



Smart Food Delivery Box with Peltier-Based Cooling and Heating System

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ABSTRACT—

Food that travels from a kitchen to a customer rarely arrives at the temperature at which it left, and insulated boxes can only slow that drift, not correct it. This paper presents the design, construction and testing of a smart food delivery box with two independent zones, a hot zone and a cold zone, each served by Peltier modules. Two NTC thermistors measure the zone temperatures, and an ESP32 microcontroller switches the modules through a ULN2003A driver and a relay stage using hysteresis thresholds that the user can change from a Wi-Fi web dashboard. The dashboard also offers manual relay control, and the readings and relay states are uploaded to the ThingSpeak cloud platform for remote monitoring. Heat sinks and fans carry the rejected heat away, a 12 V, 10 A switched-mode power supply feeds the power circuits, and a 7805 regulator provides the 5 V logic rail. A 16×2 I²C LCD shows both temperatures, the relay status and the operating mode. The insulated enclosure measures 45 cm × 35 cm × 21 cm. A first-order heat-load model gives estimated coefficients of performance of about 0.30 for cooling and 0.41 for heating, and these figures are discussed alongside the results of a baseline Peltier food-box study. The completed prototype was tested for cooling, heating and temperature regulation. The work shows that a compact, quiet and compressor-free unit can hold a hot and a cold zone at once, and it also brings out the power-supply and heat-rejection limits that later versions will need to address.

Index Terms—thermoelectric cooler, Peltier module, food delivery, ESP32, NTC thermistor, hysteresis control, IoT monitoring, coefficient of performance.

I. Introduction

Home delivery of cooked meals, beverages and desserts is now routine, yet the journey from kitchen to doorstep is the least controlled part of the chain. A curry that leaves the pan steaming can be lukewarm on arrival, and a chilled dessert can sit in a warm bag long enough to spoil. Food-safety guidance treats roughly 5 °C and 57 °C as the practical limits for cold and hot holding, and the band between them is where bacteria multiply most readily [1]. A container that cannot stay on the right side of those limits is a quality problem at best and a health risk at worst.

Most delivery boxes and bags depend on insulation alone. Insulation reduces how quickly the contents exchange heat with the surroundings, but it cannot add heat or take it away. On a long trip, a hot afternoon or a cold evening, the contents slide toward ambient temperature however well the box is built. Compressor-based refrigeration and resistive heaters can do the job, but a compressor is bulky, noisy and awkward to carry on a two-wheeler, and fitting separate cooling and heating hardware into one small box adds weight and cost.

Thermoelectric (Peltier) modules offer a neat way out. When a DC current flows through a module, heat is pumped from one face to the other, and reversing the current reverses the direction of pumping. The module has no moving parts and needs no refrigerant; the only noise comes from the fans that clear heat from the hot side. These traits suit small portable enclosures [2], [3].

This paper reports a smart food delivery box built around four TEC1-12706 modules and an ESP32 microcontroller. Its main contributions are: a dual-zone design in which one box keeps a hot zone and a cold zone at the same time; hysteresis control with thresholds the user can adjust from a Wi-Fi web dashboard, together with cloud logging of temperatures and relay states; a power architecture based on a 12 V, 10 A switched-mode supply with a 7805 regulator for the logic rail; a first-order heat-load model that estimates the cooling and heating effort; and a discussion of expected prototype behaviour in light of a baseline experimental study [4].

The remainder of the paper is arranged as follows. Section II reviews related work and Section III recalls the thermoelectric principle. Section IV describes the hardware, Section V the control logic, and Section VI the analytical model. Section VII covers fabrication and testing, Section VIII discusses results, and Sections IX to XI deal with merits, limits, future scope and conclusions.

II. Related Work

Thermoelectric cooling has been studied for decades. Standard texts cover the underlying physics and the semiconductor materials involved, most commonly bismuth telluride alloys for operation near room temperature [5], [6]. Snyder and Toberer explain how material quality, expressed through the thermoelectric figure of merit, caps what such devices can achieve [7], which is why commercial modules still run at modest efficiency. Bell surveyed how thermoelectric systems can cool, heat, generate power and recover waste heat, and discussed the conditions under which they make practical sense [2].

Application-oriented reviews follow the same thread. Riffat and Ma examined present and potential uses ranging from refrigeration to air conditioning [3], and Zhao and Tan reviewed materials, modelling methods and applications of thermoelectric cooling [8]. A systematic review has since covered the applications and limitations of Peltier devices [9], and another follows advances in Peltier refrigeration [10].

