Project Plan: Multi-Stage TEC based compressor-less Refrigerator

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Instrumentation, Sensors, Actuators

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Contents

1 Project Overview

Project Title: Design and Implementation of a Multi-Stage TEC based compressor-less Refrigerator

Objective: The goal of this project is to design, prototype, and build a compact refrigerator using **TEC1-12703, or TEC1-12706** modules in a stacked or parallel configuration. The system will be controlled by an **Arduino board** (either Uno or Due) and will integrate temperature sensors, an LCD interface, Rotary encoders, Power MOSFEts and appropriate power electronics (such as a buck converter and MOSFET drivers) to regulate the cooling. The final unit must be capable of maintaining a set temperature adjustable between **2°C and 12°C** within a provided thermal enclosure (thermocol white box or a cold box for outdoor trips).

Group Work: Students will work in groups of **6–7** members, with each student dedicating approximately **4 hours per week** (resulting in a total of approximately **28 hours per week collectively**). Weekly progress reports, including photographs, data logs, working arduino codes, design sketches, 3d Printed parts (If required by design) etc will be submitted and graded according to the weekly goals. A formal mid-project presentation is scheduled at the end of Week 4, with the final demonstration and presentation occurring in Week 9.

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2 Components & Materials

The following components and materials will be required for this project. I will provide as many things as I can so that the project can be kick started right away. **Note:** While specific models are suggested, alternatives with similar specifications are acceptable, if student has a familiarity as well as have that available.

- **Thermoelectric Cooler (TEC) Modules:**
  - Model: **TEC1-12703**
  - Quantity: **1–4** modules (depending on the chosen configuration: series stacking for higher ΔT or parallel for increased cooling capacity)
- **Arduino Board:**
  - Options: **Arduino Uno** or **Arduino Due**
  - Quantity: **1 per group**
- **LCD Display:**
  - Recommendation: **128x64 LCD** with an **I²C adapter** (e.g., UCTRONICS 0.96 Inch OLED Module 12864 128x64 Yellow Blue SSD1306 Driver I2C Serial Self-Luminous Display)

  - Quantity: **1 per group**
  - **Link:** UCTRONICS 0.96 Inch OLED Module 12864 128x64 Display Module

- **Temperature Sensors:**
  - Model: **DS18B20 waterproof digital temperature sensor** (one-wire interface)
  - Quantity: **At least 2** (for measuring the internal temperature and optionally an additional sensor for ambient temperature)

- **Control & Power Electronics:**
  - **Buck Converter:** e.g., **LM2596 adjustable buck converter** (rated for at least 3–5 A)
  - **MOSFETs:** Logic-level MOSFETs (e.g., **IRLZ44N** or its alternatives) with appropriate heatsinks
  - Additional PWM control components for fan speed regulation (if not integrated into the MOSFET driver circuit)

- **Thermal Interface Materials:**
  - **Thermal Paste:** e.g., **Arctic Silver 5** or similar high-quality thermal paste
  - **Thermal Epoxy/Adhesive:** For permanent mounting where needed, with high thermal conductivity
  - **Silicone Adhesive:** For mechanical mounting or sealing parts as required
  - **PU Foam Spray:** For insulation and closing the gaps to retain cooling.

- **Cooling Hardware:**
  - **Heatsinks & Fins:** Appropriately sized for the hot side of the TEC modules
  - **Cooling Fans:** One or more fans, preferably with PWM control capability, for the cold and/or hot side
  - **Radiator (if applicable):** For effective heat dissipation

- **Enclosure:**
  - Use the provided **thermocol white box** (medicine transport box) or a **cold box** for family trips.

- **User Interface Components:**
  - **Rotary Encoder with Integrated Push Button:**
  - Quantity: **1 per group**
  - **Purpose:** Allows the user to set the temperature setpoint (e.g., 2°C to 12°C) by rotating the knob and, optionally, pressing the button for confirmation or mode switching.

