# Comparative Analysis of Mamdani, Sugeno And Tsukamoto Method of Fuzzy Inference System for Air Conditioner Energy Saving

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*Abstract:* Air Conditioner (AC) nowadays is one of the electrical equipment commonly used in human daily life to reduce the heat, especially for communities who live in the hot weather area. But in the other side, air conditioner usage has a shortage such as a huge electrical energy consumption of air conditioning and it reach 90% of the total electrical energy that was needed by a household, and that especially happen when operated at the peak load electricity time or around 17:00 until 22:00, and it will cause a deficit of power supplies for use by other household appliances. In this paper will be conducted analysis and comparison between Mamdani, Sugeno and Tsukamoto method on fuzzy inference systems to find a best method in terms of reduction in electrical energy consumption of air conditioner by using Room Temperature and Humidity as input variables and Compressor speed as output variable. In this research, experiments was performed by using crisp input of room temperature 11$^{O}$C, 21% humidity, room temperature 14$^{O}$C, 41% humidity, room temperature 27$^{O}$C, 44% humidity and room temperature 33$^{O}$C, 68% humidity. The results of experiments showed that the best method in terms of reduction in electrical energy consumption of air conditioning system is a method of Tsukamoto where the average electrical energy efficiency achieved by 74,2775%.

*Keywords:* Air Conditioner, Energy Saving, Fuzzy Inference System, Best Method.

## 1 INTRODUCTION

Air conditioner known as one electrical equipment commonly used in human daily life to reduce heat, especially for communities who live in the hot weather area. Air conditioner use to change the room air temperature to make people feel comfortable because the air conditioner able to change the temperature it self and humidity due to user desire.

The Indonesian electricity energy presently not sufficient to support for all the human being activity, it can proof by commonly rotating blackouts happen in some area in Indonesia, so that realy necessary to save energy and use energy efficiently as possible (Sudirman, 2011). Due to the data who has been release by Indonesia Ministry of Energy and Mineral Resources (PUSDATIN KESDM, 2011) show that the electrical energy consumption of household appliance in 2011 reach 59.309 GWh is equal approximately 41,1% from total of 148.359 GWh, where the consumption of air conditioner it self take 40 % from all electrical energy that supply for household scope.

Reducing the use of electrical energy and providing comfort room (optimal temperature) are two important considerations in the design of air conditioning systems (Nasution, 2008). Proper cooling load claulations (SNI, 2000) will be able to ensure as much as posible the attention of energy saving opportunities at the planning stage.

Air conditioner energy saving research has been made with fuzzy logic Mamdani model implementation and optimized by genetic algorithm achieve energy saving for 31,5% (Parameshwaran, Karunakaran, Iniyan, & Samuel, 2008) , and further research mention that air conditioner using wich controlled by fuzzy logic control Sugeno model and optimized by genetic algorithm achieve energy saving for 23,8% with temperature set in 23$^{0}$C. (Wang, 2009)

Some other research claim that fuzzy logic control with Sugeno model using on energy saving of air conditioner energy consumption are better than proportional integral derivative (PID) control, by performing measurements over a periode of two hours achieve energy saving for 22,97% with temperature set at 20$^{0}$C (Nasution, 2011). further some research about comparison between Mamdani model of fuzzy logic and neuro fuzzy for control the air conditioner to obtain energy saving achieve 20% of energy saving by using fuzzy logic and achieve 40% of energy saving by using neuro fuzzy to control the air conditioner (Kaur & Kaur, 2012), in this study also expressed that fuzzy logic can be used for the process of setting up a non linear or hard to do with conventional systems (Kaur & Kaur, 2012). Fuzzy logic also allows the implementation arrangements in accordance with the feeling that possessed by humans (Kaur & Kaur, 2012).

## 2 FUZZY LOGIC

Fuzzy theory was first introduced by Dr. Lotfi Zadeh in 1965 from the University of California, to develop qualitative concept that has no precise boundaries, for example there is no clear or definite value that represents the boundary between normal and low, normal or high and (Sivanandam, Sumathi, & Deepa, 2007). Fuzzy logic is an appropriate way to map an input space into a space of output, similar to the black box to do something to compute a solution, the value of output (Prats, 2001).