Heat rejection has drawn particular attention. Astrain *et al.* showed that the coefficient of performance of a thermoelectric refrigerator can be raised by improving how heat leaves the hot side [11], a finding that agrees with the practical experience of most prototypes, ours included. On the modelling side, Lineykin and Ben-Yaakov proposed equivalent circuits that a circuit simulator can use to analyse thermoelectric modules [12], which helps when electrical and thermal behaviour have to be studied together.

Experimental work on simultaneous cooling and heating with a thermoelectric module has also been reported [13], and a baseline study of a Peltier-based food delivery box used cooling and heating tests, temperature stability and energy use as its performance measures [4]. What remains scarce is a low-cost, fully integrated delivery box that brings together simultaneous hot and cold zones, adjustable thresholds, a live local display and Wi-Fi monitoring on a modest microcontroller in one portable unit. The present work aims at that gap.

III. Thermoelectric Principle

The Peltier effect, reported by Jean Charles Athanase Peltier in 1834, is the absorption or release of heat at the junction of two dissimilar conductors when current passes through it [6]. A commercial module such as the TEC1-12706 packs many p-type and n-type semiconductor pellets between two ceramic plates. The pellets are joined electrically in series and thermally in parallel, so the current that threads through them also carries heat from one plate to the other. One face turns cold, the other turns hot, and swapping the polarity swaps the faces.

For a module carrying current I , with cold-side temperature T_c , hot-side temperature T_h and $\Delta T = T_h - T_c$, the heat absorbed at the cold face is commonly written as [5]

$$Q_c = S I T_c - \frac{1}{2} I^2 R - K \Delta T \quad (1)$$

where S is the effective Seebeck coefficient of the module, R its electrical resistance and K its thermal conductance. The three terms stand for Peltier cooling, half of the Joule heat that flows back to the cold side, and heat conducted from hot to cold. The electrical power drawn and the coefficient of performance (COP) are

$$P = V I = S I \Delta T + I^2 R \quad (2)$$

$$\text{COP}_c = Q_c / P \quad (3)$$

Two practical points follow. First, Q_c falls as ΔT grows, so a module that pumps freely against a small temperature difference turns sluggish against a large one. That is why hot-side heat sinks matter so much: every degree the hot face rises above ambient is a degree the cold face cannot reach. Second, the electrical input is itself turned into heat, so the heat delivered at the hot face is $Q_h = Q_c + P$. Delivering heat therefore costs less electrical energy per watt than removing it does, a pattern that shows up in the estimates of Section VI. A two-zone box exploits both faces: modules serving the hot zone deliver heat to it, and modules serving the cold zone remove heat from it.

IV. System Design

A. Overall Architecture

The architecture is shown in Fig. 1. A 12 V, 10 A switched-mode power supply (SMPS) is the single source for the whole unit. Its 12 V output feeds the relay contacts, the Peltier modules and the fans directly, while a 7805 linear regulator steps it down to 5 V for the ESP32, the LCD and the logic side of the circuit. Two NTC thermistors, one in the hot zone and one in the cold zone, feed the analogue inputs of the ESP32. The ESP32 judges each zone against its own pair of thresholds and operates the ULN2003A driver, which energises the relay coils; the relays then connect the Peltier modules and fans to the 12 V bus. The LCD shows both temperatures, the relay status and the operating mode throughout. In parallel, the ESP32 joins a Wi-Fi network, serves a web dashboard and uploads its readings to the ThingSpeak platform [14].

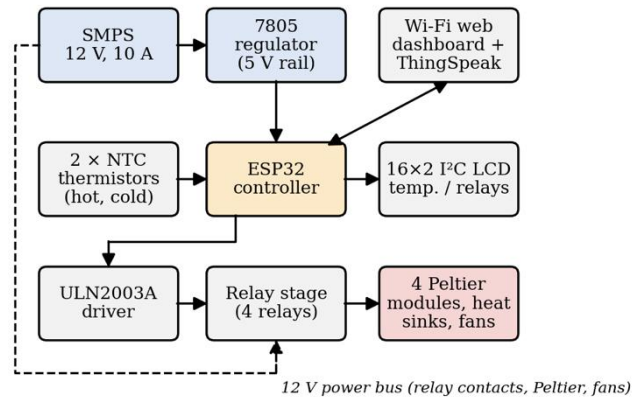


Fig. 1. Block diagram of the smart food delivery box.

