Perancangan Sistem Pendingin Ruangan Rapat Berbasis Fuzzy Logic Control

Mohammad Harry Khomas Saputra,Teknologi Rekayasa Informatika Industri,Politeknik Manufaktur Bandung,harry@ae.polman-bandung.ac.id[1]*
Ridwan,Teknologi Rekayasa Otomasi,Politeknik Manufaktur Bandung,ridwan@polman-bandung.ac.id[2]
Nenden Siti Nurkholipah,Program Studi Matematika,Universitas Kebangsaan Republik Indonesia, nenden@gmail.com[3]
Siti Hadiaty Yuningsih,Pemeliharaan Mesin,Politeknik Manufaktur Bandung,yuni@polman-bandung.ac.id[4]
Marta Hayu Raras Sita Rukmika Sari,Teknologi Rekayasa Manufaktur,Politeknik Manufaktur Bandung,martahayuraras@polman-bandung.ac.id[5]
Aan Eko Setiawan,Teknologi Rekayasa Otomasi ,Politeknik Manufaktur Bandung, aaneko@polman-bandung.ac.id[6]

Corresponding Author : harry@ae.polman-bandung.ac.id*

Abstract

Background : Indoor thermal comfort is influenced not only by room temperature but also by occupant density. Conventional cooling systems generally regulate fan speed or air conditioning based solely on temperature, resulting in inefficient energy consumption and reduced comfort under varying occupancy conditions

Purpose : This study aims to design and implement an automatic room cooling system that adjusts fan speed based on room temperature and visitor density using Mamdani Fuzzy Logic Control (FLC)..

Methodology : The proposed system integrates a DHT22 sensor to measure room temperature and an ultrasonic sensor to estimate visitor density. A Mamdani fuzzy inference system was developed using linguistic variables for temperature (*cold*, *normal*, and *hot*) and visitor density (*sparse*, *crowded*, and *very crowded*) to determine the appropriate fan speed through Pulse Width Modulation (PWM).

Findings : Experimental results demonstrate that the proposed system successfully adapts fan speed to different environmental conditions. At 17°C with 6 visitors (*sparse*), the fan operated at a low speed with a PWM value of 39.6. At 22°C with 25 visitors (*crowded*), the system increased the fan speed to a medium level with a PWM value of 125. Under the highest load condition of 34°C with 37 visitors (*very crowded*), the fan operated at high speed with a PWM value of 211. These results indicate that the fuzzy logic controller effectively integrates temperature and occupancy information to provide adaptive cooling while improving energy efficiency and occupant comfort.

Implications : The proposed system provides a practical and low-cost intelligent cooling solution for enclosed spaces with dynamic occupancy levels. However, this study was conducted under controlled experimental conditions using a prototype system. Future research should validate the approach in larger real-world environments and compare its performance with other intelligent control methods, such as Sugeno fuzzy logic or machine learning-based controllers.

Originality : This study contributes by integrating room temperature and visitor density into a Mamdani fuzzy logic-based fan speed control system using an ultrasonic sensor for occupancy estimation. Unlike previous studies that relied on a single control parameter, the proposed approach enables more adaptive and energy-efficient cooling

suitable for meeting rooms, seminar halls, conference facilities, and other indoor public spaces.

Keywords: Automatic room cooling; DHT22 sensor; Fan speed control; Fuzzy logic control; Indoor thermal comfort; Occupant density.

INTRODUCTION

The comfort of an indoor environment is strongly influenced by air temperature and the quality of air circulation. Rooms used for activities such as meetings, seminars, and large events generally experience increases in temperature and humidity as the number of occupants rises. Therefore, the implementation of an automatic and energy-efficient cooling system is essential to maintain occupant comfort and support productivity during indoor activities. One promising solution is to develop a technology-based cooling system capable of adjusting fan speed according to both room temperature and occupant density.

Conventional cooling systems generally regulate air conditioning based solely on temperature settings, without considering the number of occupants in the room. As a result, these systems often fail to operate optimally in terms of both energy efficiency and thermal comfort. Consequently, there is a need for an adaptive cooling system that can respond to real-time changes in both room temperature and occupancy levels. This study aims to design a room cooling system based on a Mamdani Fuzzy Logic Controller (FLC) that regulates fan speed using two primary input variables: room temperature and occupant density.

