

Comparative analysis of versatile temperature-controlled systems using fuzzy logic controllers

Ivan I. Gorial*

Control and Systems Engineering
Department, University of
Technology, Baghdad, Iraq

*E-mail: Ivan.I.Gorial@uotechnology.
edu.iq

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Abstract

This article presents a comparison of versatile temperature-controlled systems utilizing fuzzy logic (FL) controller, highlighting their unique functionalities and verifying objectives. The meditate focuses on the following four primary systems: a temperature-controlled fan system, a temperature-controlled warmer system, a cool-controlled warmer system, and a cool-controlled fan system. The primary quill function of each system, control objectives, identify stimulant and output variables, response characteristics, normal applications, system complexity, vitality efficiency, and situation suitability are examined. The temperature-controlled fan system primarily cools by regulation airflow, achieving a mean temperature error of -0.0319°C . The temperature-controlled heater system heats the environment, with a mean temperature error of 1.4696°C . The cool-controlled heater system of rules prevents overheating by modulating heat output and maintains a stable environment, while the cool-controlled fan system of rules maintains a tankful undefined by increasing airflow. Differences in system complexity with fan systems managing humidness and warmer systems focused on a temperature increase are noted. The wallpaper provides a comprehensive overview, making it clear how each system of rules is the best right for particular conditions and applications.

Keywords

FL controller control, temperature, cooling, fan, heater, mechatronics engineering

1. Introduction

Integration fuzzy logic controller (FLC)-based temperature and cooling control systems in mechatronics technology importantly advances precise and energy-efficient temperature regulation. FLC systems tackle complex, non-linear control problems in varied applications, such as heating, ventilation, and air conditioning (HVAC), industrial processes, and electronic cooling systems. This paper evaluates the following four systems: a temperature-controlled fan, a temperature-controlled heater, a cool-controlled heater, and a cool-controlled fan, analyzing their control objectives, response characteristics, and application

suitability. FL, introduced by Zadeh [1], addresses uncertainty and imprecision and linguistic rules to mimic human decision-making, making FLCs adaptable and resilient. These systems present improved energy efficiency, verified precision, and the power to wield moral force environments without detailed mathematical models. The temperature-controlled fan system adjusts airflow to wield desired temperatures and apotheosis to prevent data center overheating. The temperature-controlled warmer modulates ignite output for homogenous warming in residential and industrial spaces. The cool-controlled heater prevents overheating by regulating heat and ensuring

safe conditions. The cool-controlled fan maintains cooler environments, which is essential for electronic cooling and HVAC systems. This meditate highlights the significant potential of FL-based systems in an onward temperature rule in mechatronics [2–20].

The design and development of temperature-controlled and cool-controlled fan and heater systems have been the focus of extensive research in recent years. These systems aim to provide efficient and well-informed temperature regulation, undefined to the growing demand for energy-efficient and user-friendly mood control solutions. Many studies have explored the design and implementation of temperature-controlled fan systems.

Nyiekaa et al. [21] presented the design and construction of a temperature controller system that is capable of maintaining an enclosed area temperature to a desired value.

Similarly, Ahmad et al. [22] investigated the challenges of cancelling the ventilation system in warm climates, highlighting the importance of thermal comfort, heat wave resilience, and indoor air quality, which can be addressed through the development of advanced temperature-controlled fan systems.

Furthermore, researchers have explored the integration of inexhaustible vitality sources, such as star power, with temperature-controlled winnow systems. Ramasubramanian et al. [23] developed a temperature-controlled solar-powered ventilating system that adjusts the winnow speed based on the ambient temperature, demonstrating the potential for energy-efficient and property cooling system solutions. The design and implementation of temperature-controlled heater systems have also been the subject of extensive research. These systems are able to exert a desired temperature by automatically adjusting the heating yield based on the measured ambient conditions.

A study by Jiang and Ding [24] presented the design and construction of an automatic temperature control system capable of maintaining a specified temperature in an enclosed area.

Similarly, Ding and Li [25] explored the temperature distribution control in boom furnaces, highlighting the importance of microscopic temperature regulation in industrial processes.

Researchers have also investigated the integration of advanced control algorithms, such as FLC, to raise the performance of temperature-controlled warmer systems.

Kang and Ahn [26] developed a FLC-based temperature control system of rules for a dying process,

demonstrating the effectiveness of this approach in maintaining the wanted temperature and improving vim efficiency.

In addition to temperature-controlled fan systems, researchers have as well explored the development of cool-controlled fan systems. These systems aim to use a comfortable indoor undefined by adjusting the fan speed based on the sensed cooling sensory faculty rather than just the close temperature.

Luhung et al. [27] investigated the integration of cool-controlled fan systems with natural ventilating system strategies, highlighting the importance of considering both thermal comfort and indoor air quality. The plan and implementation of cool-controlled heater systems have also been a research. These systems focalize on maintaining a wide caloric sensation by adjusting the warming yield based on the sensed coolness rather than just the ambient temperature.

Schuster et al. [28] explored the desegregation of cool-controlled heating systems with building automation, demonstrating the potential for improved vitality undefined and user satisfaction.

Overall, the literature review highlights the ontogeny interest and advancements in the area of temperature-controlled and cool-controlled winnow and heater systems. Researchers have explored various approaches, including the integrating of sensors, microcontrollers, and sophisticated control algorithms, to prepare intelligent and energy-efficient climate control solutions.

The plan and development of temperature-controlled fan systems have been an active orbit of research in recent years. Some studies have been conducted to improve the efficiency, intelligence, and multi-functionality of these systems.

Ahmad and Kumar [29] presented the plan and twist of an automatic temperature control system susceptible of maintaining a desired temperature in an enclosed area, which can be practical to temperature-controlled fan systems.

Ibrahim et al. [30] designed and enforced an automatic room temperature-controlled fan using an Arduino Uno and an LM35 heat sensor, allowing the fan speed to set mechanically supported on temperature changes.

These studies exhibit the ongoing efforts to create intelligent, energy-efficient, and user-friendly temperature-controlled fan systems that can raise thermal comfort and interior air quality.

The current problem or the motive of this paper lies in the fast advancement of mechatronics

engineering, which has heightened the demand for efficient and punctilious temperature control systems. While traditional verification systems are effective to some extent, they often fight with the complexities and non-linearities implicit in modern temperature regulation tasks. With heavy-duty processes and electronic cooling applications becoming progressively intricate, thither is an imperative need for innovative solutions that offer superior control precision, vim efficiency, and adaptability to changing conditions. Incoherent logic-based control systems undefined as a likely alternative, employing science rules and human-like logical thinking to address complex control challenges without relying to a great extent on careful mathematical models. This capacity proves especially valuable in environments where temperature fluctuations can significantly impact process efficiency, safety, and undefined lifespan. This study aims to research the potentiality of FLC in delivering cost-effective, reliable, and adaptable solutions for temperature and cooling system of rules control across diverse mechatronics applications.

Our study is motivated by the need to enhance the efficiency and reliability of temperature verification systems crosswise various applications, including residential, industrial, and physical science cooling. Traditional methods often rely on intolerant mathematical models and fight in dynamically changing environments. Fuzzy Logic (FL) controllers offer a more adaptive approach, capable of optimizing vitality efficiency, achieving hairsplitting temperature control, and reduction operational costs. Their flexibility and adaptability work them suitable for diverse real-world scenarios. This research aims to demonstrate the potential of Sunshine State controllers in advancing temperature control applied science in mechatronics engineering.

The primary objective of this paper is to assess the effectiveness and cost-efficiency of FL-based temperature and cooling verify systems within the field of mechatronics engineering. Through an undefined analysis of various verify systems such as temperature-controlled winnow and heater systems, as well as cool-controlled heater and fan systems, the contemplate aims to underscore their distinct functionalities, advantages, and potential applications. The overarching goal is to offer a comprehensive insight into how these systems tin be deployed to enhance control precision, decrease energy consumption, and optimize boilers suit system public presentation across industrial and act settings. The study promote seeks to analyze how FLCs execute in regulating temperature and cooling system systems,

evaluating different systems based on their response characteristics, control strategies, and vitality efficiency. Additionally, it examines the potential cost savings of adopting fuzzy system of logic controllers over traditional methods, while identifying appropriate applications considering system of rules complexity, vim efficiency, and environmental factors. Practical implementation guidelines for FL-based temperature control systems in mechatronics technology are also provided, addressing describe plan considerations and potential implementation challenges.

Identified research gaps, through this expanded literature review, we identified several gaps that our study addresses: Comparative Analysis of FLC-Based Systems: While many studies focus on individual applications of FLCs, there is a lack of comparative analysis across different types of temperature-controlled systems. Our study fills this gap by providing a detailed comparison of temperature-controlled fan, heater, cool-controlled fan, and cool-controlled heater systems, all utilizing FLCs.

Energy Efficiency in FLC Systems: Although energy efficiency is often mentioned in the context of FLCs, few studies provide a comprehensive evaluation of how FLCs impact energy consumption across different systems. Our research contributes by analyzing the energy efficiency of each system and discussing how FLCs can be optimized for better performance.

Adaptability and Precision: Traditional controllers often struggle with non-linear dynamics and rapidly changing environments. While FLCs are known for their adaptability, there is limited research comparing their effectiveness in various environmental conditions. Our study addresses this by evaluating how different FLC-based systems respond to changing temperatures and how they maintain control precision.

This paper is structured into five main sections, each addressing a vital aspect of the study: In Section I: Presentation provides an overview of temperature and cooling control systems in mechatronics, highlighting FLC controllers' advantages in plus to literature reexamine that reviews recent research in FLC-based temperature verification systems. Segment II: System methodology and controller design detail the design and implementation of four temperature control systems using incoherent logic controllers. Section III: Simulation results and discussion. Section IV: Performance evaluation and comparison analyses of system performance based on response characteristics and vim efficiency and in Section V: Conclusion.

II. System methodology and controller design

This section explains the mathematical models and the FLCs used for various temperature control systems. These systems include a temperature-controlled fan system, a temperature-controlled heater system, a cool-controlled fan system, and a cool-controlled heater system. Each system utilizes a fuzzy inference system (FIS) to determine the control actions based on input variables such as temperature error and rate of temperature change. This section details the unquestionable models and FLCs used in the following four temperature control systems: a temperature-controlled fan system, a temperature-controlled heater system, a cool-controlled fan system, and a cool-controlled heater system. Each system employs a fuzzy inference system (FIS) to set control actions supported on stimulant variables such as temperature inappropriate behavior and the rate of temperature change. The FLCs demonstrate the ability to handle non-linear and undefined temperature control problems effectively, adjusting system outputs based on linguistic rules that mimic human being reasoning. The system of rules designs highlight the adaptability and efficiency of FLCs in real-world engineering applications, providing robust and sensitive verify solutions. Figure 1 presents a block representation of a knowledge-base and inference engine, likely used within the context of FLC controllers for temperature control systems.

a. Temperature-controlled fan system

For the temperature-controlled fan system, the FIS is designed with two input variables: Error and Change

in Error (Delta Error). These inputs represent the difference between the desired and actual temperature and the rate of change of this error, respectively.

