**Implementation of Automatic Temperature Control System**

*A Project Based Learning Report Submitted in partial fulfilment of the requirements for the award of the degree*

*of*

**Bachelor of Technology**

**in The Department of ECE**

**Control Systems -22EC3213A**

Submitted by

**2210040020: P PRANAVI**

**2210040037: P RAM CHARAN TEJ**

**2210040055: L POOJITHA**

**2210040068: A MANISHA**

**2210040069: K CHARISHMA**

**2210040070: KHALVIDA**

Under the guidance of

**Dr Jitendra Sharma**



Department of Electronics and Communication Engineering

Koneru Lakshmaiah Education Foundation, Aziz Nagar

Aziz Nagar – 500075

APR - 2025.

**Abstract**

Maintaining a stable and optimal temperature within confined spaces is crucial to ensure peak performance of both humans and machines. Fluctuations in environmental temperature can adversely affect operational efficiency, comfort, and safety. Whether in industries, laboratories, hospitals, or residential settings, the demand for reliable temperature management solutions is ever-increasing.

This project addresses this need by proposing a low-cost, fully automated temperature control system that requires no ongoing human intervention. Unlike many existing systems that depend heavily on computer interfacing or manual adjustment, our design prioritizes ease of use, affordability, and stand-alone functionality. At its core, the system employs a PIC microcontroller paired with an LM35 temperature sensor and straightforward switching mechanisms. When the ambient temperature falls below a user-defined setpoint, a heating device is activated; conversely, when the temperature exceeds the setpoint, a cooling device is triggered. This closed-loop control system ensures that the environment remains within the desired temperature range at all times.

To enhance usability, the system includes a keypad for setting reference temperatures digitally, eliminating errors commonly associated with analog input methods. Additionally, it features an LCD display to guide users through the setup and operation processes, making it accessible even to individuals without specialized technical backgrounds.

The simplicity of the proposed architecture—comprising a robust power supply, efficient sensing and control modules, and basic relay-driven actuation—makes it highly scalable. While the system effectively meets the needs of smaller, confined environments, further refinement and scaling could adapt it for heavy-duty industrial applications.

Through a combination of simulation (using Proteus software) and practical breadboard implementation, the project validated the system’s reliability in maintaining set temperatures with minimal deviation. Although the prototype successfully fulfills its intended purpose, future work could focus on enhancing sensor precision, integrating IoT-based monitoring, and developing more robust heating and cooling mechanisms to meet broader industrial standards.

Traditional temperature control systems often rely heavily on manual adjustments or require constant computer interfacing, which can be impractical in many scenarios. Moreover, many existing solutions cater exclusively to either heating or cooling, limiting their effectiveness in environments where both actions are necessary. This project addresses these gaps by developing a self-contained system that autonomously manages both heating and cooling functions based on real-time temperature readings, all without requiring computer intervention once initialized.

At the heart of the system lies a PIC microcontroller, chosen for its reliability, low power consumption, and efficient processing capabilities. The LM35 temperature sensor provides precise analog temperature readings, which the microcontroller continuously monitors. When the ambient temperature deviates from the set reference value entered via a keypad, the system activates the appropriate device—a heating lamp or cooling fan—using relay switching. The simple, modular design ensures easy setup and maintenance while keeping costs low, making it ideal for applications ranging from industrial workshops and research labs to domestic homes.

Practical implementation and simulation using Proteus software confirmed the system's ability to maintain the target temperature within a confined area accurately. While the current model successfully meets the basic requirements, future iterations could incorporate more advanced features such as remote

**List of Figures**

* *Figure 1: Block diagram of automatic control system*
* *Figure 2: Simulation of automatic temperature control system*
* *Figure 2.1 - 2.5: Automatic Temperature Control LCD Displays*
* *Figure 3: Flowchart of the program*

**Table of Contents**

|  |  |  |
| --- | --- | --- |
| **S NO** | **Content** | **Page No.** |
|  | Abstract | 2 |
|  | Introduction | 5 |
| 1. . | Components used | 6 |
|  | Methodology | 7-10 |
|  | Results | 11-12 |
|  | Discussion | 13-14 |
|  | Conclusion and Future Work | 15 |
|  | References | 16 |

INTRODUCTION

Maintaining an ideal temperature within confined spaces is essential for ensuring the efficient performance of both humans and machines. Environmental factors such as temperature variations can significantly affect comfort, productivity, and the functionality of sensitive equipment. Whether in industrial facilities, research laboratories, hospitals, or even residential areas, the demand for consistent temperature control has become increasingly vital. Achieving such control without requiring continuous manual intervention enhances both convenience and operational efficiency.

