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Research Article

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Develop a Fresh Water Production Method from Atmosphere

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Abstract
Fresh water scarcity represents a major world challenges, in addition, the water consumption is increasing with population growth and evaporation due to global climate changes. Furthermore, seawater desalination is considerably cost, requires additional energy to extract it, and negatively affecting water quality. The modern technologies adopted deferent methods to extracting the fresh water from the atmosphere. This work aims to contribute in solving this scarcely fresh water problem through, condensing the humidity in the air and transform it to fresh water. The proposed system is integrated into three parts; mechanical, electrical, and water treatment with filtration unit. The mechanical system consists of a refrigerant cycle with a compressor capacity of 1.5 horse power. The electrical system is responsible of controlling the mechanical system through the Arduino Uno circuit and relay. The filtration system is used to remove sediments and contaminants from the harvest water. The water treatment unit is used to supply the filtered water with the required additives of minerals to transform the distilled water to fresh drinkable water. The system design takes the energy efficiency into account. The system behavior is analyzed, taking into account real climatic conditions of Egypt. Preliminary calculations show that the water extracted from air by condensation is ranged from (8.25 to 12) litters during six operational hours per day. The produced quantity of fresh water can be support the needs from three to four persons per day. The total saving of produced water from the proposed system compared with the price of water in the market is 80,416.8 L.E per year.

Keywords: Evaporator, Condensation, Desalination, Relative humidity, Dehumidifier Unit.

1. Introduction

Water is the lifeblood of human beings and life on Earth. Rising water consumption and diminishing water resources are increasing water scarcity in most world regions. Conventional approaches relying on rainfall and river runoff in water scarce areas are no longer sufficient to meet human demands. Unconventional water resources, such as harvesting water from air, is expected to play a key role in narrowing the water demand-supply gap, and contribute in reducing the effect of global water crisis [1]. There are three main fresh water resources, groundwater, desalinated water, and treated wastewater. Statistics show that the demand of water is expected to increase by 130% from household use by 2050. Condensing the air and transforming it to fresh water through the cooling units in the air conditioner is a promising solution. Under the concept of product development, adding another cooling circuit to the main air conditioner device, leads to increase the condensed air and transform it to fresh water [2]. Recycling wastewater for direct use and sewage desalination solutions requires a high cost and had side effects which can be at least similar to the seawater desalination [3]. Different technologies about extracting water from air humidity are discussed to contribute in reducing the effect of the global water scarcity. The water vapor and droplets in the atmosphere, estimated to be around 13,000 trillion liters, is a natural resource that could address the global water problem. Extracting water from the air is a promising solution. The atmospheric water generator was proposed, but the average price of the equipment and its maintenance is quite high. Therefore, the idea of developing an air conditioner device by integrating two units together could be a promising solution for extracting water from air [4]. This work aims to explore new perceptions regarding water resources development of an air conditioner unit to transform higher amount of condensed air to fresh water. The objective of this work is to develop an air conditioning outdoor unit to harvest the water from air humidity and design an automation unit for the developed device to control its operation in different environmental conditions. The collected water passes through a water treatment process and filtration system to remove sediments and contaminants and gain the required additives of minerals to change the condensed distilled water to fresh drinkable water. The measured quantity of the extracted water from humidity is ranged from (1.6 to 2) liters during six operational hours per day.

2. Background and Survey

2.1 Atmospheric Water Harvesting (AWH)

Atmospheric water harvesting (AWH) is unique in that it uses a desiccant to collect water vapor from the air and has higher thermal efficiency than traditional AWH systems. The main advantage is that the dried material can be regenerated with solar thermal energy and the condensation process can be carried out under ambient conditions. The adsorption-based AWH process consists of two stages. In the first stage, the desiccant comes into contact with the surrounding air at night and absorbs water vapor. The second stage, the desiccant is packed in a closed system where, a large amount of heat is applied to regenerate the desiccant. During the regeneration process, the material absorbs water vapor and the collected vapor is condensed into a liquid form. Atmospheric pressure rainwater harvesting may be possible in areas with low relative humidity [5]. According to a developed system by use two-step device mechanisms [6]. The novelty of this device is the use of two absorbent layers to improve daily water production. The lower tier was absorbed using the latent condensation from the upper tier as shown in figure 1. This approach can improve thermal efficiency and the system may be more suitable for everyday use.

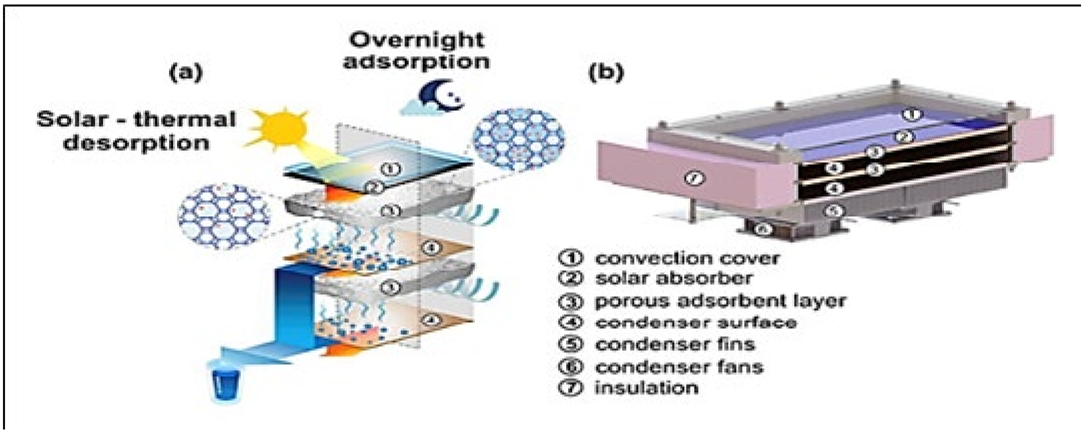


Figure 1: Atmospheric water harvesting [6]

2.2 Atmospheric Water Generator

The increasing in demand of freshwater resources has been motivated to develop a new water harvesting methods. The Atmospheric Water Generator is a device that uses dehumidification technology to extract water from the moisture in the air. The water is then filtered and purified through multiple filters, including carbon and reverse osmosis and UV sterile lights as shown in figure 2. The result is pure drinking water from the air. Water generators in the atmosphere operate on the same principle as refrigerators and air conditioners on the principle of cooling by evaporation. Condensation is the primary method of atmospheric wire gauge (AWG) for converting water vapor into liquid water. Moist air cools to a temperature below the dew point, causing a vapor-to-liquid water phase transition across the collected cooling surface. The main advantage of using atmospheric water as a drinking water source is that it does not require a water transportation infrastructure. Harvesters can be installed virtually anywhere [7].

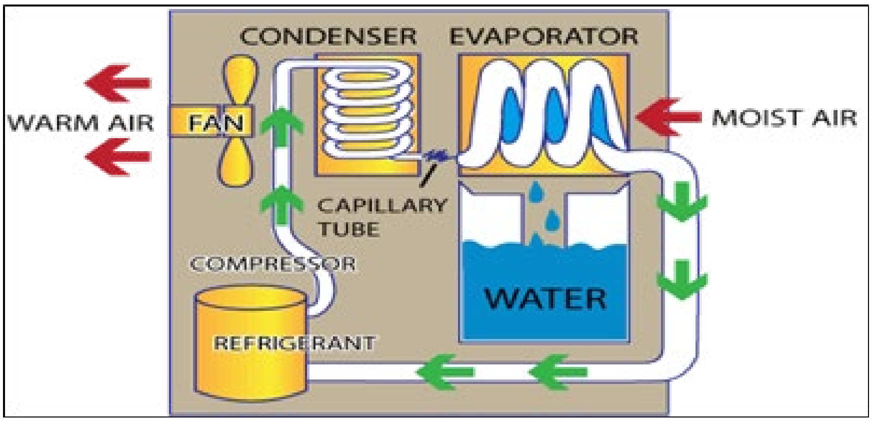


Figure 2: Atmospheric water generator components [7]

The atmospheric water generator uses a compressor to convert the air into compressed air developed by which is passed through a condenser tube to reach the dew point [8]. The Atmospheric Water Generator (AWG) uses technology to generate drinking water from the surrounding air. The methodology for extracting water from air is common to all techniques and involves promoting the condensation of air vapor content. Atmospheric Water Generator (AWG) is a range of household devices that can generate 1 to 20 liters of water per person per day. The way to bypass the energy issue in water extraction from air is represented by integrated AWG systems based on a compression reverse cycle, can produce from tens to hundreds of liters per day with relatively small space requirements represents a way to avoid energy problems when getting water from the air. A simple atmospheric water generator unit uses only the reverse cycle to cool the surrounding air below the dew point, consuming some energy and condensing some of the humidity in the air. Instead, the integrated AWG system is designed to use the multiple beneficial effects of reverse cycling with the same power consumption as a simple AWG device as shown in figure 3 [9].

