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Fuzzy Logic Controller for Roof Sprinkler Cooling System

Faizzudin Sahazudin[1], Nooraini Yusoff[2*] and Fadzilah Siraj[3]

[1,2,3]School of Computing, College of Arts and Sciences, Universiti Utara Malaysia, 06010 UUM Sintok, Kedah, Malaysia
[2*]nooraini@uum.edu.my
faizsahazudin@gmail.com , fad173@uum.edu.my
[*]Corresponding author

Abstract: In Malaysia, a cooling system is very efficient in reducing the heat from outside temperature. Normally, for those who afford, the best equipment will be utilized to make homes in a cool and comfort temperature. This may take an equipment such as air-conditioner or super insulation to their house. However, those equipments are costly for their installation, maintenance and energy. In this study, we propose a design of roof sprinkler cooling system using fuzzy logic (FL). The water sprinkler works by triggering the controller to open the valves to release and spray water. FL could benefit the cooling system by intelligently controlling the actual water quantity based on the observed daily weather condition captured from a sensor. This technique is the key approach to saving both water and energy. The system has been simulated and tested accordingly with a number of conditions and parameters, and it has been shown that the proposed design is feasible and practical to be implemented.

Keywords: Roof Sprinkler, Cooling System, Controller, Fuzzy Logic, Intelligent System

1 Introduction

Fuzzy logic(FL) has been proven well for its broad potentials in many kinds of applications for many years. FL is much closer in a way of human thinking and natural language than the traditional logical systems. For some problems in the real world, traditionally, system modeling and analysis techniques are way precise. Nevertheless, it is quite challenging to deal with the problems that involve some degrees of uncertainty or can be termed as vagueness. As a solution, the experts introduce an appropriate simple technique (i.e. FL) to achieve a satisfactory between the actual information and the amount of vagueness that willing to accept. Fuzzy systems theory is similar to other application theories, in which they characterize the real world in an approximate manner.

Real world contains level of uncertainty that makes many things are too much complex. In 1965, Lotfi Zadeh introduced a mathematical tool called Fuzzy Logic that is able to deal with complexity of uncertainty. The limitation of traditional mathematical models had inspired Zadeh to engineer a technique with multiple variable that can be suited to a prospect which the value falls between 0 and 1. This has allowed things in the range of binary structure to be defined. The fuzzy logic technique provides theory of mechanism for showing linguistic constructs. Generally, it provides an inference mechanism that imiatiate particular human reasoning capabilities.

The traditional binary set theory describes crisp events, events that either do or do not occur. It uses probability theory to explain if an event will occur, measuring the chance with which a given event is expected to occur. In contrast, The theory of FL is based on the notion of relative graded membership and so are the functions of mutation and cognitive processes. The utility of fuzzy sets lies in their ability to model uncertain or ambiguous data. The steps in a fuzzy system is depicted in Figure 1.

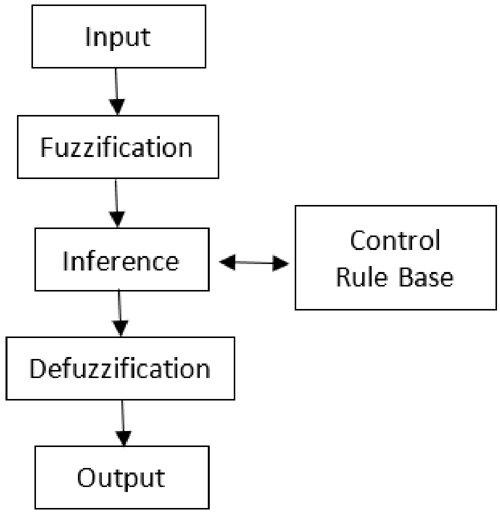


Figure 1: How fuzzy logic system (FLS) operates, reproduced from [1]

In this study, we integrate FL into a design of roof sprinkler cooling system. For brevity, FL is used to control the water release based on the temperature sensors information. The system has been successfully tested with various conditions and parameters.