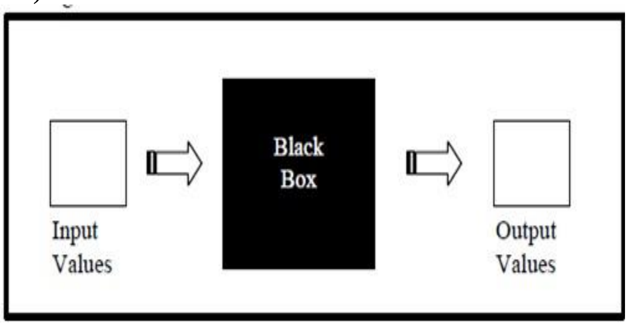


Figure 1 Input – Output System

Fuzzy set has 2 atribute, wich is:
a. Linguistic.
b. Numeric.

Some few things need to know for understanding fuzzy system is:
a. Fuzzy variable.
b. Fuzzy sets.
c. Universe of discourse.
d. Domain

This study used fuzzy inference system specification as follows:
a. Room Temperature variable divided into four sets, wich is:
   Very low = [0 15]
   Low = [10 30]
   High = [25 35]
   Very high = [30 45]

Membership function for room temperature as input variable is on figure 2.

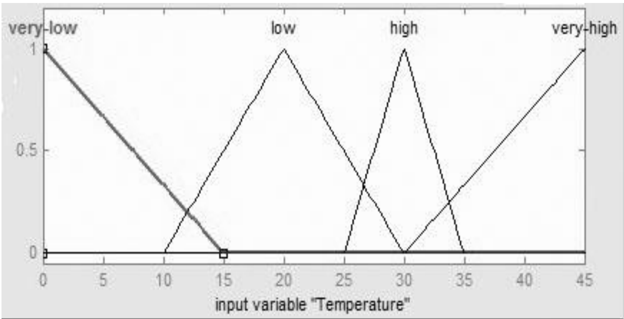


Figure 2. Room Temperature Variable

b. Humidity variable divided into four sets, wich is:
   Dry = [0 30]
   Comfortable = [20 50]
   Humid = [40 70]
   Sticky = [60 100]

Membership function for Humidity as input variable is on figure 3.

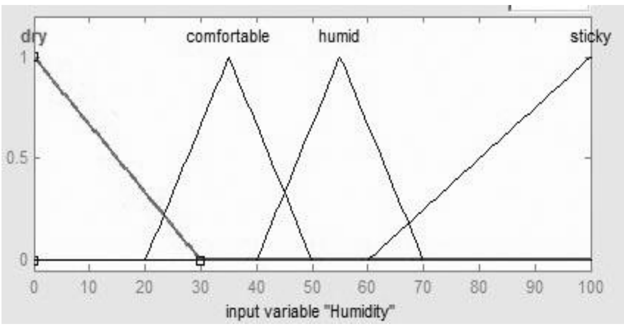


Figure 3. Humidity Variable

The output variable of Mamdani and Tsukamoto model is:
a. Compressor Speed variable wich divided into four sets, namely:
   Off = [0]
   Low = [30 60]
   Medium = [50 80]
   Fast = [70 100]

Membership function for Compressor speed Humidity as output variable is shown on figure 4 .

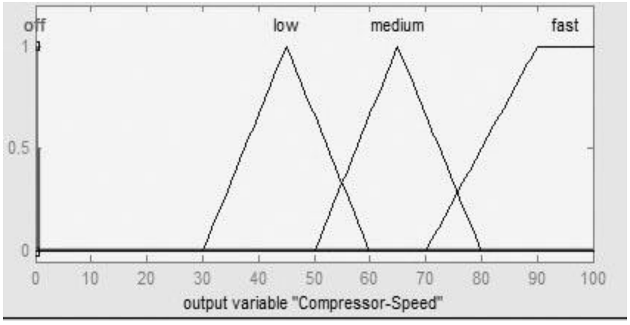


Figure 4. Compressor Speed Variable

The Sugeno model output variable, fuzzy sets and domains is shown in table 1

Table 1 Sugeno Model Output Variable

| Compressor Speed | Constant Value |
|---|---|
| Off | 0 |
| Low | 0.3333 |
| Medium | 0.6667 |
| Fast | 1 |