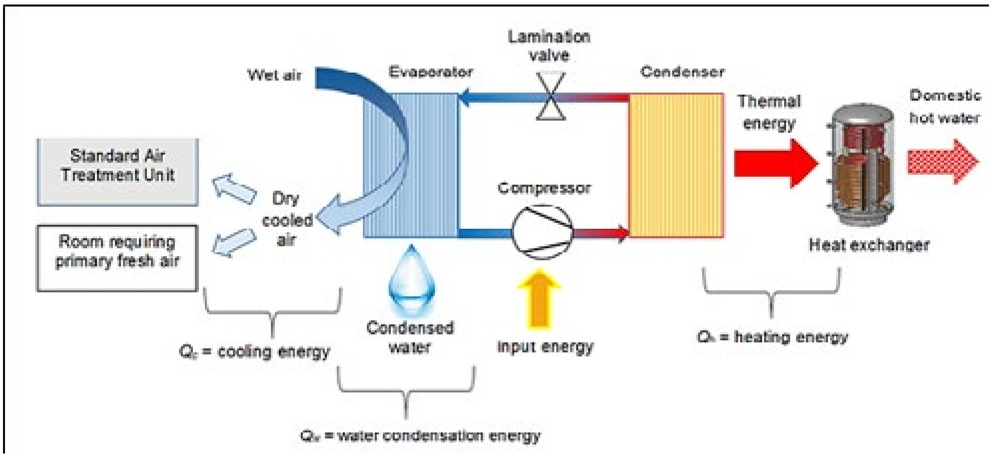


Figure 3: AWG integrated system scheme [9]

One of its most important features in the AWG is the ability to collect water from relatively dry air and low temperatures. Relative humidity is important to the AWG's performance, but it is less affected than passive condensates due to abiotic variables such as sky radiation, wind speed, and terrain location. As a result, it can operate in a variety of weather conditions. As a means of extracting water from the atmosphere, the use of plants aimed at producing the best water with the least power and the highest efficiency was introduced. The study take in account whether, the solar energy could be used as a new source of freshwater in an AWG. The recommended AWG solar panels were designed and evaluated by using HOMER software. The studies showed that the water produced is safe to drink and that the AWG technology for photovoltaics is technically feasible. AWG technology generates consumable water at a lower cost than bottled water and is more environmentally friendly [10]. Advised to use the cooling and dehumidifying procedures for air conditioning as useful method for fresh water production and suitability for use in areas of high temperature and relative humidity. However, it depend on several elements to enhance the amount of condensation to be produced such as, the characteristics of moisture in the air, air velocity, cooling coils surface area, and the arrangement of heat exchange [11]. Study the constrains of water production from water vapor in atmospheric air when the hot and moist air is cooled over refrigerator desiccant coils and then, directed to an open area. In this approach, water is the result of the air conditioning process, so a limited amount of fresh water can be provided free of charge. An advanced model was used to calculate the water yield from the cooling process of the finned coil. As a result of the experiment, water productivity decreases when the wind speed increases. This decreases in produced water happened due to insufficient capacity of the evaporator, frost is generated on the pipe surface and there is a shortage of refrigerant that hinders water extraction, and when the wind speed becomes insufficient, water productivity decreases. Performance prediction released for estimating the water production (liters per day) in specific and different humidity percentage and temperature degree Celsius as shown in table 1 [12].

Humidity%	Temperature °C			
	55°C	68°C	77°C	85°C
30	-	-	3.79 L	4.73 L
40	-	3.79 L	4.73 L	6.81 L
50	3.79 L	4.73 L	6.81 L	7.95 L
60	3.97 L	5.87 L	7.95 L	11.73 L
70	5.87 L	7.19 L	11.73 L	15.52 L
80	5.87 L	7.16 L	14.75 L	18.36 L
85	6.01 L	-	15.06 L	18.82 L
90	7.75 L	-	17.03 L	20.82 L

Table 1: Atmospheric water generator testing results [12]

2.3 Water Absorption in Porous Metal−Organic Frameworks

The water absorption of porous materials is important for a variety of applications such as dehumidification, thermal batteries, and the supply of drinking water to remote areas. This study identified three criteria for achieving high-performance water-absorbent porous materials [13]. These criteria deal with the condensation pressure of water in the pores, adsorption capacity, recyclability, and water stability of the material. In search of a porous material with excellent performance, the water absorption characteristics of the twenty three materials were investigated and the water absorption was measured.

2.4 Air Condition Waste Water Recovery

Air conditioning works on the principles of phase transformation, which is the conversion of a substance from one state to another. The material absorbs heat when a change occurs from a liquid to a gas. The water vapor in warm domestic air will strikes the cold evaporator coils then, the water vapor condenses into liquid form and drains the water away outdoors. The air will undergo the inverse process when the evaporator coil reduces the humidity in the home. Then, the evaporator takes the air from the external environment and directs it to circulate through cooling coils to the evaporator unit, which releases the cooled air to the internal environment as shown in figure 4 [14].

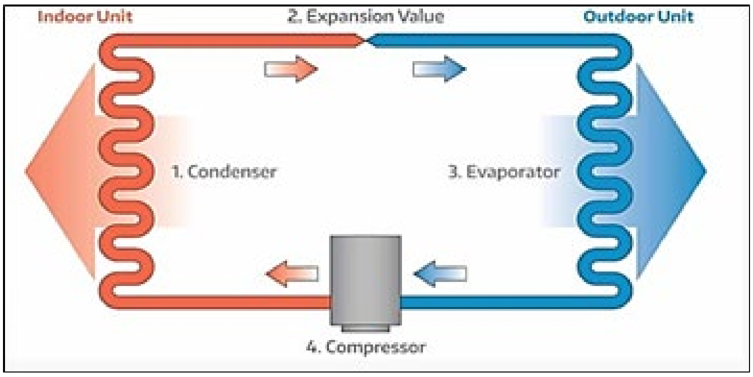


Figure 4: Refrigerant cycle [14]

The air-cooling process in the coils promotes the condensation of the gaseous water present in the hot air mass, resulting in liquid water. Air conditioners operate in temperatures ranging from 20 to 24 °C, with the city's annual average temperature being 26.57 °C and the relative humidity of the air being 55.95% [14]. Preliminary testing was made using a home Air conditioner unit, and revealed that a conventional home air conditioning unit produces an average of twenty three liters of water per day. If the air conditioner is turned on for ten months of the year then, the amount of wastewater can be increased to 8000 liters. Experiments also showed that the volume of water produced during the day does not vary significantly. This water can be used to irrigate plants or gardens. The cooling mechanism of this device is similar to the cooling systems found in most home and commercial buildings [15]. In order to know how many liters can be collected from the air conditioner, simply try to collect the water in a tank or bucket rather than letting the water to flow to the ground as shown in figure 5. The amount of water that can be collected in this way depends on the size of the air conditioner unit, the ambient temperatures and the level of humidity in the air [15]. People, who live in an environment with high humidity (65-70%), such as a coastal area, will be able to collect more water than those who live in dry places with humidity levels below 45%. Air conditioner in an area with high humidity with 1 HP (9000 BTU) may generate up to 9 liters of water in 8 hours per day.

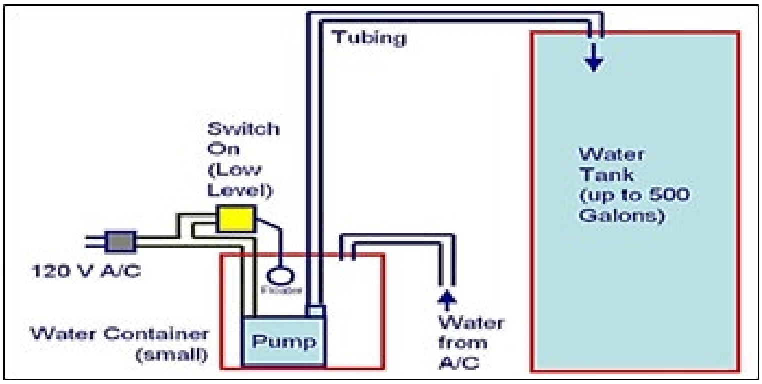


Figure 5: Water collection process from Air condition unit [15].

In 2015, The Ministry of Environment and Water in the United Arab Emirates (UAE) started a new project to make use of the air condition devices, which converts water from air-conditioning devices into water for irrigating gardens and farms, and also using it as a source to raise the groundwater level in cities that suffer from drought, and reduce the humidity in the air [16]. In addition, lines can be connected to desalination plants, and when desalinated, a large part of the costs of desalinating highly saline seawater will be saved. The project proposed by is based on collecting air-conditioning water in a network of pipes directed into the ground, which raises the level of groundwater in large quantities, and supports water security in the country, indicating that the collected water can be directed to desalination plants and become potable, or stored in tanks for other uses such as putting out fires as shown in figure 6 [17]. A study was conducted on the volume of water released from 10,000 air conditioners of the common type in the country in 100 days, and it was estimated at about two million liters, which is a large amount of water wasted without any use. In addition, this water can be desalinated at a cost that is 60% less than desalinating sea water.

