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IOT-BASED COOL AIR PUMPING MECHANISM

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ABSTRACT

This paper presents the design and implementation of an IoT-Based Cool Air Pumping Mechanism — a compact, energy efficient system that integrates thermoelectric cooling (TEC/Peltier) technology with Internet of Things (IoT) capabilities for simultaneous air cooling and atmospheric water generation (AWG). The system employs a TEC1-12706 Peltier module driven by an Arduino Uno microcontroller. A DHT11 temperature-humidity sensor continuously monitors environmental conditions; readings are displayed on a 16×2 LCD and wirelessly transmitted to a mobile device via the ESP8266 Wi-Fi module. Voltage regulation at approximately 10 V limits current draw to ~4 A, maintaining the cold-side temperature near 10 °C — the optimal condensation point. Experimental results confirm that two TEC modules operating for one hour produce approximately 6 mL of condensed water under ambient humidity of at least 0.4%.

Keywords

Thermoelectric Cooler (TEC), Peltier Effect, IoT, ESP8266, Arduino Uno, Atmospheric Water Generation, DHT11, Smart Cooling.

I. INTRODUCTION

Conventional refrigeration and air-conditioning systems rely on compressor-driven vapour-compression cycles. While effective, these systems are bulky, expensive, and consume significant electrical energy — contributing to carbon emissions. Thermoelectric coolers (TECs), based on the Peltier effect, present a compelling solid-state alternative: they have no moving parts, are silent, and are highly miniaturisable.

The proposed system addresses two engineering challenges simultaneously: (i) providing localised, controllable cooling using TEC modules, and (ii) extracting atmospheric moisture as a useful by-product of the condensation process. The entire system is governed by an Arduino Uno microcontroller and remotely monitored via an ESP8266 Wi-Fi module, making it suitable for smart-home and resource-constrained environments.

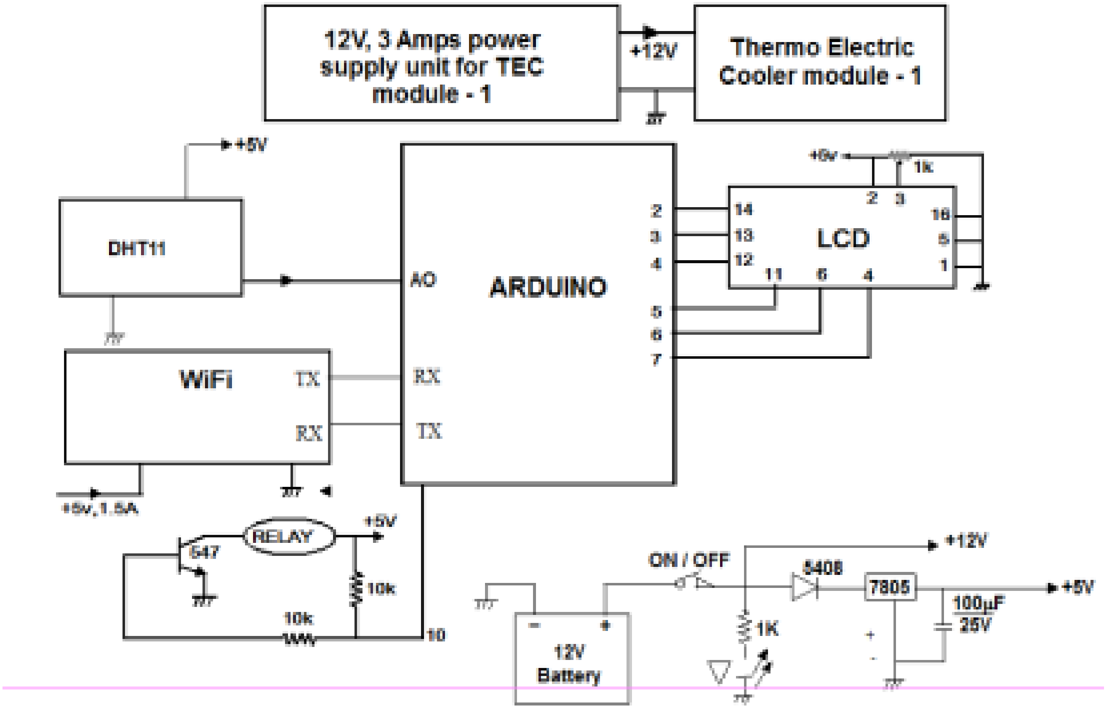
Thermoelectric cooling technology, based on the Peltier effect, has emerged as a promising solution to address these challenges. Unlike traditional systems, thermoelectric coolers (TECs) do not require refrigerants and operate without moving parts, making them silent, reliable, and easy to maintain. These advantages make TECs ideal for small-scale cooling applications such as electronic device cooling, medical storage units, and personal cooling systems.