- **Miscellaneous:**
  - Wires, connectors, prototyping boards (breadboards/PCBs), fasteners, and a suitable DC power supply (e.g., 12 V with sufficient amperage for the TEC load)

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3 Week-by-Week Plan & Weekly Reports

Each week, students must submit a formal progress report that includes:

- **Photographs** (e.g., wiring, mechanical assembly, prototypes)
- **Data/Graphs** (e.g., temperature profiles, PID tuning curves)
- **Design Documents/Sketches** (circuit diagrams, mechanical layouts)
- **Code Listings** (with detailed comments)
- A summary of challenges encountered and planned next steps

Below is the detailed weekly breakdown:

3.1 Week 1 – Project Initiation, Research, and Planning

Objectives:

- Understand project requirements and assign team roles.
- Perform a literature review on TEC technology, thermodynamic fundamentals, and multi-stage cooling systems.
- Identify the parts given and their working.
- Develop an initial block diagram covering the system's electrical and mechanical interfaces.
- Define key performance targets (e.g., setpoint temperature range, cooling power, response time).

Deliverables:

- A summary report detailing research findings.
- A preliminary design document and block diagram. Please incorporate all the suggested activites.
- Photographs of initial sketches or whiteboard brainstorming sessions.

Suggested Activities:

- Read technical papers on TEC stacking vs. parallel configurations.
- Investigate case studies on similar refrigeration projects.
- Identify the plan on how to remove the water condensation water collected.
- Identifying the key areas on the efficiency of the system if the cold side radiator has an ice build up.
- Hold a kickoff meeting to assign responsibilities. One leader is identified who is responsible for timely submissions of reports, and identify the roles of presentations.

3.2 Week 2 – Detailed Design and Circuit/Mechanical Planning

Objectives:

- Develop detailed circuit schematics integrating the Arduino, sensors, LCD, buck converter, MOSFET drivers, and the rotary encoder interface.
- Finalize the mechanical layout for mounting the TEC modules, heatsinks, fans, and interfacing with the provided box.
- Decide on the configuration for the TEC modules (series stacking for higher ΔT vs. parallel for increased capacity).

Deliverables:

- Finalized circuit diagrams (electrical schematics and wiring diagrams).
- Mechanical design sketches and, if available, CAD models.
- A list of any additional components required based on the finalized design.

Suggested Activities:

- Create the schematic using design software (e.g., Eagle, KiCad, or any other software of your choice. No hand drawn sketches will be accepted).
- Develop a detailed design with any additional components - (Please keep in mind, that there are fair chances that those components may not reach us in time, so alternative solutions are to be proposed)
- Discuss thermal management strategies (application of thermal paste/epoxy and heatsink selection).

3.3 Week 3 – Prototyping the Control System & Sensor Testing

Objectives:

- Set up the Arduino with the DS18B20 sensor(s) and LCD.
- Develop and test basic code to read the temperature and display it.
- Validate sensor calibration and wiring integrity on a breadboard.

Deliverables:

- A working prototype that displays temperature readings on the LCD.
- Source code for sensor interfacing (with initial comments).
- Photographs of the sensor and LCD test setup.
- Data logs demonstrating accurate temperature readings.

Suggested Activities:

- Assemble the one-wire circuit for the DS18B20 sensor.
- Verify I^2C communication with the LCD.
- Your first code displaying the fun things on LCD. Moving letters, blinking letters, name of the group whatever, just make us laugh.!
- Perform calibration checks using ambient room temperature as a reference. Perhaps check also a boiling water temperature so that proper calibration is enforced (please be careful while handling anything, extremely hot, cold, sharp.) You are entirely responsible for any actions that may result in any injury, and I expect all of you to behave in a responsible way. Avoid eating a lot of stuff at the Iftaar time so that you are not sleepy like me right before the taraveeh prayer.

3.4 Week 4 – Integration of TEC Modules & Preliminary Temperature Control

Objectives:

- Integrate a single TEC module (mounted on a test heatsink) into the control circuit.
- Develop the initial power control circuitry using the buck converter and MOSFET.
- Write code to control TEC power using a simple PWM signal (open-loop control) based on temperature sensor input.
- Begin exploring PID control strategies.