Several previous studies have investigated the development of automatic cooling systems. Ramadhan et al. (2024) designed a microcontroller-based cooling system employing a Passive Infrared (PIR) sensor to detect human presence inside a room. Meanwhile, Khairi et al. (2024) developed an automatic air-conditioning control system that responds to changes in room temperature. These studies demonstrated that automated systems have considerable potential for improving indoor temperature regulation. However, their approaches remain limited because most existing systems consider only a single parameter, such as room temperature or human presence, without directly integrating occupant density into the control strategy.

In reality, thermal comfort is influenced not only by air temperature but also by the number of occupants within the room. Two rooms with identical temperatures may provide different levels of comfort when occupant density varies, as human presence contributes additional heat loads through metabolic activity. Therefore, an effective cooling system should respond not only to temperature fluctuations but also to changes in occupant density. This research addresses this gap by integrating both room temperature and occupant density into an adaptive cooling control system, thereby enabling more realistic and responsive environmental control.

In this study, occupant density is detected using an ultrasonic sensor. This sensor was selected because it measures object distance through reflected ultrasonic waves, enabling more measurable detection of object presence within a designated area. Unlike PIR sensors, which detect changes in infrared radiation caused by human movement, ultrasonic sensors are more suitable for applications requiring distance-based object detection regardless of motion. Consequently, the ultrasonic sensor is expected to provide more relevant information for estimating room occupancy as one of the control variables in the cooling system.

The decision-making process is implemented using the Mamdani Fuzzy Logic model. This approach was chosen because it effectively represents environmental conditions using intuitive linguistic variables, such as *low*, *normal*, and *high* temperature, as well as *low*, *medium*, and *high* occupant density. Such characteristics are well suited to room cooling applications, where control decisions depend on combinations of multiple environmental conditions rather than strict numerical thresholds. Compared with the Sugeno fuzzy model, which typically produces outputs in the form of constants or mathematical equations, the Mamdani model offers greater interpretability and is more appropriate for rule-based room cooling control. Through this approach, the proposed system is expected to provide more responsive cooling performance, improve energy efficiency, and maintain occupant comfort under varying environmental conditions.

Corresponding Authors : : harry@ae.polman-bandung.ac.id

The objective of this study is to design and implement an automatic room cooling system capable of adjusting fan speed according to room temperature and occupant density using fuzzy logic control. By utilizing a DHT22 sensor to measure room temperature and an ultrasonic sensor to estimate occupant density, the proposed system is expected to achieve optimal performance under various environmental and occupancy conditions.

METHODOLOGY

This study adopts the **Prototyping** methodology, an iterative system development approach that involves designing an initial prototype, conducting performance testing, and continuously refining the system based on the evaluation results. This methodology is particularly suitable for research involving the integration of hardware and software components. In this study, the prototyping approach facilitates the development and validation of an automatic room cooling system based on Mamdani Fuzzy Logic Control, which regulates fan speed using room temperature and occupant density as the primary input parameters. Fig 1 shown research design

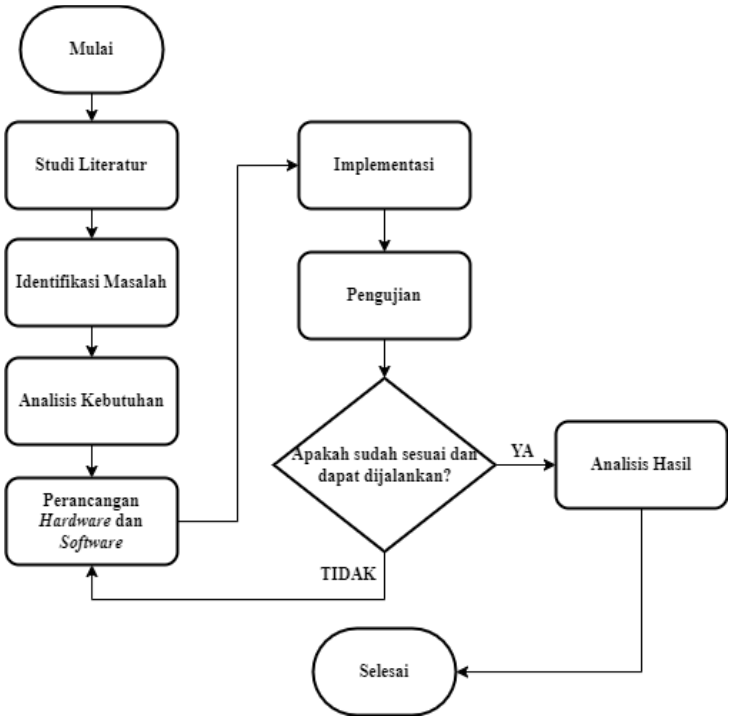


Figure 1. Design Research

The development process begins with a comprehensive literature review, followed by problem identification, requirements analysis, system design, implementation, and testing. The testing phase is conducted to evaluate whether the developed system meets the predefined functional and performance specifications. Based on the test results, iterative refinements are carried out by modifying both the hardware and software components during the design phase, followed by subsequent rounds of testing. This iterative cycle continues until the system achieves the desired level of performance, reliability, and functionality.