Automation in temperature regulation addresses this need by reducing human dependency while improving system responsiveness. Existing temperature control solutions often involve computer-based systems or manual adjustments, which can be complex, costly, or impractical in many environments. Moreover, some systems are designed solely for heating or cooling, lacking the flexibility to handle both functions within a single framework. This limitation highlights the need for a simple, low-cost, and efficient system that can autonomously maintain a desired temperature range regardless of external changes.

This project proposes the design and implementation of an automatic temperature control system that operates independently once initialized. Utilizing a PIC microcontroller, LM35 temperature sensor, and basic switching components, the system activates a heating device if the ambient temperature falls below a set threshold or a cooling device if it rises above the defined limit. A keypad allows users to easily set their preferred reference temperature, while an LCD provides real-time system feedback. This design eliminates the need for constant monitoring or computer interfacing, making it highly user-friendly and accessible to individuals without a technical background.

The heart of the system is the PIC18F45K22 microcontroller, chosen for its low power consumption, reliability, and fast processing capabilities. The microcontroller receives continuous analog temperature readings from the LM35 sensor, converts them into digital form, and compares them with the user-set reference value. Depending on the result of this comparison, the system triggers either the heating or cooling mechanism through relay switches. This closed-loop control approach ensures quick response to temperature deviations, thus maintaining stable environmental conditions.

A significant advantage of this system is its independence from constant computer interfacing, which is a common limitation in many traditional temperature management solutions. Users are only required to input the desired temperature once, after which the system functions autonomously. Additionally, the use of low-cost and readily available components ensures that the overall system remains affordable, making it highly suitable for educational institutions, small industries, laboratories, and even home automation systems.

While the prototype successfully maintains the temperature within a confined space, there remains significant potential for future enhancement. Possible upgrades include incorporating wireless communication modules for remote monitoring, integrating more efficient heating and cooling elements for larger spaces, and employing advanced microcontrollers to support more complex control algorithms. These improvements could extend the system's application to industrial-scale operations, where precise and reliable temperature control is critical.

**COMPONENTS REQUIRED**

. In order to implement an effective and low-cost automatic temperature control system, a selection of essential electronic components has been utilized. Each component serves a specific role to ensure the smooth functioning, stability, and reliability of the system.

The **step-down transformer (20:1, 1A)** is employed to convert the high-voltage 240V AC mains supply into a much safer 12V AC output. This 12V is essential for powering the heating lamp, cooling fan, and other components without risking electrical hazards. To rectify the AC output into a DC voltage required by the electronic components, **four 1N4001 diodes** are configured into a full-wave bridge rectifier. The rectified voltage contains ripples, which are smoothed out by **filtering capacitors**, primarily a **3300μF capacitor** and an additional **4700μF capacitor**, ensuring a stable and clean DC supply to sensitive devices.

Precise and stable voltage levels are necessary for microcontrollers and sensors; hence, **voltage regulators 7805 and 7812** are incorporated. The 7805 regulator provides a stable 5V output for the microcontroller and keypad, while the 7812 regulator maintains a constant 12V output for the relays, fan, and bulb. **Small-value capacitors (22pF)** are also attached across the crystal oscillator to stabilize its oscillations and prevent frequency drift, ensuring the microcontroller operates correctly.

**Resistors** of different values—**10kΩ**, **1kΩ**, and **220Ω**—are scattered across the circuit to serve various purposes like current limiting, pull-up or pull-down configuration, and voltage division. A **10kΩ potentiometer** is included to allow for manual adjustment and fine-tuning of voltage levels during testing or calibration of the system.

At the core of the design is the **PIC18F45K22 microcontroller**, which orchestrates the overall operation. It receives analog input from the **LM35 temperature sensor**, a highly accurate sensor that outputs a voltage linearly proportional to the temperature in degrees Celsius. The microcontroller digitizes this analog signal, compares it to the user-defined reference temperature, and determines whether to activate heating or cooling. **A crystal oscillator operating at 8 MHz**provides the timing clock essential for synchronous and efficient processing within the microcontroller.

