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Decision Support System Based on Fuzzy Logic for Energy Auditing in Hospital Buildings

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Abstract

Excessive electrical energy consumption will cause inefficient use of energy in a building. This has an impact on increasing electricity bill payments. The right step as a solution to implement energy management by conducting an energy audit. This research discusses of energy inefficiencies in hospital buildings, focusing on Muhammadiyah Hospital Jepara. Energy audits are determined from electrical loads including lighting, air conditioning and electronics. Specified parameters: total electric power (kWh) and energy consumption intensity. Fuzzy logic is used to support decision-making. The result showed that fuzzy logic can be used for decision support system for energy audits in hospital buildings. This is proven by energy consumption intensity of 284.61 kWh/m^2/year, lighting (8%), HVAC (87%), and electronics (5%) as daily load contributors. Through direct calculation methods and fuzzy logic implementation, the hospital's electrical energy consumption is deemed efficient at 343.54 kWh/m^2/year. Continuous improvement measures are vital for sustained energy efficiency.

Keywords: Decision Support System, Fuzzy Logic, Energy Audit, Hospital Building

1. Introduction

Healthcare facilities, including hospitals, play a pivotal role in society by providing critical services to the community. Hospitals faced significant challenges, especially in terms of electricity consumption, due to the high energy requirements in their operations. Generally, the electrical load in a hospital includes a lighting system, air conditioning system and other utilities in the hospital[1]. The problem that occurs is excessive and uncontrolled consumption of electrical energy causing increasing electricity bills[2]. Excessive electrical usage is generally caused by improper energy management or inefficient usage[3]. The solution to this problem is how to make energy saving by conducting an energy audit. Energy audits function as a system to assess and evaluate energy consumption in a building[4]. Hospital has a requirement for efficient energy utilization, not only for cost savings but for sustainable and environmentally friendly. Energy audits involve inspection and surveying energy flows. The aims of energy audit a reduce energy waste without harming the system output, which can minimize overall usage costs[5]. Some of the previous studies on energy audits has been carried out, including: preliminary audit of electrical energy using the energy consumption intensity calculation method[6], study of energy management methods using energy consumption intensity (ECI) calculations[7], energy saving opportunities (ESO)[8], energy audit in mental hospitals[9] direct measurement method, study of lighting and cooling systems[10], direct measurement method in energy management systems, ECI analysis [11], direct measurement method, audit and implementation design of ISO 50001-based energy management system[12], energy audit simulations in hospitals with computer simulation methodologies using energy plus[13]. This research has succeeded in calculating the ECI in a building, but the method used is to manually calculate the intensity of energy consumption and potential savings.

This research focuses on the implementation of a decision support system based on fuzzy logic. In this research, the ECI standards serve as guidelines for developing a decision support system that leverages fuzzy logic[14], The fuzzy logic approach is employed to identify an event as a basis for improving policies related to forthcoming occurrences [15]. The fuzzy logic-based decision support system will provide deeper insights into potential policy improvements that can be implemented to enhance energy efficiency in hospital buildings.

2. Methodology

Energy audit activities involve systematic calculations and accumulation of energy consumption used periodically in a building, such as schools, universities, hospitals, offices, and others [16]. Building energy audits are based on calculations derived from ECI standard values for hospital buildings, as shown in Table 1.

Table 1: Standard ECI for Electricity in Indonesia

No	***Building Type***	***Standard ECI (kWh/m2/year)***
1	Commercial (Office)	240
2	Shopping Center	330
3	Apartment, Hotel	300
4	Hospital	380

Building energy audits are divided into two stages, namely initial energy audits and detailed energy audits[17]. The first stage is an initial energy audit, which can be carried out by the building owner using energy bill data and visual observations. This involves collecting building data, including documentation such as technical drawings that include site plans, floor plans, sections and lighting installations[18]. The audit also includes data on electricity and fuel payments for the last year. The second stage is a detailed energy audit involving energy consumption analysis based on theory using equation (1).

$$Ke = D_t \times W_p \qquad (1)$$

with *Ke* = building energy consumption (kWh), *Dt* = power used in the building (kW), *Wp* = usage time (hours).

