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Fuzzy Logic Controller Design for Intelligent Lighting and Air-Conditioning Management Systems

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ABSTRACT- In an effort to conserve energy and optimize the use of resources, this research explores the application of fuzzy logic control techniques to improve energy efficiency in intelligent lighting and air conditioning (AC) management systems. This research aims to investigate how fuzzy logic control strategies can be incorporated into intelligent systems to regulate lighting and air conditioning operations with greater precision, adaptability, and energy efficiency. By utilizing a fuzzy logic algorithm, this research develops a model that is able to dynamically adjust lighting levels and AC settings based on environmental conditions, housing patterns, and user preferences. Fuzzy logic control has proven useful for maintaining the desired level of comfort and optimizing electrical energy consumption through trials. The research results show that the integration of fuzzy logic control methodology offers significant potential to improve energy efficiency in lighting and air conditioning management systems, leading to reduced energy consumption and operational costs. These findings highlight the importance of intelligent control in the sustainable management of electrical equipment and provide valuable insights for the design and implementation of energy-efficient systems in a variety of contexts.

KEYWORDS- Energy Efficiency, Fuzzy Logic Control, Lighting and AC Management, and Intelligent Systems

I. INTRODUCTION

In an era where environmental challenges are increasingly pressing and awareness of the importance of energy efficiency is increasing, innovative thinking in resource management is crucial. Commercial and residential buildings are significant contributors to global energy consumption, with much of it used for lighting and space cooling [1][2]. Thus, intelligent building automation systems are one of the most researched areas, driven by the high demand for economical systems designed to provide enjoyable controlled spaces for various organizations [3]. In addition, the development of this system can increase efficiency in this case, addressing not only economic issues but also moral and environmental issues. Therefore, the development of intelligent lighting and air conditioning management systems is becoming increasingly important to reduce inefficient energy consumption.

In order to overcome these challenges, there is increasing interest in the application of fuzzy logic control technology in building energy management. Reducing the associated energy consumption while maintaining comfortable conditions inside the building is a goal to be achieved, but it still has typical optimization problems that require intelligent system design [4]. Fuzzy logic control offers an adaptive and responsive approach to complex and changing environmental conditions. With its ability to handle uncertainty and variation, this technique allows the system to optimize energy use while maintaining the desired level of comfort [5].

There is a lot of research that reveals the advantages of fuzzy control in electrical equipment. Smart room lighting systems using ESP32-based fuzzy logic methods to control lighting in rooms to save electricity usage are very beneficial. The results of the design of this tool can control the light from bright to dim to off. The results obtained by smart room lighting systems can reduce power consumption by up to 93% and energy consumption by up to 70% [6]. In addition, the fuzzy logic control model can be combined with artificial neural network techniques, which show that the fuzzy logic controller is able to stabilize the heat exchanger temperature well [7].

Based on the previous explanation, this research aims to explore the potential of fuzzy logic control for increasing energy efficiency in lighting and air conditioning systems. By integrating fuzzy logic control into intelligent energy management systems, we hope to develop models capable of dynamically adjusting lighting and air conditioning settings based on environmental conditions, occupancy patterns, and user preferences. This will allow buildings to significantly reduce energy consumption while maintaining the comfort of their occupants.

This research is very important because lighting and air conditioning systems are the main components of energy consumption in many buildings. Several fuzzy logic controllers (FLCs) for energy management systems in smart homes have been widely studied in previous research. The controller is proposed to manage the energy consumption of lighting devices and HVAC systems [8]. By optimizing energy use in lighting and air conditioning systems, we can reduce a building's carbon footprint and save on long-term operational costs. Additionally, by considering environmental factors and user preferences in system setup, we can create a more comfortable and sustainable environment for building occupants. Innovations in fuzzy logic control technology, as well as their integration with intelligent energy management systems, can be an important step in achieving these goals.

By understanding the importance of efficient energy management in the context of sustainable development, this research is expected to make a valuable contribution in this direction. Apart from providing insight into the potential application of fuzzy logic control in energy management systems, this research is also expected to encourage innovation in environmentally friendly building design and operation. Through this approach, we hope to raise awareness of the need to adopt environmentally friendly technologies and provide sustainable solutions to future energy challenges.