B. Hardware Components

Table I lists the components of the final prototype together with their ratings.

TABLE I

Components of the prototype

Component	Rating / specification
SMPS	12 V DC, 10 A
Peltier module × 4	TEC1-12706, 12 V, 3.5 A each
Microcontroller	ESP32, 3.3–5 V, about 80–160 mA
Temperature sensor × 2	NTC thermistor, 10 kΩ, $\beta = 3950$
Driver IC	ULN2003A
Voltage regulator	7805, 12 V in / 5 V out
Relay × 4	12 V coil, 10 A contacts
Display	16×2 I ² C LCD, 5 V
Fan	12 V DC
Diode × 2	6 A
Capacitor × 2	1000 μF and 470 μF
Resistor × 3	1 kΩ

C. Power Supply and Load Budget

An earlier version of the design used 12 V, 6 A modules with 15–20 A relays. The final unit moved to TEC1-12706 modules rated 12 V, 3.5 A and 10 A relays, all fed from a 12 V, 10 A SMPS. A switch-mode supply was selected because it delivers a steady 12 V under changing load and is far smaller and lighter than a linear supply of equal rating, which matters in a portable box.

A budget check is needed all the same. Four modules at their listed rating draw $4 \times 3.5 \text{ A} = 14 \text{ A}$, or 168 W, while the SMPS can deliver 120 W (10 A at 12 V), and the fans and control circuit add a little more. In practice the modules need not all run at rated maximum at the same moment, and relay switching lets the load be managed, but the true simultaneous current has to be measured during testing. If all four modules are to run flat out together, a supply of higher current rating will be required.

The 7805 deserves attention too. Dropping 12 V to 5 V, it dissipates about $7 \text{ V} \times I$ as heat, so a logic load of 250 mA already produces roughly 1.75 W and calls for a small heat sink [15].

D. Driver and Relay Stage

The ESP32 output pins cannot drive relay coils directly, so a ULN2003A Darlington array serves as the interface. Each of its channels can sink up to 500 mA [16], which is ample for a 12 V relay coil. The relays, with 10 A contacts, connect the Peltier modules and fans to the 12 V bus. Relays 1 and 2 serve the hot zone and relays 3 and 4 the cold zone, so each zone is switched independently. Two 6 A diodes protect the power and switching path, the 1000 μ F and 470 μ F capacitors smooth the supply rails, and three 1 k Ω resistors complete the biasing network. The assembled control board is shown in Fig. 2.

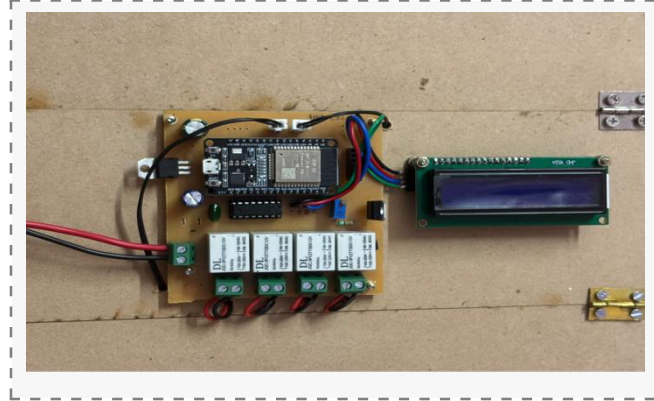


Fig. 2. Control board of the prototype (ESP32, ULN2003A driver, relay stage and 7805 regulator).

E. Sensing and Display

Each zone temperature is measured by a 10 k Ω NTC thermistor ($\beta = 3950$ K) connected in a voltage divider with a 10 k Ω fixed resistor and read by the 12-bit analogue-to-digital converter of the ESP32. To limit noise, every reading is the average of ten samples taken 2 ms apart. With the fixed resistor R_s on the supply side and the thermistor to ground, the thermistor resistance follows from the divider voltage V at the 3.3 V reference:

$$R_{NTC} = R_s V / (3.3 - V) \quad (4)$$

The temperature is then obtained from the beta form of the Steinhart–Hart relation [17],

$$1/T = 1/T_0 + (1/\beta) \ln(R_{NTC}/R_0) \quad (5)$$

with T in kelvin, $R_0 = 10$ k Ω at $T_0 = 298.15$ K (25 $^{\circ}$ C). Thermistors are inexpensive and respond quickly, but their accuracy depends on the stated β value and on the converter, so calibration against a reference thermometer is advisable.

