Journal of Electrical Engineering and Automation (ISSN: 2582-3051)
www.irojournals.com/iroeea/

Thermotwin Water Controller

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Abstract

Long-time and effective control of water temperature is critical for both commercial and domestic use. This project designs a new dual-application water temperature control system for drinking and bathing water use by integrating thermoelectric cooling and immersion heating technology. The system employs a Peltier coil water flow block in cooling and an immersion water heater in heating. A fan-based heat dissipation scheme enhances thermal efficiency to ensure optimal system performance. An ESP-based microcontroller offers automated water level control and real-time monitoring through tank refilling control and monitoring of water levels. A temperature sensor DS18B20, with its precise thermal measurements within the storage tank, offers precise feedback control. The switching process of heating and cooling is maintained through a relay-based switching mechanism, ensuring that maximum energy efficiency is retained with optimal temperature levels. This system provides an innovative, energy-efficient, and affordable means of regulating the temperature of water in domestic and business premises. Monitoring enabled through IoT further increases user-friendliness by allowing real-time monitoring of temperatures and automated regulation of the system. The suggested method increases convenience for users and promotes eco-friendly use of resources by offering a flexible and scalable solution to existing issues of water heating and cooling.

Keywords: Peltier Cooling, Immersion Water Heater, Water Temperature Regulation, ESP Microcontroller, DS18B20 Temperature Sensor, Relay-Based Control, IoT-Enabled Monitoring, Heat Dissipation, Smart Water Management, Energy-Efficient System.

DOI: https://doi.org/10.36548/jeea.2025.2.002
Received: 17.04.2025, received in revised form: 20.05.2025, accepted: 08.06.2025, published: 20.06.2025

1. Introduction

Water temperature control is a requirement for residential and commercial purposes, especially in the provision of safe and pleasant water use for bathing and drinking purposes. Conventional water heating and cooling systems are usually associated with high energy usage, sluggish response rates, and poor automation features. To overcome these challenges, this project suggests an intelligent two-in-one water temperature control system that effectively supplies both hot and cold water from a Peltier-based thermoelectric cooling module and an immersion water heater. The system utilizes a Peltier coil water flow block to cool the water quickly, and for heating processes, an immersion heater is utilized. An umbrella-shaped fan cooling mechanism maximizes cooling effectiveness to avoid Peltier module overheating. A water level control and temperature monitoring feature are enabled through the incorporation of an ESP microcontroller. The DS18B20 temperature sensor provides accurate temperature measurements in the storage tank, and a relay control system effectively toggles heating and cooling states. This system not only increases the convenience of users by providing hot and cold water instantly but also helps in energy efficiency and intelligent automation. Integration with IoT-based monitoring also facilitates remote monitoring and control, positioning it as a scalable solution for new-age water management requirements. The subsequent sections discuss the design of the system, implementation, and performance analysis to detail how this method enhances efficiency, reliability, and sustainability of water temperature control.

2. Related Work

Current research encompasses different areas, documenting heightened interest in system optimization through multi-physics integration and control techniques. Djebko et al. developed an integrated model of simulation and calibration for system optimization of heating systems with enhanced efficiency through real-time feedback and adjustable parameters [1]. Anyanwu et al. developed an industrially applicable practical water-level controller with sensor-based feedback for reliable automation [2]. There is large interest in thermoelectric generators (TEGs) driven by passive cooling and renewable energy. Wang et al. introduced a critical review of solar and/or radiative cooling–driven TEGs, including their design issues and operation aspects [3]. Yang et al. built upon this by investigating TEG systems incorporating solar concentration, greenhouse effects, and radiative cooling to generate nearly round-the-clock power generation [4], subsequently extrapolated in a subsequent study to add energy storage components [6]. Shi et al. comprehensively investigated maximizing energy generation from radiative cooling–based TEGs, determining performance trade-offs in various climatic conditions [5]. Pan and Zhao further created enhanced designs for wearable radiative-cooling TEGs, maximizing portability and human-oriented energy harvesting [7]. Emphasizing structural modeling, Lv et al. first published a pilot study of TEGs through concentrated radiative cooling [8], and later refined system components (such as plate structures) to the maximum for optimizing performance [9]. At the same time, Poredoš et al. achieved a breakthrough in demonstrating radiative sky cooling with thermal concentration to deliver over 1 kW/m²—a class-leading standard for passive cooling technology [10]. Both of these articles document the increasing sophistication of integrated energy systems, ranging from beneficial controllers to highly efficient thermoelectric designs.