Relevant aspects include ECI, calculated by comparing it with the Indonesian ECI standard, electrical energy costs, which represent the ratio of building budget to energy consumption, and payback time to determine how long an energy saving measure will recover its costs, such as when building energy consumption (kWh) is equal to the power used in the building (kW) multiplied by the time of use (hours).[3]

2.1 Fuzzy Logic

The fuzzy logic method consists of different stages: fuzzification, fuzzy rules, fuzzy inference, and defuzzification. The first stage is fuzzification, which involves mapping from crisp (real) values to fuzzy sets, with input variables originating from IKE values obtained through direct measurement methods and ECI values according to standards. The membership function for triangle representation is defined according to equation (2).

$$\mu[X] = \begin{cases} 0; & x \le a \text{ or } x \ge c \\ (x-a)/(b-a); & a \le x \le b \\ (c-x)/(c-b); & b \le x \le c \end{cases} \qquad (2)$$

In this study, boundaries are determined to classify low, medium, or high values for the input variables Direct ECI and Hospital Standard ECI, as described in Tables 2 and 3.

Table 2: Direct ECI Input Variable

Input Variable	***Membership***
Low	≤ 250 kWh/m²/year
Medium	> 250 to ≤ 380 kWh/m²/year
High	> 380 kWh/m²/year

Table 3: Hospital Standard ECI Input Variable

Input Variable	***Membership***
Low	≤ 250 kWh/m²/year
Medium	> 250 to ≤ 385 kWh/m²/year
High	> 380 kWh/m²/year

The ECI variable membership function is defined with three values: low, medium, and high. A low value is defined as ≤ 250 kWh/m²/year, indicating that the closer the value is to 250, the higher the level of membership in the "Low" set. The middle values, which range from > 250 to ≤ 380 kWh/m²/year, graph shows increasing membership levels as the ECI value increases from 250 to 380. High values, exceeding 380 kWh/m²/year, correspond to higher membership levels in the "High" set. The ECI membership function is shown in Figure 1.

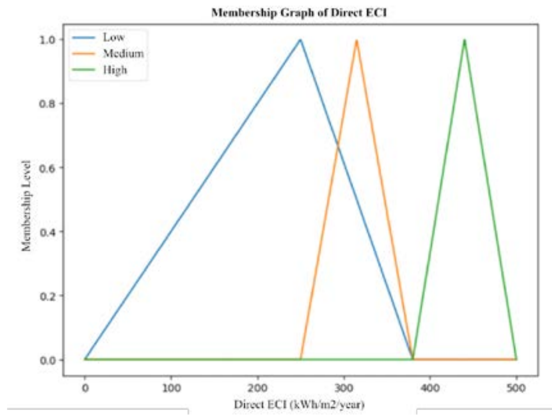

Fig. 1 Membership Graph of the Direct ECI Variable

ECI Variable RS Standard ECI values are categorized into three groups: "Low", values less than or equal to 250 kWh/m²/year, and the graph shows that the closer the value is to 250, the higher the membership level. The "Medium" category includes values between 250 and 385 kWh/m²/year, with the graph illustrating increasing membership levels as the ECI Standard RS value increases from 250 to 385. Meanwhile, the "High" category includes values above 385 kWh/m²/ year, and the graph shows that the higher the RS Standard ECI value is above 385, the RS Standard ECI variable Figure 2.

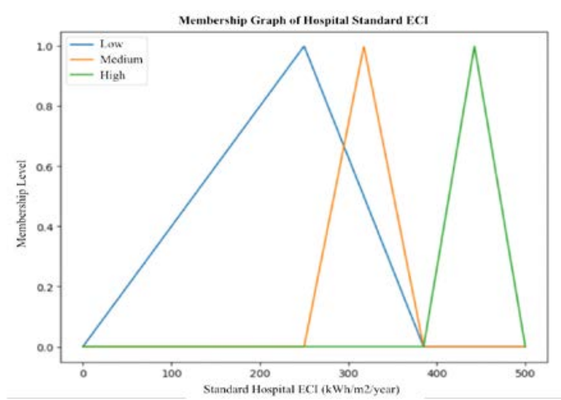

Fig. 2 Membership Graph of the Hospital Standard ECI Variable

The output variable of the ECI value has two memberships: efficient with a value ≤ 380 kWh/m² and not efficient with a value ≥ 380 kWh/m², as explained in Table 4. The membership function of the output variable is also illustrated in Figure 3.