Deliverables:

- A prototype test rig demonstrating basic TEC operation.
- Updated circuit diagrams showing TEC module integration.
- Photographs of the TEC mounting (including application of thermal paste/epoxy).
- Preliminary temperature data capturing the cooling response.

Suggested Activities:

- Test the basic on/off and PWM control of the TEC.
- Ensure proper heatsinking on the hot side.
- Record temperature drop data over time.

Mid-Project Presentation: At the end of Week 4, each group will present their progress, including design rationale, test data, and challenges encountered.

3.5 Week 5 – PID Control Algorithm Development & Testing

Objectives:

- Develop and integrate a PID control loop into the Arduino code for precise temperature regulation.
- Use sensor feedback to adjust the PWM signal applied to the TEC module.
- Experiment with and fine-tune PID constants (K_p, K_i, K_d) for optimal system response.

Deliverables:

- Fully integrated PID control code with comprehensive comments.
- Graphs and data logs showing temperature response under various PID settings.
- A summary report documenting the PID tuning process and selected parameters.

Suggested Activities:

- Compare open-loop versus closed-loop performance.
- Utilize Arduino PID libraries (e.g., **PID_v1**) or implement a custom PID algorithm.
- Document how variations in ambient temperature affect control performance.

3.6 Week 6 – Mechanical Integration & Thermal Management Enhancements

Objectives:

- Transition from a bench prototype to full mechanical integration using the provided thermal box.
- Mount multiple TEC modules (if applicable) using proper stacking techniques.
- Install and secure heatsinks, fans, and radiators on both the hot and cold sides.
- Evaluate the effectiveness of thermal interface materials (thermal paste, epoxy, silicone).

Deliverables:

- A mechanically integrated refrigeration unit.
- Detailed assembly documentation (photos and annotated diagrams).
- Preliminary performance data (temperature profiles inside the box under load).

Suggested Activities:

- Decide on and test the method of TEC stacking vs. parallel configuration.
- Ensure proper application of thermal interface materials to minimize thermal resistance.
- Verify optimal positioning of cooling fans for uniform internal cooling.

3.7 Week 7 – Full System Integration & Enhanced User Interface

Objectives:

- Integrate the complete electrical system (Arduino, sensors, TEC control circuit, fan control) with the mechanical assembly.
- Develop an enhanced LCD user interface that displays:
  - Current temperature.
  - Temperature setpoint.
  - System status (e.g., fan speed, PID output).
- **Integrate the Rotary Encoder with Integrated Push Button:**
  - Use the rotary encoder to adjust the temperature setpoint (e.g., between 2°C and 12°C) by counting the pulses and determining rotation direction.
  - Utilize the integrated push button for additional functions (such as mode switching or confirming the setpoint).

Deliverables:

- A fully integrated system prototype with a user-adjustable temperature setpoint via the rotary encoder.
- Updated Arduino code with routines for reading rotary encoder inputs and updating the setpoint.
- Photographs and demonstration videos showing the rotary encoder in action and the LCD displaying the updated setpoint.
- Revised circuit diagrams reflecting final wiring (including the rotary encoder).

Suggested Activities:

- Test and calibrate the rotary encoder interface.
- Map encoder pulses to temperature setpoint increments (e.g., one detent per 1°C change).
- Integrate and test the push button function (if available) on the encoder.

3.8 Week 8 – System Testing, Data Collection & Troubleshooting

Objectives:

- Conduct extensive testing under different ambient and load conditions.
- Collect detailed data on system performance (temperature profiles, energy consumption, cooling response time).
- Identify and troubleshoot any issues (electrical, thermal, or mechanical).
- Optimize PID parameters and system response based on testing feedback.

Deliverables:

- A comprehensive testing report including data graphs, photos of the test setup, and a troubleshooting log.
- A final updated version of the Arduino code with any necessary modifications.
- Documentation of any changes made to the design following testing.