3. Proposed Work

This 2-mode automatic water temperature controller system is meant for drinking and household use. To supply power to high-power appliances such as the heating and cooling systems through a relay module, the system is energized by a 220V AC main supply which is converted to 12V DC through a 10A converter. The ESP8266 Wi-Fi controller and sensors are also powered at the same time through a 5V 2A converter. The main control unit, ESP8266, is responsible for reading temperature and water level information as well as decision-making logic for heating and cooling switching.

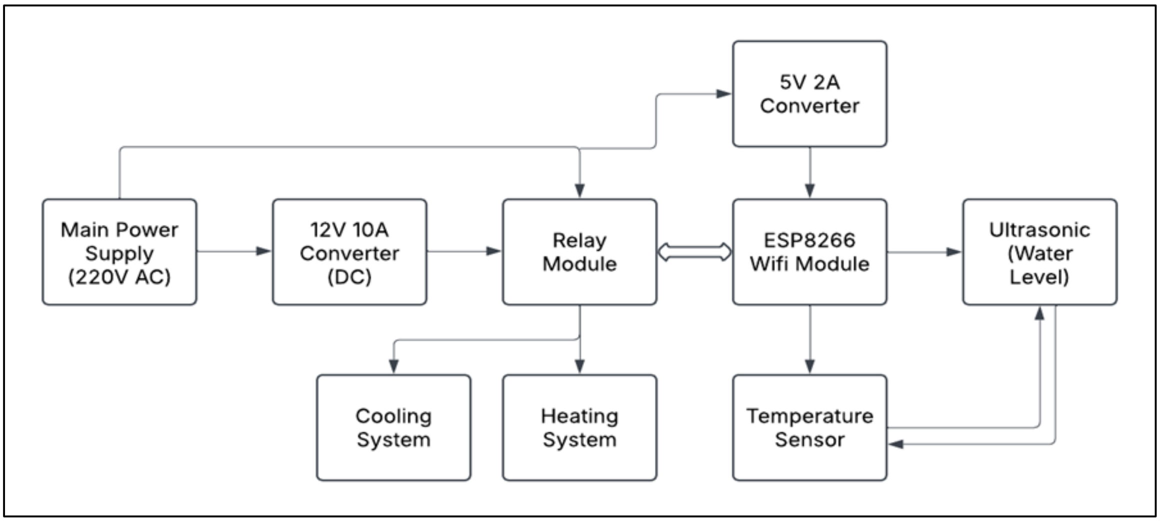

Figure 1. Block Diagram of the Working Model

For the sake of sufficient availability and to prevent dry-run, an ultrasonic water level sensor reads the water level, and a DS18B20 digital temperature sensor continuously reads the tank's momentary water temperature. The ESP8266 is coded to execute a threshold-based control system. The ESP8266 activates the relay to switch on the immersion heater when the temperature is below a user-defined minimum (say, 25°C). The system, however, switches on both a fan-assisted heat dissipation mechanism and a Peltier-based cooling system when the temperature is above a higher threshold (say, 40°C). With the Blynk IoT platform, the ESP8266 allows users to be presented with real-time sensor reading and system status for remote monitoring and control through an app. With the capability to enable energy-efficient operation via smart relay switching, the integrated system provides precise, efficient, and effective water temperature control that is ideal for contemporary environmentally friendly residential and commercial use.

4. Methodology

4.1 Materials and Methods

The system integrates a collection of sensors, actuators, and IoT components in order to regulate and regulate water temperature effectively. The ESP8266 (Seeed Xiao) microcontroller is the core component in charge of data processing and relay control, enabling optimal communication with the connected components. There are two DS18B20 temperature sensors with precise temperature readings from the hot and cold regions with ±0.5°C accuracy. A 12V submersible pump delivers dynamic water flow between heating and cooling modules, while a Peltier thermoelectric cooler and heat sink with fan manage cooling. For heating, a 12V/220V immersion heater uses resistive heating. An HC-SR04 ultrasonic sensor monitors the water level in the storage tank to avoid dry running and refill automatically. Heating and cooling switching is provided by a 2-channel relay module, with electrical isolation and safety. Real-time system data, including water temperature and height, appears on a tiny 0.96-inch OLED (I2C) screen. Power is supplied by a rugged 220V AC to 12V DC converter (10A) with voltage regulators (5V/3.3V) for microcontroller and sensor interfacing. Remote monitoring and control are achieved through a Blynk-based mobile app, allowing users to easily manage the water system over Wi-Fi. Figure 2 illustrates the suggested circuit diagram.