1.1 Water Sprinkler

In defining a water sprinkler, it is a tool of applying irrigation water and it considered as an artificial rainfall. Water sprinklers are used to water plants or grass, or to put out fires in buildings. Different sprinkler indicates different abilities. spray water in a very high pressure while some do not. Usually, water is distributed by pumping through a system pipes. The water sprinkler works by sending a signal using a controller to the control valves in the control valve box. The valves open, sending the water through the water line which causes the sprinkler heads to pop up and spray. The power to sprinkle out is based on the water pressure and the sprinkler's head. By these two factors, amount of water can be control. A well-planned irrigation system can avoid over usage of water which leads to not only wastage of water but can be harmful if it is used for plants. In this study, the sprinkler attached with a sensor are installed on the roof of the house and it is aimed to decrease the temperature inside the house.

1.2 Roof Sprinkler Cooling System

In Malaysia, houses are equipped with a cooling equipment as a heat relief due to local weather conditions. Some people choose to utilize an air-conditioner, while the rest might get any other types of equipment. Basically, those types of equipment are powered up by using electricity. Amount of the charge is calculated according to the usage per hour. The longer we use the higher the cost of charges. Usually, most users have to turn them on long hours. More over, due to warm climate during the year [2], it is unlikely that the cost ould be reduced. In this study, fuzzy logic control is presented as an application of roof sprinkler cooling system. It is a water-based system and yet, the charges of water usage are not as much as the electricity.

For current practice, a timer is applied as the sprinkler switch [3]. During the hot days, there is a need of more water to be sprinkled on the roof surface. This has to be done constantly in order to substitute the room's heat with a cold breeze. Nevertheless, timer is solely depends on the setting period regardles the weather condition. It might stop working while the day reaches a high level of temperature or it would release the same amount of water even during the rainy days. Hence, a sprinkler integrated with a weather alert sensor controlled by a fuzzy system is proposed in this study. The sensor detects five kinds of weather phenomena such as sunny, cloudy, windy, humidity and rainfall. This intelligent technique allows user to control the actual water quantity based on the observed daily weather condition. This could save water and energy.

2 Literature Review

From the previous studies, a study by Archana and Priya [4], implements water sprinkler sensors which detect the humidity in the soil (agricultural field) and supply water to the field that indicate the need of water. The project is a microcontroller based design which controls the water supply and the field to be irrigated using water sprinkler. Once the field gets dry, the sensors sense the requirement until the sensors is deactivated again. In case when there is more than one signals for water requirement then the microcontroller prioritizes the first received signal and irrigates the field accordingly.

In a similar study by Kumar et al. [5], they provide information about automatic irrigation of plants which helps in saving money and water. The entire system is controlled using ATMEGA 328 microcontroller that passes the interrupt signal to the motor. The temperature sensor and humidity sensor are connected to the internal ports of micro controller via comparator, whenever there is a fluctuation in temperature and humidity of the environment, these sensors sense the change in temperature and humidity and triggers an interrupt signal to the micro-controller and thus the motor is activated, along with this buzzer is used to indicate that pump is on.

3 Materials and Method

In this study, the fuzzy engine is developed using Visual Basic 2010. The proposed controller is a two-layered fuzzy system. Figure 2 shows the input variables consisting of the first two inputs namely number of people and rooms that need be defuzzified to get the first output (i.e. heat capacity) in the form of measurable process variables. The inputs are identified based on what is the preferred output. This output is then to be paired with the third input namely weather temperature in order to obtain the final output (i.e. water pressure). In the rest of this section, we explain FL components which consist of two fuzzifications, fuzzy inferences and defuzzification processes for generating the initial and the final output.