The input variable Error is defined with a range of $[-10, 10]$ $[-10, 10]$ $[-10, 10]$ and has the following three membership functions: Negative, Zero, and Positive, each represented by triangular membership functions (trimf).

Similarly, the Delta Error variable is defined within the range $[-5, 5]$ $[-5, 5]$ $[-5, 5]$ and also has the following three membership functions: Negative, Zero, and Positive.

The output variable is Fan Speed, ranging from $[0, 100]$ $[0, 100]$ $[0, 100]$ and defined by the following three membership functions: Low, Medium, and High.

The rules for the FIS are structured to control the fan speed based on combinations of Error and Delta Error.

For instance, if both the Error and Delta Error are negative, the fan speed is set to low; if the Error is zero and the Delta Error is positive, the fan speed is high. This structure ensures that the fan adjusts its speed to maintain the desired temperature by cooling down the system when necessary.

Mathematically, the cooling effect is calculated as a function of the fan speed and the temperature difference:

- o Basic assumptions:
 - The cooling effect is directly proportional to the difference between the actual temperature T_{actual} and the set temperature T_{set} .
 - The cooling effect is also proportional to the fan speed, which determines how much air is

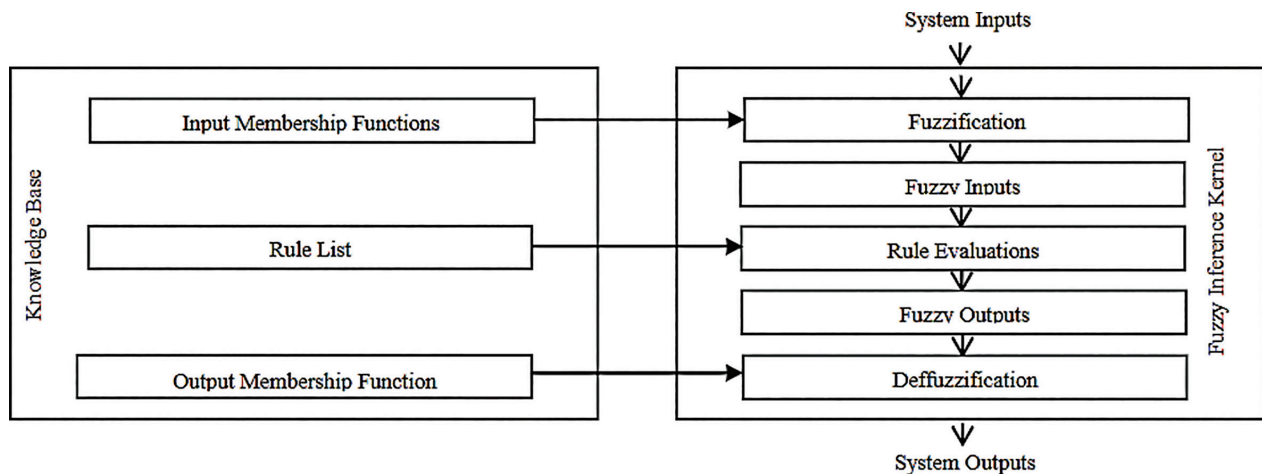


Figure 1: Block representation of a knowledge-base and inference engine.

moved by the fan and consequently how much heat is removed.

o Formulation:

- The cooling effect can be considered as a product of the following two main factors: the temperature difference and the normalized fan speed. Mathematically, we can write:

$$\text{cooling_effect} \propto (T_{\text{actual}} - T_{\text{set}}) \times \frac{\text{fan_speed}}{100} \quad (1)$$

$$\text{cooling_effect} = k \times (T_{\text{actual}} - T_{\text{set}}) \times \frac{\text{fan_speed}}{100}$$

where, $k = 0.1$.

T_{actual} and T_{set} are the actual and desired temperatures, respectively.

Figures 2, 3, and 4 illustrate the FLC design for a temperature-controlled fan system.

A rule base for a temperature-controlled fan system, employing FLC to determine the appropriate fan speed based on error and delta error values. These rules are essential for translating temperature deviations and their rates of change into actionable control signals.

The following are the six rules of those nine rules.

If both Error and Delta Error are Negative, then Fan Speed is Low.

If Error is Negative and Delta Error is Positive, then Fan Speed is Medium.

If Error is Zero and Delta Error is Negative, then Fan Speed is Low.

If Error is Zero and Delta Error is Positive, then Fan Speed is High.

If Error is Positive and Delta Error is Negative, then Fan Speed is Medium.

If Error is Positive and Delta Error is Zero, then Fan Speed is High.

The rule base effectively captures the dynamic force nature of temperature verification using FLC. By adjusting the fan speed based on e and its Δe , the system ensures a equal and sensitive approach to maintaining the desired temperature. This frame-up highlights the flexibility and precision that the FLC system brings to temperature control systems.

b. Temperature-controlled heater system

The temperature-controlled heater system is modeled similarly to the fan system but focuses on heating. The FIS for this system includes the following input variables, Temp Error and Temp Change Rate, which represent the temperature error and its rate of change.

Temp Error ranges from $[-10, 10]$ $[-10, 10]$ $[-10, 10]$ and has the following five membership functions: Very Cold, Cold, OK, Hot, and Very Hot, represented

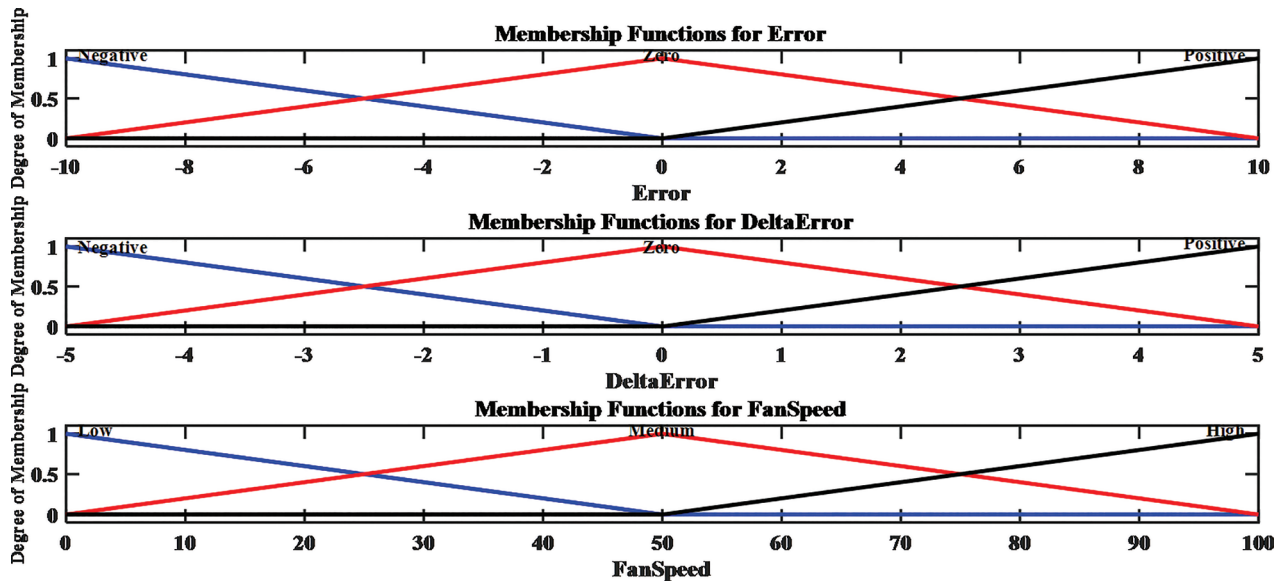


Figure 2: FLC for a temperature-controlled fan system: input and output membership functions. FL, fuzzy logic; FLC, fuzzy logic controller.

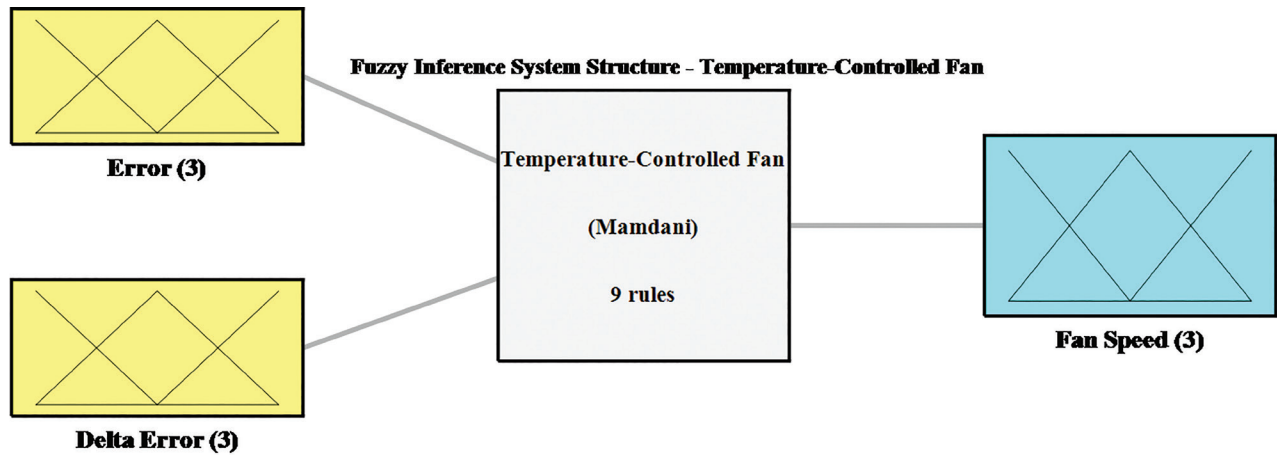


Figure 3: FLC-based temperature control for a fan system structure: inputs and output regulation. FL, fuzzy logic.