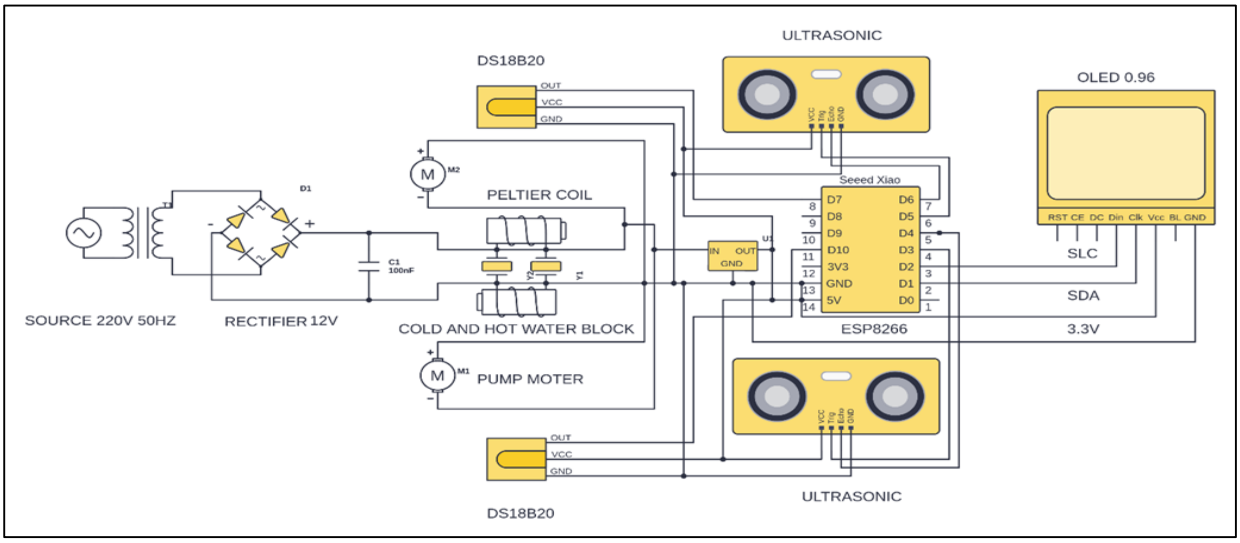

Figure 2. Circuit Diagram of the Proposed System

The system integrates a combination of sensors, actuators, and IoT components that regulate and modulate water temperature efficiently. ESP8266 (Seeed Xiao) microcontroller is the core unit that handles data processing and relay control to enable proper communication with the mounted components. There are two DS18B20 temperature sensors with precise temperature readings from the hot and cold areas with ±0.5°C accuracy. A 12V submersible pump delivers dynamic water circulation between heating and cooling modules, and a Peltier thermoelectric cooler and heat sink with fan regulate cooling. For heating, a 12V/220V immersion heater uses resistive heating. An HC-SR04 ultrasonic sensor monitors the storage tank water level to avoid dry running and automatically refill. Heating and cooling switching is serviced by a 2-channel relay module with electrical insulation and safety. Real-time system data, including water level and temperature, are displayed on a compact 0.96-inch OLED (I2C) screen. The system utilizes a high-capacity 220V AC to 12V DC converter (10A) with voltage regulators (5V/3.3V) for sensor and microcontroller interface. Remote monitoring and control are facilitated through a Blynk-based mobile app, allowing users to easily operate the water system over Wi-Fi. Figure 2 indicates the circuit diagram suggested.

4.2 Control Algorithm and Decision Logic

The control logic for the proposed system is implemented on the ESP8266 microcontroller using embedded C/C++ in the Arduino IDE. The system employs an event-driven, structured architecture that continuously monitors sensor inputs and applies decision logic to transition between heating, cooling, or standby modes. This logic is defined by static temperature thresholds and water level conditions to ensure hardware safety and functional accuracy.

1. **Phase of Initialization:** All GPIO pins, relays, and sensors (HC-SR04 for water level and DS18B20 for temperature) are initialized when the system first boots up. The ESP8266 connects to the Blynk IoT platform via Wi-Fi and configures the OLED display.

