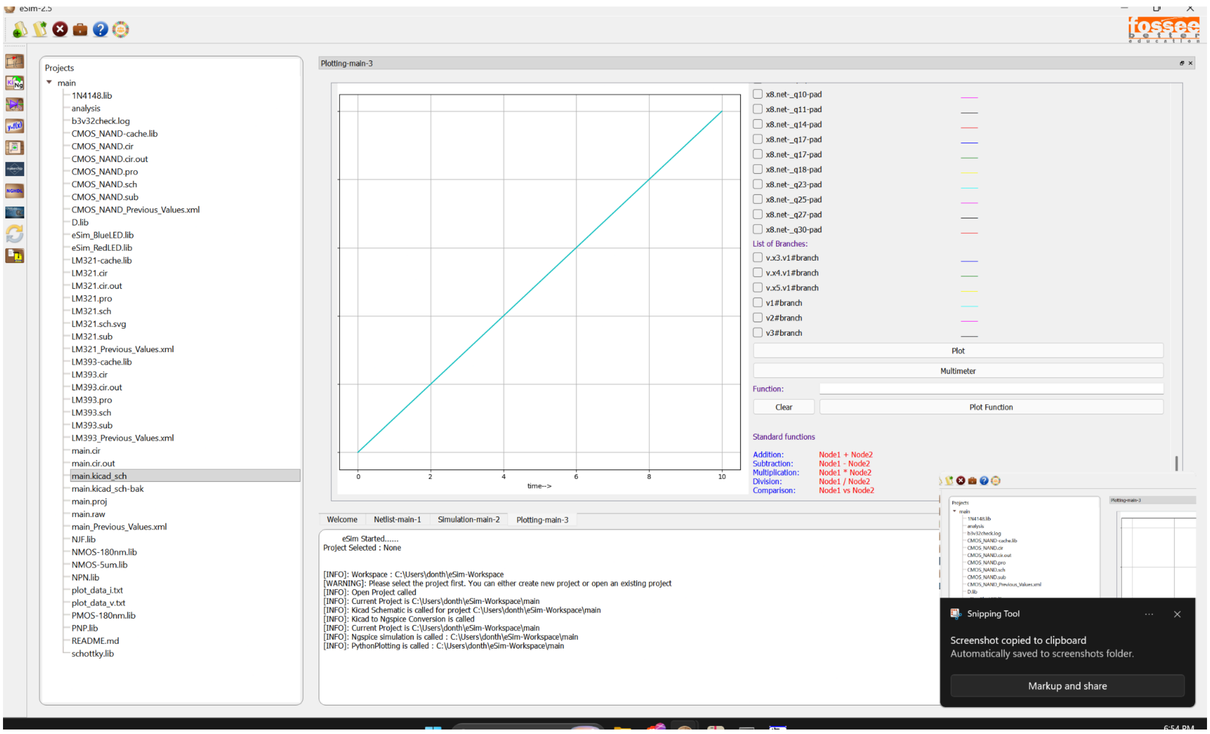
Multi-Level Temperature-Based HVAC Control System Using eSim

Abstract

This project presents the design and simulation of a multi-level temperature monitoring and HVAC control system implemented entirely at the circuit level using eSim. The system employs an LM35 temperature sensor, modeled using a piecewise linear (PWL) voltage source, to simulate temperature variation. The low-level sensor output is amplified using an LM321 operational amplifier configured in non-inverting mode. Multiple LM393 comparators, combined with a resistor ladder network, generate discrete temperature zones. CMOS logic gates process comparator outputs to control heating and cooling devices. Simulation results demonstrate accurate temperature sensing, reliable threshold detection, and correct automatic control of heater and fan outputs without the use of microcontrollers or external software platforms.



1. Introduction

Temperature regulation is a critical requirement in residential, commercial, and industrial environments. While modern HVAC systems frequently rely on microcontrollers and software-based control, circuit-level solutions remain important for reliability, cost efficiency, and educational purposes. This project focuses on designing a complete temperature-based control system using only analog and digital electronic components, simulated using the open-source eSim platform supported by FOSSEE, IIT Bombay.