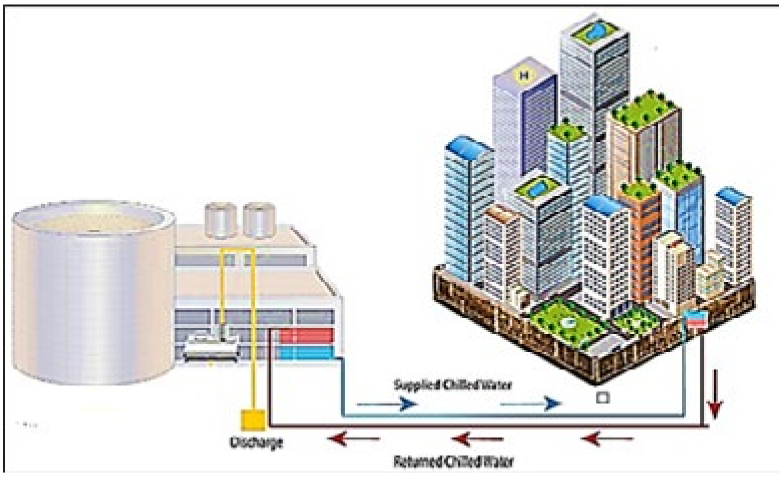


Figure 6: Air condition waste water re-uses [17]

Home air conditioning units typically produce a flow rate of 3.09 Liter per hour, which ranges from 2.8 to 4.2 Liters per hour, which represents 30.8 Liters of water produced from 8 am to 6 pm daily as shown in figure 7. Test was carried out on 3 different types of air conditioner units at 23°C and 45% humidity. As a result, a flow rate of 0.55 Liters per hour was observed for the 1.5 horse power (12,000 BTU) device, 0.39 Liters per hour for the 1 horse power (9000 BTU) device, and 1.2 Liters per hour for the 2.25 horse power (24,000 BTU) device. The flow rate produced by the air conditioner is variable and depends on the output of the unit. For air conditioners from 1 to 2.25 hp, the relationship with air volume was found to be linear. In addition, other factors can affect the device's water production, including: Temperature, relative humidity of ambient air, device model, and maintenance.

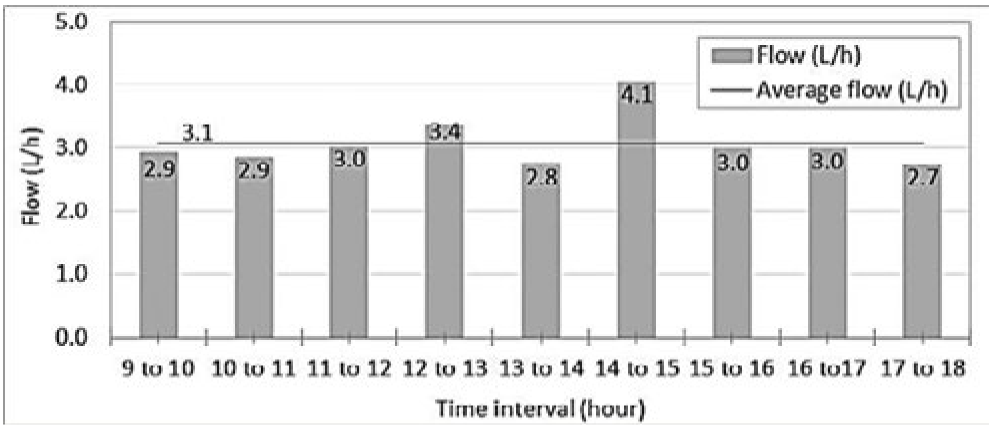


Figure 7: Average flow rate from Air conditioning waste water [14]

In order to increase the likelihood of using condensed water, it should be treated to reduce or minimize the number of heterotrophic bacteria. According to standard methods, some processes, such as distillation, filtration, and ultrafiltration, are considered to be good at reducing bacteria. Therefore, condensed water used as reagent grade water must be filtered to be suitable for daily use [18].

2.5 Summary of Literature Review

Since the last decade, scientists invented and proposed a lot of methods to contribute in reducing the effect of water scarcity in the world. The first method was published in Russia in 1947; the outcome of the water collected by this method was 250 ml of water during the day. Thereafter, the desiccant system was found in 1981 and was getting developed until 1997. It finally reached an amount of water outcome up to 1.5 liters of water per day. In 2008, a new method was used which is known as the dew collection methodology; which gained up to 3.5 liters per day. Another solutions are the seawater desalination and sewage water desalination; However, these solutions are economically very costly and affecting the environment. Nowadays, the most updated method is the atmospheric water generators, but the amount of water to be collected is actually based on the cooling capacity of the unit. After reviewing the methodologies of the past solution, it was found that the best methodology and the most effective solution is to develop an air conditioner device to transform the condensed air to fresh water. The proposed system unit in this work is very effective as it depends on the temperature degree Celsius, humidity percentage, and the cooling unit capacity. If integrated the new proposed system unit with the air conditioner device out door unit as shown in figure 8. The quantity of collected water due to humidity condensation is ranged from (10 to 18) liters during 6 working hours. This proposed system unit is effective solution and economically viable compared to the other solutions in the literature review.

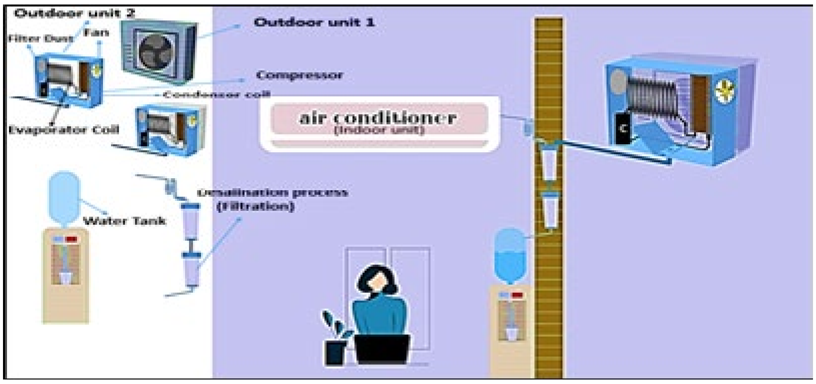


Figure 8: Proposed system design

3 Main Design Characteristics

3.1 Air Conditioning Units

The air conditioner device consists of indoor and outdoor units as shown in figure 9. The outdoor unit mainly consists of compressor, evaporator, and condenser. Air conditioning is a process used to create and maintain optimal temperature levels in indoor spaces. The water drains from the air conditioner unit are water vapor that has been extracted from the air as a result of the dehumidifying process. The amount of water removed varies according to the degree of air humidity, and the performance of the air conditioner. The air condition with 1.5 HP normally can produce about 1 Liter of waste water per hour at humidity (45 - 70) %. Usually, the water coming out from this condensation has been simply allowed to run off, often to the ground, city drains and other-places. However, it was found that the amount of water can be increased by adding the proposed unit for collecting, recycling, and purifying the water to be used as a clean drinking-water as it has no salts or residue solids in it. They are basically distilled water.

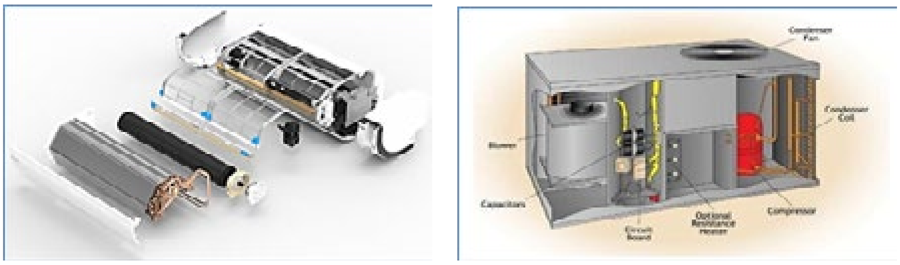


Figure 9: Air conditioner device Indoor and outdoor units [19]

3.2 Proposed Additional Unit

The proposed refrigerant cycle includes; compressor which circulates refrigerant through a condenser and evaporator coil to cool the surrounding air as shown in figure 10. This process will lower the air temperature to reach the dew point for achieve condensed water. A controlled-speed fan is pushing the filtered air over the coil. Finally, the water passes into a holding tank for treatment by purification and filtration system. The treatment system is held to reduce the risks of presence viruses or bacteria in the condensed water and keep the water safe for human use. The rate of producing water depends on relative humidity, air temperature, and the compressor size. The proposed unit becomes more effective and useful at high air temperature and high percentage of humidity in air. The effectiveness of the proposed unit depends on the unit capacity, humidity and temperature conditions, and the unit cost. Water is condensed from the air conditioners when the ambient air is humid and hot in coastal areas. This water can be conveniently used for daily use and drinking purpose.