2. **Sensor Sampling:** At regular intervals (every 2 seconds), the microcontroller reads:

   - T_current: Water temperature from DS18B20.
   - H_level: Water level from the ultrasonic sensor.

3. **Water Level Validation:** If H_level is below the predefined minimum (20% of tank capacity), both heating and cooling operations are disabled to prevent dry-run damage, and an alert is displayed locally and via Blynk.

4. **Temperature Regulation Logic:**

If T_current ≤ T_min (e.g., 25°C):
→Activate Relay_Heat to turn ON the immersion heater.
→ Deactivate Relay_Cool and fan module.
→ Display "Heating Mode" on OLED and Blynk dashboard.
Else If T_current ≥ T_max (e.g., 40°C):
→ Activate Relay_Cool and cooling fan.
→ Deactivate Relay_Heat.
→ Display "Cooling Mode" on OLED and Blynk dashboard.
Else (i.e., 25°C < T_current < 40°C):
→ Both relays are OFF (standby mode).
→ Display “Standby Mode”.

5. **Data Logging and Communication:** The Blynk cloud collects all sensor data and system status messages through Wi-Fi and the TCP/IP protocol. The relay states, tank level, and temperature can be monitored in real-time by users through the Blynk mobile app.

6. **Safety and error handling:** The function of timeout tests is to prevent prolonged heating or cooling cycles. Fail-safes are implemented to cover dry-running conditions, sensor fault (NaN values), and loss of Wi-Fi.

To minimize overshoot and maximize energy efficiency, future optimizations could include closed-loop control algorithms such as PID (Proportional-Integral-Derivative), which would adaptively modulate output duty cycles as a function of temperature gradients. This implementation, though, relies on a deterministic threshold control model for ease of implementation and reliability.

5 Results and Discussion

To verify the performance of the envisioned system, an entire prototype was installed, as shown in Figure 3. The system was enclosed in a specially designed wooden cabinet that housed the power supply, ESP8266 controller, relay modules, temperature sensors, submersible pump, and heating and cooling systems. The two water tanks visible on the top inner view were used to separate and manage hot and cold water supplies. Every section was independently monitored by DS18B20 sensors to allow accurate temperature monitoring, while the refilling process was controlled by the ultrasonic sensor depending on water levels. The power supply, cooling fans, and the output taps were delivered on the outside panel in an easy-to-use manner for easy deployment. The system was successful in performance testing as it switched between heating and cooling modes autonomously based on real-time temperature input. The immersion heater raised the water temperature from ambient (~28°C) to 40°C in approximately 5 minutes, and the Peltier module lowered the temperature from 32°C to 24°C in approximately 7–8 minutes under optimum ambient conditions. ESP8266 was operated in real time without any latency problems and effectively updated the sensor readings to the Blynk IoT platform. They were able to monitor remotely water temperature and tank levels, as well as toggle heater/cooler control from smartphones. The OLED display continuously displayed live feedback on location, delivering transparency and control even without mobile access. In terms of structure, the wooden casing offered effective thermal insulation, and modules and wiring were secured to avoid loose wiring or electrical hazards.

These results confirm that in addition to meeting functional requirements, the system prototype offers useful modularity and ease of use. Repeated 72-hour testing revealed that the system functioned satisfactorily, but it was pointed out that higher-quality modules or more complex heat sink designs could improve the Peltier cooling performance. Furthermore, utilizing advanced control logic (like PID or AI-based scheduling) and integrating with solar power is a promising path for future advancement. Overall, the system offers a dual-mode real-time water temperature control solution that is scalable, user-friendly, and energy-efficient.