A. Litelatur Review

During the literature review stage, relevant studies on automatic room cooling systems, temperature sensing technologies, occupancy detection, and intelligent control methods were systematically examined to establish the theoretical and technical foundation of the proposed

Corresponding Authors : : harry@ae.polman-bandung.ac.id

system. Previous studies, including Ramadhan et al. (2024), who developed a microcontroller-based automatic cooling system using a Passive Infrared (PIR) sensor for human presence detection, and Khairi et al. (2024), who designed an Arduino-based automatic air-conditioning control system using room temperature as the primary control parameter, were critically reviewed. These studies provided valuable insights into the implementation of automated cooling systems while also highlighting the need for a more adaptive approach that integrates both room temperature and occupant density to improve thermal comfort and energy efficiency.

B. Identification Problems

The research problem was formulated through a comprehensive literature review and an analysis of real-world operational conditions. The primary focus of this study is to develop an automatic room cooling system capable of adjusting fan speed based on two critical parameters: room temperature and occupant density. The proposed approach aims to address the limitations of conventional cooling systems, which typically rely on temperature alone and therefore fail to respond effectively to dynamic occupancy conditions. The ultimate objective is to enhance indoor thermal comfort while minimizing unnecessary energy consumption by implementing a more adaptive and intelligent cooling control strategy.

C. Needed Analyis

During the requirements analysis phase, the functional and technical requirements of the proposed system were identified to ensure that the developed prototype satisfies the intended operational objectives. This process involved defining the essential system functionalities, input and output parameters, hardware components, and control mechanisms required for automatic room cooling. The functional requirements of the proposed system are presented in the following table.

Table 1. Fungsional Needed

ID	Needed Fungsi Description	Category
F1	Mengukur suhu ruangan menggunakan sensor DHT22	Sensor
F2	Mengukur kepadatan pengunjung menggunakan sensor ultrasonic	Sensor
F3	Menyesuaikan kecepatan kipas secara otomatis berdasarkan suhu dan kepadatan pengunjung	Kontrol

F1 (Temperature Sensor) :
This requirement ensures that the system can accurately measure room temperature using a DHT22 sensor, providing reliable temperature data for the cooling control process.
F2 (Occupancy Sensor):
This requirement ensures that the system can estimate occupant density using an ultrasonic sensor installed at the room entrance, enabling real-time monitoring of occupancy levels.
F3 (Automatic Control):
This requirement ensures that the system can automatically adjust the fan speed based on room temperature and occupant density using the Mamdani Fuzzy Logic Control algorithm, thereby providing adaptive cooling while improving thermal comfort and energy efficiency.

D. Development Simulatrion coold in the room of the basis FLC

Corresponding Authors : : harry@ae.polman-bandung.ac.id

The hardware design of the proposed system consists of a DHT22 temperature sensor, an ultrasonic sensor, and an Arduino Uno microcontroller serving as the central processing unit. The Arduino Uno receives input data from both sensors, processes the information using the Mamdani Fuzzy Logic Control algorithm, and generates a Pulse Width Modulation (PWM) signal to regulate the fan speed. Sensor data are subsequently integrated into a simulation environment to evaluate the relationship between the input variables and the resulting fan speed under different operating conditions. As the initial stage of the system design, the input–output architecture of the automatic room cooling system was developed, as illustrated in **Figure 2**. The proposed system employs two input variables—room temperature and occupant density—and one output variable, namely the fan speed.