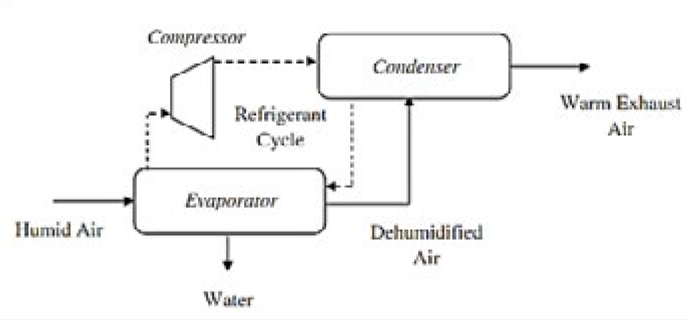
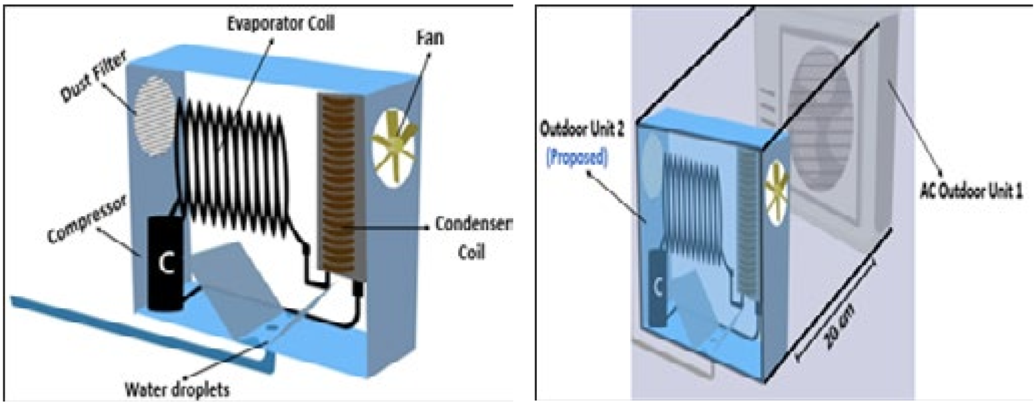


Figure 10: Dehumidification by refrigerant cycle

The proposed additional system is similar to the cooling systems found in most private and commercial air conditioners, in which the water is condensed from the refrigeration coils. The Air conditioner device can be developed by adding a new refrigerant cycle that consist of a compressor with 3/4 horse power, evaporator, condenser coil, and a fan to get more air carrying humidity to be directed to the new refrigerant cycle as shown in figure 11(a). In addition, the hot air coming out from the condenser of the main air conditioner outdoor can be used to avoid getting the evaporator coils frosted, and to increase the condensed water droplets from the evaporator at the proposed refrigerant cycle that will be linked to the outdoor unit 1 of the air conditioner device at a distance of 20 cm as shown in figure 11 (b).



(a) Proposed additional outdoor unit components **(b) Integration of the two outdoor Units**

Figure 11: Proposed additional system components

3.3 Specifications of the Proposed Additional Unit Components

The proposed unit components consist of compressor, evaporator, refrigerant, condenser, and an axial fan. The specifications of the unit components are presented in table 2.

Elements	Specifications
Compressor	• Motor power: 550 Watt • Max. Output power: 3/4 HP • Evaporating temperature range -35 °C to 15 °C • Capacity = 2.72 kw
Evaporator	To be calculated based on experiments.
Refrigerant Type	• R-134a
Condenser (Refrigerator condenser)	• Dimension : 42.7 X 48.3 X 34 cm • Capacity = 3.23 kw • No. of channels: 26
Fan (Axial)	• Air Flow = 2800 m3/h • Voltage = (200-277) V • Frequency = 50/60 Hz
Thermal expansion valve	• 0.55 ml tube with
Proposed unit	• Dimensions: 84.5 X 30 X 59.5 cm

Table 2 Proposed unit specifications

4. Refrigerant Cycle Calculations

The refrigeration cycle primarily involves the transfer of refrigerant from one state to another. The refrigeration cycle begins with the compressor and ends with the compressor as shown in figure 12. Refrigerant flows into the compressor where, it is compressed and pressurized. At this point, the refrigerant is in a hot gas state. The refrigerant flows into the condenser which, turns the vapor into a liquid and absorbs some of the heat. The refrigerant moves to the expansion valve, where it expands and loses pressure and heat. The refrigerant leaves the expansion valve and moves slowly due to pressure loss then, enters the evaporator in a liquid state, where heat is exchanged, thereby cooling the load on the refrigerator. After that, it absorbs heat and becomes gaseous. Finally, the gas is pushed back into the compressor, where the cycle can start again. The changes of the temperature and pressure in every cycle state are presented in table 3.

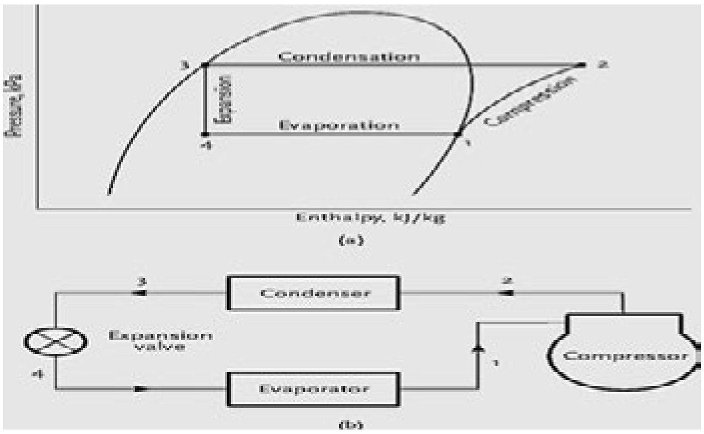


Figure 12: Refrigerant cycle diagram

State 1	State 2
Low Temperature Low Pressure Saturated Vapor	High Temperature High Pressure Superheated Vapor
State 3	State 4
Medium Temperature High Pressure Saturated Liquid	Low Temperature Low Pressure Liquid Vapor Mixture

Table 3 Refrigerant Cycle States

1. Refrigerant enters the compressor as superheated gas at low pressure.
2. The compressor pressurizes the gas and turns it into superheated high-pressure gas.
3. Inside the condenser, the gas begins to cool, turning its state into steam. Further cooling in the condenser condenses the refrigerant vapor into a high-pressure supercooled liquid.
4. When the high-pressure liquid refrigerant flows through the thermal expansion valve, it enters the low pressure and turns into vapor.
5. Refrigerant vapor enters the evaporator and absorbs heat from the space cooled there to boil the refrigerant. As the steam continues to pass through the evaporator coil, it overheats, converting the refrigerant into gas before entering the compressor and restarting the cycle as shown in figure 13.

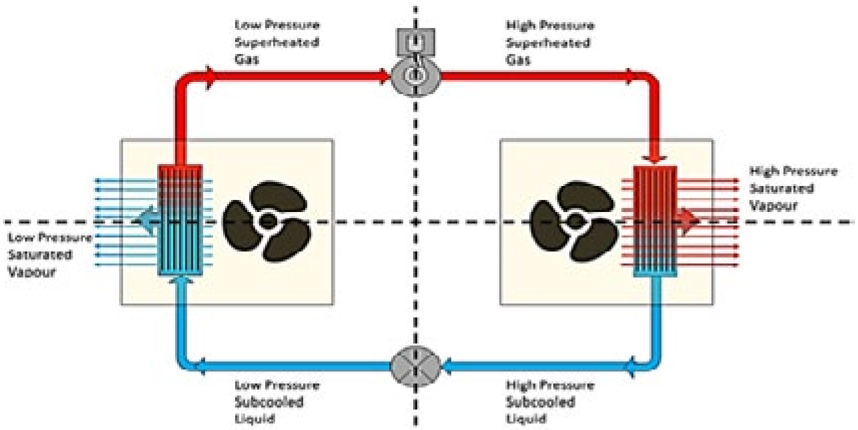


Figure 13: Completed refrigeration cycle process

Carnot Refrigeration Cycle explains the specifications of the four states, the values of the refrigerant pressure and temperature can be calculated in order to reach the dew point to collect water from the air humidity as presented in table 4. Temperature affects the amount of water vapor stored in the air. At higher temperatures, more water vapor can be stored. When the temperature drops, the amount of water vapor that can be extracted from air will decrease, as the water vapor begins to form water droplets on the surface below the dew point. As long as the future test will be done in Cairo, it is required to know the average of the temperature degree Celsius as shown in figure 14 and the humidity during the year to reach a successful result as shown in figure 15.

	State 1	State 2	State 3	State 4
Temperature (°C)	6	50.5	46.29	6
Pressure (kPa)	360	1200	1200	360
Enthalpy (H, kj/kg)	253.86	279.3	117.8	117.8
Entropy (s, kj/kg.k)	0.92856	0.92856	0.4245	0.4623

Table 4: Refrigerant Cycle States calculations

Figure 14: Temperature degree along the year in Cairo

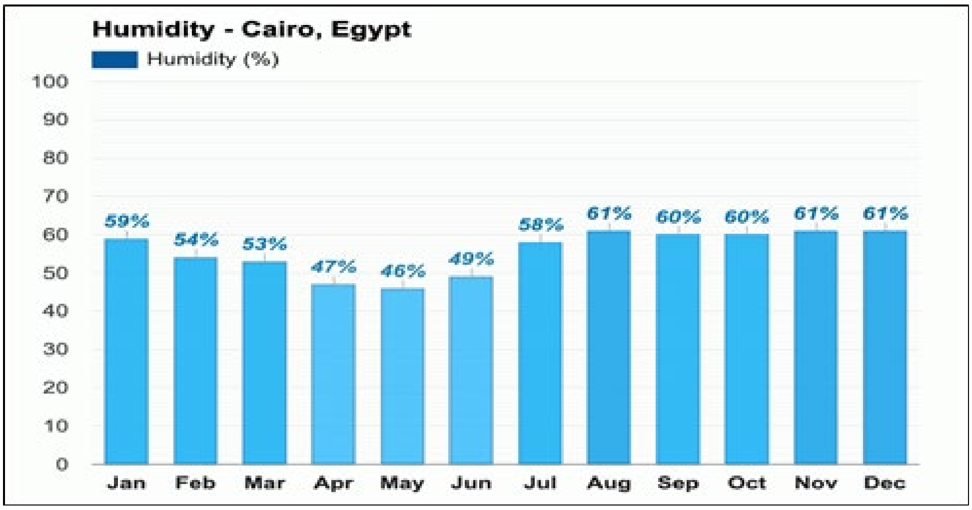


Figure 15: Humidity percentage along the year in Cairo

By testing the new unit according to the temperature degree and humidity percentage in a specific month such as in March, the expected water outcome to be collected during only 6 hours a day from 12.00 PM to 6.00 AM is 12 to 15 liters from the proposed unit and 6 liters from the air conditioner unit. The psychrometric chart has been developed relating to all relevant variables such as the equations of relative and specific humidity, temperature (dry bulb and wet bulb), pressure (air and steam), and enthalpy. The psychrometric chart is very useful for designing and evaluating air conditioning systems and cooling towers as shown in figure 16.