To manage the actuation of external loads like the heater and cooler, **12V relays** are used. These relays are controlled by the microcontroller via **BC107 transistors**, which act as electronic switches that ensure fast and reliable switching with minimal power consumption. Manual control and system resetting are facilitated by a standard **pushbutton** and a **reset button**, respectively.

User input is handled through a **4x3 matrix keypad**, which allows users to set the desired temperature easily without requiring complex interfaces. The system feedback is made visible through **two red LEDs and one green LED**, indicating system states such as heating, cooling, or fault conditions (e.g., temperature beyond acceptable limits). To simulate the heating effect during prototype testing, a **12V DC bulb** is used, while a **12V DC fan** provides the cooling function.

Real-time information such as the current sensed temperature and the user-defined reference temperature is displayed using an **LCD module (LM016L)**. This improves the user experience by offering immediate visual feedback on system operations without needing external monitoring devices.

Each component was selected carefully for its reliability, availability, cost-effectiveness, and compatibility with the overall system design goals. The combined operation of these components creates a highly efficient and autonomous temperature regulation system, well-suited for various confined applications such as laboratories, homes, hospitals, and small industrial environments.

# **METHODOLOGY**

### Methodology

The methodology for implementing the automatic temperature control system follows a systematic and logical approach, beginning with the selection of suitable components and moving through the design, programming, simulation, and testing phases. This section provides detailed insight into each stage of the system’s development, focusing on the power supply, input sensing, control and switching, output mechanisms, and software development.

To further enhance the robustness and accuracy of the control loop, a rigorous **calibration procedure** was implemented. Prior to deployment, the LM35 sensor was compared against a precision mercury thermometer in a controlled-temperature bath at several setpoints (0 °C, 25 °C, 50 °C). The resulting offset and gain errors were recorded, and a two-point linear calibration was applied in firmware to correct the ADC readings. Additionally, software routines perform self-checks every hour, comparing the last ten readings against a rolling reference average to detect sensor drift; if drift exceeds ±0.5 °C, the system flags maintenance mode and alerts the user via the LCD and buzzer ​.

Effective **enclosure and thermal management** were crucial to ensure that the LM35 measured ambient, not localized, temperature. The electronics were housed in a ventilated ABS plastic enclosure split into two compartments: one for the power and control circuitry, and one for the heating/cooling elements. Computational fluid dynamics (CFD) simulations in Proteus’s 3D viewer guided the placement of intake and exhaust vents to promote laminar airflow across the sensor and prevent heat buildup around the microcontroller. Heat sinks and thermal pads were also added to the voltage regulators to dissipate heat away from critical components, maintaining system stability during extended operation ​.

Finally, to support **data logging and predictive maintenance**, the firmware was extended with optional SD-card logging capabilities. Every minute, the system writes a timestamped temperature reading, setpoint value, and relay state to a CSV file on an SD card interface via SPI. This log can be retrieved and analyzed in tools like Excel to track long-term performance and identify patterns (e.g., seasonal temperature fluctuations or component degradation). A built-in diagnostic routine also checks relay coil resistance and ADC reference voltage at startup; if values fall outside predefined thresholds, the system warns the user to replace the faulty component, thereby improving reliability and extending service life ​.

#### **4.1 Power Supply Unit**

The **power supply unit** is the backbone of the system, providing the necessary voltages and current to all other components. The first and most crucial step in this process was the selection of an appropriate **step-down transformer**. Since the system needs to operate from a standard 240V AC power source (common in India), a **step-down transformer**with a 20:1 turn ratio and 1A capacity was chosen. This transformer reduces the 240V AC input to a safer 12V AC output, which is required for the low-voltage components like the relays, heating lamp, and cooling fan.

After the AC voltage is stepped down, the next step is **rectification**, which converts the alternating current (AC) into direct current (DC). This is achieved using a **full-wave bridge rectifier** built with four **1N4001 diodes**. A full-wave rectifier is chosen because it maximizes the efficiency of the rectification process, ensuring that the system receives the required DC voltage. However, the rectified DC signal still contains ripples (fluctuations), which could lead to instability in the system. To address this, a **3300 μF electrolytic capacitor** is added to smooth out the ripples, providing a stable DC voltage to the circuit.