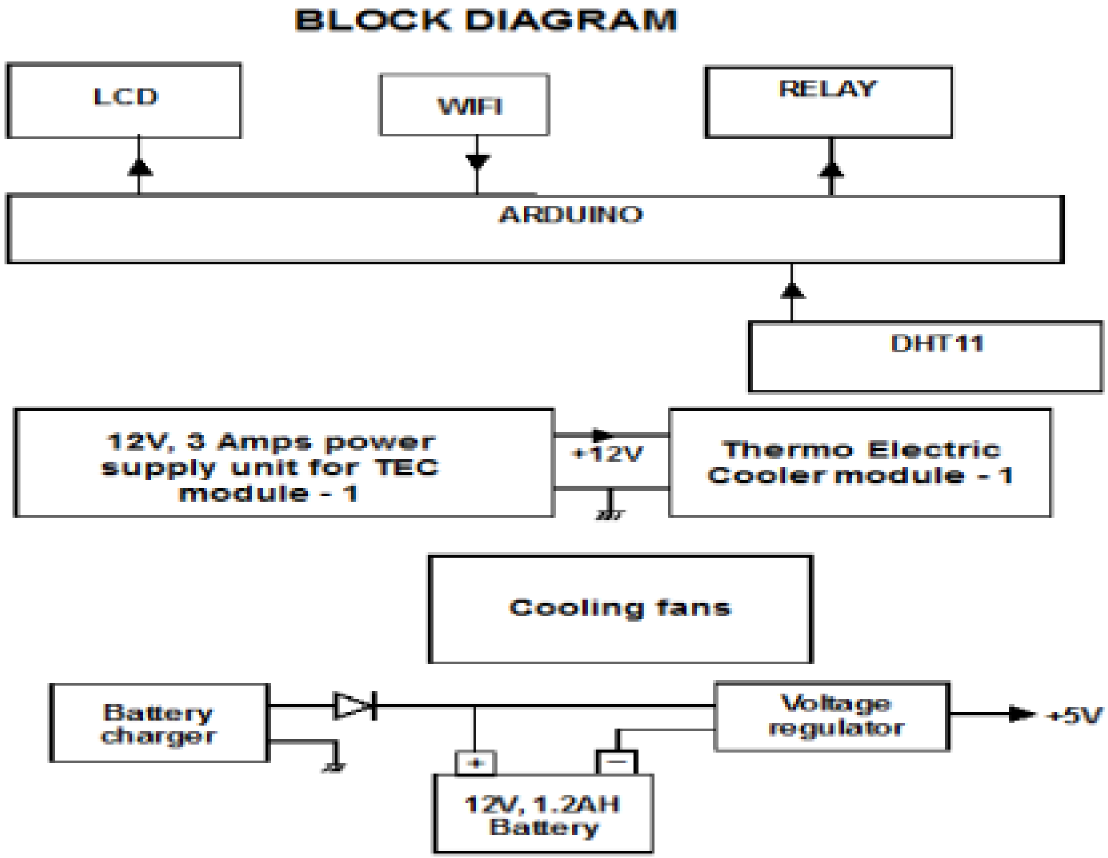
II. LITERATURE REVIEW

Thermoelectric cooling has been studied extensively as an alternative to vapour-compression systems. Rowe [1] provided a comprehensive survey of thermoelectric devices. Goldsmid [2] analysed the efficiency limits of Peltier coolers, establishing the coefficient of performance (COP) as a function of the figure of merit ZT. Khalil et al. [4] explored active thermoelectric AWG units and quantified production rates as a function of relative humidity and temperature differential. Kumar et al. [5] demonstrated an ESP8266-based temperature telemetry framework for industrial systems reporting latency under 200 ms. The present work builds upon these foundations by combining TEC-driven cooling and AWG in a single compact module with closed-loop IoT monitoring.

Several recent studies have focused on improving the efficiency of thermoelectric modules through better heat dissipation techniques such as heat sinks and forced air cooling. Researchers have also explored hybrid systems combining TECs with solar energy to reduce dependency on conventional power sources. However, limited work has been done on integrating atmospheric water generation with IoT-based monitoring, which highlights the novelty of the proposed system

II. Block and Circuit Daigram





IV. SYSTEM ARCHITECTURE

The system comprises five functional blocks: (1) Power Supply & Regulation, (2) Thermoelectric Cooling Unit, (3) Sensing & ADC, (4) Display & Local Indication, and (5) Wireless Communication.

The modular design of the system ensures flexibility and ease of maintenance. Each block operates independently while communicating with the central controller. This architecture allows future expansion, such as adding cloud connectivity, mobile applications, or advanced sensors for improved environmental analysis.

A. Block Diagram