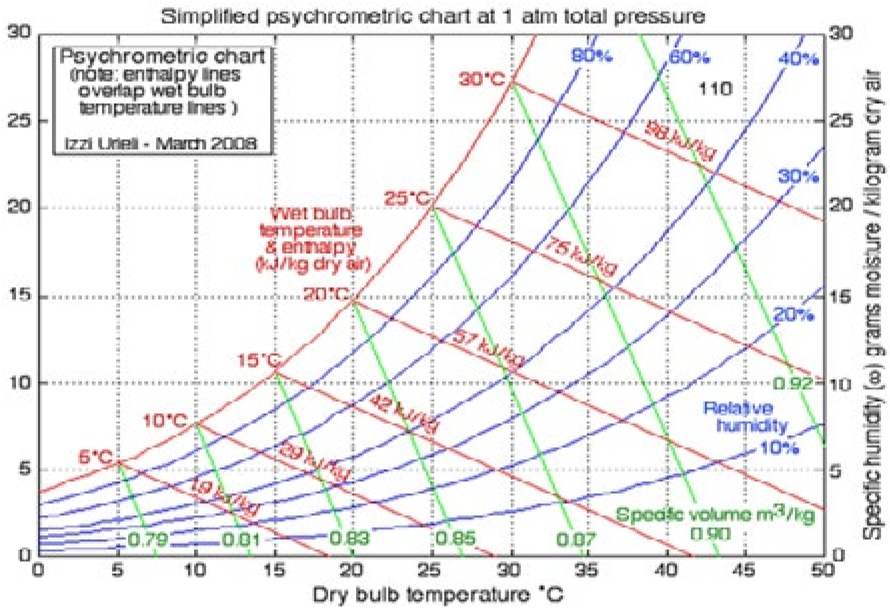


Figure 16: Psychometric chart

5. Water Treatment Filtration System

The condensed water from humidity must be purified with a good filtration system to get rid of all Microbial Pathogens and become safe for human use. The filtration system should include sediment filter, pre-carbon filter, RO membrane, and total organic carbon (TOC) filter. It also necessary to add salt and bare minimum is 9 grams per liter. According to the World Health Organization (WHO) and many other studies, most drinking water sources contain less than 20 grams of salt per liter, so this can be taken as the top. the maximum can go as high as ten times that, 200 mg/l, but that is becoming dangerous on the salty side, or use mineral + pH filter in line instead [15].

Therefore, the filtration system will include the five required stages to have pure and clean drinking water as shown in figure 17:

1. Sediment Filter: Removes large contaminants and dissolved solids larger than 10 microns, or roughly the size of a piece of sand, from the water.
2. Pre-carbon Filter: Uses activated carbon to remove anything larger than 5 microns, or the size of a spec of flour, while attracting and bonding with any positively charged ions in the water to prevent chemical compounds, like chlorine, from passing through.
3. Reverse Osmosis (RO) Filtration: Pressure is used to pass water molecules through the semipermeable membrane, removing all contaminants, including salts and fluorides, from the water and reducing lead.
4. Mineral + Alkaline Water Filter: Adding important electrolytes and minerals to pure reverse osmosis water. Water absorbs calcium, magnesium, potassium, sodium, and other beneficial minerals by flowing over mineral balls in the sterile environment of the filter.
5. Polishing Filter: Using carbon and fine coconut shell fiber, cleanse the water again at the end before putting it in the glass/cup.

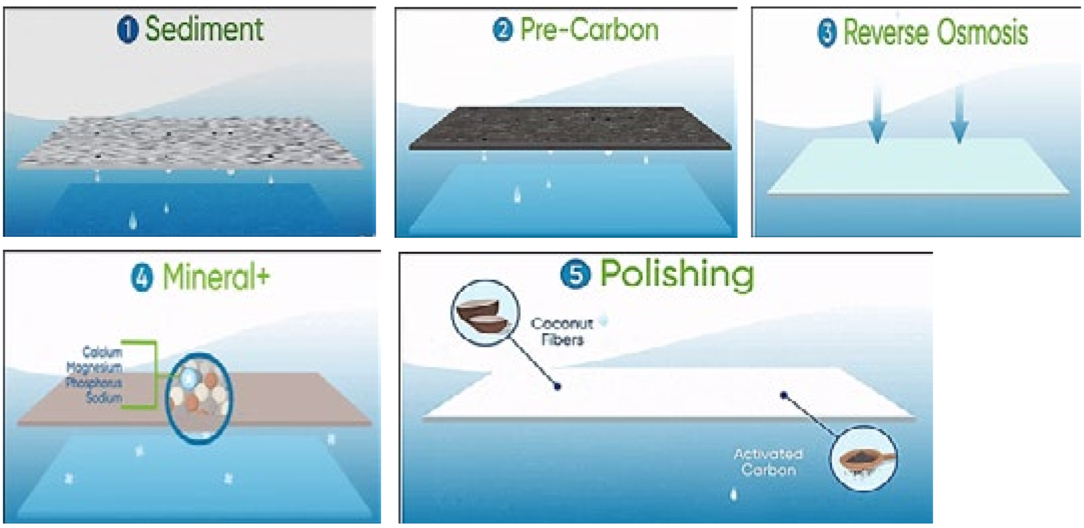


Figure 17: Filtration system with five stages

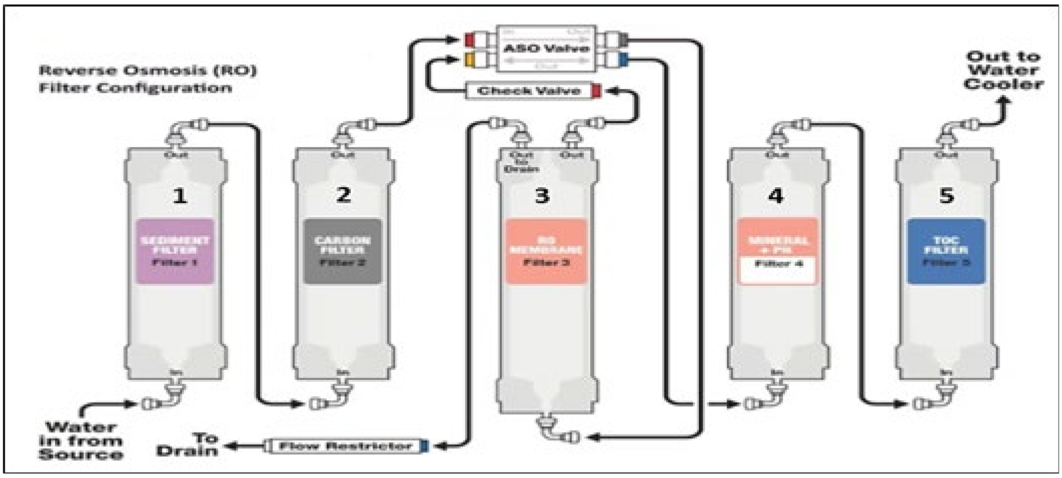


Figure 18: Water Treatment Filtration System [15]

Water treatment filtration system according to is presented in figure 18 [15]. The expected water to be collected after condensation during 6 working hours only is 6 Liters from the Air Conditioner device with 1.5 HP and at least 12 Liters from the proposed unit with only 3/4 HP which is 50% capacity less than the Air conditioner unit and condensing at least double the amount of water. Thereafter, the water extracted from air through the proposed unit, and the waste water produced from the Air conditioner device can be collected in one meeting point to drop in one tank, and start the water treatment process for the water collected. Therefore, the collected water can be used as fresh and clean water suitable for daily use and drinking as shown in figure 19.