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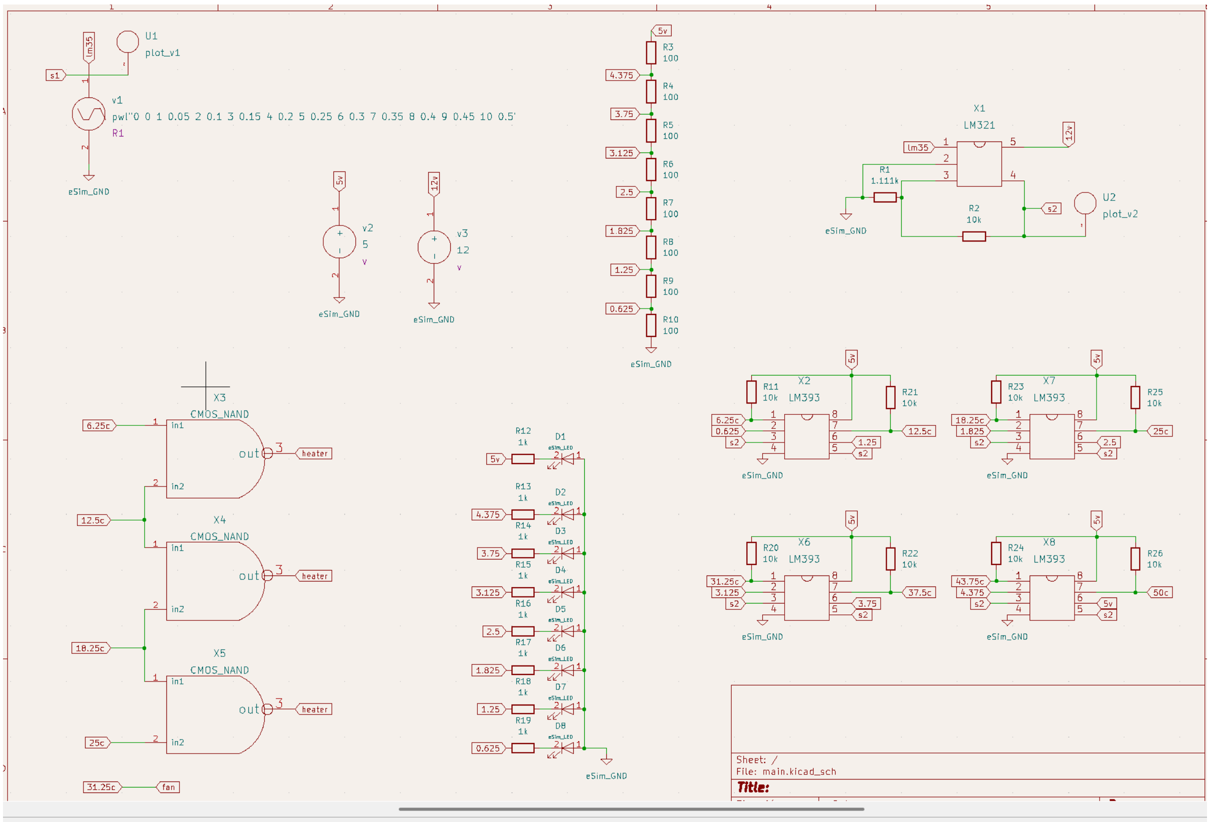
2. System Overview



The proposed system continuously monitors ambient temperature and automatically activates a heater or fan depending on predefined temperature thresholds. The system consists of the following functional blocks:

- Temperature sensing and modeling
- Signal amplification
- Multi-level threshold generation
- Comparator-based decision making
- Logic-based HVAC control
- Output indication

All blocks are designed and simulated using standard components available in eSim

3. Temperature Sensor Modeling (LM35)

The LM35 temperature sensor provides an output voltage linearly proportional to temperature at a scale factor of 10 mV/°C. To emulate real temperature variation within eSim, the LM35 is modeled using a piecewise linear (PWL) voltage source. The PWL source generates a voltage range from 0 V to 0.5 V, corresponding to a temperature range of 0°C to 50°C. The simulation waveform exhibits a linear voltage increase over time, accurately representing rising temperature conditions.