Table 4: Output Variable

Output Variable	***Membership***
Efficient	≤380 kWh/m²/year
Not Efficient	>380 kWh/m²/year

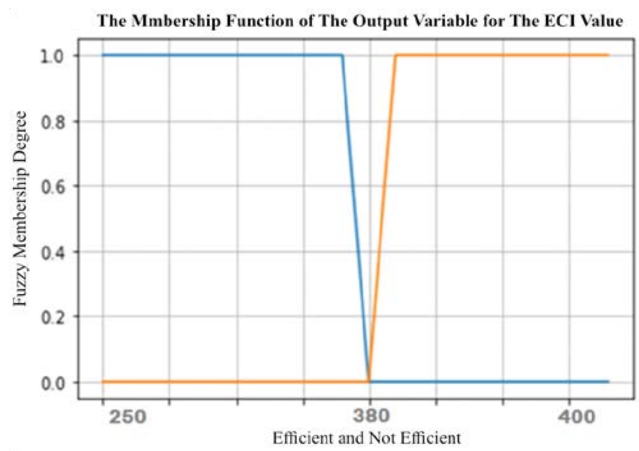

Fig. 3 Membership Function of the Hospital Standard ECI Variable

The second stage in the implementation of Fuzzy Logic involves defining Fuzzy Rules. In this research, 9 rules or statements are formulated based on the variables used, described as follows:

- IF the Direct Energy Consumption Intensity (ECI) is Low AND the Hospital Standard ECI is Low, THEN the ECI Value is Efficient.
- IF the Direct ECI is Low AND the Hospital Standard ECI is Medium, THEN the ECI Value is Efficient.
- IF the Direct ECI is Low AND the Hospital Standard ECI is High, THEN the ECI Value is Efficient.
- IF the Direct ECI is Medium AND the Hospital Standard ECI is Low, THEN the ECI Value is Efficient.
- IF the Direct ECI is Medium AND the Hospital Standard ECI is Medium, THEN the ECI Value is Efficient.
- IF the Direct ECI is Medium AND the Hospital Standard ECI is High, THEN the ECI Value is Not Efficient.
- IF the Direct ECI is High AND the Hospital Standard ECI is Low, THEN the ECI Value is Not Efficient.
- IF the Direct ECI is High AND the Hospital Standard ECI is Medium, THEN the ECI Value is Not Efficient.
- IF the Direct ECI is High AND the Hospital Standard ECI is High, THEN the ECI Value is Not Efficient.

These rules serve as the basis for the fuzzy inference system, facilitating the determination of the ECI value as either efficient or not efficient based on the input variables of Direct ECI and Hospital Standard ECI.

The third stage in the fuzzy logic system is fuzzy inference, where the previously defined fuzzy rules are applied to generate decisions or fuzzy outputs based on the given fuzzy inputs. With the nine fuzzy rules established earlier, a fuzzy inference mechanism is utilized to determine the membership level of the output ECI value. The process involves combining the results from each fuzzy rule to generate an overall output. Common methods include the Max method or the Mamdani method. In this research, the MIN implication function is used to obtain the α-predicate values for each rule (α_1, α_2, α_3, ..., α_n). Each α-predicate value is then used to calculate the explicit inference output for each rule (z_1, z_2, z_3, ..., z_n). The fourth stage in the fuzzy logic system is defuzzification, where the fuzzy values obtained from the inference stage are converted into precise or firm values. The resulting fuzzy output is the ECI value in the form of an "efficient" and "inefficient" fuzzy set. Defuzzification produces precise values based on this fuzzy set. The defuzzification method used in this research is the average method. The z* value is calculated using equation (3).

$$z^* = \frac{\sum a_1 z_1}{\sum a_1} \qquad (3)$$

This research began with a thorough literature review to gather references that support the study, with a particular focus on ECI energy audit standards. The following steps involve initial and detailed energy audit methods to determine ECI values that are utilized in formulating and simulating energy savings opportunity analysis, using direct calculation methods to assess equipment effectiveness and performance. both primary data and secondary data contribute to measurement analysis. Fuzzy logic is strategically incorporated into decision support systems to improve the accuracy of energy audits [17]. This approach aims to improve the identification and evaluation of energy consumption patterns in buildings. as illustrated in Figure 4.