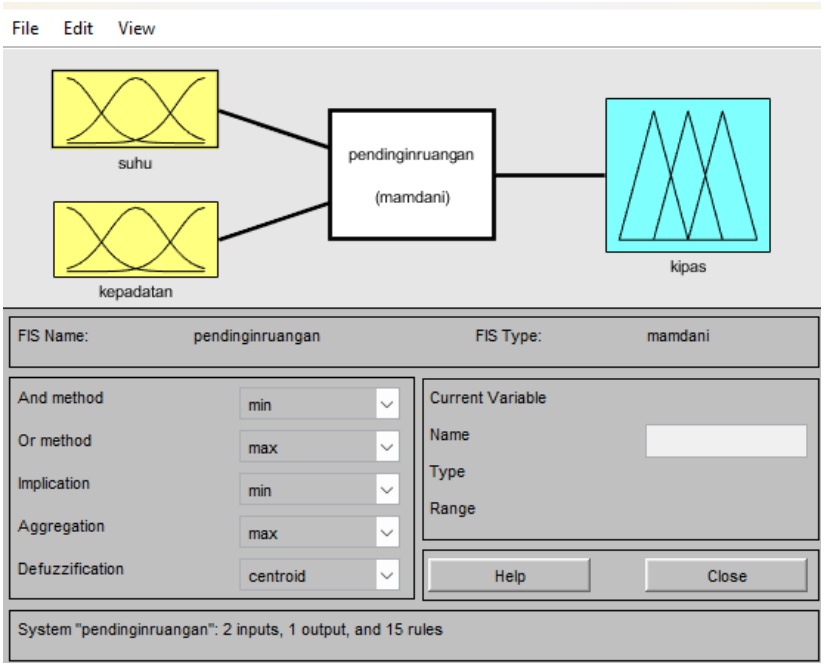


Figure 2. Simulation cold room design

The control strategy employs the Mamdani Fuzzy Logic approach due to its capability to effectively represent linguistic variables and handle uncertainty in decision-making processes. In the proposed system, room temperature is described using three fuzzy sets—*cold*, *normal*, and *hot*—while occupant density is represented by *sparse*, *crowded*, and *very crowded*. These linguistic variables enable the controller to emulate human reasoning when determining the appropriate fan speed under varying environmental conditions.

The Mamdani fuzzy inference model is particularly suitable for this application because it provides flexible and adaptive control for continuous input variables without requiring precise mathematical models of the system. The membership functions for room temperature, occupant density, and fan speed were therefore designed to represent the operating conditions of the cooling system. Specifically, the temperature variable consists of three fuzzy sets (*cold*, *normal*, and *hot*), whereas the occupant density variable is divided into *sparse*, *crowded*, and *very crowded*. The membership function for the temperature variable is illustrated in **Figure 3**.

Corresponding Authors : : harry@ae.polman-bandung.ac.id

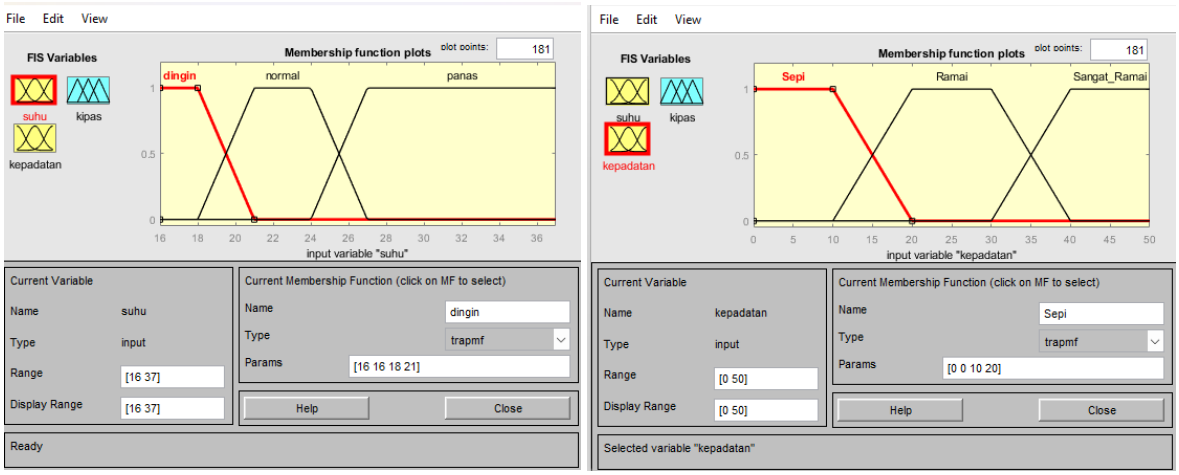


Figure 3. Function input design membership

Following the definition of the input variables, the output variable was designed in the form of a single fuzzy membership function representing the **fan speed**. The output variable is divided into three linguistic terms: *low*, *medium*, and *high*, corresponding to the operating speed of the cooling fan. These membership functions enable the Mamdani fuzzy inference system to determine the appropriate Pulse Width Modulation (PWM) value based on the combination of room temperature and occupant density. The design of the fan speed membership function is presented in **Figure 4**.