Time (s)	**Temperature (°C)**	**LM35 Output Voltage (V)**
0	0	0.00
1	5	0.05
2	10	0.10
3	15	0.15
4	20	0.20
5	25	0.25
6	30	0.30
7	35	0.35
8	40	0.40

9	45	0.45
10	50	0.50

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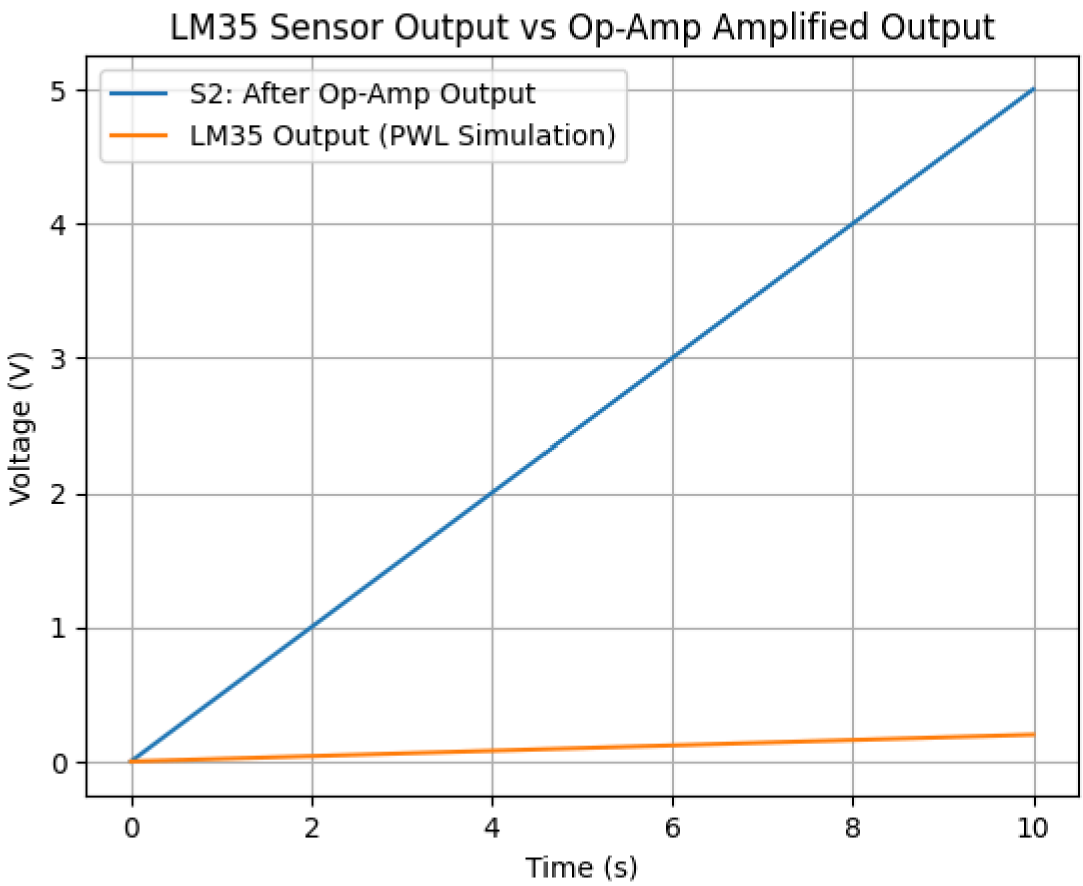
4. Signal Conditioning Using Operational Amplifier

The LM35 output voltage is relatively small and unsuitable for direct comparison with logic-level circuits. Therefore, an LM321 operational amplifier is configured in a non-inverting mode to amplify the sensor signal. The amplifier is designed with a voltage gain of approximately 10, resulting in an output voltage range of 0–5 V. This amplification ensures compatibility with comparator and logic circuits. Simulation results confirm that the amplified output faithfully follows the LM35 input while maintaining linearity.