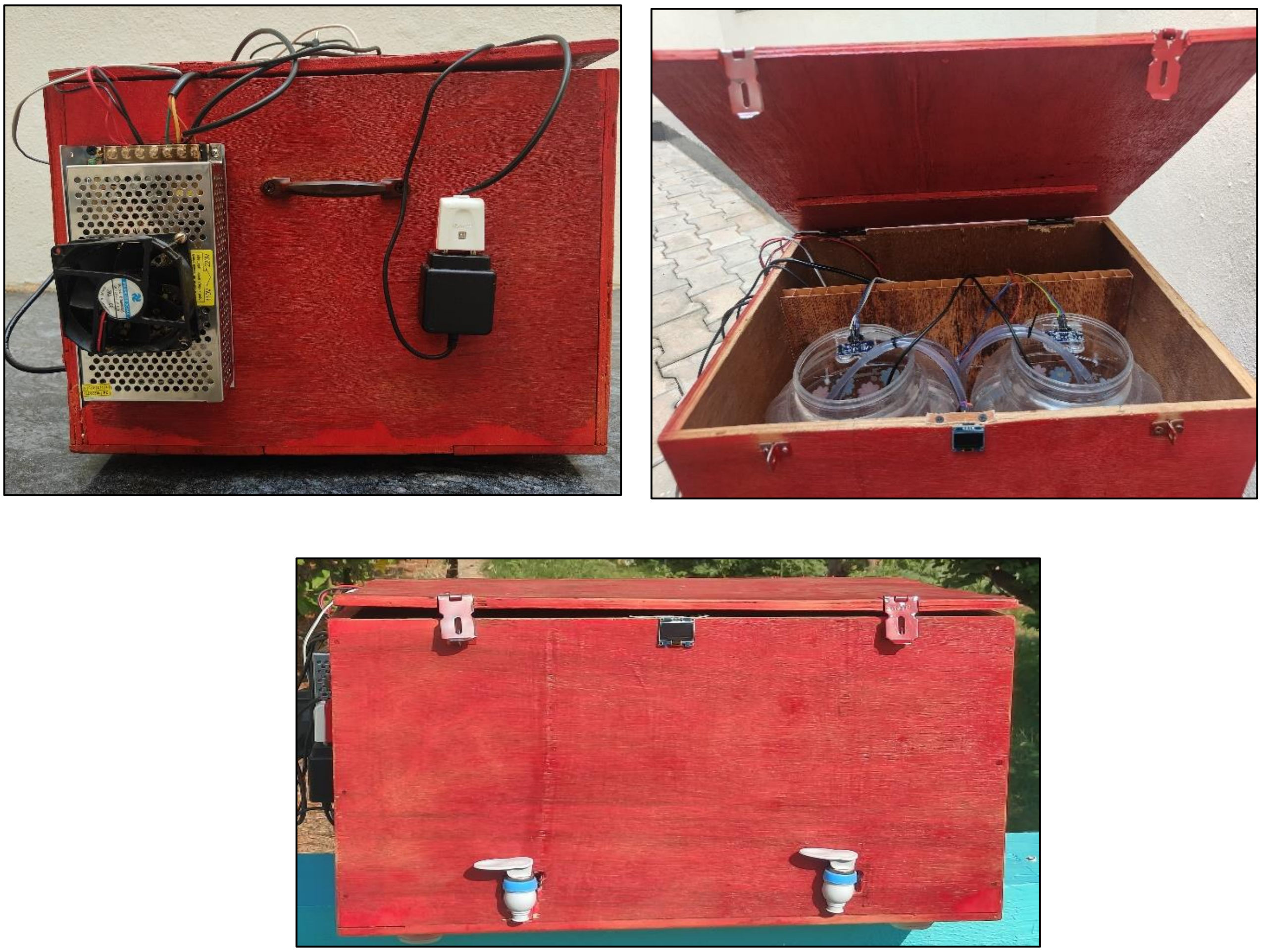

Figure 3. Hardware Output of the Proposed Work

5.1 Power Consumption Analysis

The system was tested under both steady-state and dynamic operating conditions to ascertain its energy profile. The analysis considered the power consumption of the immersion heater, Peltier cooling module, ESP8266 microcontroller, relay drivers, sensors, and display. All measurements were taken using a calibrated digital wattmeter with an accuracy of ±1%.

The system elements make low to moderate power consumption levels, as indicated in Table 1, which ensures energy efficiency during operating cycles. The proposed system power consumption analysis, as detailed in Table X, provides data on the major components' energy efficiency of the system. The immersion heater with a maximum power of 370 W was able to bring the water temperature from ambient condition (~28°C) to desired level (~40°C) in 7 minutes with approximately 30.5 W·h per cycle.