## 3 FUZZIFICATION

In this study used 4 times experiments using sampling data as shown in table 2

Table 2 Data Sampling

| Room Temperature | Humidity |
|---|---|
| $11^{O}C$ | 21% |
| $14^{O}C$ | 41% |
| $27^{O}C$ | 44% |
| $33^{O}C$ | 68% |

Fuzzification for Room Temperature variable with crisp input $11^{O}C$ shown on figure 5:

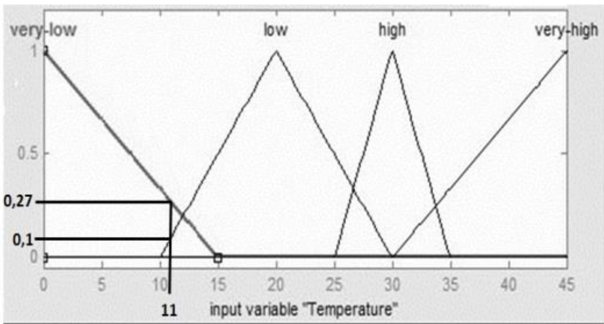


Figure 5. Room Temperature Fuzzification With Crisp Input $11^{O}C$

$$\mu[x] = \begin{cases} 0; & x \leq a, x \geq c \\ (x-a)/(b-a) & a < x \leq b \\ (c-x)/(c-b) & b < x \leq c \end{cases}$$

$$\mu\text{Very Low}[x] = \begin{cases} 0; & x \geq 15 \\ (15-11)/(15-0) & 0 < x \leq 15 \end{cases}$$

$$\mu\text{Very Low}[x] = 0.27$$

$$\mu\text{Low}[x] = \begin{cases} 0; & x \leq 10 \\ (11-10)/(20-10) & 10 < x \leq 20 \end{cases}$$

$$\mu\text{Low}[x] = 0.1$$

Fuzzification for Humidity variable with crisp input 21% shown on figure 6:

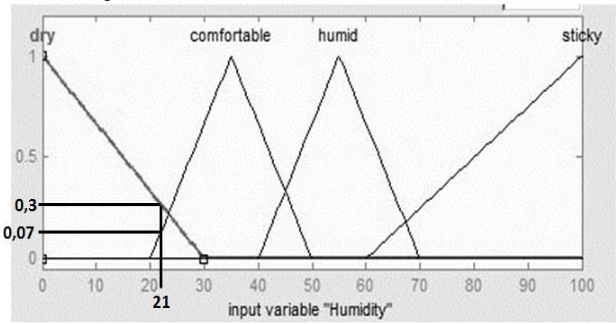


Figure 6. Humidity Fuzzification With Crisp Input 21%

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

$$\mu Dry[x] = \begin{cases} 0; & x \ge 30 \\ (30-21)/(30-0) & 0 \le x \le 30 \end{cases}$$

$$\mu Dry[x] = 0.3$$

$$\mu Comportable[x] = \begin{cases} 0; & x \le 20 \\ (21-20)/(35-20) & 20 \le x \le 35 \end{cases}$$

$$\mu Comportable[x] = 0.07$$

## 4 INFERENCE

Rule base used in this study shown in table 3

Tabel 3 Rule Base

| Humidity / Room Temperature | Dry | Comfort able | Hum id | Sticky |
|---|---|---|---|---|
| Very Low | Off | Off | Off | Low |
| Low | Off | Off | Low | Medium |
| High | Low | Medium | Fast | Fast |
| Very High | Medium | Fast | Fast | Fast |

## 5 DEFUZZIFICATION

### A. TSUKAMOTO METHOD

The experiment results of Tsukamoto method using crisp input of room temperature 14$^{O}$C and 41% of humidity, the motor speed reaches 5,63%, so it can be conclude that the motor speed only take 81,635 Rpm with the energy saving achieves approximately 94,37.