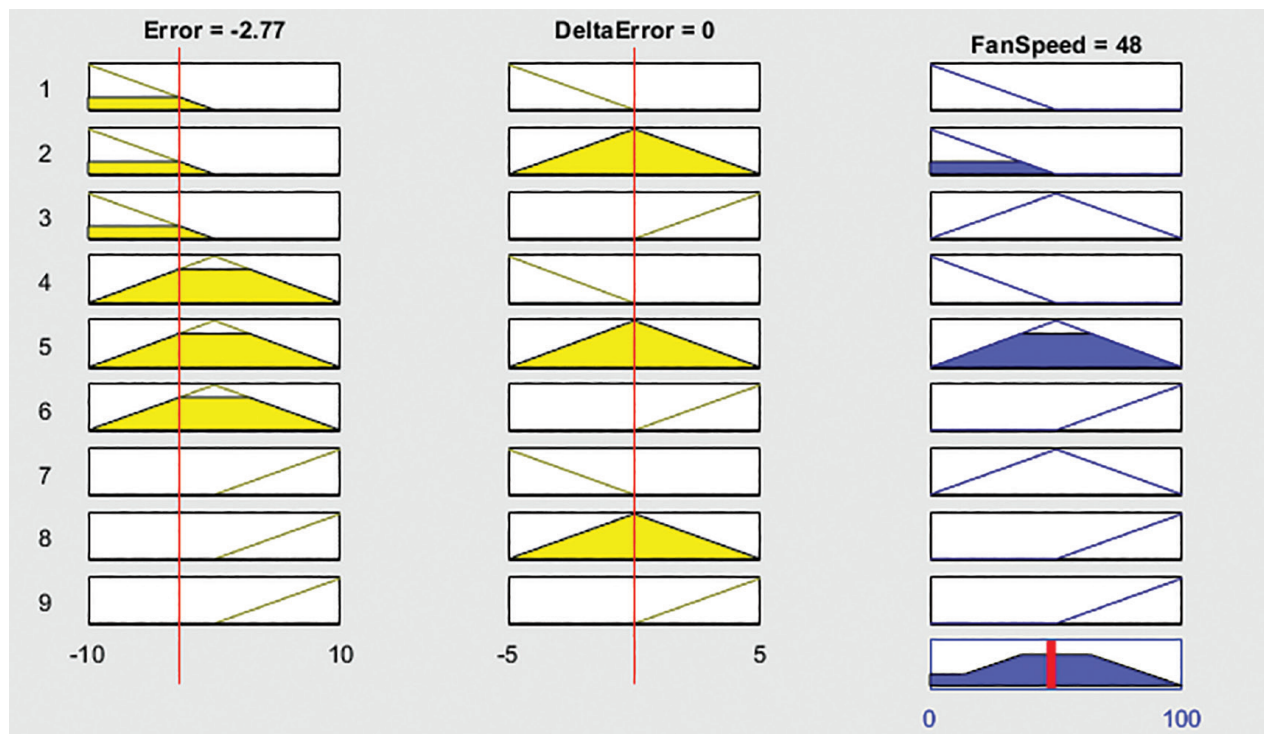


Figure 4: FIS for temperature-controlled fan: membership functions and rule base.

by a combination of trapezoidal (trapmf) and triangular (trimf) membership functions.

Temp Change Rate ranges from $[-5, 5]$ $[-5, 5]$ $[-5, 5]$ and includes membership functions such as Rapid Cooling, Cooling, Stable, Heating, and Rapid Heating.

The output variable is Heater Power, defined in the range $[0, 100]$ $[0, 100]$ $[0, 100]$ with the following five membership functions: Very Low, Low, Medium, High, and Very High.

The fuzzy rules dictate the heater power based on the inputs. For example, if the Temp Error is Very Cold

and the Temp Change Rate is Rapid Cooling, the Heater Power is set to Very High to quickly increase the temperature. The heater power influences the temperature change as follows:

$$T_{\text{current, new}} = T_{\text{current}} + k_1 \times (T_{\text{desired}} - T_{\text{current}}) \times \frac{\text{heater_power}}{100} + k_2 \times (T_{\text{ambient}} - T_{\text{current}}) \quad (2)$$

where, $k_1 = 0.1$, $k_2 = 0.01$, T_{ambient} is the ambient temperature.

Figures 5, 6, and 7 show the FLC design for a temperature-controlled heater system.

The rules adjust the heater power based on temperature conditions and their value of change to maintain optimal comfort and energy efficiency. Higher great power settings react to fast cooling in very cold conditions, while lower settings undefined

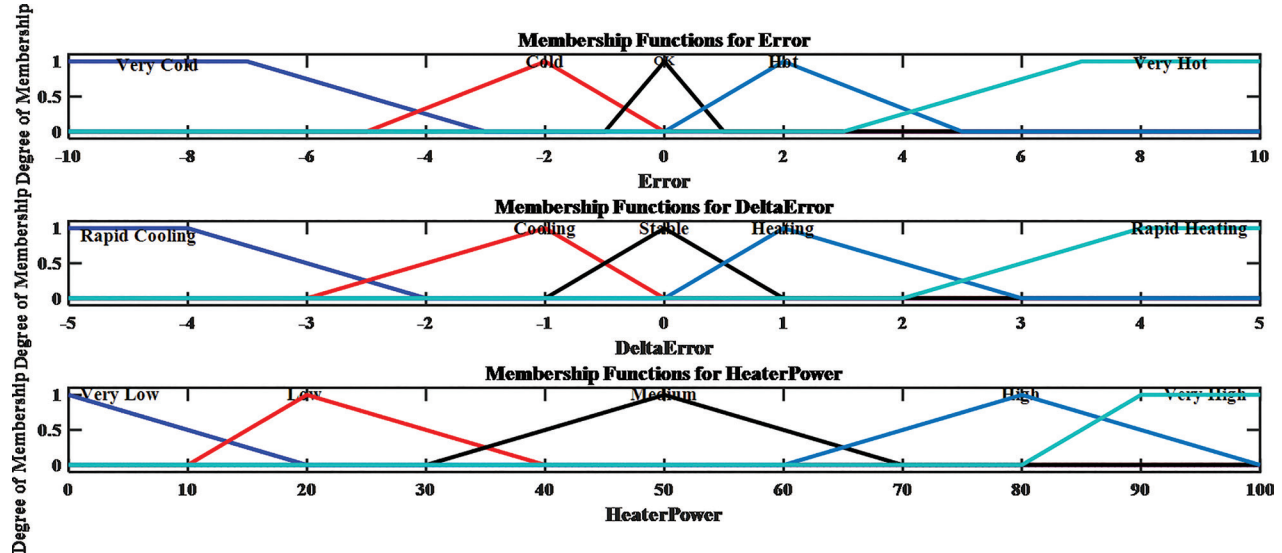


Figure 5: FLC for a temperature-controlled heater system: input and output membership functions. FL, fuzzy logic; FLC, fuzzy logic controller.

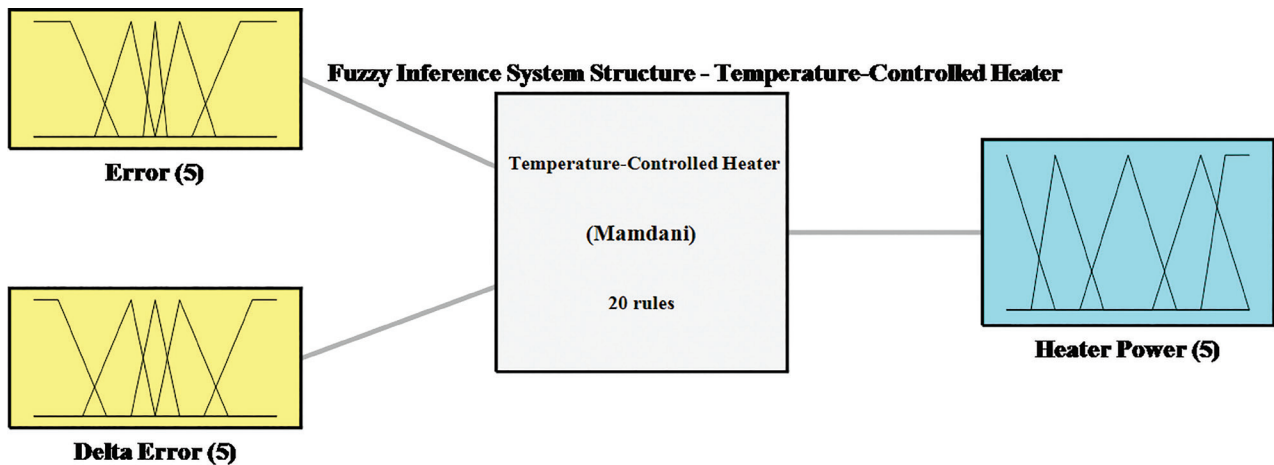


Figure 6: FLC-based temperature control for a heater system structure: inputs and output regulation. FL, fuzzy logic.

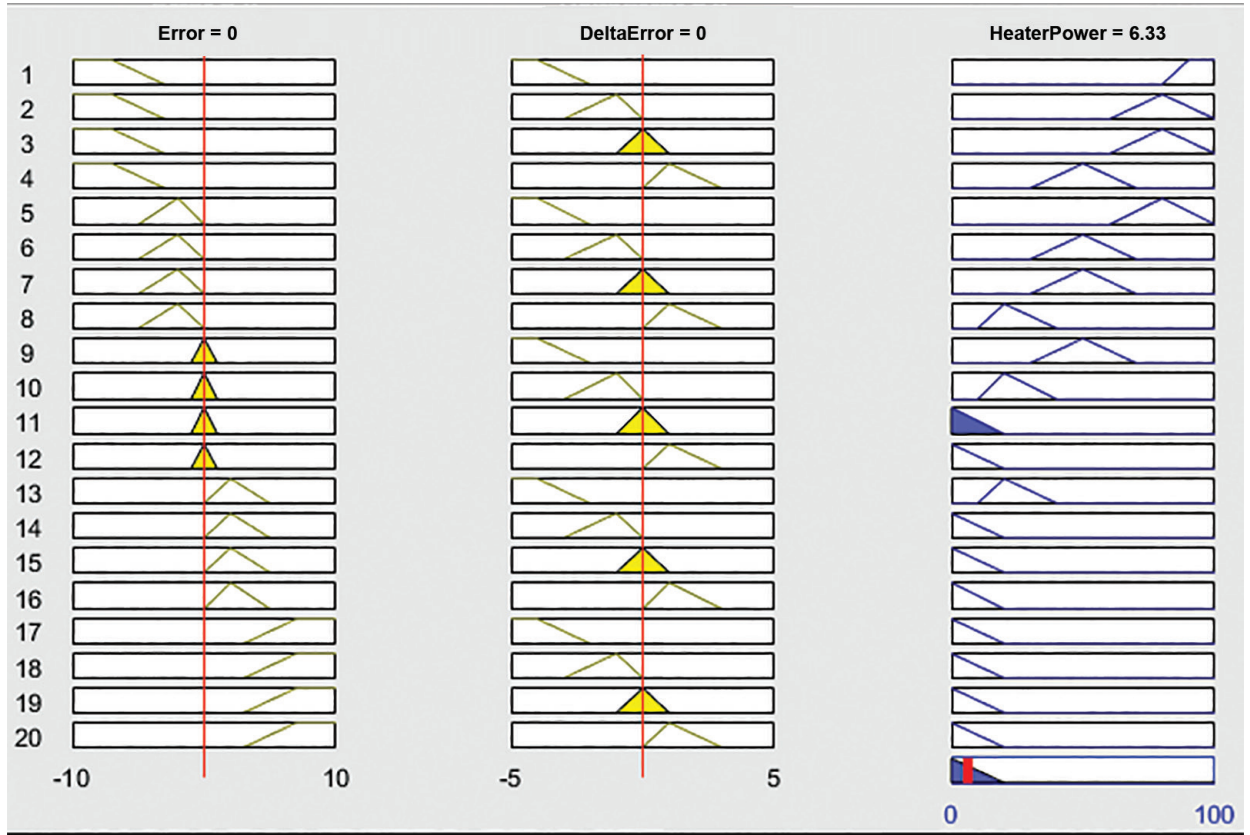


Figure 7: FIS for temperature-controlled heater: membership functions and rule base.

energy when temperatures are stable or hot. This approach ensures a balanced and adaptive temperature control system.