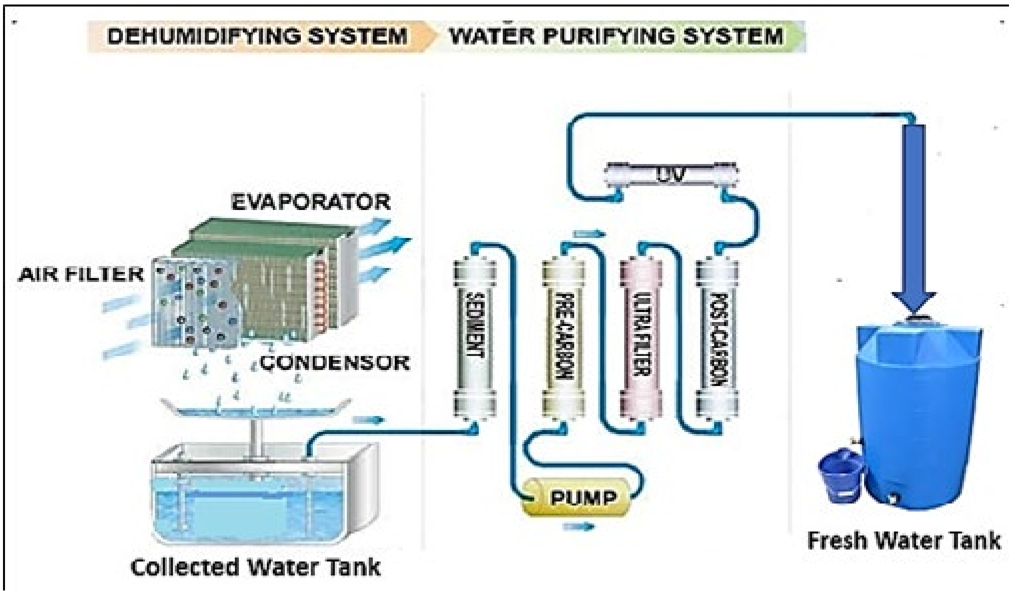


Figure19: Proposed system design outline

6. Manufacturing and Assembly

The experiment has been conducted based on a mechanical system of a refrigerant. A refrigeration cycle has four major components: the compressor, condenser, expansion device, and evaporator. The device consisted of components that have been purchased such as, condenser, and compressor (1.5 HP). While the manufactured components are 2 meters of capillary tube and 27 meters of an evaporator coils in 7.94 mm diameter wrapped on a tube diameter of 15 cm to gain the largest surface area as shown in figure 20. The new system depends on the adjustment and development of a window air conditioner unit by controlling the operation system working time. Controlling the working time main purpose is not only to avoid collecting ice on the evaporator coils but also melting the frozen water on the evaporator coils to collect largest amount of water from the relative humidity. The collected amount of water will pass through the water treatment process to transform the distilled water to fresh water. The specifications of the mechanical components of the proposed system are presented in table 5.

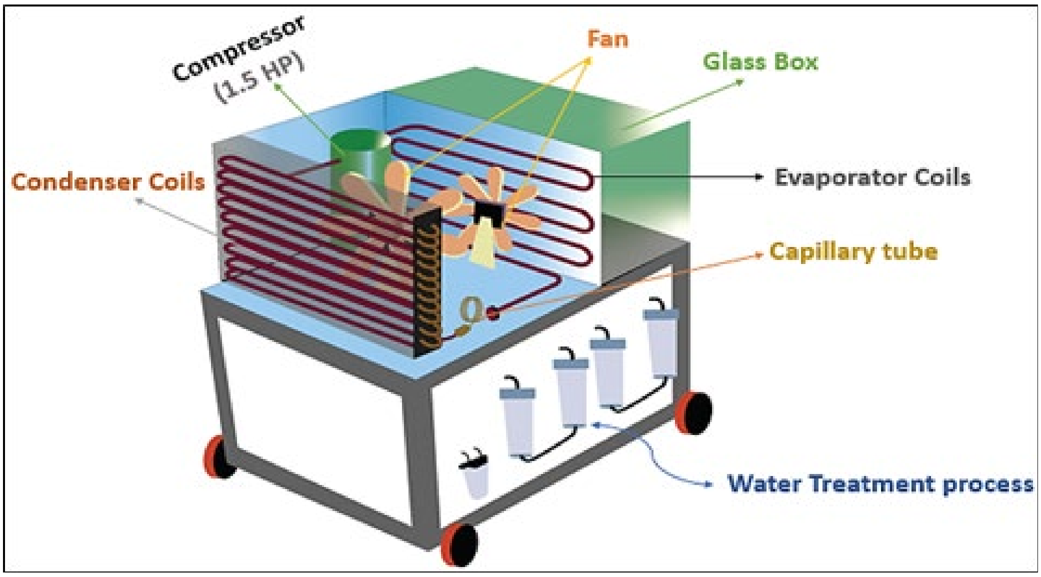


Figure 20: Proposed system design

Components	Specification	Cost (L. E)
Compressor (used)	• Type: Rotary Compressor • Capacity: Btu17000 - 19000. 1.5tn • Horse power: 1.5 HP	1100
Condenser coil (used)	• Copper tube diameter: 9.52mm, thickness: 0.31mm • Air volume: 1250 m3/h • Power: 60 W • Dimensions (cm): 36 x 15 x 30 cm	450
Evaporator coil	• Tube diameter: 7.94 mm • Tube Length: 27 meters • Tube Material: Copper • No. of channels: 40	500
Axial Flow Fan	• Voltage: 220 V • Speed: 1550 RPM • Dimensions (cm): 5 x 12 x 8.2	100
Condenser cooling fan	• Model Number: 4890 N • Speed: 2500 rpm • Weight in KGs: 0.550 kg • No. of blades: 5 • Dimensions (cm): 13.54 x 10.63 x 7.17	150
Capillary tube	• Tube length: 2.8 meters • Tube diameter: 0.55 ml	120
Refrigerant fluid	• Refrigerant type: R-22 • Phase transition: From liquid to gas and back again.	100
Carrying stand	• Cabinet dimensions: 90 X 49 X 80 cm	300
	Total Cost	2,830

Table 5: Specifications of the mechanical components

7. Electrical Control Components

The control system is mainly responsible of allowing the system to make three operational cycles during every working hour. In addition, controlling the start and finish time of some components to maintain the efficiency and performance of the proposed unite the electrical control components are presented in table 6. Software control system consists of Arduino, relay, DHT-11 sensor, and LCD display screen as shown in table 6.

Components	Specification	Cost (L. E)
Arduino	• Type: Arduino UNO • Operating Voltage: 5 V	260
Breadboard	• Type: BB400 • Dimensions: 84 x 55 x 9 (mm)	25
DHT-11 Sensor.	• Type: Temperature & humidity detector • Operating Voltage: 5V • Humidity Range: 20% to 80% • Temperature Range: 0 °C to 50°C	45
Jumper wires	• Length: 20 cm	5
Relay	• Switching Automation • Voltage: 220 V	55
	Total cost	390

Table 6: Specification the electrical control components

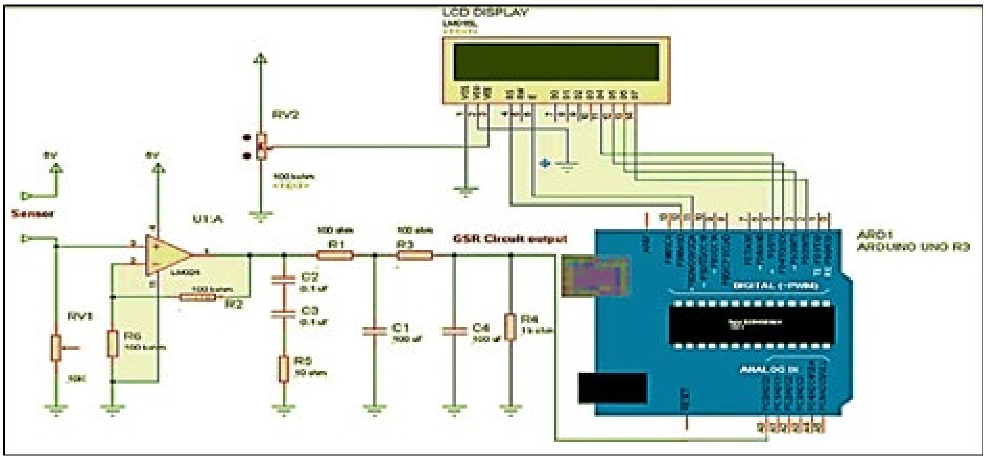


Figure 21: Circuit design with Arduino

The microcontroller is connected to the temperature and humidity sensors (DHT-11) to indicate the temperature degree and the humidity percentage in the atmosphere. The programing code is dedicated in calculating the dew point that change rapidly based on the changes in temperature and humidity. The Arduino UNO is connected to a relay to control the position of turning the electrical circuit (on / off) according to the temperature of the evaporator to prevent freezing the water on the evaporator and keep continuous flow of condensed water as shown in figure 21. The programming code is used to detect the temperature degree and humidity percentage to allow the relay to control switching the compressor (on / off) to reach the required temperature in the evaporator coil as shown in figure 22.

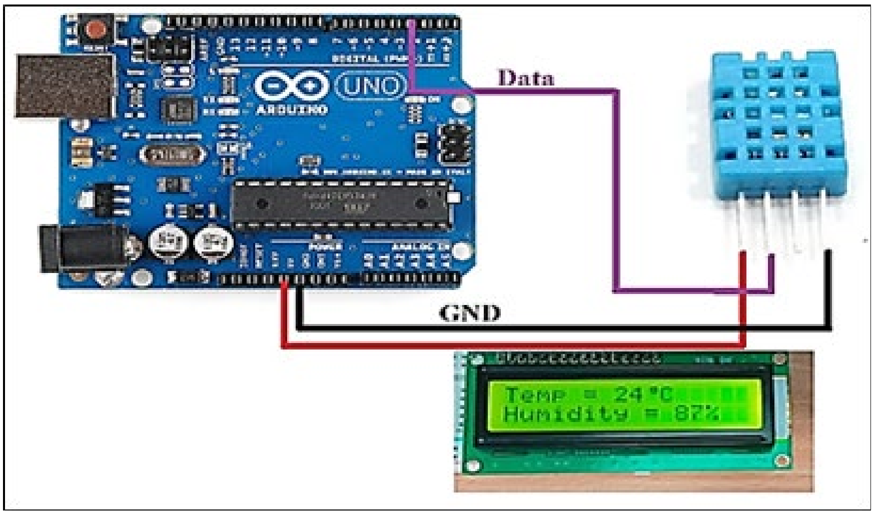


Figure 22: The Control System of the circuit

8. Control System Flow Chart

After starting the system, the DHT-11 sensor detects the temperature degree and the humidity percentage in the atmosphere. Thereafter, the second sensor starts to detect the temperature degree on the evaporator coils until it reaches the dew point. The control system is created to allow the compressor to work until the temperature degree exceeds the dew point by 2 degrees, and to turn on again once the evaporator coils temperature increases by 4 degrees as shown in figure 23.