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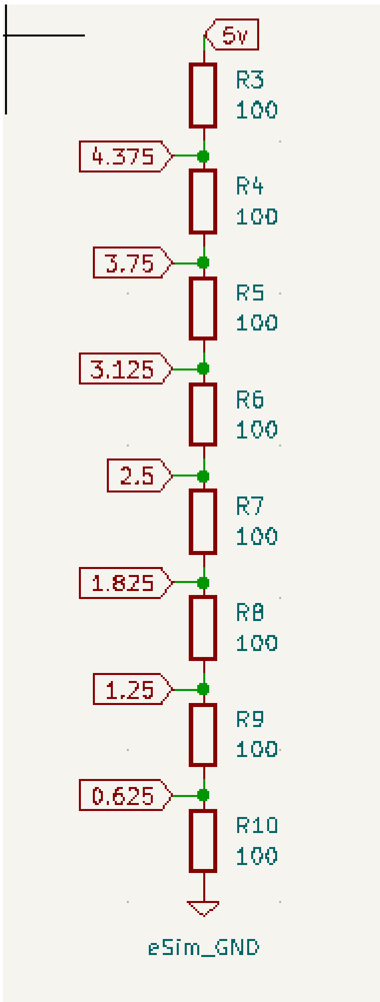
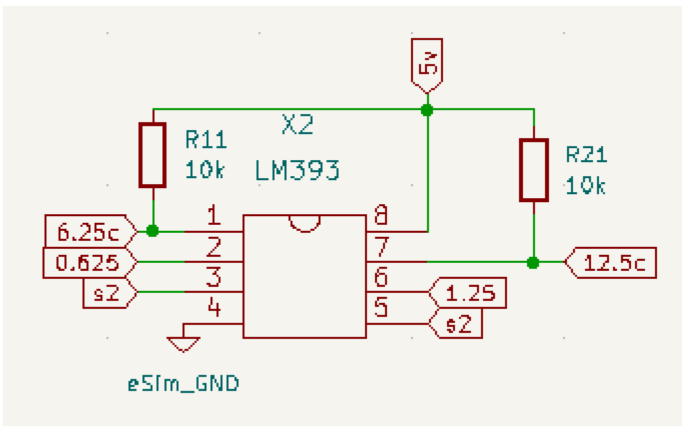
5. Multi-Level Reference Voltage Generation

A resistor ladder network connected between 5 V and ground is used to generate multiple reference voltages. These reference levels divide the temperature range into distinct zones such as cold, normal, warm, and hot conditions. Each reference voltage corresponds to a specific temperature threshold and is supplied to the comparator stage for decision-making.