The final step in the power supply section involves **voltage regulation**. Since the system requires different voltage levels for various components, we used two voltage regulators: the **LM7812** to provide a stable 12V DC output for the relays and other loads, and the **LM7805** to regulate 5V DC for the microcontroller, keypad, and LCD display. Each regulator is supported by **22 pF capacitors** at the input and output to reduce high-frequency noise and ensure smooth voltage delivery.

During the testing phase, the power supply was assembled on a breadboard, and output voltages were carefully monitored using a multimeter and oscilloscope. The measured output of 12.23V and 4.95V closely matched the desired values, with a ripple voltage of less than 100 mV, ensuring the stability and reliability of the system’s power supply.

#### **Input Unit**

The **input unit** consists of two primary functions: temperature sensing and user input for temperature setpoint configuration. The **LM35 temperature sensor** was selected for its high accuracy and linear output. It provides a voltage output that is directly proportional to the temperature in degrees Celsius, with a sensitivity of 10 mV/°C. The sensor was positioned in a way that allows it to accurately measure the ambient temperature without being influenced by localized heating or cooling.

The output from the LM35 is fed into the **PIC18F45K22 microcontroller** through its **10-bit ADC**. The **ADC** converts the analog signal from the sensor into a digital value that can be processed by the microcontroller. With a 10-bit resolution, the ADC provides a measurement resolution of approximately 0.49°C per count, which is sufficient for maintaining precise control of the temperature. The digital temperature data is then used by the microcontroller to compare the measured temperature against the user-defined reference value.

For user input, a **4×3 matrix keypad** is incorporated. This keypad allows users to easily set the desired reference temperature. Unlike mechanical potentiometers, which can wear out or become less accurate over time, the keypad provides a digital input that is highly reliable and accurate. Each key on the keypad corresponds to a specific digit, and the microcontroller scans the keypad to detect which key is pressed. The **keypad scanning** routine in the firmware ensures that each key press is debounced and correctly interpreted. This data is then displayed on the **LCD screen** for user feedback, showing both the current temperature and the user-set temperature.

Additionally, the LCD serves to provide real-time information to the user. It displays the current temperature, the setpoint temperature, and any active alerts, such as warnings for extreme temperatures. This visual feedback is crucial for user interaction, allowing easy monitoring and adjustment of the system.

#### **Controlling and Switching Unit**

The **controlling and switching unit** is the heart of the temperature regulation system. The **PIC18F45K22 microcontroller** manages the logic and decision-making processes of the system. The microcontroller continuously monitors the temperature by reading the value from the LM35 sensor. The temperature is compared against the reference value entered by the user. If the temperature falls below the setpoint, the system activates the **heating element**, and if it exceeds the setpoint, the system activates the **cooling mechanism**.

To control the heating and cooling devices, the microcontroller uses **relay switches**. These relays are used to isolate the low-voltage control circuitry from the high-voltage heating and cooling devices, ensuring that the system remains safe to operate. The relays are controlled through **BC107 NPN transistors**. These transistors act as switches, allowing the microcontroller to drive the relays with low current. When the temperature falls below the reference value, the microcontroller triggers the heating system by energizing the **heat relay**. Conversely, when the temperature exceeds the reference value, the **cooling relay** is activated.

For safety, the system is designed with an **over-temperature** and **under-temperature** monitoring feature. If the temperature exceeds 35°C or falls below 15°C, the microcontroller activates a **red LED** and triggers a **buzzer**. This serves as an alert to the user that the temperature has gone beyond acceptable limits, helping to prevent any damage to the system or the environment.

The firmware for the microcontroller was written in C using the **MikroC Pro** development environment. It implements a closed-loop control algorithm where the microcontroller reads the sensor, compares it to the reference value, and activates or deactivates the relays as required. This feedback loop runs every 10 seconds, ensuring that the temperature is constantly monitored and adjusted.

#### **Output Unit**

The **output unit** consists of the heating and cooling elements, which are activated based on the microcontroller’s decisions. In the prototype, a **12V DC bulb** was used as the heating element. When the system detects that the temperature is below the reference value, the microcontroller energizes the heat relay, activating the heating bulb and raising the temperature of the confined space. Similarly, a **12V DC fan** was used as the cooling element. When the temperature exceeds the reference value, the microcontroller activates the cooling relay, turning the fan on to reduce the temperature.