The ESP32 is a 32-bit dual-core controller with built-in Wi-Fi and Bluetooth [18]. Its processing, analogue inputs and Wi-Fi are all used here. A 16 $\times$ 2 character LCD on the I ^{2} C bus, powered from the 5 V rail, shows the hot-zone temperature (H) and the cold-zone temperature (C) on its first line. The second line shows the letter R followed by four digits giving the state of relays 1 to 4 (1 for on, 0 for off), and then the operating mode, AUTO or MAN (Fig. 6).

F. Wireless Dashboard and Cloud Logging

The ESP32 connects to a Wi-Fi network as a station and runs a small web server. The dashboard page shows both temperatures, the state of each relay and the current mode, and refreshes every second. From the same page the user can switch between automatic and manual mode, operate each relay by hand, and edit the four thresholds, which are then saved in the non-volatile memory of the controller. The firmware also writes the two temperatures and the four relay states to a ThingSpeak channel at a fixed interval, which gives a time-stamped record that can be used to plot test runs [14].

G. Mechanical Construction

The enclosure is an insulated box with external dimensions of 45 cm $\times$ 35 cm $\times$ 21 cm, giving a volume of about 33 L. The Peltier modules are fitted with heat sinks, and fans on the hot-side sinks blow heat out of the box. A second fan inside the food compartment circulates air so that the chamber temperature stays reasonably even. One thermistor sits in the hot zone and the other in the cold zone, and the control electronics and power section are kept in a separate part of the box. Figs. 3 and 4 show the finished prototype and its interior.

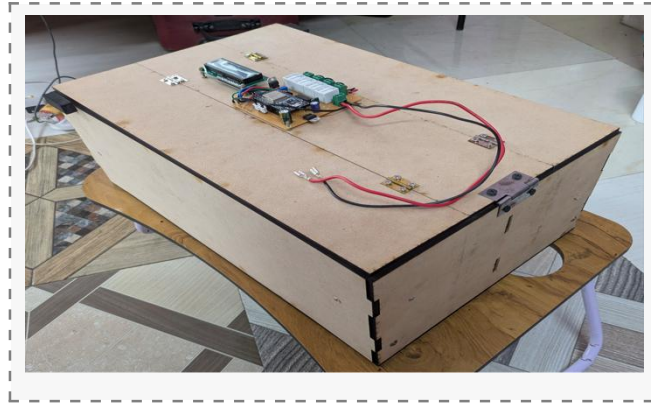


Fig. 3. Assembled prototype of the smart food delivery box (external view).



Fig. 4. Interior of the food chamber showing the Peltier modules, heat sinks, fans and temperature sensors.

V. Control Algorithm

The controller treats the hot and cold zones as two independent on-off loops, each with its own hysteresis band, a standard and robust choice for relay-operated loads [19]. The ESP32 reads both thermistors once per second. In the hot zone, relays 1 and 2 are switched on when the hot-zone temperature T_H falls to the lower threshold, 38 °C by default, and switched off when it reaches the upper threshold, 40 °C by default. In the cold zone, relays 3 and 4 are switched on when the cold-zone temperature T_C rises to 12 °C and switched off when it falls to 10 °C. Between the two thresholds of a zone the relays keep their previous state. This 2 °C band prevents rapid relay chatter, which would wear the contacts and waste energy. The sequence is summarised in Fig. 5.

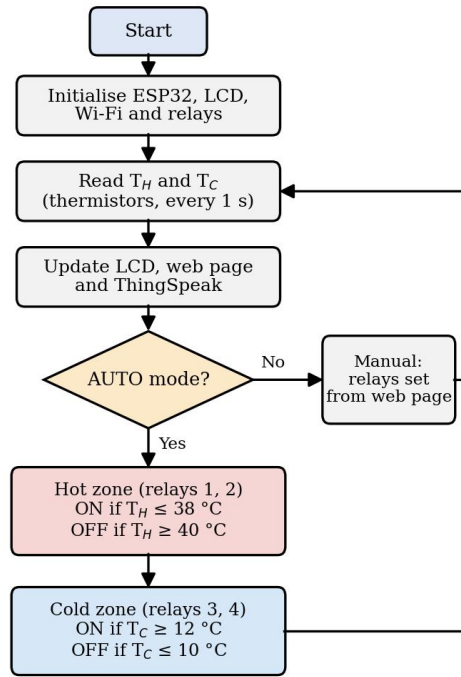


Fig. 5. Flowchart of the dual-zone control algorithm (default thresholds shown).