The following are the 13 rules of those 20 rules.

If the temperature is Very Cold and it is Rapidly Cooling, set the Heater Power to Very High.

If the temperature is OK and it is Heating, set the Heater Power to Very Low.

If the temperature is Hot and it is Rapidly Cooling, set the Heater Power to Low.

If the temperature is Cold and it is Cooling, set the Heater Power to Medium.

If the temperature is Cold and it is Stable, set the Heater Power to Medium.

If the temperature is Very Hot and it is Cooling, set the Heater Power to Very Low.

If the temperature is Very Hot and it is Stable, set the Heater Power to Very Low.

These rules ensure that the heater power is adjusted according to the current temperature and the rate of change of the temperature to maintain a comfortable environment efficiently.

c. Cool-controlled fan system

In the cool-controlled fan system, the FIS considers the Temperature and the Temperature Rate of Change. The Temperature input ranges from [0, 40] [0, 40] [0, 40] with the following membership functions: Low, Medium, and High. The Temperature Rate of Change is within [-5, 5] [-5, 5] [-5, 5], represented by the following membership functions: Cooling, Stable, and Heating.

The output variable Fan Speed is defined from [0, 100] [0, 100] [0, 100] with the following four membership functions: Off, Low, Medium, and High. The fuzzy rules for this system ensure that the fan speed adjusts to maintain a cooler environment based on the temperature and its rate of change.

The temperature change in this system is influenced by:

$$T_{\text{new}} = T_{\text{current}} - k_3 \times (T_{\text{desired}} - T_{\text{current}}) \times \frac{\text{fan_speed}}{100} + k_4 \times (T_{\text{ambient}} - T_{\text{current}}) \quad (3)$$

where k_3 and k_4 are constants that represent the effects of fan speed and ambient temperature. The fan speed reduces the system's temperature, while the ambient temperature influences it based on the difference between the system and ambient temperatures.

Where $k_3 = 0.1$, $k_4 = 0.05$.

Figures 8, 9, and 10 clarify the FLC design for a cool-controlled fan system.

These rules modulate the fan speed based on the temperature and its rate of change. Higher fan

speeds are used in high-temperature conditions to enhance cooling, while the fan is turned off in low-temperature conditions to conserve energy and avoid unnecessary cooling. This ensures efficient and responsive control of the cooling system. The following are the six rules of those nine rules.

If the temperature is High and it is Cooling, set the Fan Speed to High.

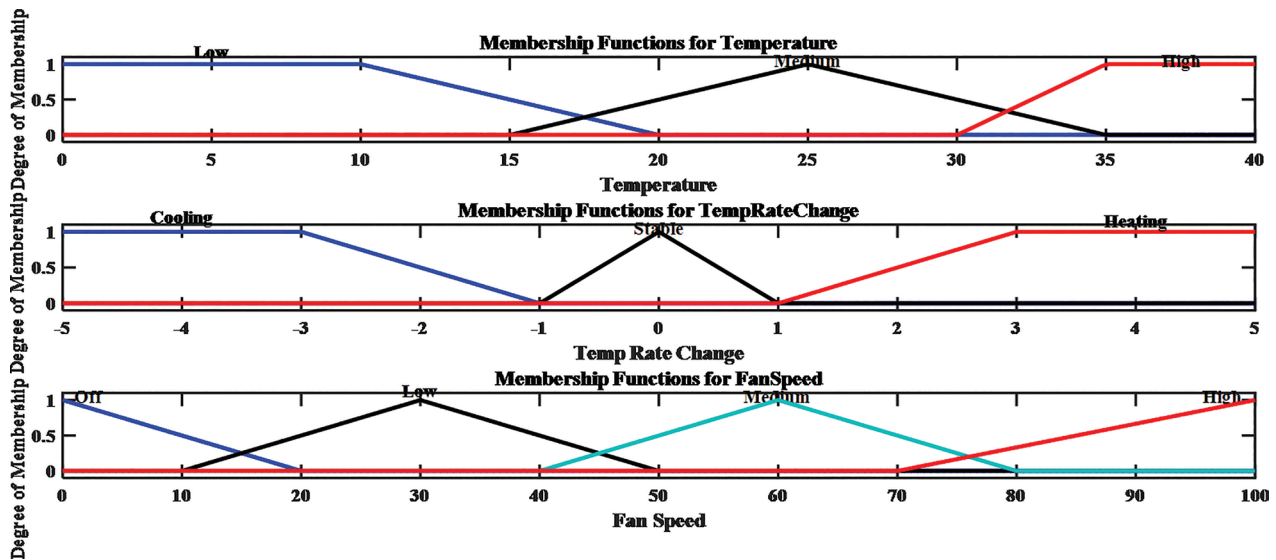


Figure 8: FLC for a cool-controlled fan system: input and output membership functions. FL, fuzzy logic; FLC, fuzzy logic controller.

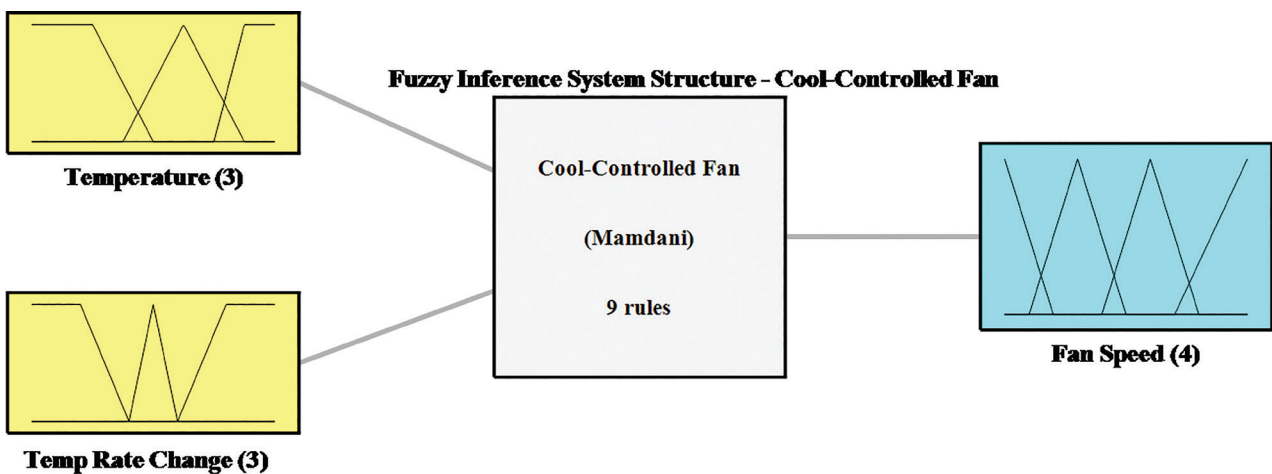


Figure 9: FLC-based cool control for a fan system structure: inputs and output regulation. FL, fuzzy logic; FLC, fuzzy logic controller.

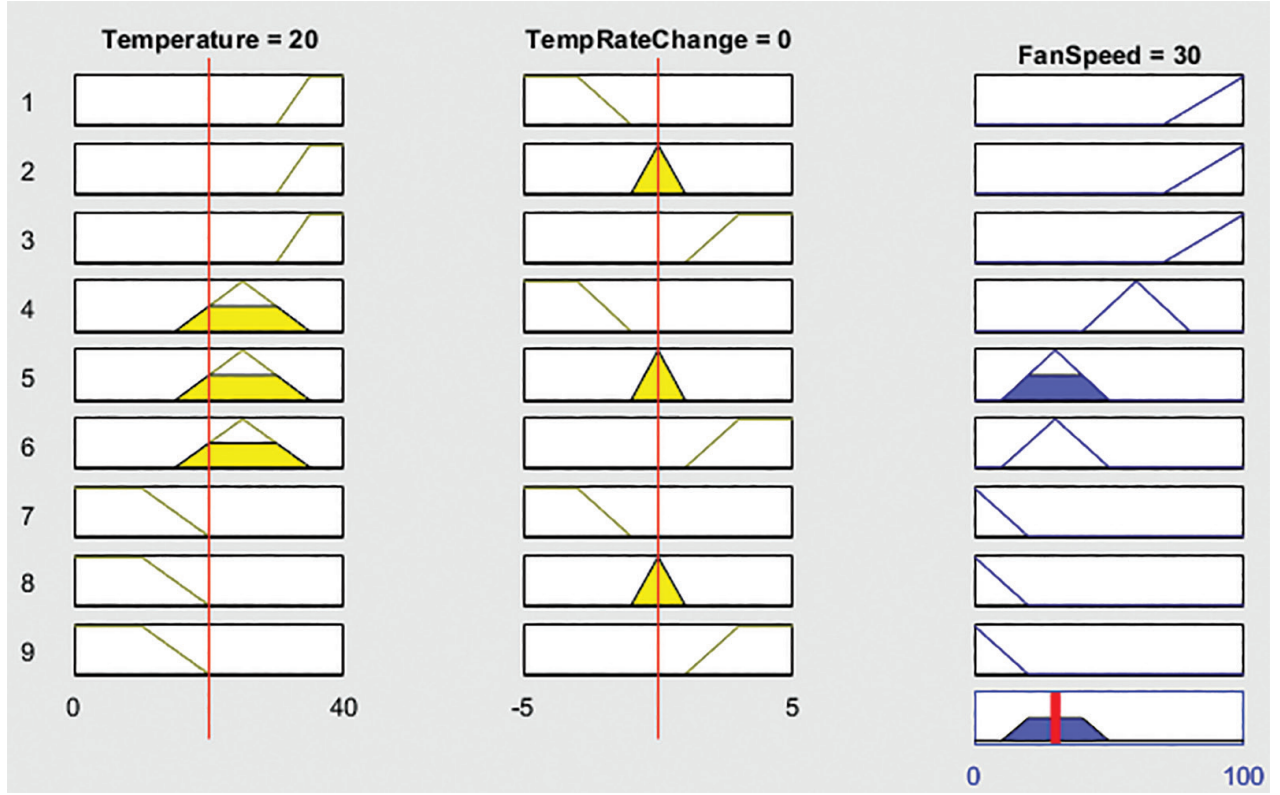


Figure 10: FIS for cool-controlled fan: membership functions and rule base.