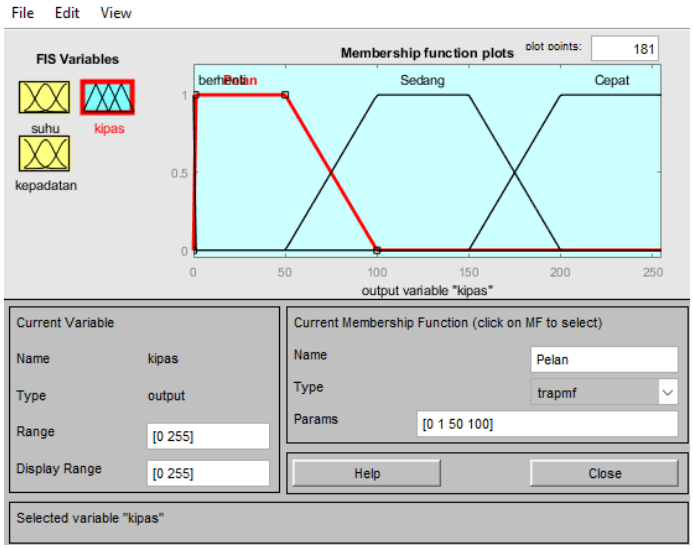


Figure 4. Function output design membership

After defining the membership functions, the fuzzy rule base was developed to establish the relationship between the input variables and the output variable. In this study, the Mamdani fuzzy inference system consists of nine inference rules derived from the combination of two input variables: room temperature and occupant density. Each input variable is represented by three linguistic terms. Room temperature is classified as *cold*, *normal*, and *hot*, whereas occupant density is categorized as *sparse*, *crowded*, and *very crowded*. Consequently, the combination of these linguistic variables produces a total of **3 × 3 = 9** fuzzy rules. These rules represent expert knowledge and serve as the decision-making mechanism for determining the appropriate fan speed under different environmental conditions. The complete set of fuzzy inference rules is presented as follows.

Corresponding Authors : : harry@ae.polman-bandung.ac.id



Figure 5. Fuzzy Rule

E. Development Simulation Cold Room Based on FLC

After the system architecture and fuzzy rule base had been established, the proposed room cooling system was evaluated using the Mamdani Fuzzy Logic Control approach. The testing process was conducted by validating each fuzzy inference rule to ensure that the generated fan speed corresponded to the intended control strategy under different combinations of room temperature and occupant density. The evaluation results were then analyzed to verify the accuracy and consistency of the fuzzy controller. The complete testing results for all inference rules are presented in **Table 2**.

Table 2 Testing of the System

No	Temparature	Values oC	Density	People	Fan	PWM
1	Cold	17	sepi	6	pelan	39.6
2	Cold	17	ramai	27	pelan	39.6
3	Cold	17	sangat ramai	37	sedang	108
4	Cold	22	sepi	6	pelan	39.6
5	normal	22	ramai	25	sedang	125
6	normal	22	sangat ramai	37	cepat	178
7	Hot	34	sepi	6	sedang	125
8	Hot	34	sepi	25	cepat	214
9	Hot	34	sangat ramai	37	cepat	211

RESULT AND DISCUSSION

A. Result

The experimental evaluation assessed the performance of the proposed cooling system by analyzing fan speed under different combinations of room temperature and occupant density. The controller output was represented by Pulse Width Modulation (PWM), which determines the rotational speed of the cooling fan. The experimental scenarios were categorized into three temperature conditions (*cold*, *normal*, and *hot*), each combined with three occupancy levels (*sparse*, *crowded*, and *very crowded*).

Under the cold temperature condition (17°C), the controller maintained a low fan speed (PWM = 39.6) when the room was occupied by 6 visitors (sparse), indicating that minimal cooling was required. When the occupancy increased to 27 visitors (crowded), the controller still selected the low fan speed (PWM = 39.6), suggesting that the low ambient temperature remained the dominant factor in the control decision. However, when the occupancy reached 37 visitors (very crowded), the controller increased the fan speed to the medium level (PWM = 108) to compensate for the additional heat generated by the large number of occupants.