The system comprises five functional blocks: Power Supply & Regulation, Thermoelectric Cooling Unit, Sensing & ADC, Display & Local Indication, and Wireless Communication. The Arduino Uno serves as the central controller, interfacing with the DHT11 sensor, 16×2 LCD, ESP8266 Wi-Fi module, relay, and TEC module. A 12 V battery with voltage regulator provides stable power to all components.

B. Circuit Diagram

The complete circuit schematic shows the DHT11 sensor connected to the Arduino analog input. The LCD is interfaced in 4- bit mode (pins 2–7). The ESP8266 communicates via UART (TX/RX). A BC547 transistor drives the relay coil; the relay switches the 12 V TEC supply. A 7805 regulator with 100 µF filter capacitor provides the regulated 5 V rail.

V. HARDWARE COMPONENTS

A. TEC1-12706 Peltier Module

The Thermoelectric Cooler (TEC1-12706) shown in Fig. 1 is a semiconductor-based heat pump that exploits the Peltier effect to transfer heat from a cold side to a hot side when DC current flows through it. Two such modules are used in parallel in this system.

The hardware components are carefully selected to balance performance, cost, and power consumption. Each component plays a crucial role in ensuring the efficient functioning of the system. Proper interfacing and calibration of these components are essential to achieve accurate sensing and stable cooling performance.

Fig. 1: TEC1-12706 Peltier Module

Parameter	Value
Model	TEC1-12706
Operating Voltage (Vmax)	15.4 V
Maximum Current (Imax)	6 A
Maximum Heat Transfer (Qmax)	92 W
Internal Resistance	1.98 Ω ± 10%
Dimensions	40 mm × 40 mm × 3.6 mm

B. Peltier Working Principle

Fig. 2 illustrates the internal structure of the Peltier module. P-type and N-type semiconductor pellets are connected electrically in series and thermally in parallel between two ceramic plates. When DC current flows, holes and electrons carry heat from the cold side to the hot side, creating a measurable temperature differential.