If the temperature is High and it is Heating, set the Fan Speed to High.

If the temperature is Medium and it is Cooling, set the Fan Speed to Medium.

If the temperature is Medium and it is Heating, set the Fan Speed to Low.

If the temperature is Low and it is Cooling, turn the Fan Off.

If the temperature is Low and it is Stable, turn the Fan Off.

The heater power adjustment rules ensure appropriate heating to maintain the desired temperature:

$$T_{\text{new}} = T_{\text{current}} - k_5 \times \left(\frac{\text{heater_power}}{100} \right) + k_6 \times (T_{\text{ambient}} - T_{\text{current}}) \quad (4)$$

Figures 11, 12, and 13 show the FLC design for a cool-controlled heater system.

Where k_5 and k_6 are constants that determine the contributions of heater power and ambient temperature and are equal to 0.05 and 0.1, respectively. This equation models how the heater power and ambient temperature affect the system's temperature.

Each of these systems demonstrates the flexibility and effectiveness of FLC controllers in handling non-linear, complex temperature control problems. The controllers adjust the system based on linguistic rules that mimic human reasoning, making them robust and flexible to varied control scenarios.

So, the equations and FLC presented in this study demonstrate a comprehensive approach to

d. Cool-controlled heater system

For the cool-controlled heater system, the FIS uses the same input variables as the cool-controlled fan system but aims to maintain a controlled heating environment.

The Temperature input ranges from [0, 40] [0, 40] [0, 40] and the Temperature Rate of Change from [-5, 5] [-5, 5] [-5, 5].

The Heater Power output variable ranges from [0, 100] [0, 100] [0, 100] with the following membership functions: Off, Low, Medium, and High.

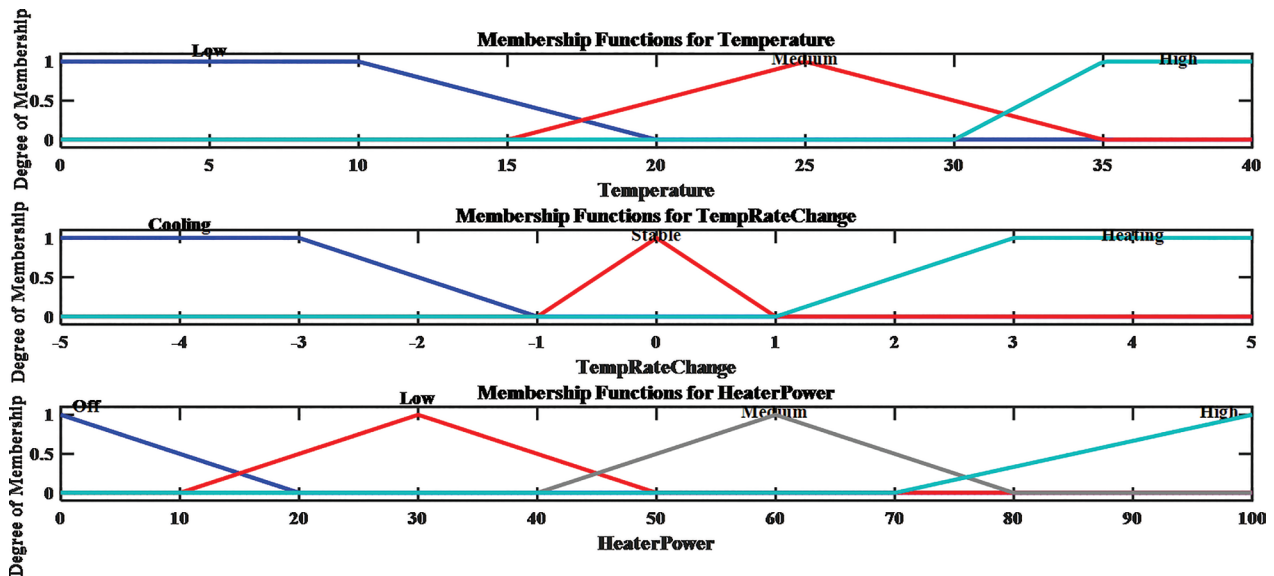


Figure 11: FLC for a cool-controlled heater system: input and output membership functions. FL, fuzzy logic; FLC, fuzzy logic controller.

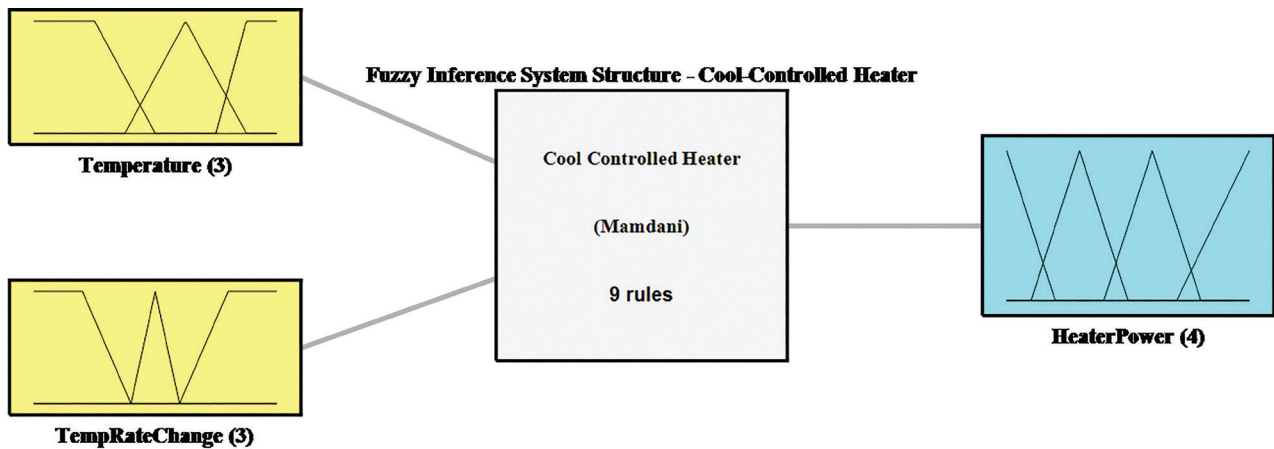


Figure 12: FLC-based cool control for a heater system structure: inputs and output regulation. FL, fuzzy logic; FLC, fuzzy logic controller.

temperature regulation across unusual systems. For each one, the controller uses a unique undefined of inputs and rules to ensure the wanted temperature is maintained effectively, casing the adaptability and efficiency of incoherent logic in handling undefined verify tasks. These systems serve as unrefined examples of how the incoherent system of the system of logic can be practical to real-world engineering problems, providing very and sensitive control solutions.

These rules adjust the heater power based on the current temperature and its rate of change. The

warmer is sour off when the temperature is high, disregardless of the rate of change, to undefined energy. As the temperature decreases, the heater super-power is gradually increased, ensuring competent and sensitive warming control.

The following are the seven of those nine rules.

If the temperature is High and it is Cooling, turn the Heater Power Off.

If the temperature is High and it is Stable, turn the Heater Power Off.

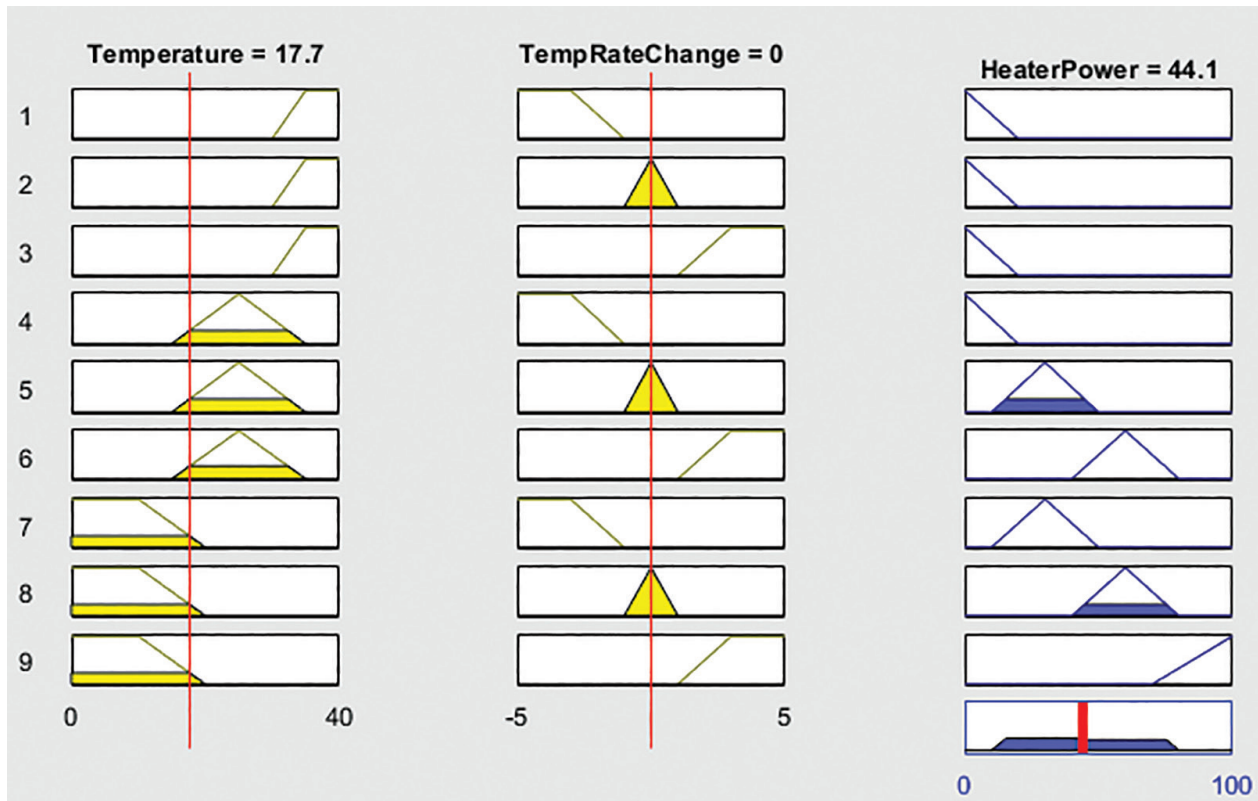


Figure 13: FIS for cool-controlled heater: membership functions and rule base.