II. METHODOLOGY

This research methodology is intended to provide a comprehensive framework for investigating the potential of fuzzy logic control to improve energy efficiency in the context of intelligent energy management. It is hoped that this research, with a combination of appropriate analytical methods and careful use of technology, can make a valuable contribution to the development of science and practice in this field. The steps taken for electricity management in lighting and AC using fuzzy techniques can be described as follows:

A. *Determine Input and Output Variables*

a. Input Variables

Input variables in a fuzzy logic controller allow the system to receive information about environmental conditions or inputs that will be used to make decisions [9]. These input variables play a role in determining the output or action taken by the system. Several input variables used in this research can be described as follows:

1. Room temperature (20°C–40°C): a measure of room temperature in the range from 20°C to 40°C. This range covers the general temperature conditions in a room.
2. Light intensity (0–1000): a measure of the light intensity in the room. The range from 0 to 1000 may cover conditions from very dark to very bright rooms.
3. Number of people in the room (0–20): measures the number of people in the room at any one time. The range from 0 to 20 captures the scale from an empty room to a room a room crowded with people.

b. Output Variables

The output variables in the fuzzy logic controller determine the system's actions or decisions based on the environmental conditions given by the input variables [10]. These output variables represent the results of the fuzzy logic processing process and determine how the system will behave. This research used several output variables, which can be described as follows:

1. Lighting level (0%–100%): the desired light level in the room expressed as a percentage. This range reflects adjustments from very dark to very bright conditions.
2. AC or room temperature settings (16°C–28°C): settings for the AC system or room temperature. This range covers comfortable temperatures for most people, from 16°C to 28°C.

B. *Determine Membership Functions*

The membership function is a concept in fuzzy theory that describes how well an element satisfies a fuzzy set [11]. Membership functions determine an element's membership level in a fuzzy set, which can be partial or total. In this research, a fuzzy membership function in triangular form will be used. A triangular membership function has the shape of a triangle and has three parameters: a start point, a vertex, and an end point. This function is used to define linguistic variables with a certain range.

a. Room Temperature

Cool: [20, 23, 26],
Moderate: [23, 26, 30], and
Warm: [26, 30, 40].

Figure 1 below shows an image of the membership function for the input variable Room Temperature.

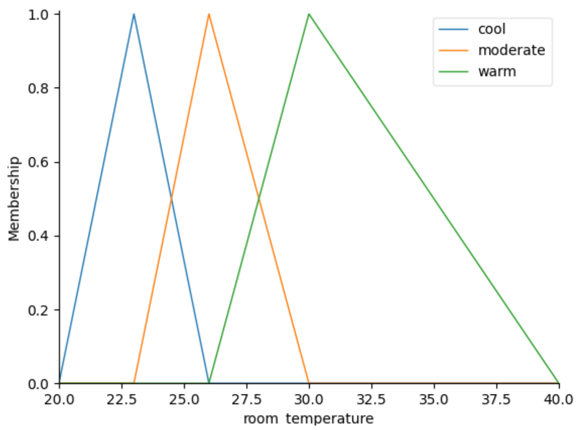

Figure 1: Membership Functions for Room Temperature

b. Light Intensity

Low: [0, 250, 500],
Medium: [250, 500, 750], and
High: [500, 750, 1000].

Figure 2 below shows an image of the membership function for the light intensity input variable.

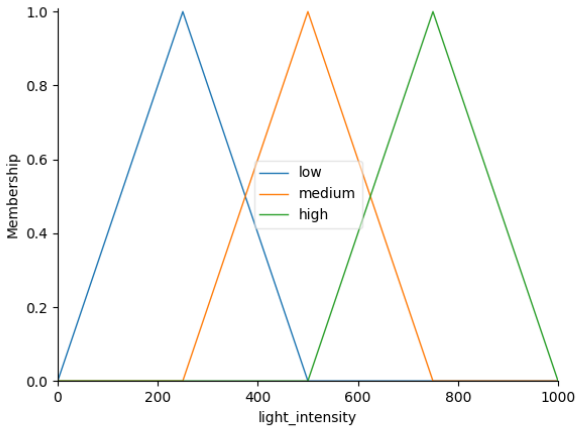

Figure 2: Membership Functions for Light Intensity

c. Number_of_People

Few: [0, 5, 10],
Moderate: [5, 10, 15], and
Many: [10, 15, 20].

Figure 3 below shows an image of the membership function for the input variable number of people.