In manual mode the automatic rules are suspended and each relay follows the buttons on the dashboard; returning to automatic mode applies the rules at once. The LCD is refreshed every 100 ms, so the display responds quickly even though the sensors are sampled once per second. On-off control was preferred to a proportional scheme because the food has a large thermal mass and the heat sinks respond slowly, so fast corrections bring little benefit, and relays are poorly suited to rapid switching. A PWM-driven MOSFET stage with PID control remains an option for later versions.

VI. Analytical Estimation

Before testing, a first-order heat-load model was used to estimate the effort demanded of the Peltier unit. The parameters are those of the baseline study [4], so that the estimates can be compared with its measurements: inside temperature 25 °C, outside 30 °C ($\Delta T = 5$ K), insulation conductivity $k = 0.03$ W/m·K, effective area $A = 0.5$ m², thickness $L = 0.01$ m, a test load of $m = 0.5$ kg of water with $c_p = 4200$ J/kg·K, and one module drawing $12\text{ V} \times 4\text{ A} = 48$ W. Values for the present box should replace these once its insulation has been characterised.

Heat leaking through the walls follows Fourier's law [20]:

$$Q_{\text{cond}} = k A \Delta T / L = 7.5\text{ W} \quad (6)$$

Air exchange when the lid is opened is taken as $Q_{\text{air}} = 2$ W. The sensible heat to be removed from, or added to, the water is

$$Q_{\text{sens}} = m c_p \Delta T_w \quad (7)$$

which is 16.8 kJ for cooling from 28 °C to 20 °C and 35.7 kJ for heating from 28 °C to 45 °C. Spreading this over one hour gives an equivalent power, and the total load becomes

$$Q_{\text{tot}} = Q_{\text{cond}} + Q_{\text{air}} + Q_{\text{sens}} / 3600 \quad (8)$$

The estimated COP and settling time are then taken as

$$\text{COP} = Q_{\text{tot}} / P, \quad t = Q_{\text{sens}} / Q_{\text{tot}} \quad (9)$$

Table II gives the results. The model is deliberately simple and lumped, so it should be read as an order-of-magnitude guide and not as a prediction. It does bring out one clear trend: heating needs more total power than cooling for this load, yet it returns a higher COP, which matches the energy balance $Q_h = Q_c + P$ noted in Section III. Since the prototype carries four modules, its real pumping capacity is expected to exceed that of the single module assumed here, a point that testing must confirm.

TABLE II

Estimated heat load and COP

Parameter	Cooling	Heating
Water temperature (°C)	28 → 20	28 → 45
Sensible heat (kJ)	16.8	35.7
Equivalent load (W)	4.67	9.92
Conduction load (W)	7.5	7.5
Air infiltration (W)	2.0	2.0
Total load (W)	14.17	19.42
Input power (W)	48	48
Estimated COP	0.30	0.41
Estimated time (min)	19.8	30.6

VII. Implementation and Testing

A. Fabrication and Integration

Work proceeded in stages. After the concept, principle and component selection were settled and the parts procured, the control circuit was designed and assembly began. The box was then fabricated, the Peltier modules were integrated with their heat sinks and fans, and ESP32-based temperature sensing and control were implemented. The LCD display, the adjustable temperature thresholds, the Wi-Fi dashboard and cloud logging, the relay and driver circuitry and the power supply section were added last. The complete prototype was then tested for heating, cooling and temperature regulation. An earlier design iteration used a box of 45 cm × 30 cm × 20 cm; it was enlarged to the final 45 cm × 35 cm × 21 cm.



Fig. 6. LCD showing the live hot-side (H) and cold-side (C) temperatures, relay status and AUTO mode during a test run.

B. Test Procedure

The test procedure is modelled on the baseline study [4]. A known load, such as a 0.5 L water bottle, is placed in the cold zone, and hot water or hot food in the hot zone. The thresholds are set from the dashboard, and the zone temperatures, relay states and heat-sink temperatures are recorded at regular intervals, the first two through the ThingSpeak log, while the supply current is observed. Table III lists the start and target temperatures used for each zone.