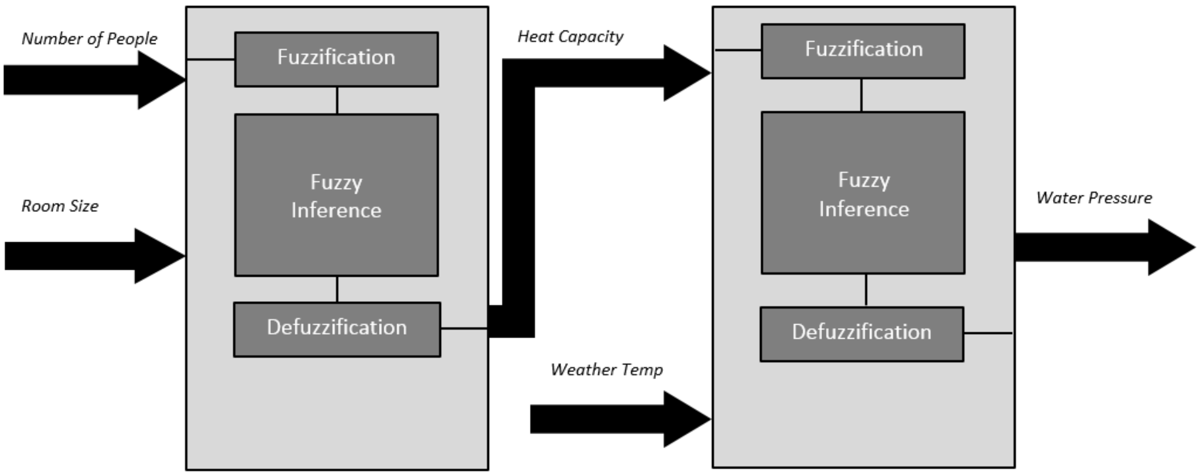


Figure 2: Fuzzy Logic Controller of Roof Sprinkler Cooling System

3.1 Fuzzy Logic System for Heat Capacity

The first output is heat capacity and it is generated from two types of real inputs which are the number of people(#1) and room size(#2). The value of input #1 is captured by observing the number of people inside the room, whilst, input #2 is based on the size of the room in square feet. Input #1 has to be an input value whether the room is full or with no occupancy. As a result of these two inputs provides human body's heat reading that is used to obtain the output of heat capacity. In order to count the number of people in a room, there is a sensor that will be installed at each of the door of room. It counts the number of people who enter and leave the room. Shadows are not detected and therefore it will never affect the count. In fact, the background features are totally ignored by only capturing the entry from a moving target.

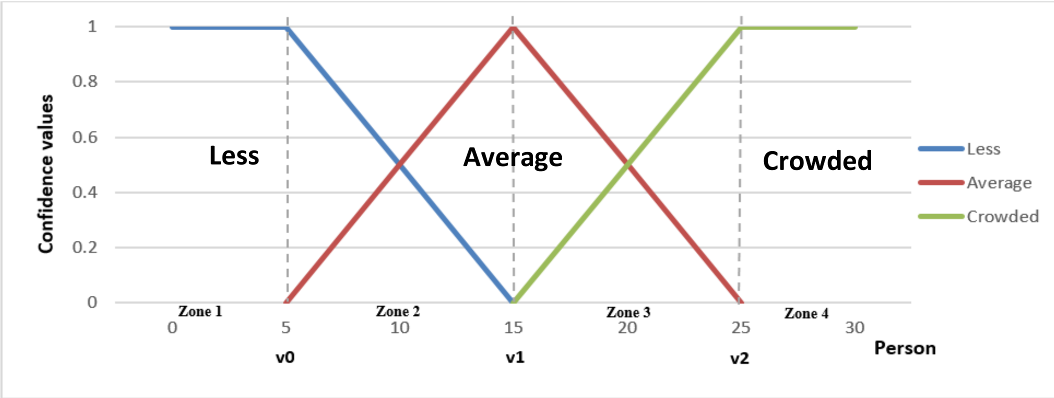
Fuzzification: Fuzzification is the process of converting the crisp input (i.e. raw input) into fuzzy values [6]. Some calculations have to be done in order to apply the graphic analysis to the input values in the horizontal (X-axis) and the confidence values in vertical (Y-axis). There are different types of membership functions, in which the commonly used are triangular and trapezoidal membership functions [7] [8] [9] [10] [11]. Several ranges are applied in the first two inputs to measure the degree of membership for each. These ranges are known as the linguistic variables. Table 1 states the chosen linguistic variables and the universe of discourse for the both input variables.