A. Rule 1

If Room Temperature Very Low and Humidity Comfortable then Speed Off

$\alpha_1$ = µTempVeryLow ∩ µHumComfortable
= min(µTempVeryLow[11], HumComfortable[21])
= min (0,07; 0,6)
= 0,07

If Room Temperature Very Low (0,07) and Humidity Comfortable (0,6) then Speed Off (0,07)

$Z_1$ = (Z-0) / 0 = 0,07
$Z_1$ = 0

B. Rule 2

If Room Temperature Very Low and Humidity Humid then Speed Off

$\alpha_2$ = µTempVery Low ∩ µHumHumid
= min (µTempVery Low[14], µHumHumid[41])
= min (0,07; 0,06)
= 0,06

If Room Temperature Very Low (0,07) and Humidity Humid (0,06) then Speed Off (0,06)

$Z_2$ = (Z-0) / 0 = 0,06
$Z_2$ = 0

C. Rule 3

If Room Temperature Low and Humidity Comfortable then Speed Off

$\alpha_3$ = µTempLow ∩ µHumComfortable
= min (µTempLow[14], µHumComfortable[41])
= min (0,3; 0,6)
= 0,3

If Room Temperature Low (0,3) and Humidity Comfortable (0,6) then Speed Off (0,3)

$Z_3$ = (Z-0) / 0 = 0,3
$Z_3$ = 0

D. Rule 4

If Room Temperature Low and Humidity Humid then Speed Low

$\alpha_4$ = µTempLow ∩ µHumHumid
= min (µTempLow[14], µHumHumid[41])
= min (0,3; 0,06)
= 0,06

If Room Temperature Low (0,3) and Humidity Humid (0,06) then Speed Low (0,06)

$Z_4$ = (Z-45) / 15 = 0,06
$Z_4$ = 45,99

$$\frac{\propto 1 * Z1 + \propto 2 * Z2 + \propto 3 * Z3 + \propto 4 * Z4}{\propto 1 + \propto 2 + \propto 3 + \propto 4}$$

$$\frac{0,07 * 0 + 0,06 * 0 + 0,3 * 0 + 0,06 * 45,99}{0,07 + 0,06 + 0,3 + 0,06}$$

$$= \frac{0 + 0 + 0 + 2,7594}{0,49}$$

= 5,63

### B. SUGENO METHOD

The experiment of Sugeno method as shown in figure 7 with crisp input of Room Temperature 14$^{O}$C and Humidity 41% the compressor speed reaches 3,7 %. It can be concluded that the motor speed take approximately 53,65 Rpm with energy saving achieves approximately 96,3 %, the results of calculations using Sugeno method showed better results than calculations using the Tsukamoto.

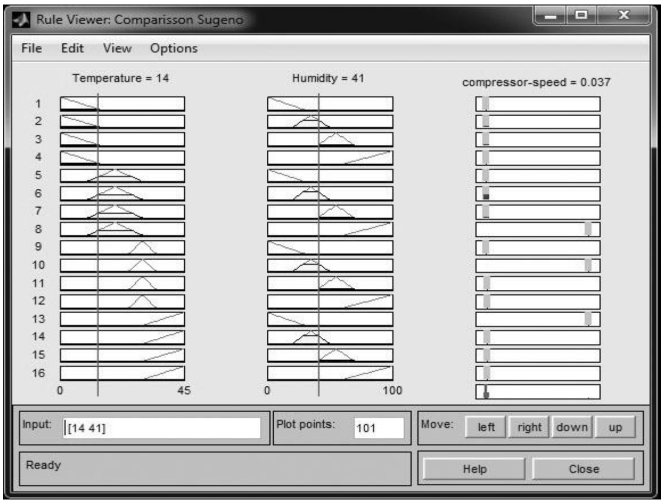


Figure 7. Sugeno Method Defuzzification With Crisp Input Of Room Temperature Is 14ºc And Humidity Is 41%

C. MAMDANI METHOD

The experiment of Mamdani method as shown in figure 8 with crisp input of Room Temperature 14$^{O}$C and Humidity 41% the compressor speed reaches 37,3 %. It can be concluded that the motor speed take approximately 540,85 Rpm with energy saving achieves approximately 62,7%.

