A Smart Embedded System for Humid Air Condensation and Water Harvesting

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Abstract. The people in the south of Iraq in the coastal region of the Arabian Gulf, especially in the Basra government, are suffering from waves of high humidity throughout the year, average annual humidity of 60.6%. The increment of salinity of the Shatt-Al-Arab river, the main source of the drinking water in this city, effected by the gulf water caused a lack of drinking water. What made matters worse is the frequent power outages caused by many reasons, one of these reasons that Basra considers one of the highest temperature cities in the world. For that, it is required to design an efficient device to harvest the water from the air to reduce the humidity and consider as a source for drinking water, taking into consideration it's adopting a renewable source of energy. This article is presenting a low cost, portable, power-efficient, multi-purpose device that able to harvest water from the air efficiently. The results show a promising prototype that able to reduce significantly the relative humidity (RH), produce water, and consumed low power, with overall efficiency 40%-60%.

Keywords: Dehumidifier; Water harvesting; Embedded system; Dew point calculation; Basra city, Enhanced the quality of life; Electronics circuit design.

1. Introduction

Most of the coastal cities are suffering from humid weather in most times of the year, especially equatorial tropical countries [1], and the cities that have coasted on the seas. In the south of Iraq, specifically in Basra, summer is humid [2]. Table 1 shows the RH and average dew point temperature in this city. This city also considers the hottest city in Iraq, it recorded a 50°C temperature in July 2019 according to the Accuweather website [3]. At the same time, this city has a long day length and high sunlight intensity which makes it is promising for the renewable energy project especially for the photovoltaic system. Basra has a frequent power outage caused by many reasons, one of these reasons that it is considered one of the highest temperature cities in the world. This has a river called Shatt-Al-Arab, which consider the main source of drinking water for the city, its 200 km in length, formed by the confluence of the Euphrates and the Tigris. Unfortunately, this river has a high salinity level because of the anthropogenic and tidal influences[4-6].

Iraq has experienced repetitive water shortages in recent years which ignited the scientific community to find alternative sources for water; one of the most affected provinces in this shortage is Basra. By taking advance of one of the neutral phenomena which are condensation[7], a solution can help with solving this issue. Cooling condensation method in the proposed system is, a controlled Peltier cool the condenser...
chamber and then cools the air passing through it. This lowers the air ambient temperature (AAT) to its dew point, causing water to condense. Fans push air inside the chamber. The resulting water is then passed into a holding tank. The rate at which water can be produced depends on RH and AAT and the size of the condenser chamber. The whole chamber control process can be automated and monitored in real-time by an Arduino processor.

Several studies carried out in on this subject. The authors, in [8], presented a water harvesting for young trees using Peltier modules that powered by photovoltaic solar energy. Experimental investigations on a portable fresh water generator using a thermoelectric cooler is adopted in [9]. Nevertheless, a module for air dehumidifier that controlled by Arduino using Peltier is offered in [10]. Researchers, in [11], presented a comprehensive and critical review of state-of-the-art research on atmospheric water harvesting. While a thermal analysis and optimization of a system for water harvesting from humid air using thermoelectric coolers are discussed in [12]. In [13], An R-134a reciprocating compressor is used for cooling the condenser, and in the same matter, the authors in [14], are proposed to harvesting water under Iraq weather condition.

### Table 1. Relative humidity in Basra, Iraq [2]

| Month | Relative Humidity (%) | Average Dew Point Temperature °C | Interpretation |
|-------|-----------------------|----------------------------------|----------------|
| Jan   | 81                    | 9.3                              | A bit dry      |
| Feb   | 74                    | 10.4                             | Very comfortable |
| Mar   | 65                    | 12.3                             | Comfort able   |
| Apr   | 58                    | 15.7                             | Comfort able   |
| May   | 53                    | 19.4                             | Humid          |
| Jun   | 49                    | 20.4                             | Humid          |
| Jul   | 49                    | 21.8                             | Very humid     |
| Aug   | 48                    | 21                               | Humid          |
| Sep   | 46                    | 17.6                             | Ok             |
| Oct   | 55                    | 16.7                             | Ok             |
| Nov   | 69                    | 14.1                             | Comfortable    |
| Dec   | 80                    | 11.1                             | Very comfortable |
| Annual| 60.6                  | 15.8                             | Comfortable    |