If the temperature is Medium and it is Cooling, turn the Heater Power Off.

If the temperature is Medium and it is Stable, set the Heater Power to Low.

If the temperature is Low and it is Cooling, set the Heater Power to Low.

If the temperature is Low and it is Stable, set the Heater Power to Medium.

If the temperature is Low and it is Heating, set the Heater Power to High.

These detailed descriptions of the FL restrainer designs for each system demonstrate the preciseness and the adaptability of the control strategies employed in the study. By dynamically adjusting the outputs based on real-time temperature data and its rate of change, the systems effectively manage temperature with minimal vitality consumption, making them unsuitable for various industrial and residential applications.

Figure 14 presents the four 3D surface plots illustrating the relationships between versatile input variables and the corresponding control outputs for FLC controllers.

The top left plot shows the effect of error and delta error on fan speed.

The top-off-right plot depicts the impact of the temperature change rate and temperature error on heater power. The left plot displays the mold of the temperature rate change and temperature on fan speed, while the bottom plot illustrates the effect of the temperature rate change and temperature on heater power. These plots are necessary for understanding the controller's response to unusual error and value of transfer conditions.

III. Simulation results and discussion

The plots in Figure 15 display the performance of a temperature-controlled fan system managed by FLC over a 10-s interval. The fan speed initially rises rapidly from 44% to nearly 48% inside the first second, screening a swift response to the temperature difference. The system of rules successfully reduces the start temperature from 30°C to round 25°C, hitting the target without overshooting. The smooth curves of the fan speed and temperature plots suggest that the system is stable barn and the controller

Surface Views for Temperature Control Systems

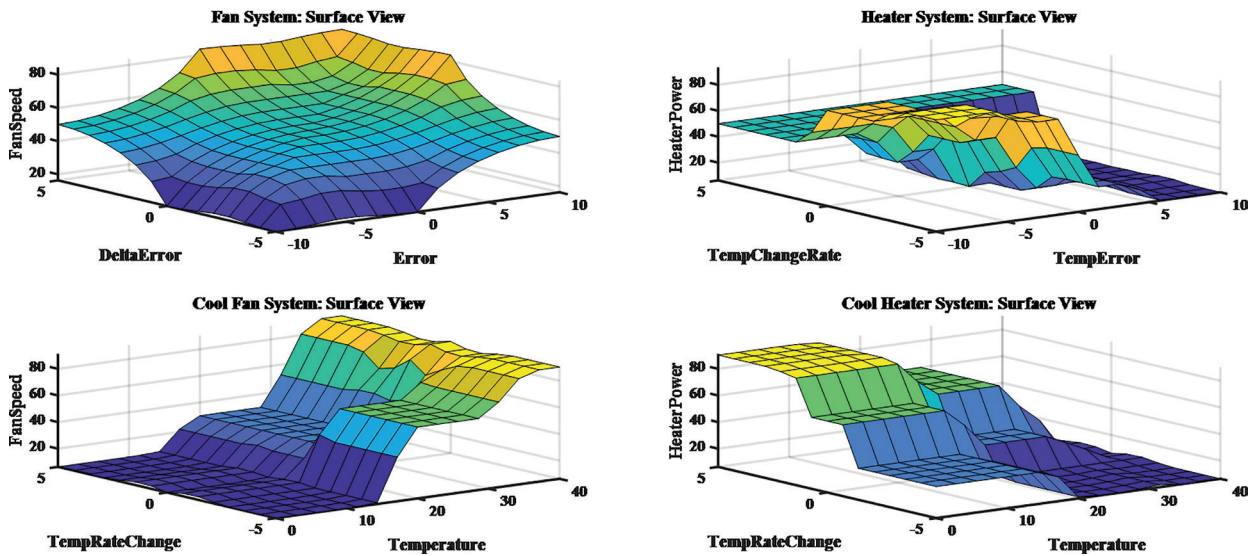


Figure 14: 3D FLC control surface plots for fan speed and heater power adjustments. FL, fuzzy logic; FLC, fuzzy logic controller.

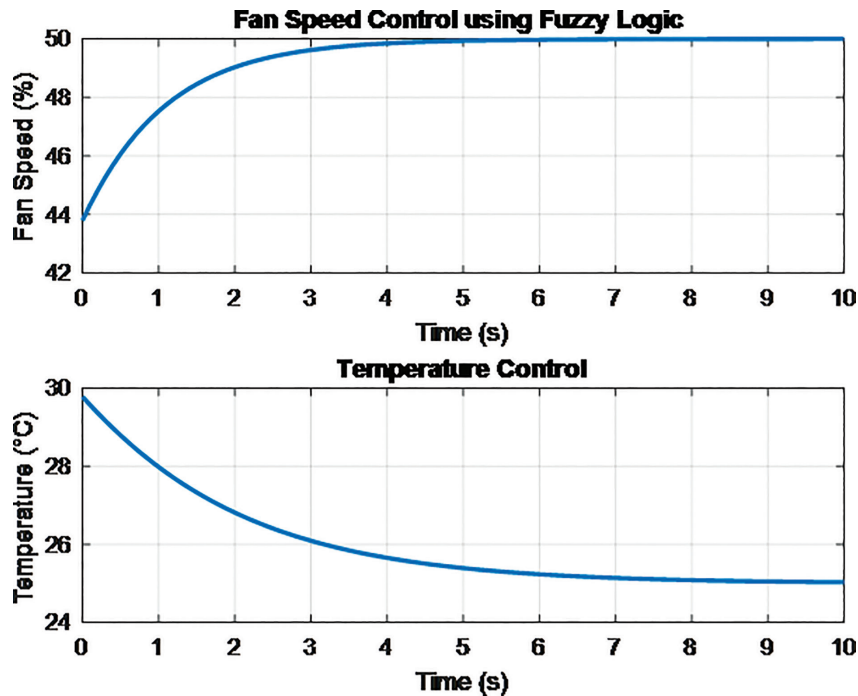


Figure 15: Temperature-controlled fan system using FLC. FL, fuzzy logic; FLC, fuzzy logic controller.

is well-tuned. The moderate error value of -0.0319 demonstrates a high accuracy. This system's effective management of temperature suggests that it is suitable for applications requiring precise environment control. Overall, the FL CONTROLLER

performs efficiently, achieving the desired temperature set point with minimal undefined and robust control.

The fan speed quickly adjusts to tighten the first temperature from 30°C to around 25°C within

the number 1 s, showing a stable and well-tuned response.

The system achieves the desired temperature with negligible error, indicating its suitability for precise environmental control.

The plots in Figure 16 illustrate the deployment of a temperature-controlled warmer system using the FL system controller.

The top graph shows the variation in the current temperature (solid blue line) compared to the ambient temperature (dashed red line) over a 10-s period. The ambient temperature fluctuates sinusoidally “tween 18°C and 22°C, creating a dynamic environment for the warmer to regulate. Despite these fluctuations, the current temperature remains relatively stable, averaging close to the desired temperature of 22°C simply ending somewhat lower at 20.842°C. This indicates that the FLC manages to keep the temperature within a specialized range, though not perfectly at the set point.

The bottom graph represents the heater power production as a percentage, which varies swimmingly between 6% and 7.5% in reply to the changing ambient temperature. The heater superpower graph shows minor adjustments over time, reflecting the system’s efforts to exert the desired temperature. The final warmer power stabilizes at 7.2501%, indicating a continuous moderate heating exertion to counteract the lower ambient temperature.

The think of temperature wrongdoing of 1.4696°C and a maximum error of 1.9873°C propose that the system maintains the temperature comparatively undefined to the desired set point just with some deviations undefined to the dynamic ambient conditions. These errors highlight the challenges in achieving perfect temperature control in a fluctuating environment. However, the overall performance of the FLC is commendable as it ensures a homogeneous temperature range despite the undefined variations. This demonstrates the controller’s robustness and ability to varying conditions while maintaining a reasonably stable internal environment.

The system maintains a stable temperature round the desired 22°C undefined unsteady ambient conditions. Heater superpower adjusts smoothly, demonstrating the system’s power to wangle temperature with moderate deviations due to dynamic ambient changes.

The plots in Figure 17 depict the performance of a cooling system restricted by an incoherent logic controller. The top graph compares the restricted temperature (solid bluing line) and the ambient temperature (dashed red line) over a 100-s period. The close temperature fluctuates around 25°C, varied between 15°C and 35°C in a sinusoidal pattern. Despite these substantial fluctuations in ambient temperature, the controlled temperature remains relatively stable,

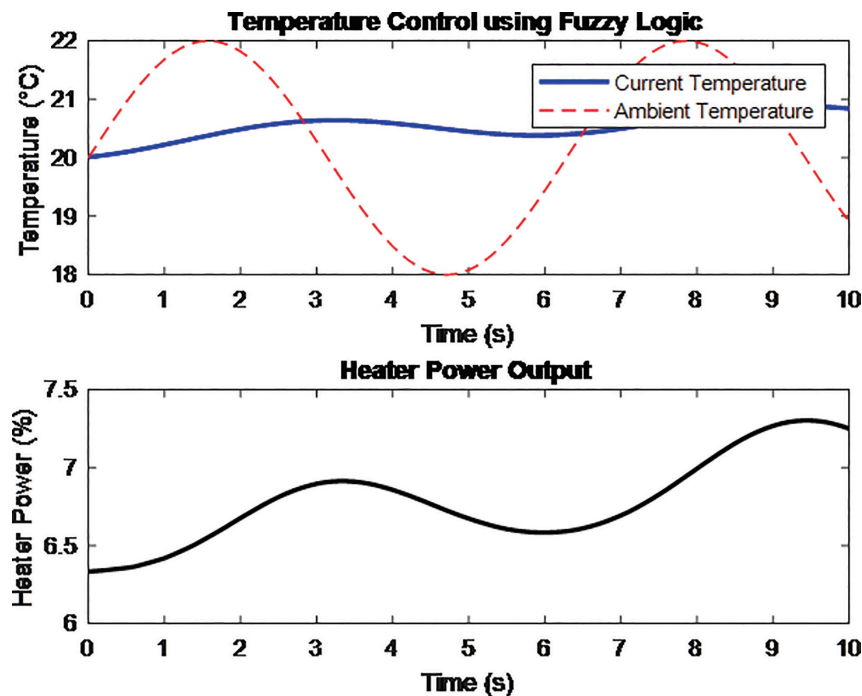


Figure 16: Temperature control performance and heater power output over time.