TABLE III

Measured performance of the prototype

Test	Start (°C)	Target (°C)
Cold zone	12	10
Hot zone	38	40

VIII. Results and Discussion

A. Baseline Experimental Findings

The baseline study ran each test for 120 minutes [4]. In cooling, the heat-sink temperature fell from about 30 °C to 16 °C, while the object cooled more slowly, from about 28 °C to 21 °C. The heat sink led because of the thermal resistance between the cold source and the load. In heating, the heat sink climbed to about 60 °C within 30 minutes and close to 100 °C by the end, while the object rose from about 28 °C to 46 °C. The gradual rise of the object reflects heat travelling through the enclosed air and the approach toward thermal equilibrium.

Measured COP values were lower than the theoretical ones (Table IV and Fig. 7). The baseline study attributed the gap to heat leakage, imperfect insulation, non-ideal operating conditions, measurement error and component inefficiency.

TABLE IV

Theoretical and experimental COP in the baseline study

Parameter	Theoretical	Experimental
Cooling COP	0.31	0.25
Heating COP	0.405	0.301

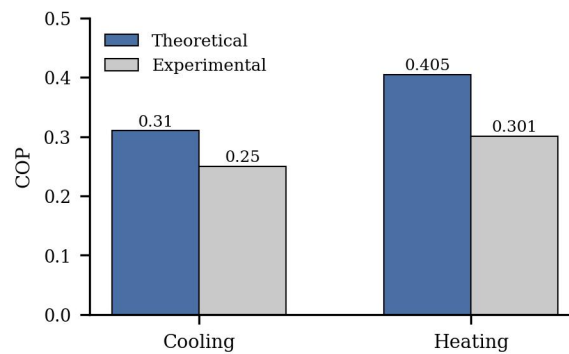


Fig. 7. Theoretical and experimental COP reported in the baseline study.

B. Discussion

Several lessons carry over to the present prototype. The first is heat rejection. The large gap between heat-sink and object temperatures in both baseline tests shows that the sink, and not the module, usually sets the pace; this agrees with the findings of Astrain *et al.* [11]. Hot-side airflow and sink area deserve more design effort than the module count.

The second is insulation. With a COP below 0.5 in every case, each watt of heat leaking in has to be paid for several times over in electrical input, so good insulation and a well-sealed lid are the cheapest way to save energy.

The third is the power budget discussed in Section IV-C. With a nominal module demand of 168 W against a 120 W supply, the measured simultaneous current is a necessary check, and the supply should be upgraded if all four modules must run at full rating together.

The fourth is food safety. The default thresholds, 38–40 °C for the hot zone and 10–12 °C for the cold zone, are practical for short trips but lie outside the 57 °C and 5 °C holding limits mentioned in Section I [1]. The dashboard allows higher hot and lower cold thresholds to be entered, but a single-stage module working against a warm ambient may not reach 5 °C, so any claim of safe cold-chain delivery should rest on measured data. For heating, a heat-sink temperature approaching 100 °C calls for a thermal cut-off to protect components and wiring.

IX. Advantages and Limitations

The system's strengths follow from the technology. One box holds a hot zone and a cold zone at the same time, the unit is compact and portable, and it needs no compressor and no conventional refrigerant. Operation is quiet, mechanical maintenance is low, the control concept is simple, the temperatures are visible on the LCD at all times, and the thresholds can be changed and the readings monitored remotely through the dashboard and cloud log. These features suit small-scale deliveries.

The limitations are equally clear. Efficiency is lower than that of conventional refrigeration, and continuous electrical power is needed. Cooling is strongly affected by how well the hot side is cooled, retention depends heavily on insulation, and performance varies with ambient temperature, airflow and heat-sink design. Thermistor accuracy depends on calibration, and the remote features need a working Wi-Fi connection.

X. Future Scope

Several improvements are planned. Better insulation and a more effective heat-dissipation arrangement should raise the COP. A PWM-based power stage would trim electrical consumption by matching module power to demand, and PID or other intelligent control could tighten temperature stability. A heat-sink thermal cut-off and a supply with higher current rating would improve safety and margin. The Wi-Fi link could be extended with alarms for out-of-range temperatures, and the dashboard could be protected by a password. Finally, careful temperature calibration and a full performance analysis against the figures in Section VI will help optimise the system.