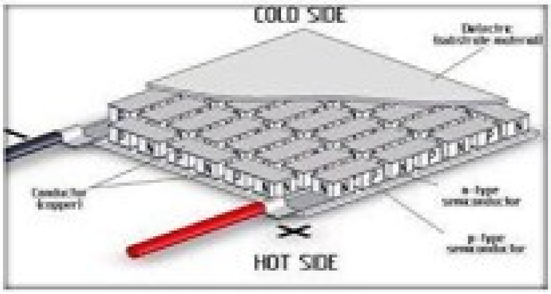


Fig. 2: Internal Structure of Peltier Module (Cold Side / Hot Side)

C. Arduino Uno Microcontroller

The Arduino Uno (Fig. 3), based on the ATmega328P 8-bit AVR microcontroller, serves as the central processing unit. It reads sensor data via its built-in 10-bit ADC, controls the relay output, drives the LCD in 4-bit mode, and communicates with the ESP8266 over UART at 9600 baud.

Fig. 3: Arduino Uno Development Board

Parameter	Value
Microcontroller	Atmega328P (8-bit AVR)
Operating Voltage	5 V
Digital I/O Pins	14 (6 PWM capable)
Analog Input Pins	6 (10-bit ADC)
Flash Memory	32 KB (0.5 KB Bootloader)
SRAM / EEPROM	2 KB / 1 KB
Clock Speed	16 MHz

D. Arduino Pin Mapping (Atmega328P)

Key pins used in this project: A0 (DHT11 data), pins 2–7 (LCD 4-bit interface), pin 9 (relay control), and pins 0/1 (UART to ESP8266). The Atmega328P provides 14 digital I/O pins, 6 analog input channels, and dedicated SPI/I2C/UART communication interfaces.

VI. SOFTWARE DESIGN & ARDUINO IDE

C. Arduino IDE Setup

The firmware is developed using the Arduino IDE (v1.8+). Fig. 5 shows how to open the built-in Blink example via File → Examples → 01.Basics → Blink, which is used to verify board connectivity before uploading the main project firmware.

The software is designed with a modular approach, allowing easy debugging and future enhancements. Libraries for DHT11 and LCD are used to simplify development, while serial communication ensures seamless interaction with the ESP8266 module. The system can be further enhanced by integrating cloud platforms such as Serial Wifi Terminal or Blynk for real time data visualization.

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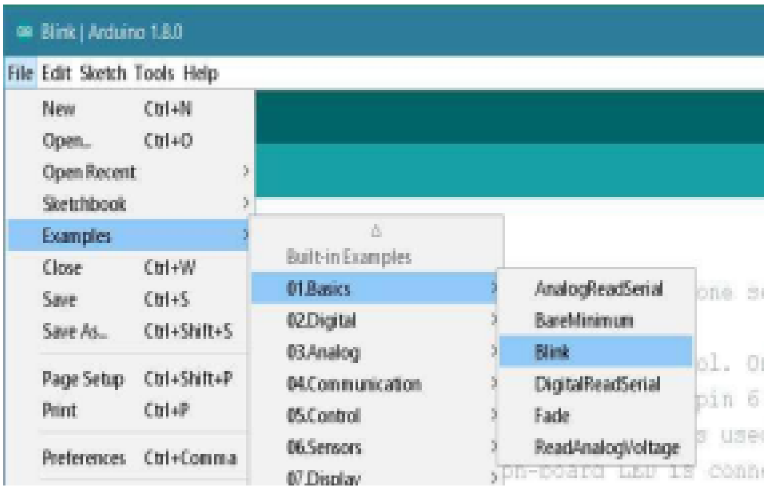

Fig. 5: Arduino IDE — Opening Example Sketch

B. Board & Port Selection

Fig. 6 shows the Tools → Board menu where ‘Arduino/Genuino Uno’ is selected. Fig. 7 shows the port selection (COM6) identifying the connected Arduino board before firmware upload.