Table 1. Measured Consumption Metrics

Component/Mode	Rated Power (W)	Typical Operating Duration per Cycle	Energy per Cycle (Wh)
Immersion Heater	370 W	7 min	30.5
ESP8266 + Sensors + OLED	2.8 W	Continuous	2.8
Peltier Module + Cooling Fan	89 W + 27 W = 116 W	12 min	13.0
Idle Mode	1.5 W	Varies	Negligible

Though it consumes high instant power, the short heating time and event-triggered operation by threshold logic prevent unnecessary energy usage. The Peltier cooling system, comprising a 89 W thermoelectric module and a 27 W fan, required 13.0 W·h to cycle through a single run of cooling. Although thermoelectric coolers are less likely to deliver as high a Coefficient of Performance (COP) compared to compressors, they deliver benefits in terms of miniaturization, silent operation, and integration-friendly safety features in low-scale domestic applications. The relatively moderate energy draw is acceptable for those uses requiring periodic water cooling with not constant running.

The ESP8266 microcontroller, OLED display, and sensors use together around 2.8 W and operate constantly with minimal energy overhead (≈2.8 W·h/h). In standby, where neither heat nor cool is available, the system uses only 1.5 W, with excellent standby performance. System-wise, the combination of threshold-based switching, Wi-Fi-enabled monitoring, and relay-controlled actuation allows the controller to achieve maximum energy efficiency by activating components only when required. Also, the modular nature of the system facilitates scalability and possible interfacing with renewable sources like solar PV modules, such that it can be deployed in both grid-connected and off-grid environments. While the current design meets the performance and efficiency requirements for home use, further enhancements like closed-loop PID control, PWM-based modulation of the Peltier module, and adaptive scheduling algorithms are feasible to improve energy savings, reduce response time, and enhance thermal stability. Additionally, adding real-time power tracking to the Blynk dashboard may provide the users with real-time information regarding current energy use, promoting more energy-aware behavior.

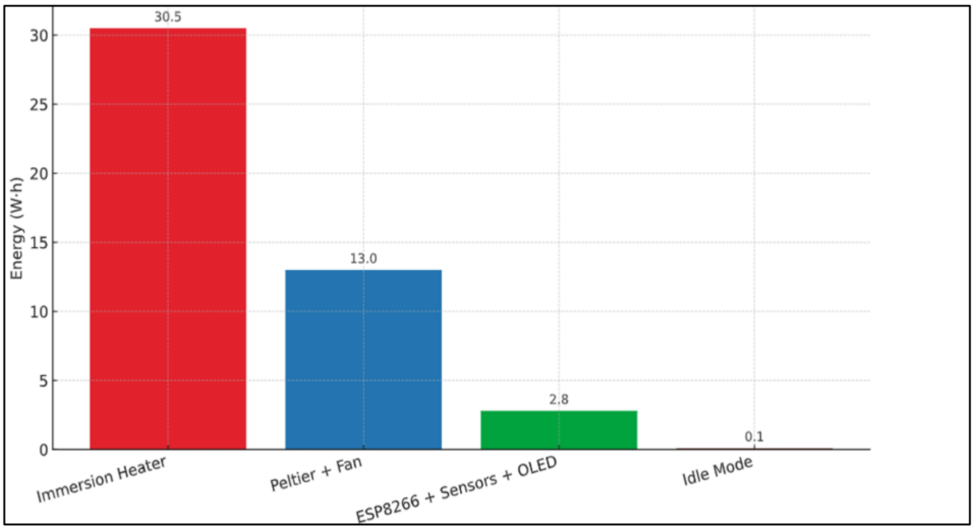

Figure 4. Energy Consumption Per Cycle by System Component

As shown in Fig. 4, the immersion heater consumes the most energy (30.5 Wh), followed by the Peltier + Fan configuration, the ESP8266 with sensors and OLED, and the system in idle mode, which consumes the least energy (0.1 Wh).

6 Conclusion

To create an automated and effective system for regulating the temperature of drinking and bathing water, the suggested system successfully integrates thermoelectric cooling, immersion heating, ESP-based automation, and relay-switch-controlled switching. Utilizing a Peltier-based cooling module, a fan-assisted heat dissipation unit, and an immersion water heater, the system offers safe temperature control while consuming little energy. The ESP8266 microcontroller is crucial for controlling water level, real-time temperature monitoring, and automation that replenishes and maintains water at a desired temperature. Relay control systems use the DS18B20 temperature sensor to obtain accurate temperature data, which allows the system to switch between heating and cooling modes with ease. Future advancements might include machine learning algorithms for predictive temperature control, smartphone app integration for remote monitoring and management, and solar power operation. Thanks to its cutting-edge technology and creative automation, the Thermotwin Water Controller represents a significant advancement in water heating and cooling sustainability and efficiency.

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