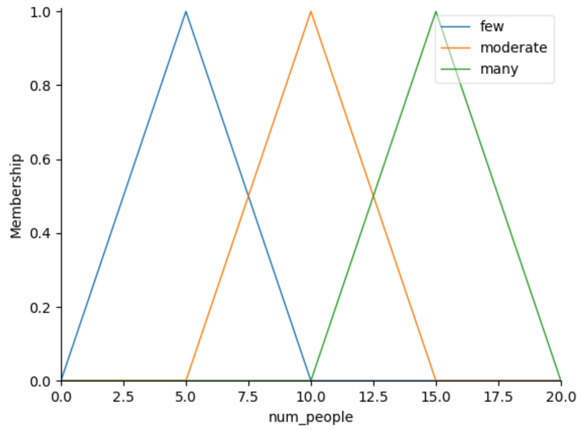

Figure 3: Membership Functions for Number of People

d. Light Level

Low: [0, 30, 60],
Medium: [30, 60, 90], and
High: [60, 90, 100].

Figure 4 below depicts the membership function for the Light Level input variable.

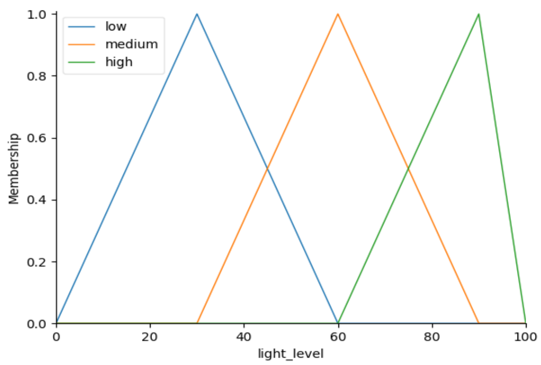

Figure 4: Membership Functions for Light Level

e. AC Setting

Low: [16, 20, 22],
Medium: [20, 22, 24], and
High: [22, 24, 28].

Figure 5 below shows an image of the membership function for the input variable AC Setting.

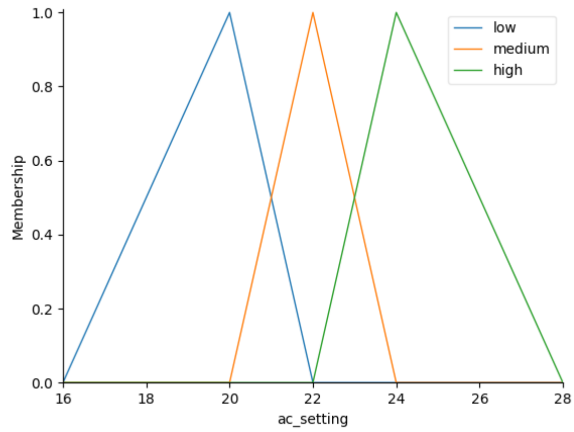

Figure 5: Membership Functions for AC Setting

C. Create Fuzzy Rules

Fuzzy rule functions are part of a fuzzy logic control system that determines the relationship between input and output variables. This rule function describes logic or human thinking about how input variables should be related to output variables in a particular context [12]. Fuzzy rule functions are generally defined as rules that describe the correlation between input conditions and output actions. Each fuzzy rule is associated with conditions (inputs) and actions (outputs). In this study, 27 rules were used in the system developed. Table 1 provides examples of the five fuzzy rules used in this research, as follows:

Table 1: Rules in Fuzzy Logic Control

Rule No.	Fuzzy Conditions	Fuzzy Outputs
1	Room Temperature: Cool, Light Intensity: Low, Number of People: Few	Lighting Level: High, AC Setting: High
2	Room Temperature: Cool, Light Intensity: High, Number of People: Moderate	Lighting Level: Low, AC Setting: Medium
3	Room Temperature: Moderate, Light Intensity: Low, Number of People: Few	Lighting Level: High, AC Setting: Medium
4	Room Temperature: Moderate, Light Intensity: Medium, Number of People: Many	Lighting Level: Medium, AC Setting: Low
5	Room Temperature: Warm, Light Intensity: High, Number of People: Moderate	Lighting Level: Low, AC Setting: Low