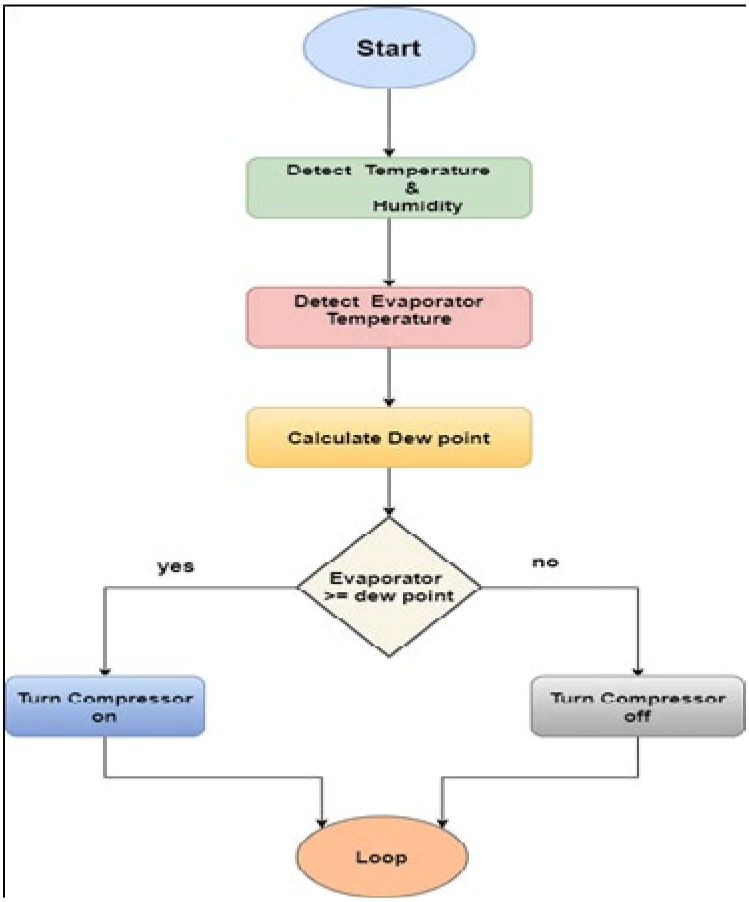


Figure 23: Control System Flow Chart

9. Water Treatment and Filtration System

Standards for fresh water are set to protect human health and are based on the technology available and the cost of testing and processing. Before starting the treatment process the water must be tested to define the water quality. The aim of this work is contributing in water conservation technologies by transforming the water extracted from humidity to fresh drinkable water. After collecting the atmospheric water through the proposed system, a sample of the collected water was sent to the laboratory to be test the water quality before treatment. It was found that the water consists of some contaminants such as; Ammonia, Nitrite, Heterotrophic plate count, total coliform, fecal coliform, and turbidity. As per the report results provided by the Water Quality Central Laboratory, the sample of the water is not conform with the Egyptian health ministry standard No. 458 / 2007 for drinking water. Then the collected water from the proposed system needs a purification process by water treatment system to be suitable for drinking as shown in figure 24.

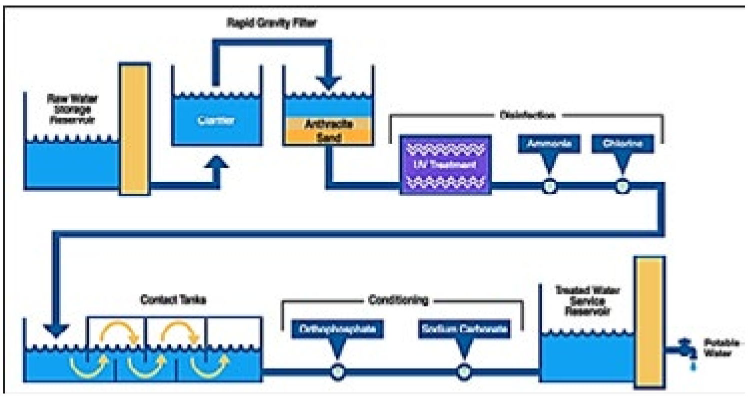


Figure 24: Water treatment process

The microbiological test analysis of water sample revealed that, six major problems must be resolved to remove the water contamination. Table 7 shows the result of the microbiological analysis that was detected in the tested water sample. The total and fecal Coliform bacteria are found in many sources such as; soil, surface water, plants, and melting snow. This type of coliform, called E. coli, indicates that feces are in the water and can cause health problems such as vomiting, fever, and stomach pain. Total coliform bacteria can be formed in many conditions, but in the current condition, it was caused due to ice melting. Heterotrophic plate count: Heterotrophs are a group of microorganisms (bacteria, molds, yeasts) that grow using organic carbon sources and are found in all types of water. In addition, heterotrophic bacteria in drinking water do not harm the health of the general public. However, some bacteria in the heterotrophic group are opportunistic pathogens that can affect individuals with a weakened immune system. Finally, the total coliform and heterotrophic plate count can be treated by using ultraviolet treatment system as shown in figure 25.

Parameter	Result	Unit	Standard guideline
Total Coliform	5 ±0	CFU/100ml	≥ 2
Fecal Coliform	2 ±0	CFU/100ml	< 1
Heterotrophic plate count	80 ±0	CFU/100ml	< 50

Table 7: Microbiological analysis

Figure 25: Ultraviolet filter

Inorganic Analysis of the tested water sample showed that the PH in water is within the range, and that the water is free from living Protozoa and pathogenic larvae. However, it was resulted that the water consists of Nitrite and Turbidity that was higher than the accepted level which requires be treating and adjusting to an accepted level based on the guidelines in the tested report. Table 8 shows results and guidelines of the inorganic analysis that was found in the tested water sample. Nitrite (NO2) are forms of nitrogen in the environment however, large amounts of nitrate in drinking water can be harmful to the human health. Nitrite can be treated by choosing the suitable place for the device, using reverse osmosis filter or post-carbon filter as shown in figure 26. In addition, it is required to schedule a periodic maintenance for the evaporator coils to reduce or prevent the unit from carrying Nitrite. Turbidity means water looks cloudy or dirty which determine the biological contaminants, presence of bits of dirt, and presence of sand or sediment in the water.

Therefore, turbidity problem can be treated by using sediment filter and ultraviolet treatment system. In this work a post-Carbon and ultraviolet filters are chosen to the filtration system.

Parameter	**Result**	**Unit**	**Standard guideline**
PH	8.231 ±14	-	
Protozoa	Not applicable	-	Not applicable
Nitrite	0.295	Mg/L	0.2
Turbidity	5.5 ± 0.29	NTU	1

Table 8: Inorganic test analysis

Figure 26: Post-Carbon Filter

10. Experimental Analysis Setup and Results

The device control system is setup to work in two different conditions. The first condition, the control system works by timing and delay so, the device will operate for 10 minutes and to be idle for 2 minutes which, means the device will work for 50 minutes during one working hour. The second condition, as the condensation often becomes more noticeable during the winter due to humidity increasing, the control system allows the device to work until the temperature degree become lower than the dew point by 2 degrees, so the device allowed to be turned off by switching off the relay, and will be turned on again once the temperature degree become higher than the dew point by 2 degrees and the process keeps looping. Based on the current weather condition in the summer, the device has been operated in different temperature degree, humidity percentage, and wind speed. Table 9 shows the water outcome in liters per hour that have been condensed from humidity through the proposed system unit in the first day. The total amount of the collected water in the first day at night is 10.8 L in six operational hours as shown in table 8. Therefore, the average of the collected water per hour is 1.8 liters. The accumulated quantity of collected water at night is presented in figure 27.

Initial Conditions				Final Conditions			Condensed Water (L)	Condensed Water (L)
Time	Temp. (°C)	RH (%)	Dew point(°C)	Temp. (°C)	RH %	Dew point(°C)	Practical	Expected
10 – 11 PM	28	53	17.5	27	59	18.3	1.6	2
11 – 12 PM	27	59	18.3	26	65	18.9	1.7	2
1 – 2 AM	25	70	19.15	24	75	19.29	1.8	2
3 – 4 AM	23	81	19.56	23	84	20.15	1.85	2
6– 7 AM	23	89	21.09	25	77	20.26	1.95	2
7– 8 AM	23	89	21.09	25	77	20.26	2.0	2
Total							10.9	12

Table 9 Conditions and collections of the condensed water in relative cold day

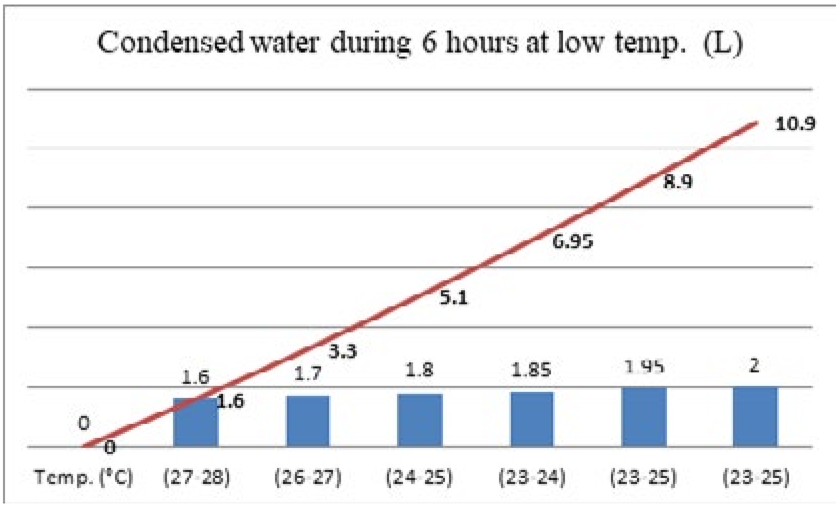


Figure 27: Accumulated quantity of condensed water at night

The total amount of the collected water in the second day in the sunny weather is 8.25 liters in six operational hours as shown in table 10. Therefore, the average of the collected water per hour is almost 1.4 liters. Based on the collected water at night and in a sunny weather, the device is more efficient in condensing water at night due to the low temperature and high humidity. The accumulated quantity of collected water in sunny day is presented in figure 28.