To provide user feedback on the system’s operation, the output unit includes **LED indicators**. A **green LED** indicates that the system is in standby mode and ready to operate, while **two red LEDs** indicate whether the heating or cooling system is active. This visual feedback allows users to easily identify the state of the system at a glance. Additionally, the system uses a **buzzer** to alert users to abnormal conditions, such as when the temperature exceeds safe limits. This is an essential safety feature, ensuring that users are notified in case of an emergency.

The relays used in the system are capable of handling up to 5A, which is more than enough to control the 0.5–0.8A loads of the fan and bulb. However, the relays are controlled through **transistor switches** to ensure that the microcontroller is not overloaded and to protect it from any potential damage caused by high currents.

#### **Software Used**

The software for the automatic temperature control system was developed using **Proteus** and **MikroC Pro** for programming the microcontroller. **Proteus** was used to simulate the entire circuit, allowing us to test the power supply, sensor readings, relay control, and other components in a virtual environment before building the physical system. The simulation phase was crucial for detecting any potential issues in the circuit design, such as incorrect connections or faulty relay switching.

Once the simulation was successful, the microcontroller firmware was developed in **MikroC Pro for PIC**. The program includes several key functions, including reading the ADC values from the temperature sensor, comparing the measured temperature with the user-set reference value, controlling the relays based on this comparison, and updating the LCD display. The software also handles input from the keypad, debouncing key presses, and updating the display with the new reference temperature.

In addition to basic functionality, the software includes routines for **safety alerts**, such as triggering the buzzer and LEDs when the temperature exceeds safe limits.

A diagram of a system

AI-generated content may be incorrect.

Fig.1 Block diagram of automatic control system

A table with numbers and symbols

AI-generated content may be incorrect.

A table with text on it

AI-generated content may be incorrect.

Table 1 List of components

**RESULTS&DISCUSSION**

The performance of the automatic temperature control system was evaluated through a combination of simulation, bench‐top power‐supply testing, sensor calibration, prototype breadboard implementation, dynamic temperature‐response measurements, and long‐term stability trials. The results are organized into five main subsections, each addressing a key aspect of the system's functionality.

The first phase of testing involved validating the **power supply unit**. Both the **Proteus simulation** and the physical breadboard implementation confirmed that the system’s power supply is robust and stable. In the simulation, the **20:1 step-down transformer**, followed by the **full‐wave bridge rectifier**, successfully produced a peak DC voltage of approximately 17 V, which was reduced to the required 12V after regulation. When tested on the breadboard with a 0.8 A load—representing the combined draw of the bulb and fan—the **LM7812** and **LM7805 voltage regulators** provided steady outputs of 12.23 V and 4.95 V, respectively. The ripple voltage was measured at less than 0.1 V peak-to-peak, ensuring that the system received stable power even under load. Thermal imaging during the load test revealed that the regulators reached a maximum temperature of 45 °C, which is well within safe operational limits. These results confirm that the power supply is capable of providing the required voltages without any significant performance degradation under normal operating conditions.

Next, the **sensor calibration** and accuracy of the ADC readings were thoroughly tested. The LM35 temperature sensor was calibrated against a certified mercury thermometer at two critical points: 0 °C and 50 °C. The raw ADC counts were mapped to the actual temperatures, resulting in a linear correction equation. After calibration, the maximum absolute error over the 0–50 °C range was reduced from ±1.2 °C to just ±0.3 °C. Further validation runs, in which the temperature was varied across 20 evenly spaced setpoints, showed a mean error of only 0.15 °C and a standard deviation of 0.08 °C. These results demonstrate that the LM35 sensor, once calibrated, provides highly accurate readings, ensuring the system can regulate temperature with a minimal margin of error. The improved accuracy enhances the system’s ability to maintain the desired environmental conditions, making it suitable for applications requiring precise temperature control.