Table 1: Linguistic variables and universe of discourse

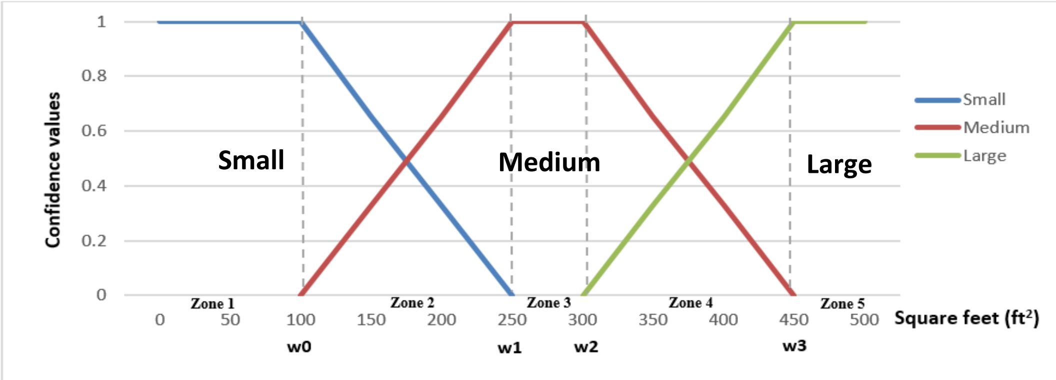
Input variables (unit)	Linguistic variables	Universe of Discourse
Number of People (person)	Less, Average, Crowded	0 to 30
Room Size (square feet)	Small, Medium, Large	0 to 500

The linguistic variables are measured by using a membership function graph. The confidence values for each set of linguistic variables for number of people ∈{less, average, crowded} and room size ∈{small, medium, large} are plotted on the graph. In FL, there are a set of input variables with one or more associated outputs. These variables are fuzzified using a pre-defined input membership functions. The type of functions chosen are dependent on the problem case. As a result from the fuzzification, the degree of membership (i.e. confidence value) of each variable is obtained from the membership functions.

Figure 3 shows the the membership functions used in this study which is the combination of triangular and trapezoidal functions. The graphs are separated with dotted lines to make it easy to read the confidence values. Each graph indicates the different zones with different functions. The intersecting lines give the same value computed using different function as being shown in Zone 2 and Zone 3.



(a)



(b)

Figure 3: Membership function graph for (a) number of people and (b) room size

For the output variable in the first FL system, a membership function is also used to define the heat capacity such that Heat Capacity ϵ {low, medium, high}

Fuzzy Inference: This section is the stage where rules are constructed. Two or more fuzzy input sets are combined in fuzzy rules (IF-THEN), called the antecedent sets and associated with them an output known as the consequent set [13]. The antecedent sets are combined using operators that are analogous to the usual logical conjunctives "AND" or "OR". The sample of fuzzy rules for the determination of heat capacity value are listed in the table below (Table 2).

Table 2: Fuzzy rules sample for heat capacity

R1	**IF** number of people is "less" **AND** room size is "medium" **THEN** heat capacity is "low"
R2	**IF** number of people is "average" **AND** room size is "medium" **THEN** heat capacity is "medium"
R3	**IF** number of people is "crowded" **AND** room size is "small" **THEN** heat capacity is "high"

Fuzzy Associate Rules (FAM) matrix is used to store and represent all the constructed rules as shown in Table 3.

Table 3: FAM matrix for heat capacity

Room Size/ Number of people	**Small**	**Medium**	**Large**
Less	Heat Capacity **Low** (μ_1)	Heat Capacity **Low** (μ_2)	Heat Capacity **Low** (μ_3)
Average	Heat Capacity **Low** (μ_4)	Heat Capacity **Medium** (μ_5)	Heat Capacity **Medium** (μ_6)
	Heat	Heat	Heat

Crowded	Capacity **High** (μ_7)	Capacity **Medium** (μ_8)	Capacity **Medium** (μ_9)

Since the "AND" operator is used, the MIN method is applied to obtain a single value derived from the antecedents. From this means, the minimum value is to be taken as the output. The computation of this method is shown by the following examples for a case study with the number of people of 23 persons and the room size is 230ft^2. From Table 3, there are 3 cells with non-zero confidence values for any of the fuzzy variables. Therefore the single value for each rule is calculated as follows.

μ_2 = min {Number of People$_{Less}$(23), Room Size$_{Med}$(230)}
= min {0, 0.87}
= 0
μ_5 = min {Number of People$_{Average}$(23), Room Size$_{Med}$(230)}
= min {0.2, 0.87}
= 0.2

μ_7 = min {Number of People$_{Crowded}$(23), RoomSize$_{Small}$(230)}
= min {0.8, 0.13}
= 0.13

For brevity, the establishment of both inputs trigger a particular sub level of output subset [12]. Figure 4 illustrates the rule evaluation of this MIN method prior to obtaining a fuzzy output value.