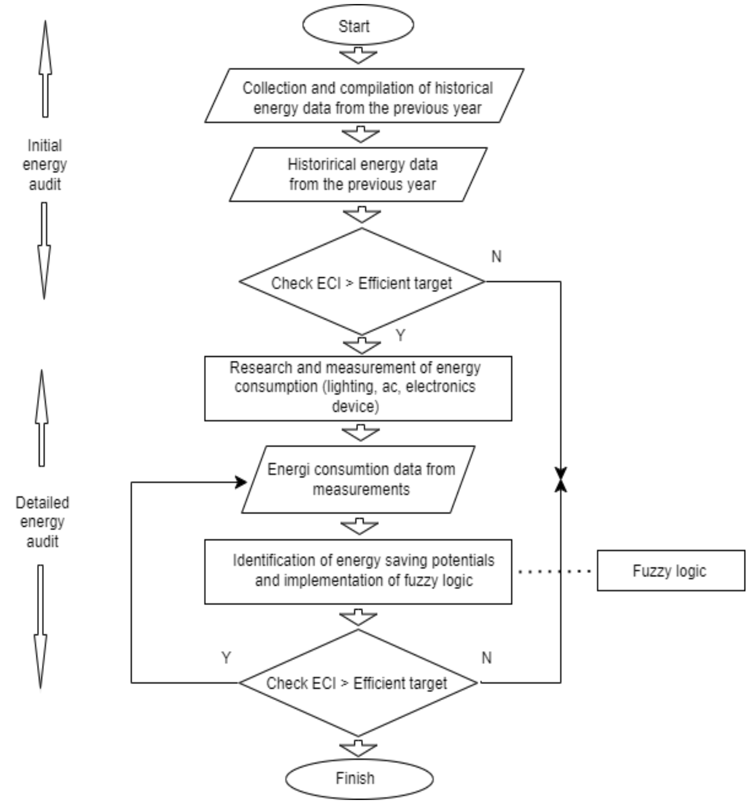

Fig. 4 Fuzzy based Energy Audit Process Flow

3. Analysis and Results

The hospital receives electrical supply from PLN at 345 KVA, supplemented by backup power from the generator at 350 KVA. The MCCB has a rating of 400 A, and the electrical power frequency is 51 Hz. Over a 12 months period from November 2019 to October 2020, the electricity bills indicated a total consumption of 717,189 kWh, as illustrated in Table 5. The building's electricity coverage area is 2,519.9 m². The pattern of electricity usage throughout the year can be understood by calculating the intensity of energy consumption, obtained by dividing the total annual electricity consumption by the covered area. The calculation resulted in a direct ECI value of 284.61 kWh/m². In line with the electricity ECI standard, derived from the Basic Energy Audit Standard established by the Indonesian National Standardization Agency (BSN) in the form of SNI6196:2011 Energy Audit Procedures for Buildings, the classification for hospitals is set at 380 kWh/m²/year. Therefore, based on the data obtained from the calculation of ECI per unit area of a hospital building, using energy consumption data from electricity bills over 12 months is shown in Table 5.

Table. 5 Monthly Usage of Electric Energy Consumption

No.	Month	Usage (kWh)
1	November 22	64.180
2	December 22	60.976
3	January 23	59.096
4	February 23	55.136
5	March 23	56.828
6	April 23	58.460

7	May 23	54.748
8	June 23	58.120
9	July 23	60.428
10	August 23	60.332
11	September 23	65.135
12	October 23	63.750

3.1 ECI of Lighting System

The calculation of the lighting system's energy consumption aims to determine the energy consumed over a specific period by the lighting system. The energy consumption of a lighting unit is contingent on the power rating of the used lamps (in Watts) and the duration of usage in a day (24 hours) according to the activities inside or outside the building[19]. If the activities necessitate high precision and prolonged usage, then the size of the lamp's power and the required usage time within 24 hours will also increase. The energy consumption of the lighting system in a room is measured in watt-hours (WH). Based on the data of the power rating of the lamps used and the duration of usage within 24 hours in the Muhammadiyah Hospital building the average data for the energy consumption of the indoor and outdoor lighting systems per day for Sang Surya building and Mentari building indicate that Sang Surya building consumes approximately 133.4 kWh, while Mentari building consumes around 68.9 kWh. Thus, the total energy consumption for the lighting systems can be determined as 133.4 + 68.9 = 202.3 kWh per day.