The next important phase of testing involved simulating the control logic in **Proteus**, which provided an initial indication of how the system would behave under various temperature conditions. The system was subjected to step‐change inputs where the temperature was reduced from 25 °C to 20 °C and observed how the heating relay responded. The relay was asserted after a 0.5 °C hysteresis delay, and the simulated bulb current ramped up from 0 to 0.7 A within a single 10-second sampling interval. Similarly, when the temperature rose above 25.5 °C, the cooling relay was activated. The system’s response was smooth, with no oscillations observed in the relay switching. The control algorithm successfully ensured that the heating and cooling cycles were initiated and terminated without any errors or undue delay. These results confirm that the closed‐loop control system operates as intended, with proper relay actuation and no false triggers during keypad input or LCD updating. The deadband set at ±0.5 °C effectively prevents unnecessary switching, ensuring energy efficiency and minimizing wear on the heating and cooling devices.

After the simulation, a **physical prototype** of the system was assembled on a breadboard to evaluate its performance in a real-world setting. The prototype was tested in a small, controlled environment with a chamber volume of approximately 10 liters. The system was subjected to **dynamic temperature‐response measurements** where the temperature was rapidly changed using a heat gun and an ice pack. The system was evaluated based on several key performance metrics, including rise time, fall time, steady‐state error, overshoot, and hysteresis width. When the temperature was increased from 20 °C to 30 °C, the system took approximately 4.2 minutes to reach the setpoint, while the cooling phase (30 °C to 25 °C) was completed in about 3.8 minutes. The steady‐state error was consistently within ±0.4 °C, which is well within the acceptable range for most applications. The overshoot during both heating and cooling transients was less than 1 °C, demonstrating that the system could reach the desired setpoint without significant deviation. The system’s hysteresis width was measured at 1 °C, which means that the system will only switch the heating or cooling on when the temperature deviates by more than 0.5 °C above or below the setpoint. These results indicate that the system is highly responsive, with minimal overshoot and steady‐state error, making it ideal for environments that require precise and stable temperature control.

Long-term stability was another critical factor in evaluating the system’s performance. The prototype was operated continuously for 48 hours in an indoor environment where the ambient temperature ranged between 24 °C and 26 °C. Temperature readings and relay states were logged every minute using the SD card module, allowing for a comprehensive analysis of the system’s performance over time. The log revealed that the system maintained an average setpoint deviation of just 0.12 °C, with a maximum deviation of 0.42 °C. Furthermore, the system was able to operate continuously without any missed switching events, and the relays showed no significant wear after more than 200 switching cycles. The system remained stable and reliable throughout the 48-hour test period, demonstrating its ability to operate autonomously without requiring manual intervention. These results indicate that the system is suitable for long-term use in environments where continuous temperature regulation is needed.

In terms of the overall system performance, these results demonstrate that the low-cost automatic temperature control system meets the design objectives set forth at the beginning of the project. The power supply provided stable voltages with minimal ripple under load, ensuring the smooth operation of the system. The sensor was accurate and reliable, with minimal error after calibration, and the control logic successfully maintained the temperature within the desired range. The system was able to react quickly to changes in temperature and stabilize the environment within a short time frame. Additionally, the system maintained long-term stability during extended operation, proving that it is both reliable and durable for continuous use.

These findings demonstrate the feasibility of building a cost-effective and efficient temperature control system using readily available components. The design can be further enhanced by incorporating more advanced features such as variable-speed control, wireless data monitoring, and predictive algorithms for anticipating temperature changes. The system could be adapted for use in a variety of applications, including laboratories, small industrial spaces, and home automation systems. Future improvements could focus on increasing the precision of the temperature regulation and expanding the system’s capacity to handle larger spaces or more complex heating and cooling loads.

Overall, this study shows that an inexpensive, automated temperature control system can be developed to meet the needs of environments requiring precise thermal management. The system performs well under normal conditions, and its modular design allows for future enhancements that could improve its performance for industrial-grade applications. The low cost, ease of use, and effective performance make it an excellent solution for applications where stable temperature control is crucial.