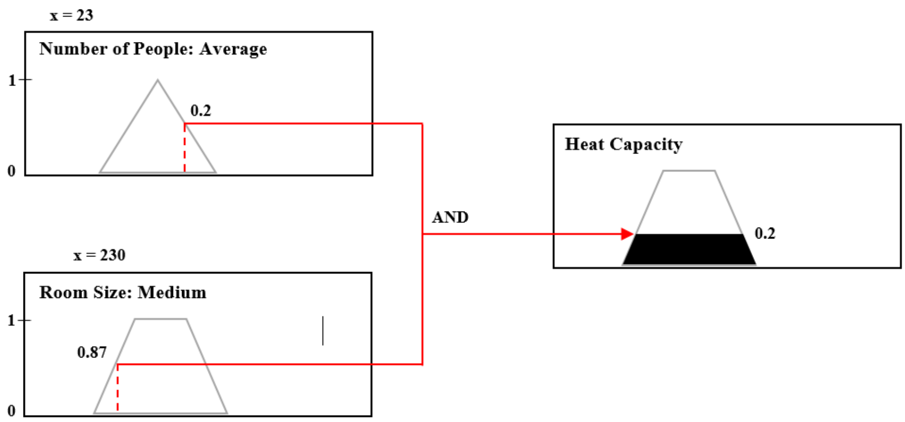


Figure 4: Rule Evaluation

Defuzzification: Once the consequent is evaluated, the defuzzification phase is performed to transform the fuzzy values to crisp values [13] using the mean of maxima method. The mean of maxima method considers the active rules with the highest degree of fulfillment [15]. Hence for the discussed problem, the confidence value of 0.2 (μ_5) is chosen for the heat capacity as this is the maximum value obtained from the rule evaluation. The actual values of Low, Medium, High are calculated from the membership function graph of heat capacity as shown in Figure 5.

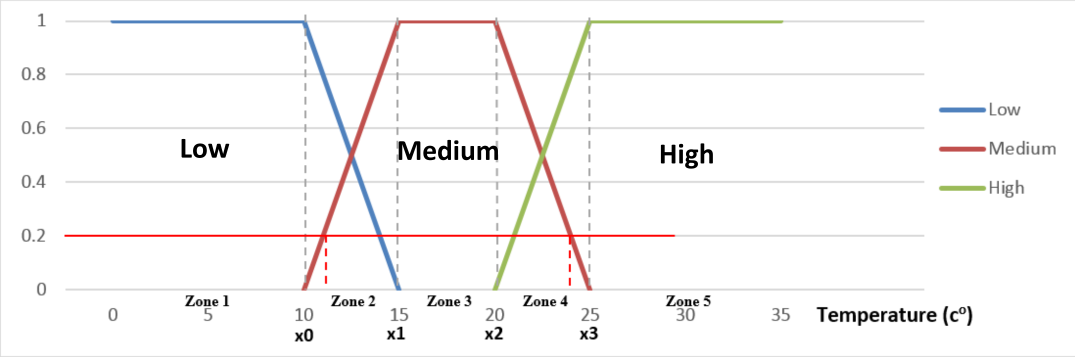


Figure 5: Membership function graph of heat capacity

Hence, the left and right sides of the Medium graph are about 11 and 24, respectively. The values of Low and High are obtained using the similar way.

3.2 Fuzzy Logic System for Water Pressure

As illustrated in Figure 2, the value obtained from the heat capacity variable is to be paired with another input variable namely weather temperature to obtain the final output (i.e. water preassure). Thus, the accuracy in calculation of the first FL system is crucial. The temperature reading that is based on the daily weather can affect and cause the heat inside in addition to the occupancy of that particular room.

The sprinkler's water pressure is measured in pounds per square inch (psi). The water pressure for a normal sprinkler could reach over 100 psi for a certain time. The strong pressure of sprinkler can cause a very long distance of fountain. This kind of pressure is used for a purpose in agriculture [4]. The average water pressure to be used on roof is between 30 psi and 50 psi [14]. Yet, most sprinkler systems are designed to use pressures of around 30 psi.

Fuzzification: For the second fuzzification, the steps are the same as the first layer. Table 4 details out the information about the linguistic variables and universe of discourse for the second FL system.

Table 4: Linguistic variables and universe of discourse for the second FLS

Input variables	Linguistic variables	Universe of Discourse
Heat Capacity (temperature)	Low, Medium, High	0 to 35
Weather Temperature (temperature)	Very Cold, Cold, Medium, Warm, Hot	0 to 40

Hence, the membership function graph for weather temperature is shown in Figure 6.