3.2 ECI of the AC System

The calculation and measurement of energy in the AC system, along with the calculation of the percentage of excess load, aim to determine the energy usage efficiency for the air conditioning system. Energy calculations for the AC system based on usage duration are performed using data on the calculation of the AC capacity needed in HP units, with an estimated power for 1 HP being 746 Watts. The daily AC energy consumption data for the Sang Surya building and the Mentari building can be determined as approximately 987.3 kWh for the Sang Surya building and around 842,5 kWh for the Mentari building. Thus, the total AC load can be calculated as 987.3 + 845,5 = 1829,8 kWh per day.

3.3 ECI of the Electronic Devices

The calculation of electricity consumption for electronic devices aims to determine the efficiency of electricity usage. This calculation involves reviewing the number of devices, the daily operating hours of each device, and the power capacity of each device to determine the electricity consumption for other electronic equipment. The average daily consumption of other electronic devices for the Sang Surya building and the Mentari building is a total of 66.6 + 62.8 = 129.4 kWh per day. Based on the calculation of the average energy consumption of the Muhammadiyah Hospital building per day, the results are: The ECI value for lighting loads is 202.3 kWh, the ECI value for AC loads is 1829.8 kWh and the ECI value for electronic equipment is 129.4 kWh, as shown in Table 6.

Table 6. Daily building energy consumption intensity

Building	ECI Lighting (kWh)	ECI AC (kWh)	ECI Electronic (kWh)
Sang surya building	133,4	987,3	66,6
Mentari building	68,9	842,5	62,8
Amount	202,3	1829,8	129,4

3.4 Fuzzy Implementation

The first stage of the fuzzification of the direct measurement input variable involves three fuzzy sets: low, medium, and high. The fuzzy membership degrees for the direct measurement method with a value of 284.61 kWh/m² can be calculated. The low fuzzy set has a low membership degree calculated with a triangular membership function[20]. The medium fuzzy set has a medium membership degree, also calculated with a triangular membership function with "infinity" as the upper limit. The high fuzzy set has a high membership degree, calculated with a triangular membership function and "infinity" as the upper limit. Figure 5 illustrates the membership function of the direct ECI variable. After running the code using Python, the fuzzy membership degrees for the direct measurement input variable are obtained, with a low value of 0.7337692307692306, a medium value of 0.2662307692307693, and a high value of 0.

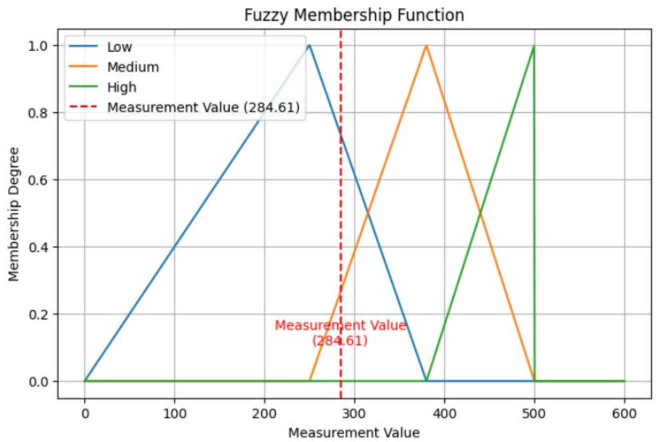

Fig. 5 Fuzzy Membership Function of Direct ECI

In the fuzzification stage of the ECI value method input variables, there are three fuzzy sets: low, medium, and high. The degree of fuzzy membership for the ECI value method with a value of 380 kWh/m² can be explained as follows. Low fuzzy sets have a low degree of membership which is calculated by the triangular membership function. Medium fuzzy sets have medium membership degrees, also calculated by a triangular membership function with "infinity" as the upper limit. High fuzzy sets have a high degree of membership, calculated with a triangular membership function and "infinity" as the upper limit. The membership function of the RS Standard ECI variable is shown in Figure 6.