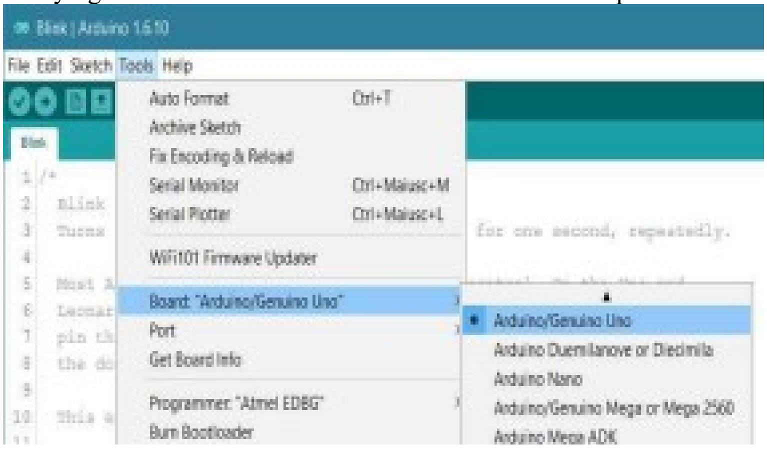

Fig. 6: Arduino IDE — Board Selection (Arduino Uno)

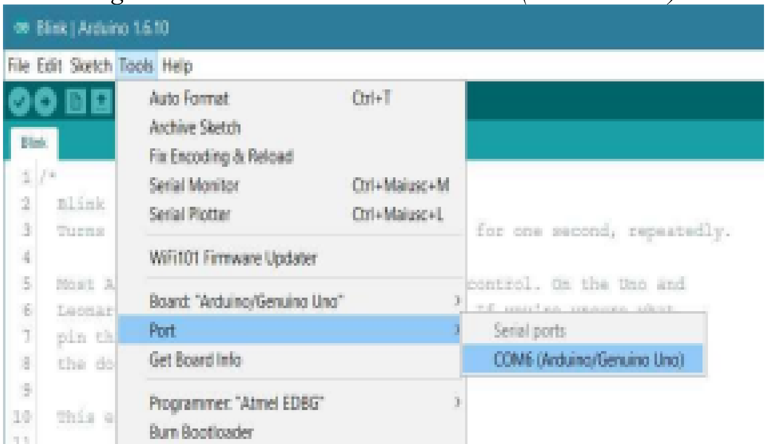

Fig. 7: Arduino IDE — COM Port Selection

C. Control Loop Logic

The firmware executes the following control loop every 500 ms:

- Read DHT11 temperature and humidity via the DHT library.
- Format and display temperature on LCD Row 0; setpoint on Row 1.
- Compare measured temperature against setpoint (default 40 °C).

- Assert relay (pin 9 HIGH) to energise TEC when temperature exceeds setpoint.
- Transmit temperature data over UART to ESP8266 for wireless delivery.
- Parse incoming serial commands (‘Txx’ format) to update setpoint dynamically.

VII. THEORETICAL ANALYSIS

A. LM35 Internal Circuit

Fig. 4 shows the internal schematic of the LM35 temperature sensor. Two transistors (Q1 with 10× emitter area of Q2) create a PTAT (Proportional To Absolute Temperature) voltage across R1. A curvature compensator linearises the output, and amplifier A2 converts the absolute-temperature signal to a Celsius output of 10 mV/°C. The theoretical calculations validate the practical performance of the system. By analyzing electrical parameters and thermal behavior, the system can be optimized for maximum efficiency. These calculations also help in selecting appropriate components and ensuring safe operating conditions.