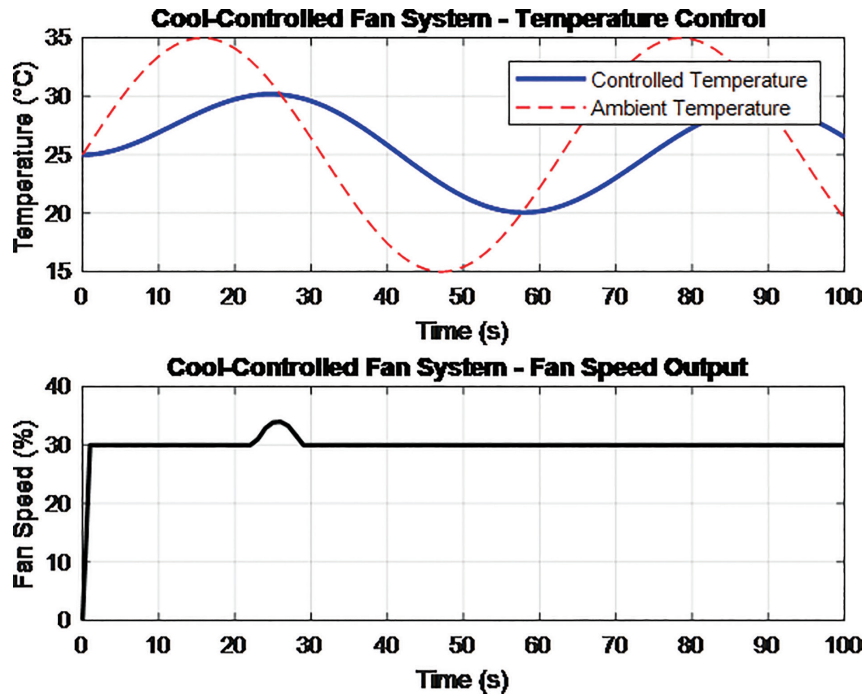


Figure 17: Cooling system performance: controlled temperature and fan speed over time.

primarily oscillating between 23°C and 28°C. This suggests that the fuzzy system of a logic controller effectively moderates the temperature changes, maintaining it inside a more affected range than the ambient conditions.

The bottom graph illustrates the fan speed percentage, which starts at 30% and remains largely steady, with only child adjustments seen around the 20–30 s mark. This stableness in fan speed indicates that the system does not need frequent changes in fan power to wield the desired temperature, highlighting the efficiency of the verify mechanism. The brief increase in fan speed to around 32% reflects a response to a substantial drop in ambient temperature, indicating the system's power to adapt quickly to sudden changes.

Overall, the FLC restrainer demonstrates robust performance in regulating the cooling system, keeping the restricted temperature inside a specialized band despite wide ambient fluctuations. The consistent winnow speed up also suggests energy efficiency, as the system avoids unnecessary adjustments, thereby conserving vitality while maintaining a comfortable temperature. This indicates that the FLC is well-tuned for managing temperature in environments with varied thermal conditions, providing a reliable cooling root that balances stability and efficiency.

The controlled temperature remains stable within a narrow straddle despite substantial ambient fluctuations.

The fan speed is consistent, reflecting the system's vim efficiency and effectiveness in maintaining a steady temperature.

The plots in Figure 18 demonstrate the performance of a cooling heater system regulated by a FLC. The top off chart shows the comparison between the controlled temperature (solid bluing line) and the ambient temperature (dashed red line) over a period of 10 s. The ambient temperature starts at about 22°C and fluctuates somewhat above and under this value.

The controlled temperature begins around the Lapp value but then significantly decreases, indicating that the system is actively cooling despite the mild fluctuations in ambient temperature. This suggests that the FLC system controller is effectively maintaining a room temperature, with the controlled temperature downward-arching steadily to around -5°C by the end of the period. The bottom graph depicts the heater power output as a percentage over the same time frame. Initially, the warmer power quickly ramps up to 60% within the number 1 s, where it remains steady for a few seconds. At the 2.3-s mark, the heater power drops to 50%

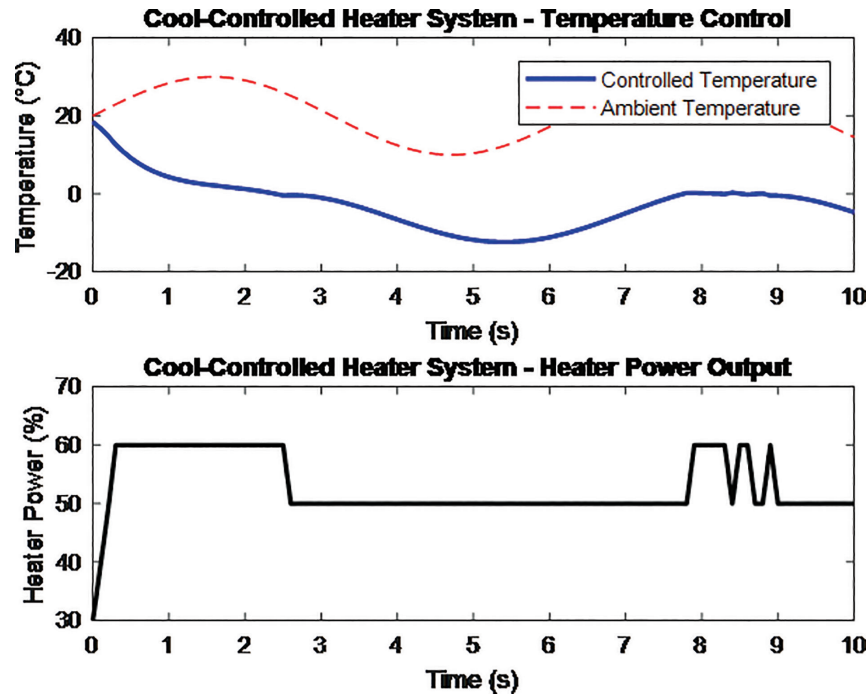


Figure 18: Heating system performance: controlled temperature and heater power over time.

and stays at this rise until approximately 8 s, after which it briefly fluctuates before returning to 50%. These fluctuations suggest the system's adjustments in response to changes in ambient conditions and the need to maintain the target temperature. The brief spikes in heater power toward the end suggest attempts by the restrainer to stabilize the temperature as the cooling effectuate progresses. Overall, the performance of the incoherent logic restrainer appears robust, as it manages to importantly lower the temperature despite comparatively minor changes in ambient temperature. The controlled temperature remains well below the close temperature, demonstrating the system's effectiveness in cooling. The steady and responsive adjustments in the heater superpower output reflect the controller's ability to exert the desired temperature with efficiency and minimal overshoot. This verifies that the strategy ensures that the system adapts well to undefined fluctuations, providing a stable cooling effect with a consistent performance.

The system effectively lowers the temperature to around -5°C undefined mild close fluctuations.

Heater power adjusts responsively, ensuring efficient cooling with minimal overshoot and demonstrating the robustness of the FLC in maintaining the desired temperature.

Overall, the FLCs exhibit robust performance, efficiently managing temperature control with stable and sensitive adjustments and making them suitable for environments with varied thermal conditions.

IV. Performance evaluation and comparison analyses of system performance

The following Table 1 provides a comprehensive comparison of four different temperature-controlled systems using FLC controllers, including comments on results, control strategies, system characteristics, and conclusions.

The following table captures the essence of the data presented, focusing on the performance metrics of the various temperature and cool-controlled systems listed. Table 2 illustrates the performance analysis of temperature and cool-controlled systems.

Figure 19 chart compares the performance of different temperatures and cool-controlled systems based on various metrics. It includes metrics, such as the final temperature ($^{\circ}\text{C}$), desired temperature ($^{\circ}\text{C}$), mean temperature error ($^{\circ}\text{C}$), max temperature

Table 1: Comprehensive comparison of temperature-controlled and cool-controlled systems using FLC

Aspect	Temperature-controlled fan system	Temperature-controlled heater system	Cool-controlled fan system	Cool-controlled heater system
Performance	Maintains target temperature with minimal overshoot	Maintains temperature close to desired with minor deviations	Efficiently maintains a cooler environment than ambient	Prevents overheating effectively by adjusting heater power
Effectiveness	Effective for precise cooling	Suitable for stable heating in varied conditions	Ideal for cooling applications with consistent airflow	Useful for environments requiring strict temperature control
Improvement needed	Slight need for error correction	Lower mean error and minor temperature fine-tuning needed	Fan speed optimization may improve energy efficiency	Better heater power management for energy efficiency
Initial temperature (°C)	30	Varies around 20	Varies around 25	Not specified (example uses 20)
Desired temperature (°C)	25	22	Cooler than ambient (e.g., maintaining 25)	Prevent temperature from exceeding a threshold
Final temperature (°C)	Slightly above 25	20.842	Not specified; focused on maintaining a cooler environment	Managed to stay around set temperature with control actions
Final fan speed/heater power (%)	Fan speed dynamically adjusted	7.2501	Fan speed: 30	Heater power: 60
Mean temperature error (°C)	-0.0319	1.4696	-	-
Max temperature error (°C)	-	1.9873	-	-
Comments on results	Maintains target temperature with minimal overshoot. Effective for precise cooling and slightly needed for error correction	Maintains temperature close to desired with minor deviations. Suitable for stable heating and requires minor fine-tuning	Efficiently maintains a cooler environment than ambient. Ideal for cooling applications with consistent control	Effectively prevents overheating by adjusting heater power. Suitable for strict temperature control and could improve energy efficiency
Control objective	Reduce and maintain temperature at a lower set point	Increase and maintain temperature at a higher set point	Reduce temperature below ambient, maintaining cooler conditions	Prevent temperature from rising above a certain point
Control strategy	Adjust fan speed based on the error and the rate of change	Adjust heater power based on the error and the rate of change	Adjust fan speed dynamically to reduce temperature fluctuations	Adjust heater power dynamically to prevent the temperature increase

(Continued)

Table 1: Continued

Aspect	Temperature-controlled fan system	Temperature-controlled heater system	Cool-controlled fan system	Cool-controlled heater system
Ambient temperature	Not directly controlled	Simulated fluctuation: $20 + 2 \times \sin(\text{time})$	Simulated fluctuation: $25 + 10 \times \sin(\text{time}/10)$	Simulated varying conditions: e.g., $20 + 10 \times \sin(\text{time})$
System complexity	Moderate, requiring dynamic fan speed adjustment	Moderate, requiring dynamic heater power adjustment	Moderate, adjusting fan speed to manage temperature variations	Moderate, adjusting heater power to manage temperature increases
Energy efficiency	Moderate efficiency, depends on fan speed adjustments	Moderate efficiency, adjusting heater power to manage temperature	Moderate efficiency, dynamic fan speed adjustment to manage cooling	Moderate efficiency, managing heater power to prevent overheating
Key output variables	Fan speed	Heater power	Fan speed	Heater power
Response characteristics	Increases airflow to cool environment	Increases heat to warm environment	Increases airflow to reduce temperature effectively	Modulates heating to prevent excessive temperature
Typical applications	HVAC systems, data centers	Residential heating, industrial processes	Cooling systems for electronics, data centers	Heating systems in environments, requiring strict temperature control
System focus	Cooling by regulating fan speed	Heating by modulating heater power	Cooling by increasing fan speed to manage temperature fluctuations	Cooling by preventing overheating through heater power modulation
Primary function	Cools the environment by regulating airflow	Heats the environment by adjusting heat output	Prevents overheating by regulating heat output	Cools the environment by increasing airflow
Key input variables	Temperature, fan speed, and sometimes humidity	Temperature and rate of temperature change	Temperature and rate of temperature increase	Temperature, fan speed, and sometimes humidity
Output variables	Fan speed adjustments	Heater power adjustments	Heater power adjustments	Fan speed adjustments
Environmental suitability	Best for warm climates, needing cooling	Best for cold climates, needing heating	Suitable for hot environments, needing to avoid overheating	Suitable for environments, needing consistent cooling
Control complexity	Requires managing airflow and sometimes humidity	Focused on direct heat output control	Balances heating and cooling mechanisms to prevent overheating	Focuses on managing airflow and sometimes additional cooling
Temperature regulation	Maintains or reduces temperature effectively	Increases and maintains temperature	Maintains a maximum temperature to prevent overheating	Reduces temperature by maximizing airflow

FL, fuzzy logic; FLC, fuzzy logic controller; HVAC, heating, ventilation, and air conditioning.