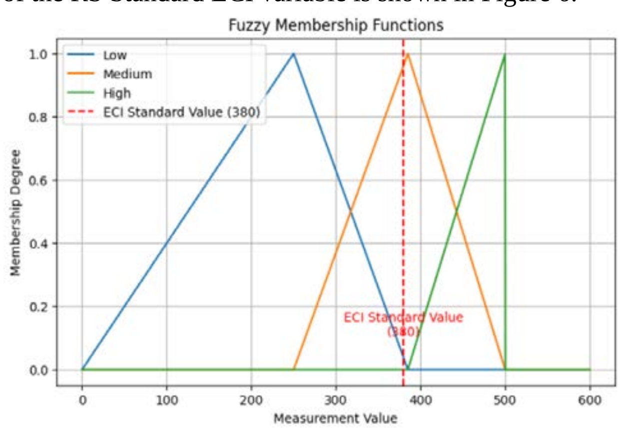

Fig. 6 Fuzzy Membership Function of Hospital Standard ECI

In the second stage of fuzzy inference, the MIN function is applied to each rule by combining the fuzzy membership degrees from the input Direct ECI and Hospital Standard ECI variables. For example, in the first rule [R1], the fuzzy membership degrees for the "low" predicate from Direct ECI and "low" from Hospital Standard ECI are calculated using the MIN function, resulting in a value of 0.037. This value is then used in the next stage to calculate the crisp or definite value of the output ECI Value, in this case it is 290. This process is carried out for each rule that has been formulated, and the fuzzy membership degrees from each rule are used to generate definite values for the output variable. This process is an integral part of the fuzzy logic system for making decisions based on predefined rules.

In the third defuzzification stage, the value of z* is calculated using Equation (4), resulting in approximately 343.54 kWh/m²/year. The testing results indicate that the fuzzy electrical energy audit system Muhammadiyah Hospital falls into the efficient category. This is reflected in Figure 7, which illustrates the membership function of the output variable ECI value.

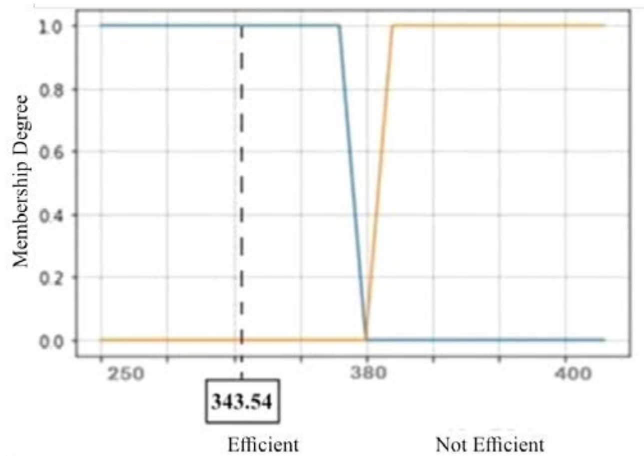

Fig. 7 Fuzzy Membership Function of Output Variable ECI Value

4. Conclusion

The energy consumption intensity (ECI) of the Muhammadiyah Hospital building in Jepara is 284,61 kWh/m²/year which means that based on the ECI standard value, it is considered efficient because it is below the standard recommendation of 380 kWh/m²/year. The energy consumption intensity is 284,61 kWh/m²/year, lighting consumption (8%), AC (87%) and electronic devices (5%) as daily load contributors. The integration of fuzzy logic into the energy audit process provided a robust decision support system, ensuring more accurate identification of energy consumption patterns and potential areas for improvement. The fuzzy logic-based system categorized the hospital's electrical energy consumption as efficient, with a calculated value of approximately 343.54 kWh/m²/year, not exceeding the standard recommendation of 380 kWh/ m²/year for hospital buildings in Indonesia.

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