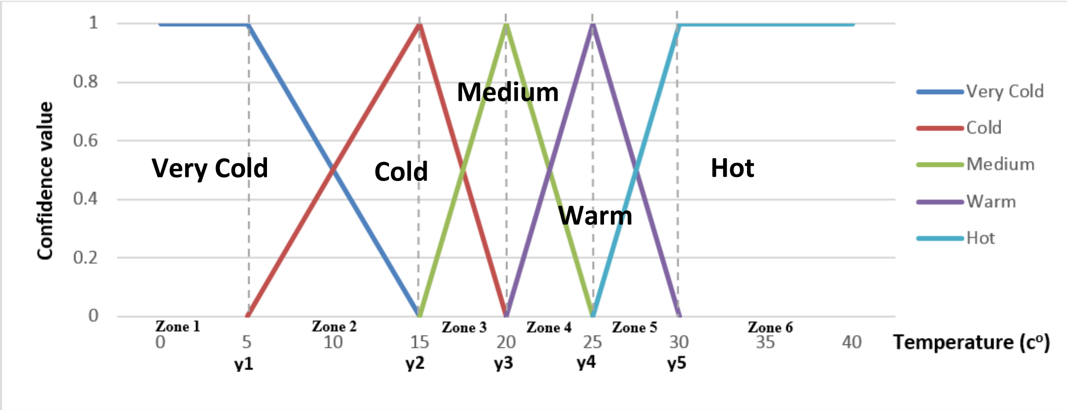


Figure 6: Membership function graph of weather temperature

For the final output, there are five linguistic variables to be displayed in the FAM Table.

Water Pressure ϵ {very low, low, average, high, very high}

Fuzzy Inference: The second inference stage describes the rules constructed using the MIN operator (Table 5).

Table 5: Fuzzy rules sample for water pressure

R1	**IF** heat capacity is "low" **AND** weather temperature is "medium" **THEN** water pressure is "low"
R2	**IF** heat capacity is "medium" **AND** weather temperature is "hot" **THEN** water pressure is "high"
R3	**IF** heat capacity is "high" **AND** weather is "warm" **THEN** water pressure is "very high"

The FAM matrix is also used in the second layer to store and represent all the constructed rules (Table 6).

Table 6: FAM matrix for water pressure

Heat Capacity/ Weather Temperature	**Very Cold**	**Cold**	**Medium**	**Warm**	**Hot**
Low	Water Pressure **Very Low**	Water Pressure **Very Low**	Water Pressure **Low**	Water Pressure **Average**	Water Pressure **Average**
Medium	Water Pressure **Low**	Water Pressure **Low**	Water Pressure **Average**	Water Pressure **High**	Water Pressure **High**
High	Water Pressure **Average**	Water Pressure **Average**	Water Pressure **High**	Water Pressure **Very High**	Water Pressure **Very High**

Similarly, the final output, water preassure is computed by following the same steps in the FL first layer (see Figure 7). For the same problem case, let the heat capacity = 16 degrees and the weather temperature takes 30 degrees.

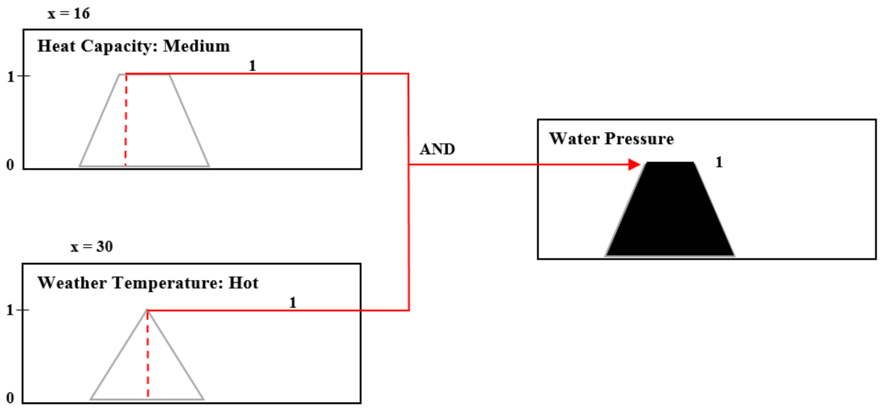


Figure 7: Rule evaluation for water pressure

The graph below displays the confidence value of 1. The membership function graph of water is read from the graph.