Initial Conditions				Final Conditions			Condensed Water (L)	Condensed Water (L)
Time	Temp. (°C)	RH (%)	Dew point(°C)	Temp. (°C)	RH (%)	Dew point(°C)	Practical	Expected
12 – 1 PM	33	30	13.1	34	25	11.2	1.5	2
1 – 2 PM	34	25	11.2	35	21	9.43	1.35	2
2– 3 PM	35	21	9.43	36	20	9.52	1.3	2
3 – 4 PM	36	20	9.52	36	20	9.52	1.2	2
5– 6 AM	35	22	10.12	32	31	12.8	1.45	2
6– 7 AM	35	22	10.12	32	31	12.8	1.45	2
Total							8.25	12

Table 10: Conditions and collections of the condensed water in a sunny day

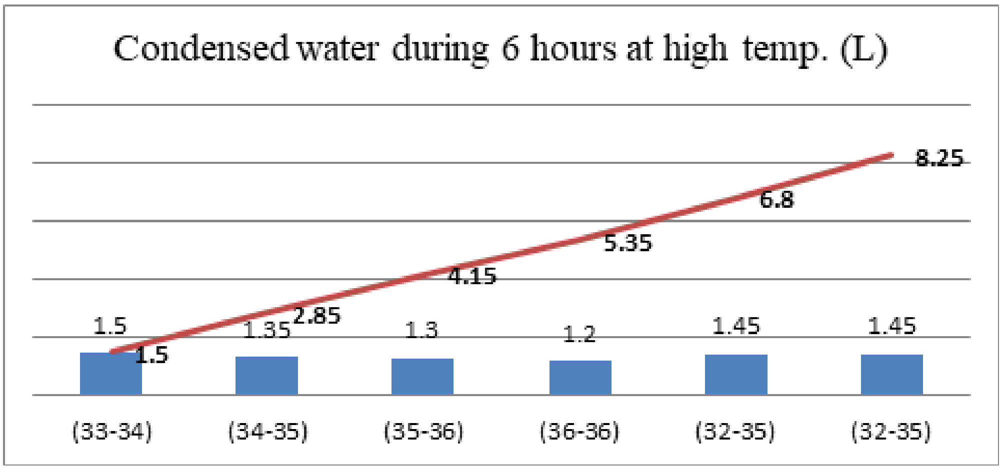


Figure 28: Accumulated quantity of condensed water in a sunny day

11. Water Specifications

The report provided by the Water Quality Central Laboratory showed that there is some of minerals appear in a better level in the collected water after treatment process and adding the required additives. Figure 29 shows the comparison in the specifications of the water in the market and the water condensed through the proposed system device after treatment.

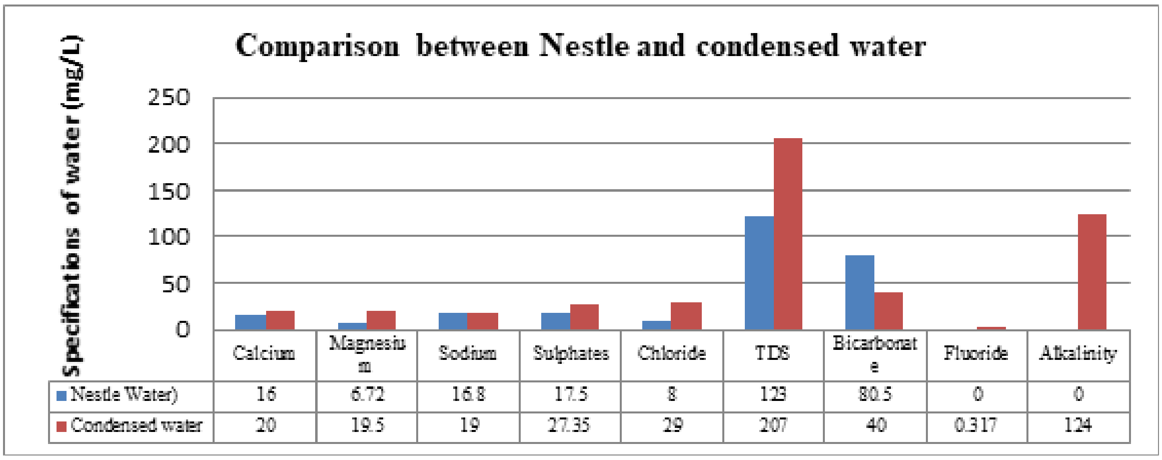


Figure 29: Comparison between market and proposed water specifications

12. Feasibility Study of the Designed Unit

The proposed system is setup to control the time of operation to be 5 cycles per hour which mean the compressor will operate five hours every six hours per day. The power consumption of the compressor is 3.5 KW/hr. According to the Ministry of Electricity and Renewable Energy in Egypt, the cost of 1 KW of power electricity consumption varies based on the usage range [20]. According to the average life span of the air conditioner devices, the device can last between 12 to 15 years [21]. The economic study assumed that the device life span is 12 years.

- The power consumed during 5 Hrs. = 3.5 X 5 = 17.5 kW.
- The cost of 1 KW/Hr. = 1 L.E
- Total cost of electricity = 17.5 X 1 = 17.5 L. E / day.
- The fixed cost in the proposed unit is divided into 3 parts; air condition device, control system, and Water treatment system.
- Total fixed cost = 2400 + 390 + 1200 = 3990 L. E
- Total fixed cost/day = 3990/12 /365 = 0.91 L. E
- Maintenance cost.
- Water filter elements must be replaced every 3 months as filters maintenance.
- Cost of filter elements = 6 filters × 45 L.E = 270 L.E
- Cost of filter /day = 270 / 3 / 30 = 3 L. E
- Changing the water tanks, clean the evaporator coils, and water testing every 6 months.
- Total cost = 100 + 100 + 500 = 700 L. E
- Cost / day = 700 / 6 / 30 = 3.8 L. E
- Total maintenance cost / day = 3 + 3.8 = 6.8 L. E
- Total cost of the proposed unit / day = 17.5 + 0.91 + 6.8 = 25.2 L. E
- The harvest fresh water / day = 10.8 Liters.
- The cost of producing 1liter fresh water = 25.2 / 10.8 = 2.3
- The cost of 1liter fresh water from the market = 4 L.E
- The cost saving / liter fresh water = 4 – 2.3 = 1.7 L.E
- The total saving / year = 1.7 X 10.8 X 365 = 6701.4
- The total saving during the life span = 6701.4 X 12 = 80,416.8 L.E

13. Conclusion

Water scarcity is the lack of fresh water resources to meet the water needs. The traditional approaches relying on rainfall and river runoff in water scarce areas are no longer sufficient to meet human needs. Non-traditional water resources will play a key role in narrowing down the water scarcity problem such as water harvesting from the humid atmosphere. Air conditioner units can be developed to extract water from air humidity and the water collected can be used as fresh water after passing through water treatment process to add the required mineral additives to be suitable for drinking. This paper explored different methods used in the review to extract water from the air. The aim of this work is to develop an air conditioning outdoor unit to harvest the water from air humidity and design an automation unit for the developed device to control its operation in different environmental conditions. The collected water passes through a water treatment process and filtration system to remove sediments and contaminants and gain the required additives of minerals to change the condensed distilled water to fresh drinkable water. The microcontroller is connected to the temperature and humidity sensors to indicate the temperature and the humidity in the atmosphere. The programing code is dedicated in calculating the dew point that change rapidly based on the changes in temperature and humidity. The Arduino UNO is connected to a relay to control the position of turning the electrical circuit (on/off) according to the temperature of the evaporator to prevent freezing the water on the evaporator and keep continuous flow of condensed water. The experimental work showed that the proposed unit can harvest 10.8 liters fresh water during six operational hours. The cost saving per year in producing fresh water compared with the price in the market is 6701.4 L. E. The cost analysis reveals that the proposed unit is economically viable [20'21].

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Authors' Contributions

SA: data collection and analysis, visibility study and writing the manuscript project administration, MH: reviewing and editing the manuscript and approved the final manuscript, HE: manufacturing the developed unit and testing the performance.

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Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate. We obtained ethical approval from MSA university.

Competing Interests

The authors declare that they have no competing interests.

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