Each rule *(Ri)* is evaluated using the membership value of the corresponding input variable. Assume that *Ri* has the following premises:

$$IF\ X1\ is\ A\ AND\ X2\ is\ B\ THEN\ Y\ is\ C \quad (1)$$

The membership level in the *Ri* rule is as follows:

$$min(\mu X1(x1), \mu X2(x2)) \quad (2)$$

D. Inference Process

The next step is to use the fuzzy rules that have been determined to infer the appropriate lighting level and AC settings based on the given input values. In this example, we will apply maximum operations using the following equation:

$$Light\_Level = max\,(R1\,, R2, R3, \ldots.) \quad (3)$$

E. Defuzzification

The final step is to convert the fuzzy form inference results into firm values that can be implemented, for example, by using the centroid method or other methods. In the fuzzy control system described previously, defuzzification is performed to convert the fuzzy output into firm values using the centroid method. Let μ(x) be the membership function of a fuzzy set that represents the lighting level. In the centroid method, the firm value of x is calculated using equation 4 as follows:

$$x = \int x \cdot \mu(x)\, dx / \int \mu(x)\, dx \quad (4)$$

Here, x is the firm value being sought, while μ(x) is the fuzzy set membership function, which describes how high the level of membership of the value x is to the fuzzy set. This process involves two main stages:

a. Weighting: Each x value is multiplied by its membership level (μ(x)).
b. Normalization: The first step's result is divided by the total membership level.

The x value, which is the fuzzy set's center point (centroid), is the final result of this process. This is a firm value representation of the setting value generated by the fuzzy control system.

III. RESULT AND DISCUSSION

In this section, we will explain the results of experiments and analyses related to the use of fuzzy logic control to improve intelligent lighting and AC management systems. The results presented include an evaluation of the system's performance in various test situations, as well as an analysis of the effectiveness of fuzzy logic control in the management of lighting and the resulting temperature. In this analysis, we explore the impact of implementing fuzzy logic control on energy usage and system operational efficiency. The findings of this study will include a comparison of actual experimental results with anticipated expectations, as well as an investigation into the factors that influence system performance. Furthermore, we will discuss the practical implications of our findings, as well as the potential for further applications in the context of sustainable energy management.

By investigating detailed experimental and analytical results, we hope to provide readers with valuable insights into the benefits and challenges of implementing fuzzy logic control to improve power efficiency in facility management systems. Moreover, these discussions can help guide future research and development efforts in this area, as well as encourage the adoption of more sustainable and environmentally friendly technologies.

Testing will be carried out in this research using input values to obtain response results from the given fuzzy model. Table 2 describes the results obtained as follows:

Table 2: Results of Fuzzy Logic Control

Rule No.	Fuzzy Conditions	Fuzzy Outputs
1	Room Temperature: 27, Light Intensity: 750, and Number of People: 19.	Light Level: 30, and AC Setting: 19.
2	Room Temperature: 28, Light Intensity: 200, and Number of People: 5.	Light Level: 82, and AC Setting: 22.
3	Room Temperature: 25, Light Intensity: 130, and Number of People: 10.	Light Level: 82, and AC Setting: 20.
4	Room Temperature: 32, Light Intensity: 50, and Number of People: 16.	Light Level: 81, and AC Setting: 19.
5	Room Temperature: 28, Light Intensity: 960, and Number of People: 8.	Light Level: 30, and AC Setting: 20.
6	Room Temperature: 31, Light Intensity: 145, and Number of People: 9.	Light Level: 82, and AC Setting: 20.
7	Room Temperature: 35, Light Intensity: 109, and Number of People: 5.	Light Level: 82, and AC Setting: 22.
8	Room Temperature: 29, Light Intensity: 480, and Number of People: 12.	Light Level: 61, and AC Setting: 19.
9	Room Temperature: 39, Light Intensity: 900, and Number of People: 5.	Light Level: 30, and AC Setting: 22.
10	Room Temperature: 38, Light Intensity: 350, and Number of People: 19.	Light Level: 66, and AC Setting: 19.

According to Table 2, the fuzzy output results are shown in Figures 6 and 7 below.