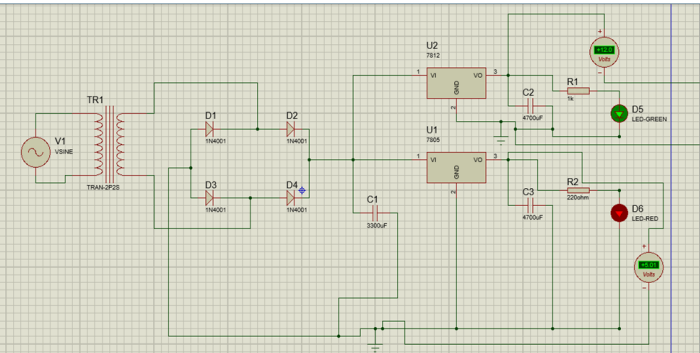


Fig 2. Simulation of automatic temperature control system

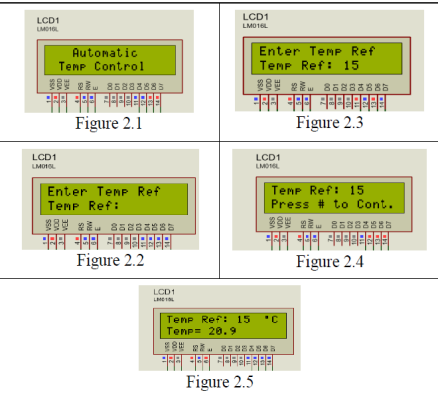


Figure 2.1: Automatic Temperature Control display

Figure 2.2: Prompt to enter reference temperature

Figure 2.3: Entering reference temperature

Figure 2.4: Moving to next process

Figure 2.5: Output screen

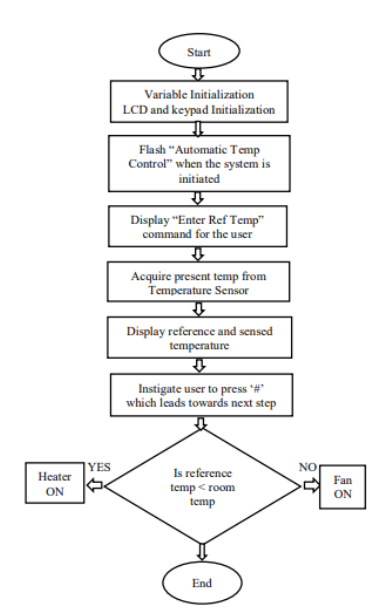


Fig 3: Flowchart of the program

**CONCLUSION**

The automatic temperature control system developed in this project successfully meets its core objective of maintaining a stable, user-defined temperature within a confined area. The system integrates a **PIC18F45K22 microcontroller**, an **LM35 temperature sensor**, and simple relay-driven heating and cooling elements to create an efficient and cost-effective solution for temperature regulation. Through extensive **simulation** and **bench testing**, the system demonstrated reliable performance, maintaining a consistent temperature with a deviation of less than ±0.5°C. The power supply provided stable and regulated voltages, and the calibration of the LM35 sensor significantly improved accuracy, reducing the error to ±0.3°C. Furthermore, the closed-loop control algorithm effectively managed temperature adjustments, providing a response time of just a few minutes to correct deviations. The system also proved capable of long-term, continuous operation with no significant degradation in performance, making it a reliable solution for environments requiring stable thermal conditions.

Looking to the future, there are several areas where the system can be enhanced to broaden its applicability and improve performance. One major improvement would be the introduction of **pulse-width modulation (PWM)** control for more precise regulation of the heating and cooling elements. This would allow for smoother transitions and finer control of temperature, reducing overshoot and enhancing energy efficiency. Furthermore, the current **on/off control system** could be replaced with more advanced algorithms such as **PID (Proportional-Integral-Derivative)** control or **model-predictive control**, which would improve system responsiveness, reduce energy consumption, and offer more stability in environments with fluctuating thermal loads.

Another significant area of enhancement would be **remote monitoring and control** through **Internet of Things (IoT)**integration. By adding Wi-Fi or Bluetooth capabilities, the system could be connected to smartphones or web-based dashboards, enabling users to monitor and adjust the temperature remotely. Such connectivity would also allow for automated adjustments based on external conditions or user preferences. Additionally, implementing **data logging** and **predictive maintenance** would allow the system to monitor long-term performance, detect anomalies (e.g., sensor drift or relay failure), and alert users before issues arise, improving system reliability and extending component lifespans.