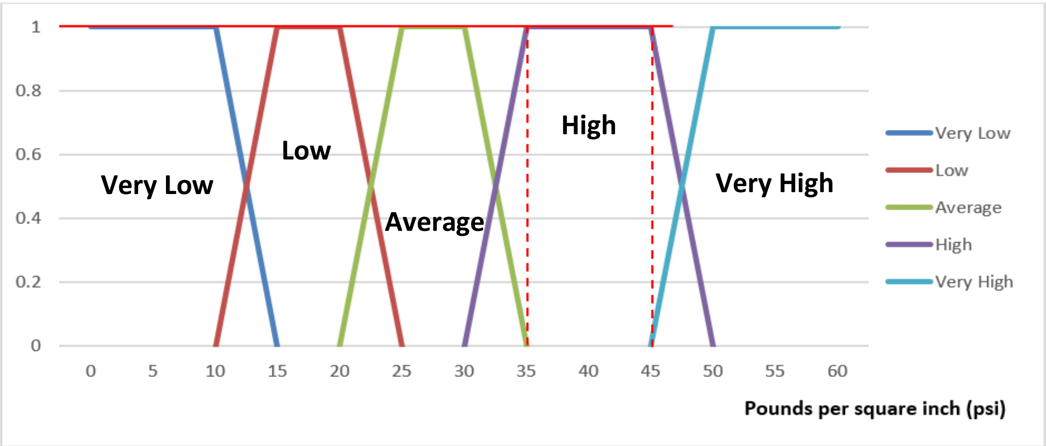


Figure 8: Membership function graph of water pressure

Figure 8 indicates that the values between 35 and 45 psi are considered as 1 for high water pressure. To be exact, for the presented problem, the obtained water preassure is 38 psi. The developed fuzzy controller for roof sprinkler system is depicted as Figure 9.

Figure 9: Interface of Fuzzy Controller for Roof Sprinkler Cooling System

For an implementation, the effectiveness of the proposed fuzzy based water sprinkler in comparison to the conventional timer-based water sprinklers can be measured through the usage of water and electricity. The fuzzy based model can be simulated and tested with multiple real cases by varying the input variable values, number of people, room size and the outside weather temperature. The final output of water preassure correlates to water usage and electrical power. The output of the system is highly dependent on the variability of the inputs, hence we conjecture that, this could efficiently optimise the use of both resources(water and electricity). Meanwhile in the conventional timer-based settings, there is no such control in the process, and the use of water and electricity are dependent on the initial settings and remain unchanged unless with human intervention.

4 Conclusion

In this study, we proposed an intelligent roof sprinkler cooling system using fuzzy logic controller. FL functions to control the quantity of water released by the sprinkler depending on the temperature sensor that captures weather condition. The proposed system is a two-layered fuzzy considering 4 input variables namely number of people, room size, heat capacity and outside weather condition, and one output namely water pressure. The heat capacity is resulted from the fuzification process of the variables number of people, room size in the initial layer, in which the heat capacity and the outside weather condition result in the final output, water preassure.

For each layer of the FL controller, the steps involved are fuzzification, fuzzy inference and deffuzification. For the fuzzification, inputs are are transformed using appropriate membership graphs including triangular and trapezoidal functions. In the fuzzy inference phase, rules are stored and represented using the Fuzzy Associate Rules (FAM) matrix and rules aggregated using the MIN operators. In the defuzzification phase, the output is transformed from the fuzzy values to crisp values using the mean of maxima method method.

Unlike the conventional timer-based water sprinklers which do not consider climate changes, the proposed system could efficiently manage the use of water and electricity by adapting to the variable changes. The conventional systems only works when the related sensors trigger them to work. In addition, for electricity usage, those sprinklers might use excessive amount of water and power to sprinkle the roof surface in response to the sensor readings. Furthermore, for the proposed system, in order to ensure water saving, there will be a water tank installed in a house or building to provide water circulation and reuse. The circulation of water is just like an aquarium equipped with a “water catch” attached to the roof to collect the used water. Whenever the room reaches a particular comfort condition with the best reading of each variables, these sprinklers will be automatically off. This consequently could provide a more cheaper system in a long term compared to other cooling equipments.

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