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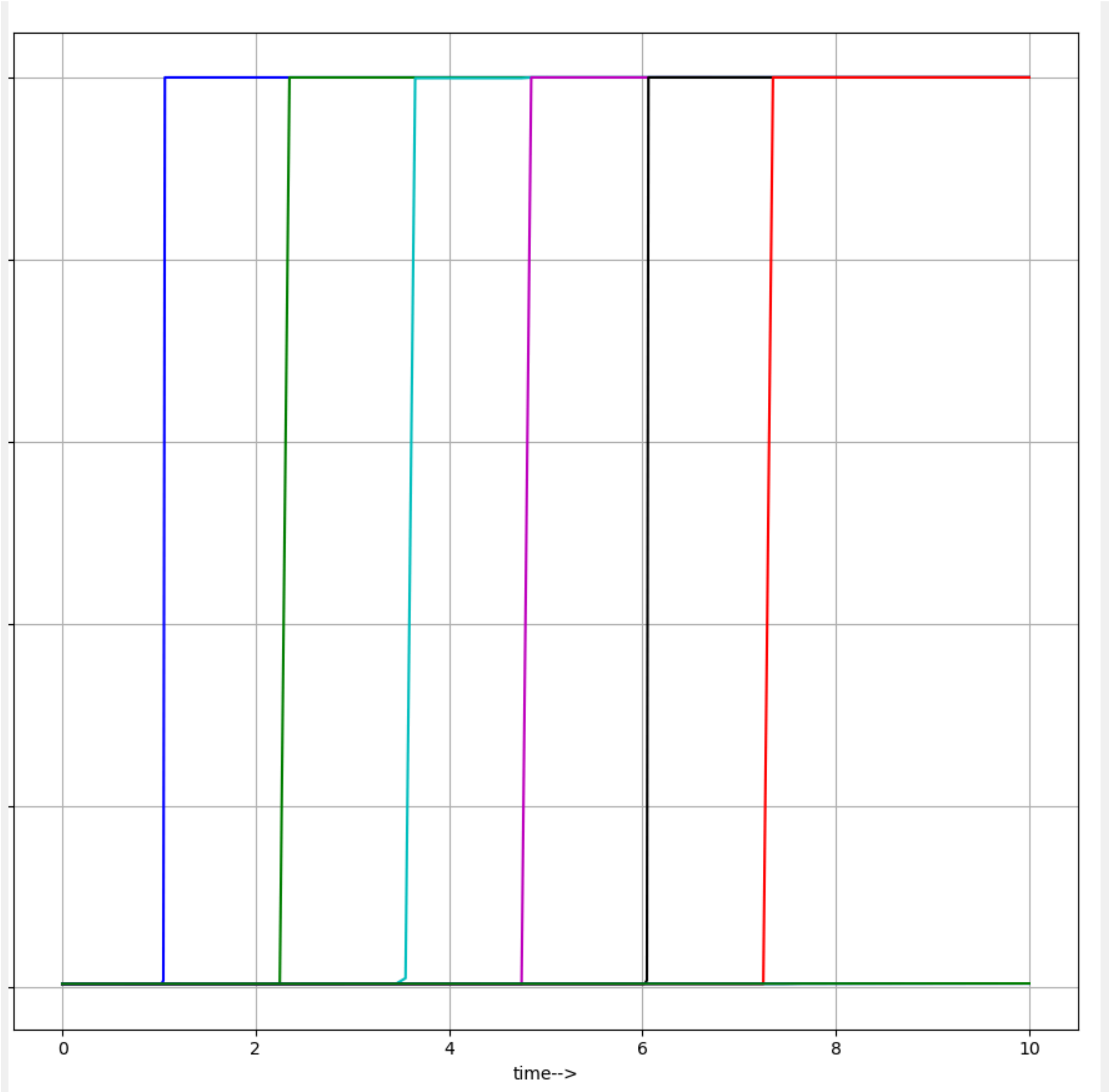
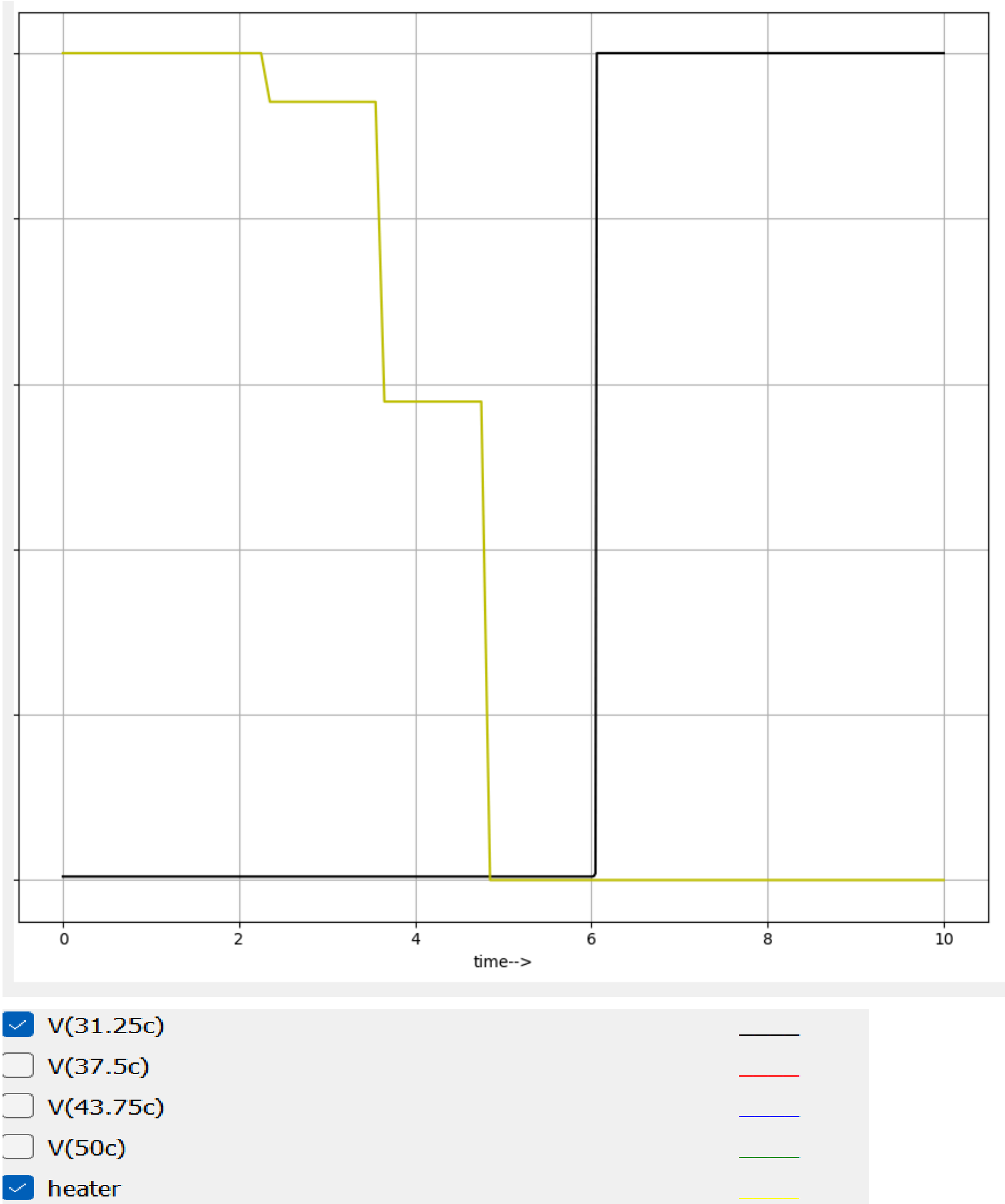
6. Comparator Stage Using LM393