The presented device is designed to track the dew point through the day according to the RH and the ambient temperature. Two Peltier elements, with efficient heat sinks, are used to condensate the water from the passing air through an air duct. The condensed water is collected in a designated tank to send for the purification stage. The developed prototype for this purpose consists of a condensation chamber, Peltier heat sinks, fans MAX6675 thermocouple, DHT 22 sensors, and an Arduino UNO. The condensation chamber is made of plywood which a good isolator from the ambient temperature, that will allow the inside of the condenser chamber to stay cold, the interior surface of the condenser chamber is covered with foil to extend the cooled surface and therefore enhance the device efficiency. To automate the process of controlling the condenser chamber climate Arduino UNO is utilized to measure the inlet air temperature and humidity thus calculate the corresponding dew point at the given time. Two Peltier heat sinks have been used as the cooling means for the system which are controlled by Arduino UNO via relays based on the measured temperature by MAX6675 (dew point) which is placed at the core of the chamber. DC fans installed at the inlet of the condenser chamber to allow high air circulation inside the chamber. An additional DHT22 sensor has been installed at the air outlet of the chamber to enable Arduino UNO to calculate the efficiency of the system. The time needed for the condenser core to reach the dew point is about ≈0.9°C/Sec.
The results show a promising efficient system that can enhance the quality of life. The system efficiency which calculated according to different purposes, water harvesting efficiency, and dehumidifying efficiency is about 60% at a steady state.

2. The Design Aspects
There are many aspects that must be taken into consideration in the design of the embedded system[15-17], this design, does not only follow these main aspects but also adopts more like:

- It must be power-efficient and depending on direct DC source to reduce the manufacturing complexity and make it compatible with the PV system.
- The system size must be as small as possible for portability.
- To increase water harvesting and dehumanization efficiency, the system must track the dew point precisely.
- The cooling chamber must be completely isolated to decrease the transferred heat.

The proposed system consisted of a condenser chamber that has an inner dimension of 7 x 8 x 60 cm, the walls of the chamber are covered with aluminum foil on the four sides of the wall to increase the cooling area. The core of the chamber is aluminum heat sinks block, having dimensions of 16 x 7 x 8 cm, the exterior of the heat sink is covered with silicone sealant to ensure that all the air is coming from the inlet is passing through the cool aluminum core. Plywood has been used to build the chamber with a thickness of 1 cm, the selection due to the good thermal isolation characteristics of wood which will keep the inside of the chamber cool with minimal influence of the ambient temperature. Two TEC-12706 Peltier each one having dimensions of 40 x 40 x 3.6mm is attached to aluminum block (cool side) using a thermal paste compound (HC-151). The hot side of the Peltier is exposed to the other side of the condenser chamber, two aluminum heat sinks block with dimensions of 7x 8 x 7cm is attached to the Peltier hot side using a thermal paste compound (HC-151). To remove as much heat from the Peltier two fans are attached to the heat sinks (12VDC, 0.6 amps), these fans will help to increase the Peltier efficiency[18]. To allow high wet air circulation inside the condenser chamber two fans have been placed at the inlet of the condenser chamber. Figure 1 shows a block diagram for the proposed system. Humid air enters from the air intake, then the RH and the AAT are measured and processed by the microcontroller, to calculate the instant dew point. The dew point is the temperature to which air must be cooled to become saturated with water vapor[19]. There are many equations that used to calculate the dew points precisely, see [20-22], and some of these equations are simplified according to the used range of the RH and the air ambient temperature. In Basra, the average RH is greater than 60%, so it is possible to use the simplified equation (1) with an acceptable accuracy of about ±1 °C, for RH>50% [23].

\[
T_{dew\ point} \approx T - \frac{100 - RH}{5} \\
RH \approx 100 - 5(T - T_{dew\ point})
\]  

Figure 1. System block diagram
3. System implementation and circuitry
An Arduino UNO development board is used to controlled, automate, and monitor, the process of RH and AAT, as shown in Figure 2. The details and working principle of the different components of the are discussed in the following:

- **Arduino UNO development board**: This controller board is adopted in the proposed system because; it is the ability to communicate with the DHT22, it has enough inputs and outputs ports, and it is compatible with all the other components.