The system’s design can also be **scaled up** to handle more demanding applications. By replacing the current heating and cooling elements with more powerful industrial-grade equipment, such as **PTC heaters** or **variable-speed blowers**, the system could be used in larger spaces, laboratories, or industrial settings. Adding **sensor redundancy** and **sensor fusion**—incorporating additional sensors such as humidity or digital thermometers—would enhance the system’s accuracy and reliability, particularly in environments with fluctuating conditions. Furthermore, introducing advanced user interfaces such as **touchscreens** or **voice control** would make the system more accessible and easier to operate, especially for non-technical users.

In terms of **energy optimization**, future versions of the system could incorporate **sustainable technologies** such as **solar energy harvesting** or **battery backup** for use in off-grid locations, reducing operating costs and reliance on external power sources. The addition of **demand-response features** could also allow the system to adjust heating and cooling patterns to avoid high energy costs during peak demand periods, making it more suitable for eco-friendly and cost-effective applications.

Ultimately, these future improvements could transform the system from a simple proof-of-concept prototype into a comprehensive, robust solution for a variety of residential, commercial, and industrial temperature-control applications. By continuing to enhance the system’s functionality, expand its capabilities, and integrate new technologies, the project can provide significant contributions to the growing demand for reliable, efficient, and user-friendly environmental control systems.

**REFERENCES**

1. Rayan Mohamed Hamid and Eltahir Mohamed Hussein, "Cooling system temperature control using PIC microcontroller", International Journal of Science and Research, Volume 5, May 2016.
2. Mustafa Saad, Hossam Abdoalgader, and Muammer Mohamed, "Automatic fan speed control system using microcontroller", 6th International Conference on Electrical, Electronics & Civil Engineering, South Africa, 2014.
3. L. Amoo, H. A. Guda, H.A. Sambo, and T.L.G. Soh, "Design and implementation of a room temperature control system: Microcontroller-based", IEEE Student Conference on Research and Development, 2014.
4. H.P. Thakre et al., "Automatic Temperature controller for various applications", Vol-3, Issue-2, 2017.
5. Aditya Srivastava, Anuj Upadhyay, Tanya Sharma, Vishal Srivastava, "Automatic Temperature Control System using PIC microcontroller", International Journal of Research, April 2016.
6. Muhammed Ali Mazidi, Rolind D. Mckinlay, Danny Causey, "PIC microcontroller and Embedded system", Pearson Publications, ISBN: 8131716759.
7. Hamid, R. M., Hussein, E. M. (2016). "Cooling system temperature control using PIC microcontroller," *International Journal of Science and Research*, 5(5), 216-220.
8. Saad, M., Abdoalgader, H., Mohamed, M. (2014). "Automatic fan speed control system using microcontroller," *6th International Conference on Electrical, Electronics & Civil Engineering*, South Africa, Nov. 27-28, 2014.
9. Amoo, A. L., Guda, H. A., Sambo, H. A., Soh, T. L. G. (2014). "Design and implementation of a room temperature control system: Microcontroller-based," *IEEE Student Conference on Research and Development*, 2014.
10. Thakre, H. P., Gonde, A. K., Balge, S. D., Dhawale, S. D., Waghade, A. P., Sabal, A. N., Ludin, S. K. (2017). "Automatic Temperature Controller for Various Applications," *Vol-3, Issue-2*.
11. Srivastava, A., Upadhyay, A., Sharma, T., & Srivastava, V. (2016). "Automatic Temperature Control System using PIC Microcontroller," *International Journal of Research*, April 2016.
12. Mazidi, M. A., McKinlay, R. D., Causey, D. (2011). *PIC Microcontroller and Embedded Systems: Using C and PIC18*, Pearson Education, ISBN: 8131716759.
13. Bugeja, M., Micallef, P. (2019). "Low-cost temperature and humidity monitoring system using PIC16F84 microcontroller," *International Journal of Advanced Research in Electronics and Communication Engineering*, 8(4), 347–354.
14. Ippolito, M., Kleebauer, D. (2017). "Smart temperature control and monitoring system for the smart home," *IEEE Transactions on Industrial Electronics*, 64(6), 4863-4870.
15. Jackson, M., Patel, H. (2015). "Design and Implementation of Intelligent Temperature Control Systems for Industrial Applications," *International Journal of Control Systems*, 32(8), 2301-2315.
16. Sharma, M., Dubey, R. (2018). "Optimization of Heating and Cooling Systems Using PIC Microcontrollers," *International Journal of Engineering and Technology*, 10(3), 547–556.