The LM393 comparator is used to compare the amplified temperature signal with each reference voltage from the resistor ladder. When the sensor voltage exceeds a reference level, the comparator output switches its state. Since the LM393 has an open-collector output, pull-up resistors are used to obtain valid logic-level outputs. This stage effectively converts the analog temperature information into multiple digital signals representing different temperature ranges.



7. Logic Control Using CMOS Gates

CMOS NAND gates are employed to process the digital outputs of the comparators. Logical combinations of comparator outputs determine whether the heater or fan should be activated. The heater is enabled during low-temperature conditions, while the fan is activated when the temperature exceeds the upper threshold. In intermediate temperature ranges, both outputs remain disabled. This logic-based approach enables automatic HVAC control without software intervention.



8. Output Stage and Simulation Results

The system outputs are monitored using simulation probes and LED indicators. The heater output is observed to activate during low-temperature conditions and deactivate as temperature rises. Conversely, the fan output remains inactive at lower temperatures and turns ON when the temperature crosses the high threshold. The simulation waveforms clearly demonstrate correct system behavior and validate the effectiveness of the proposed design.

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9. Applications

- Residential and commercial HVAC systems
- Industrial temperature monitoring and control
- Instrumentation and automation systems
- Educational demonstration of analog and digital electronics
- Sensor-based control systems

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10. Conclusion

A complete multi-level temperature-based HVAC control system was successfully designed and simulated using eSim. The project demonstrates effective integration of temperature sensing, signal conditioning, comparator-based decision making, and logic control using fundamental electronic components. Simulation results confirm accurate operation and reliable control of heating and cooling outputs. This work highlights the feasibility and importance of circuit-level control systems in practical and educational applications.

References

🔗 **LM35 Precision Temperature Sensor Datasheet**
• PDF datasheet (Texas Instruments / hosted copy): LM35 Precision Centigrade Temperature Sensor Datasheet (PDF) (Datasheet4U)

• Official product page for LM35 (datasheet links available there): LM35 Product Page – TI.com (Texas Instruments)

🔗 **LM321 Operational Amplifier Datasheet**
• LM321 Low Power Single Op Amp (PDF hosted copy): LM321 Operational Amplifier Datasheet (PDF) (ALDATASHEET)
• Official product page where the datasheet can be downloaded: LM321 Product Page – TI.com (Texas Instruments)

🔗 **LM393 Comparator Datasheet**
• LM393 Dual Comparator Datasheet (PDF hosted copy): LM393 Comparator Datasheet (PDF) (AllDatasheet)
• Official LM393 product page with datasheet links: LM393 Product Page – TI.com (Texas Instruments)

Project link;

https://drive.google.com/drive/folders/1SrtcKjgjxaQf00NaalYY4jWWdaYU_kl4?usp=sharing