Table 2: Performance analysis of temperature and cool-controlled systems

System type	Initial temperature (°C)	Desired temperature (°C)	Final temperature (°C)	Final fan speed/heater power (%)	Mean temperature error (°C)	Max temperature error (°C)	Comments
Cool-controlled heater system	Not specified	Prevents exceeding threshold	Maintains set temp.	60	-	-	Effectively prevents overheating by adjusting heater power. Suitable for strict temperature control and could improve energy efficiency
Cool-controlled fan system	Varies around 25	Cooler than ambient	Maintains cooler env.	30	-	-	Efficiently maintains cooler environment than ambient. Ideal for cooling applications with consistent control
Temperature-controlled heater system	Varies around 20	22	20.842	7.2501	1.4696	1.9873	Maintains temperature close to desired with minor deviations. Suitable for stable heating and requires minor fine-tuning
Temperature-controlled fan system	30	25	Slightly above 25	Dynamically adjusted	-0.0319	-	Maintains target temperature with minimal overshoot. Effective for precise cooling, slightly need for error correction

error (°C), and final fan speed/heater power (%). The following four system types are compared: Cool-Controlled Heater System, Cool-Controlled Fan System, Temperature-Controlled Heater System, and Temperature-Controlled Fan System. The Cool-Controlled Heater System shows the highest final fan speed/heater power percentage, while the Temperature-Controlled Fan System has a significant max temperature error. These data suggest the effectiveness and suitability of each system for different

applications, such as precise cooling, stable heating, and maintaining a cooler environment than ambient.

V. Comparison with three other studies

Table 3 provides a comprehensive comparison between our study and three selected references. It highlights key aspects, such as objectives,

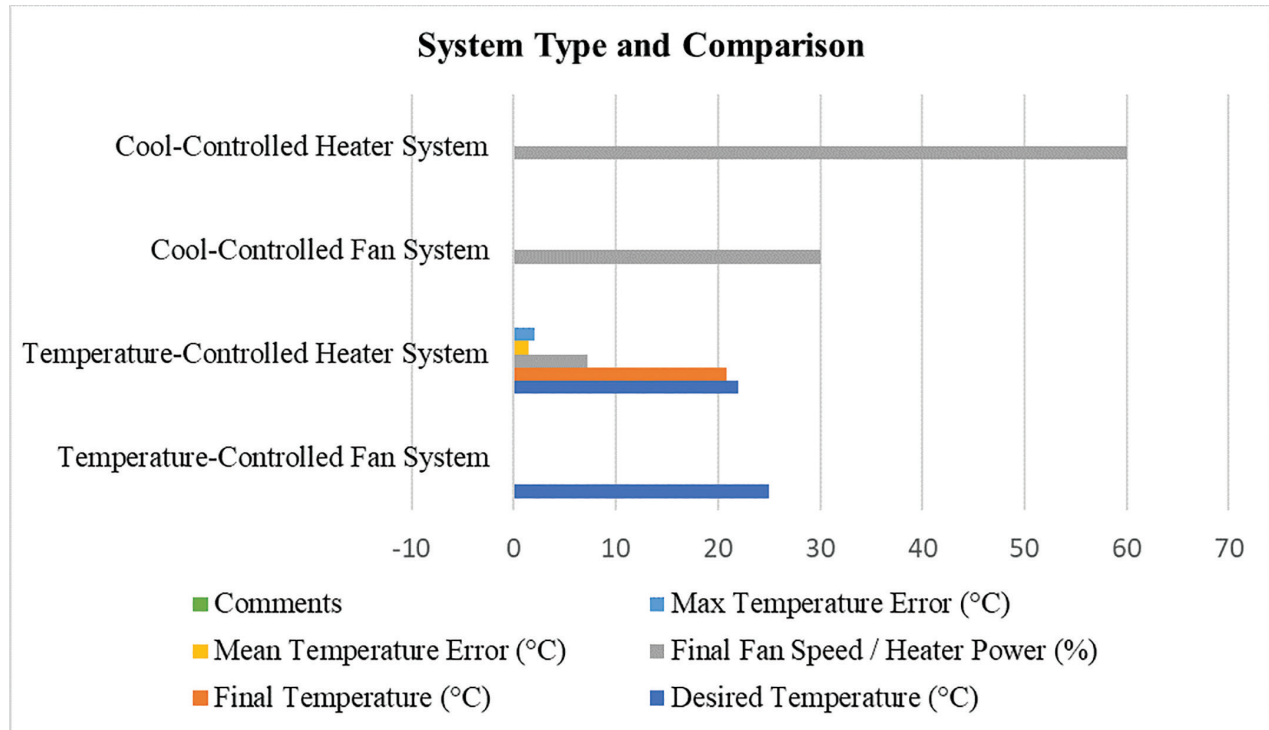


Figure 19: Comparison of temperature-controlled and cool-controlled systems using FLCs. FLCs, fuzzy logic controllers.

Table 3: Comprehensive comparison of our study with selected references [21], [22] and [28]

Aspect	Our study	Ahmad et al. [22]	Nyiekaa et al. [21]	Schuster et al. [28]
Objective	Evaluate FLC-based temperature and cooling systems for stable conditions and energy efficiency	Address thermal comfort, heat wave resilience, and indoor air quality in warm climates	Design and construct a temperature control system to maintain a desired temperature in enclosed area	Explore cool-controlled heating systems for improved thermal comfort and energy efficiency in building automation
Methodology	Utilize FIS to dynamically adjust fan speed and heater power based on input variables, such as temperature error and rate of temperature change	Investigate the integration of advanced control algorithms and natural ventilation strategies	Use a temperature controller system designed to maintain a desired temperature automatically	Integrate cool-controlled heating systems with building automation to optimize energy use
Control objective	Maintain stable conditions in residential, industrial, and electronic cooling applications	Enhance thermal comfort and indoor air quality in warm climates	Maintain a specific temperature within an enclosed area	Maintain thermal comfort and enhance energy efficiency in heating systems

(Continued)

Table 3: Continued

Aspect	Our study	Ahmad et al. [22]	Nyiekaa et al. [21]	Schuster et al. [28]
Results	Achieved a mean temperature error of -0.0319°C for fan system and 1.4696°C for heater system; effective temperature control and energy efficiency	Potential of advanced fan systems to improve thermal comfort and indoor air quality	Successfully maintained a specified temperature within enclosed area	Potential for improved energy efficiency and user satisfaction through building automation
System applications	Residential, industrial, and electronic cooling	Warm climates and natural ventilation systems	Enclosed areas requiring stable temperature control	Building automation and heating systems
System focus	Both heating and cooling applications, preventing overheating and maintaining desired conditions	Primarily cooling applications to enhance thermal comfort and air quality	Heating applications to maintain stable temperature	Heating applications for thermal comfort and energy efficiency
Energy efficiency	Substantial energy savings compared to traditional methods	Enhanced through advanced ventilation strategies	Energy-efficient temperature maintenance	Improved through integration with building automation

FIS, fuzzy inference system; FL, fuzzy logic; FLC, fuzzy logic controller.

methodologies, control objectives, results, system applications, focus, and energy efficiency. The comparison demonstrates the versatility and effectiveness of FLC-based systems in various temperature control scenarios. The selected references were chosen for their relevance to different aspects of temperature control and energy efficiency, which align with the scope of our study:

1. Ahmad et al. [22] focused on natural ventilation systems in warm climates, addressing thermal comfort, heat wave resilience, and indoor air quality. This is pertinent because it explores advanced fan systems similar to those evaluated in our study.
2. Nyiekaa et al. [21] presented the design and construction of an automatic temperature control system for maintaining specific temperatures in enclosed areas. This provides a practical example of a temperature control system similar to the ones analyzed in our study.
3. Schuster et al. [28] investigated cool-controlled heating systems for building automation, emphasizing improved thermal comfort and energy efficiency. This study is relevant as it explores energy-efficient solutions, which is a key focus of our research.

These references provide a broad perspective on the application, methodology, and results of temperature control systems, allowing for a comprehensive comparison with our study.

VI. Conclusion

This study evaluates FLC-based temperature control systems highlighting their potency in distinct temperature direction and energy efficiency. The systems, including temperature-controlled and cool-controlled fans and heaters, dynamically adjust to maintain stable conditions in residential, industrial, and electronic cooling applications. FLC controllers offer significant advantages by adapting to environmental changes without detailed mathematical models. The results demonstrate their capacity to prevent overheating, yield desired temperatures, and reduce operational costs. For instance, the temperature-controlled fan system achieved a mean temperature error of -0.0319°C , effectively maintaining the target temperature with minimal overshoot. The temperature-controlled heater system preserved a temperature close to the desired set point with an error of 1.4696°C . The cool-controlled winnow system of rules with efficiency maintained a cooler environment than the ambient temperature, while

the cool-controlled heater system effectively managed to prevent overheating by adjusting the heater superpower dynamically. This study is relevant as it explores energy-efficient solutions, which is a key focus of our research. These findings highlight the potential of FL-based systems in advancing temperature control in mechatronics engineering, providing reliable and cost-effective solutions for various applications. Future research should heighten these systems for broader real-world applications, focusing on optimizing control strategies and improving vim efficiency further.

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