XI. Conclusion

This paper described a smart food delivery box that uses Peltier modules to keep a hot zone and a cold zone under ESP32 control. The system combines an insulated 45 cm × 35 cm × 21 cm enclosure, four TEC1-12706 modules with heat sinks and fans, NTC thermistor sensing, a ULN2003A and relay stage, an I²C LCD, a Wi-Fi dashboard with ThingSpeak logging, and a 12 V, 10 A SMPS with a 7805 logic supply. A first-order model estimated COP values of about 0.30 for cooling and 0.41 for heating, and the baseline study suggests that measured values will fall below such estimates because of leakage and heat-rejection losses. The assembled prototype was tested for cooling, heating and regulation. Heat rejection, insulation and the supply current budget emerged as the factors that most influence performance, and they set the agenda for the next version.

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References

- [1] U.S. Food and Drug Administration, *Food Code 2022*. Silver Spring, MD, USA: U.S. Dept. of Health and Human Services, 2022.
- [2] L. E. Bell, "Cooling, heating, generating power, and recovering waste heat with thermoelectric systems," *Science*, vol. 321, no. 5895, pp. 1457–1461, Sep. 2008.
- [3] S. B. Riffat and X. Ma, "Thermoelectrics: A review of present and potential applications," *Appl. Therm. Eng.*, vol. 23, no. 8, pp. 913–935, Jun. 2003.
- [4] "Experimental analysis of temperature-control food delivery box using Peltier module," reference study supplied by the project team [authors, journal and year to be completed].
- [5] D. M. Rowe, Ed., *CRC Handbook of Thermoelectrics*. Boca Raton, FL, USA: CRC Press, 1995.
- [6] H. J. Goldsmid, *Introduction to Thermoelectricity*. Berlin, Germany: Springer, 2010.
- [7] G. J. Snyder and E. S. Toberer, "Complex thermoelectric materials," *Nat. Mater.*, vol. 7, no. 2, pp. 105–114, Feb. 2008.
- [8] D. Zhao and G. Tan, "A review of thermoelectric cooling: Materials, modeling and applications," *Appl. Therm. Eng.*, vol. 66, no. 1–2, pp. 15–24, May 2014.
- [9] M. K. Shilpa *et al.*, "A systematic review of thermoelectric Peltier devices: Applications and limitations," *Fluid Dyn. Mater. Process.*, 2022.
- [10] E. C. Dsouza, "Review of Peltier refrigeration: Advancements and applications," *Int. J. Sci. Res. Eng. Manag.*, 2024.
- [11] D. Astrain, J. G. Vián, and J. Domínguez, "Increase of COP in the thermoelectric refrigeration by the optimization of heat dissipation," *Appl. Therm. Eng.*, vol. 23, no. 17, pp. 2183–2200, Dec. 2003.
- [12] S. Lineykin and S. Ben-Yaakov, "Modeling and analysis of thermoelectric modules," *IEEE Trans. Ind. Appl.*, vol. 43, no. 2, pp. 505–512, Mar./Apr. 2007.
- [13] A. R. Mazhar *et al.*, "Experimental investigation of simultaneous cooling and heating using thermoelectric module," *Int. J. Thermofluids*, 2023.
- [14] MathWorks, "ThingSpeak IoT analytics platform," [Online]. Available: <https://thingspeak.com>
- [15] STMicroelectronics, "L78 series positive voltage regulators," datasheet, Geneva, Switzerland.
- [16] Texas Instruments, "ULN2003A high-voltage, high-current Darlington transistor arrays," datasheet, Dallas, TX, USA.
- [17] J. S. Steinhart and S. R. Hart, "Calibration curves for thermistors," *Deep-Sea Res. Oceanogr. Abstr.*, vol. 15, no. 4, pp. 497–503, Aug. 1968.
- [18] Espressif Systems, "ESP32 series datasheet," Shanghai, China.

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- [19] K. Ogata, *Modern Control Engineering*, 5th ed. Upper Saddle River, NJ, USA: Prentice Hall, 2010.
- [20] F. P. Incropera, D. P. DeWitt, T. L. Bergman, and A. S. Lavine, *Fundamentals of Heat and Mass Transfer*, 7th ed. Hoboken, NJ, USA: Wiley, 2011.