Suggested Activities:

- Run continuous tests over several hours to ensure stability.
- Compare performance between single-stage and multi-stage TEC configurations (if applicable).
- Ensure that all safety protocols are followed (e.g., monitor hot side temperature limits).

3.9 Week 9 – Final Presentation & Project Submission

Objectives:

- Finalize all documentation, code, and mechanical/electrical assemblies.
- Prepare and deliver a formal presentation that covers the entire project lifecycle:
  - Design rationale and component selection.
  - Challenges and lessons learned.
  - Demonstration of the working refrigerator.
  - Data supporting system performance.
- Submit a final project report that includes schematics, code listings, testing data, and assembly photos.

Deliverables:

- A fully functional refrigerator capable of maintaining temperatures between **2°C and 12°C**.
- Formal presentation slides (both digital and printed copies).
- A complete final project report archived as the project record.

Suggested Activities:

- Conduct a final system run-through and record a demonstration video.
- Organize a Q&A session for the project review panel.
- Ensure that every team member is prepared to discuss their contributions and system performance.

4 Comprehensive Components Table

Below is a table listing all possible components required for the project, including the new rotary encoder with integrated push button. This table details component categories, options/models, recommended quantities, and additional notes.

Component Category	Specific Component/Description	Possible Options/-Models	Quantity	Notes
TEC Modules	Thermoelectric Cooler	TEC1-12703 (primary)	1–4 modules	Stacking for higher ΔT or parallel for capacity.
Microcontroller	Arduino Board	Arduino Uno, Arduino Due	1 per group	Based on availability and processing needs.
Display	LCD Display	UCTRONICS 0.96 Inch OLED with I²C adapter	1 per group	Ensure correct I²C address (commonly 0x27).
Temperature Sensors	Digital Temperature Sensor	DS18B20; alternatives: TMP36, LM35	At least 1	Waterproof DS18B20 recommended.
Power Supply Components	Buck Converter	LM2596 adjustable buck converter	1	Rated for at least 3–5 A.
Switching Devices	MOSFET	IRLZ44N; alternatives: IRLB8743, IRLZ34N, FQP30N06L, etc.	Multiple (as needed)	Use with heatsinks; ensure logic-level compatibility.
Thermal Interface	Thermal Paste	Arctic Silver 5, Thermal Grizzly Kryonaut	Sufficient quantity	For optimal thermal contact.
Thermal Adhesives	Thermal Epoxy / Adhesive	Various high-conductivity epoxies	As required	For permanent mounting.
Cooling Hardware	Heatsinks & Fins	Aluminum or copper heatsinks	As required	Sized appropriately for TEC hot side.
Cooling Hardware	Cooling Fans	PWM-controlled DC fans; alternatives: brushless fans	1 or more	Consider adjustable speed control via MOSFET.

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Component Category	Specific Component/Description	Possible Options/Models	Quantity	Notes
Cooling Hardware	Radiator	Optional radiator panels	As needed	For enhanced heat dissipation if required.
Enclosure	Thermal Box	Thermocol white box, Cold box	1 per group	I bought ice box of 24 litre volume .
User Interface	Rotary Encoder with Integrated Push Button	Various generic modules	1 per group	Allows precise adjustment of temperature setpoint.
Miscellaneous	Wiring, Connectors, Fasteners, PCB/Breadboard	Standard electronic components	Sufficient quantity	Include cables, jumpers, solder, and mounting hardware.
Power Supply	DC Power Supply	12V supply (with adequate current)	1	Rated at 30 Ampere to fulfill TEC load requirements.

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5 Conclusion

This comprehensive document outlines the project plan for our Peltier module based compressor less refrigerator, weekly milestones, deliverables and a complete list of components for the **Multi-Stage TEC Refrigerator** project. The interface using the rotary encoder will provide a user-friendly, precise method for setting the temperature between 2°C and 12°C. I have tried my best to carefully structure every section to guide student teams through research, design, prototyping, testing, and final presentation phases. I really trust you guys can do it and make myself and your group proud!

Happy Building and Good Luck with Your Project!