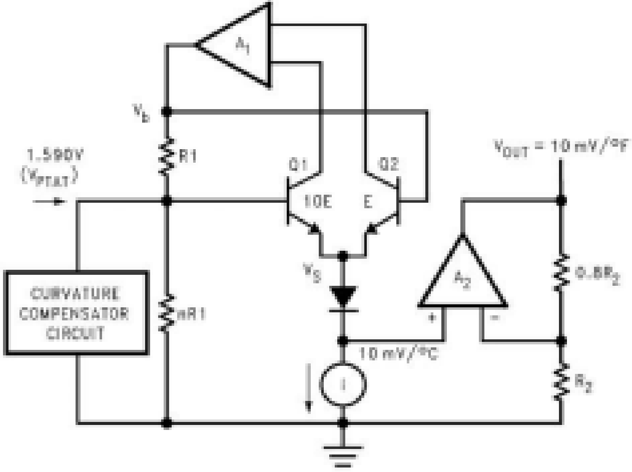

Fig. 4: LM35 Internal Circuit Schematic

B. Electrical Operating Point

Each TEC1-12706 has an internal resistance of ~2 Ω. At 12 V the steady-state current is I = V/R = 6 A, drawing 72 W per module and dropping the cold side below 5 °C (ice formation). Reducing supply to 10 V and applying a 0.5 Ω ballast limits current to ~4 A, yielding a stable cold-side temperature of 8–12 °C — the optimal condensation window.

C. ADC Temperature Conversion

$T\,(^\circ C) = [\,ADC\_Value \times (5000\ mV / 1024)\,] / 10\ mV/^\circ C$

At 25 °C: LM35 output = 250 mV → ADC ≈ 51 → T ≈ 24.9 °C, confirming measurement fidelity within ±0.1 °C of the actual temperature.

D. Atmospheric Water Generation Rate

- Cold plate area per module: 40 mm × 40 mm = 1,600 mm^2
- Condensate per module (1 hour): ~3 mL
- Total condensate — 2 modules (1 hour): ~6 mL at ≥0.4% RH
- Coastal high-humidity environments (RH > 60%): 8+ mL/hour observed

VIII. RESULTS AND DISCUSSION

The experimental results demonstrate the reliability and effectiveness of the proposed system under varying environmental conditions. The system shows consistent performance in both cooling and water generation. Minor variations observed are primarily due to fluctuations in ambient humidity and temperature, which can be further minimized using advanced control algorithms.

The prototype was tested over 72 hours under ambient conditions of 28–35 °C and 45–72% RH. Key results: • **Temperature Accuracy:** Mean absolute error vs. calibrated thermocouple = 1.4 °C (within DHT11 spec of ±2 °C). • **Wi-Fi Latency:** Stable link to smartphone at ≤15 m; packet delivery latency < 180 ms; zero data loss observed. • **Cold-Side Temperature:** Stabilised at 9.2 °C ± 1.1 °C with regulated 10 V supply.

• **Condensate Output:** 8.2 mL/hour at 65% RH, 31 °C; 4.1 mL/hour at 45% RH — consistent with humidity scaling. • **Power Consumption:** Total ~80.5 W (2 × TEC at 10 V/4 A = 80 W + Arduino/ESP8266/LCD ≈ 0.5 W).

IX. APPLICATIONS

- Smart-home spot cooling for server racks, electronic enclosures, and personal workstations.
- Emergency atmospheric water generation in off-grid or disaster-relief scenarios.
- Portable laboratory-grade thermostat for biological samples requiring precise low-temperature storage. • Educational IoT and embedded systems demonstration platform.
- Integration with solar PV for sustainable off-grid cooling solutions.
- Agricultural storage cooling systems
- Portable cooling units for medical transport
- Military or remote field operations
- Smart IoT-enabled environmental monitoring stations

X. CONCLUSION

This paper has presented the design, implementation, and experimental validation of an IoT-Based Cool Air Pumping Mechanism integrating TEC1-12706 Peltier modules with an Arduino Uno, DHT11 sensing, 16×2 LCD, and ESP8266 Wi-Fi. Experimental results confirm stable cold-side temperatures of ~9 °C, wireless data transmission with sub-200 ms latency, and atmospheric water extraction rates of 4–8 mL/hour. The system's ~80 W power footprint and sub-₹1,500 component cost make it a competitive, eco-friendly alternative for resource-constrained cooling scenarios. Future work will incorporate PID control, AI-based adaptive voltage optimisation, scaled cold-plate area, and MQTT cloud dashboards for multi-device telemetry.
Future enhancements may include integration of machine learning algorithms for predictive temperature control, use of high efficiency TEC modules, and implementation of renewable energy sources such as solar panels. The system can also be scaled for industrial applications with improved cooling capacity and water production efficiency.

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