacteriological proliferation in tanks.
- Best water taste, validated in blind water tasting events (preferred option against bottled and reverse osmosis water).
- Certified water quality analysis, compliant with US, EU and WHO drinking water standards
- Several models available ensure that supply meets demand (Marine Corps Survival Manual; at least 2.6 gallons of water per day in arid regions)
- Reduction of casualties related to resupply.
- Reduction of waste management.

On top of this, this technology will continue to evolve in the near future to reach additional milestones, such as:

- Further adaptation to air T and RH
- Further reduction of energy consumption
- Increase performance. Target:
    - 0.12 kWh per liter
    - +200% generation in unfavorable conditions
- Integration with PV without batteries
- Predictive maintenance
- Real-time water analysis

These milestones are expected as a result of the following R&D projects:

- Frequency variator full integration
- Optimal working conditions detection (simulation and climate chamber)
- Full adaptation control of compressor and fans
- Automatic data analysis from IoT
- Water quality sensors integration

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