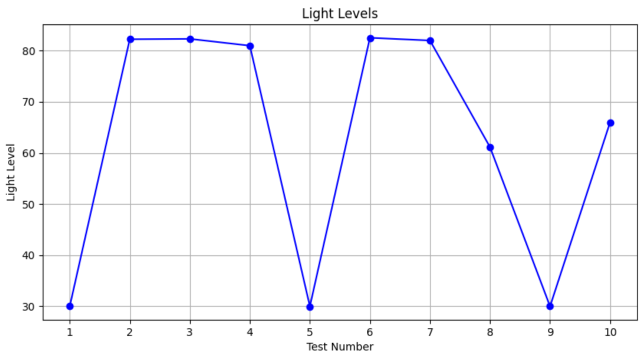

Figure 6: Results of Fuzzy Lighting Settings

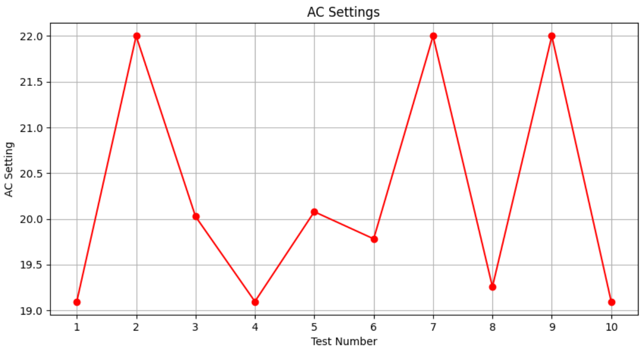

Figure 7: The Results of Setting the AC Temperature Using Fuzzy Logic

Based on testing of the fuzzy logic control system for lighting and AC management, it appears that the system can produce responses that are appropriate to the given environmental conditions. Some of the main points from the results are listed below.

1. The system is able to optimize energy use by adjusting lighting levels and room temperature settings according to changing environmental conditions.
2. Compared with conventional control methods, the use of fuzzy logic allows for more adaptive and responsive adjustments, leading to more efficient energy use without compromising the comfort of room occupants.
3. The system can be easily adapted to a variety of environments and room scales, making it suitable for applications in a variety of contexts, from households to office spaces.

Thus, fuzzy logic control systems prove an effective approach to energy management and environmental comfort in a variety of different situations. The fuzzy logic-based electricity use efficiency design system that has been developed successfully integrates environmental variables such as room temperature, light intensity, and the presence of people in the room to control energy use intelligently.

Although fuzzy logic provides great flexibility in controlling complex systems, the establishment of appropriate fuzzy rules requires a deep understanding of environmental dynamics and user preferences. Therefore, the process of designing fuzzy rules must be carried out carefully to achieve optimal results. Although this system has been tested and proven to be effective under test conditions, challenges may arise in its practical implementation, including susceptibility to external interference and the reliability of the sensors used. Routine maintenance and ongoing monitoring of the system are required to ensure its optimal performance. Although these systems can help reduce energy consumption, economic and environmental aspects must also be thoroughly considered. Cost-benefit analyses and environmental impact evaluations can help determine the long-term effectiveness of the system.

This research, taking into account the above results and discussion, provides valuable insights into the potential of fuzzy logic in optimizing energy use. In the context of global climate change and increasing awareness of sustainability, the development of systems such as these is becoming increasingly important in efforts to achieve clean and sustainable energy goals. The study Increasing Energy Efficiency through Fuzzy Logic Control for Intelligent Lighting and AC Management Systems looks at how well fuzzy logic control techniques work at reducing energy use, how well systems work at adapting to changing environmental conditions, and how this affects the overall operational efficiency of a building.

IV. CONCLUSION

This research evaluates the use of fuzzy logic control to improve power efficiency in intelligent lighting and air conditioning management systems. According to the research results, the system can automatically adjust lighting intensity and room temperature in response to changes in environmental conditions, such as temperature, light intensity, or the presence of people in the room. Fuzzy logic controls have the ability to better respond to changes in the environment and user needs, resulting in more efficient energy use while maintaining the desired level of comfort. Additionally, fuzzy logic control can be successfully implemented in a variety of environments and situations without requiring significant customization. This enables the adoption of this technology across a wide range of building types and environments, increasing the potential for widespread energy savings. Overall, this research provides valuable insights into the potential of fuzzy logic control for optimizing energy use. In the context of global climate change and increasing awareness of sustainability, the development of systems such as these is becoming increasingly important in efforts to achieve clean and sustainable energy goals.

V. FUTURE SCOPE

There are several challenges that need to be overcome, such as the establishment of appropriate fuzzy rules, susceptibility to external interference, and sensor reliability. Regular maintenance and monitoring of the system are required to ensure its optimal performance. Cost-benefit analysis and environmental impact evaluation are also important to determine the long-term effectiveness of the system.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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