For the normal temperature condition (22°C), the controller also selected a low fan speed (PWM = 39.6) when only 6 visitors were present, demonstrating energy-efficient operation under

Corresponding Authors : : harry@ae.polman-bandung.ac.id

moderate environmental conditions. As the occupancy increased to 25 visitors (crowded), the controller adjusted the fan speed to the medium level (PWM = 125). When the room became very crowded (37 visitors), the controller further increased the fan speed to the high level (PWM = 178), reflecting the greater cooling demand caused by increased occupant density.

Under the hot temperature condition (34°C), the controller responded more aggressively to maintain thermal comfort. With only 6 visitors (sparse), the fan operated at a medium speed (PWM = 125), indicating that elevated temperature alone required additional cooling. When the occupancy increased to 25 visitors (crowded), the controller selected a high fan speed (PWM = 214). Similarly, under the most demanding condition of 34°C with 37 visitors (very crowded), the controller maintained the high fan speed with a PWM value of 211, demonstrating that the fuzzy logic controller consistently prioritized sufficient cooling under high thermal loads.

Overall, the experimental results demonstrate that the proposed Mamdani Fuzzy Logic Controller effectively integrates room temperature and occupant density to determine an appropriate fan speed. The controller exhibits adaptive behavior by increasing the PWM output as thermal load rises, thereby maintaining indoor thermal comfort while avoiding unnecessary energy consumption under low-demand conditions.

B. Discussion

The experimental results indicate that the fan speed is directly influenced by two primary input variables: room temperature and occupant density. Under **cold** temperature conditions, variations in occupant density produce only minor changes in fan speed, indicating that low ambient temperature remains the dominant factor in the control decision. In contrast, under **hot** temperature conditions, the controller increases the fan speed even when the occupancy level is low, demonstrating that elevated temperature alone is sufficient to trigger a higher cooling demand.

Overall, the proposed Mamdani Fuzzy Logic Controller effectively adapts the fan speed according to changes in both environmental temperature and occupant density. As either the room temperature or the number of occupants increases, the controller automatically generates a higher PWM output, resulting in faster fan operation to maintain indoor thermal comfort. These findings demonstrate the capability of the proposed fuzzy logic-based control system to provide adaptive cooling while improving energy efficiency by avoiding excessive fan operation under low thermal load conditions.

CONCLUSION

This study successfully designed and implemented an automatic room cooling system based on Mamdani Fuzzy Logic Control that regulates fan speed according to room temperature and occupant density. The experimental results demonstrate that the proposed system effectively adjusts fan speed under different environmental and occupancy conditions, thereby improving indoor thermal comfort while reducing unnecessary energy consumption. By integrating room temperature and occupant density as input variables, the fuzzy logic controller provides adaptive and intelligent cooling decisions, particularly under high-temperature and high-occupancy conditions where greater cooling capacity is required.

The findings confirm that the proposed approach offers a practical and energy-efficient solution for intelligent indoor climate control. The system has the potential to be implemented in public indoor environments with dynamic occupancy levels, such as meeting rooms, seminar halls, conference rooms, classrooms, and similar facilities. Future research should validate the proposed system in larger real-world environments, incorporate additional environmental parameters such as humidity and air quality, and compare the performance of the Mamdani approach with other intelligent control techniques, including Sugeno fuzzy logic and machine learning-based controllers.

AUTHOR'S CONTRIBUTION

Mohammad Harry Khomas Saputra: Conceptualization, Methodology, Software, Hardware Development, Investigation, Data Curation, Formal Analysis, Validation, Visualization, Writing – Original Draft, Writing – Review & Editing.
Ridwan: Methodology, Formal Analysis, Validation, Writing – Review & Editing.

Corresponding Authors : : harry@ae.polman-bandung.ac.id

Nenden Siti Nurkholipah: Investigation, Data Curation, Validation, Writing – Review & Editing.
Siti Hadiaty Yuningsih: Supervision, Methodology, Validation, Writing – Review & Editing.
Marta Hayu Raras Sita Rukmika Sari: Resources, Investigation, Visualization, Writing – Review & Editing.
Aan Eko Setiawan: Supervision, Project Administration, Funding Acquisition (if applicable), Writing Review & Editing. All authors have read and agreed to the published version of the manuscript.

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DECLARATION OF COMPETING INTEREST
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Corresponding Authors : : harry@ae.polman-bandung.ac.id

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Corresponding Authors : : harry@ae.polman-bandung.ac.id