- **RH and AAT (DHT22)**: This sensor which used to measure RH and AAT has a calibrated digital output signal. Two sensors are used to measure the humidity and temperature of the inlet air and the outlet air, which will help to determine the proposed system efficiency.

- **Thermocouple**: it is a K-Type thermocouple temperature sensor used to measure the condensation chamber temperature. It has a data output with a 12-bit resolution with SPI compatibility, it is adopting a MAX6675 as the data converter resolves temperatures to 0.25°C.

- **Peltier (TEC-12706)**: The aluminum condensation chamber is cooled by two Peltier elements. Each one has a maximum current rating of 6.4 Amps and voltage of 12 Volts. Heat is continuously extracted from the hot side of the Peltier by dual fin arrangement equipped with DC Fans.

- **Relay Module**: One relay breakout board is used, having two relays. One of them controls the supplied power to the Peltier elements based on the temperature setpoint (dew point), whereas the other to control the Peltier elements’ cooling fans. The Peltier relays control inputs from DC power supply which are operated at 12 volts and can supply up to 30 Amps.

- **LCD Screen**: A 40×4 I2C bus LCD module which is connected to Arduino through Serial Data Line (SDA) and Serial Clock Line (SCL). It displays AAT and RH, condenser chamber core temperature, the humidity of the outlet air, current dew point and finally shows the efficiency of the system.

![Figure 2. The system wiring diagram](image-url)
4. System software strategy

The flowchart, shown in Figure 3, represents the strategy adopted by the microcontroller to control the device. When the system is starting, the initialized phase is starting by testing all the sensor and make sure everything is fine. Then, it starts reading the intake relative humidity ($RH_{in}$) and intake air ambient temperature ($T_a$), these reading will used to calculate the dew point temperature ($T_{dp}$). The microcontroller will keep the condenser chamber temperature ($T_c$) equal to the ($T_{dp}$). It used a hard limit window with a slight window. All relays are controlled by the microcontroller, it used them to control the Peltier Elements and the Fans. The system designed to display all the data on an LCD screen for monitoring the $RH_{in}$, $RH_{out}$, $T_c$, $T_a$, and the system efficiency.

![Flowchart](image)

Figure 3. Process control algorithm.
5. Results and discussions

The system is implemented, as shown in Figure 4, and tested under certain RH. Two Peltier elements are installed with cold and hot heat sinks for each, the water passes through the cold sinks under the dew point temperature. Water drops are collected by the cold sinks then collected by the water tank. The RH is significantly decreasing and the air on the outlet was comfortable and cold. By observing the temperature on the cold sink, it was decreasing in the rate of ≈0.9\(^\circ\)C/Sec. According to Table 1, the required cold sink temperature sink must be \([9.3-21.8\, ^\circ\text{C}]\) throughout the year.

Under a specific weather conditions, \(RH_{in} = 72\%, T_r = 30^\circ\text{C}\), the system has been tested for evaluation purpose. Figure 5 shows how fast the condenser temperature reaches the setpoint which is the dew point temperature, for this testing conditions it is taken about 23 seconds, after the 10 seconds for initialization, to drop the condenser temperature from 30.2 into 10.4 °C. The temperature sensor shows an approximate continuous incline in the core temperature of about 0.9°C/Sec. Figure 6 shows the decrement in the RH from humid (72%) to comfortable (32%), with an improvement reach \(\delta = 57\%\) (see eq.3) for this specific circumstances as shown in Figure 7, under high RH there is an enhancement in the efficiency reaches 65%.

\[
Dekhumidifier\ Efficiency\ (\delta_{\%}) = \frac{RH_{in} - RH_{out}}{RH_{in}}
\]

(3)

![Figure 4. The implemented prototype](image)

![Figure 5. Condenser time response to reach the dew point](image)
6. Conclusion

In this article, an accurate, efficient, and low-cost system is designed and implemented to enhance the quality of life. The presented system can enhance the room RH and harvesting water from the air with an efficiency of up to 65%. It is simulating a natural phenomenon of condensation which is can be useful for regions with high humidity and water shortage, especially for poor people. A microcontroller embedded system is used to gather data from different sensors to sense the environmental conditions and based on that it is calculated accurately the dew point.

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