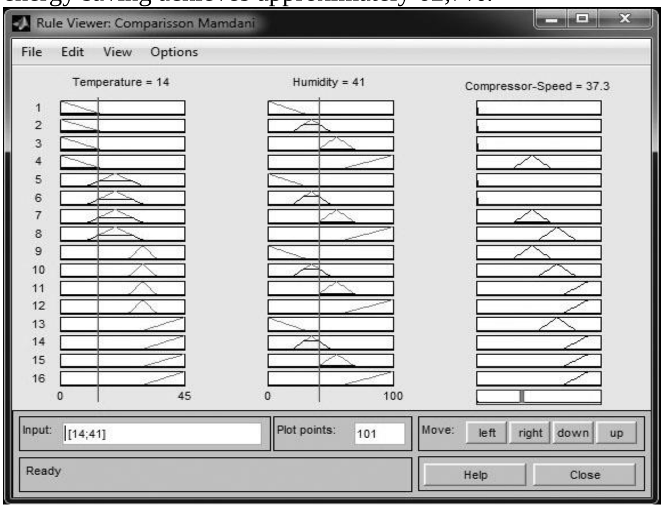


Figure 8. Mamdani Method Defuzzification With Crisp Input Of Room Temperature Is 14$^{O}$C And Humidity Is 41%

Due to compressor motor that was design for dynamicly, then to obtain a valid result all of the simulation results will be added together to find the average value of the results taken from the output variable to find wich method are better according to the simulations. All of the simulations results are shown in table 4

Table 4 Simulation Results

| Method / Crisp Input | Mamdani | Sugeno | Tsukamoto |
|---|---|---|---|
| Room Temperature 11$^{O}$C Humidity 21% | 0 % | 0 % | 0 % |
| Room Temperature 14$^{O}$C Humidity 41% | 37,3 % | 3,7 % | 5,63 % |
| Room Temperature 27$^{O}$C Humidity 44% | 65,1 % | 26,2 % | 41,9 % |
| Room Temperature 33$^{O}$C Humidity 68% | 86,2 % | 100 % | 55,36 % |
| Average | 47,15 % | 32,475 % | 25,7225 % |
| Efficiency | 52,85 % | 67,525 % | 74,2775 % |

From the above results can be calculated by the amount of electrical energy reduction calculation as shown in Table 5

Table 5 Calculation Of The Electrical Energy Consumption Of Air Conditoning

| Method | Motor rotation averages (Rpm) | Cooling energy consumption averages (Kwh) |
|---|---|---|
| Tsukamoto | 372,97625 Rpm | 29,125 Kwh |
| Sugeno | 470,8875 Rpm | 36,771 Kwh |
| Mamdani | 683,675 Rpm | 53,387 Kwh |

6 CONCLUSION

Based on experiments conducted in this study it can be concluded that the method of Mamdani, Sugeno and Tsukamoto proved to be used in air-conditioning for the reduction of electrical energy consumption, but the results are varied. The results of the first experiment using a room temperature setting 27$^{O}$C and humidity of 44% with a 34.9% yield, calculated by using Mamdani shows results that are much smaller in terms of energy savings when compared with calculations using the Tsukamoto with a level of energy savings 58.099 % and Sugeno method with the level of energy savings of 73.8%.

The results of the second experiment using the settings 33$^{O}$C room temperature and humidity of 68% calculated by using Mamdani shows energy savings rate of 13.8%, calculated by using Mamdani shows results that are much smaller in terms of energy savings when compared to calculations using Tsukamoto method with the level of energy savings of 31.176% and Mamdani method is better than the Sugeno method with high energy savings at 0%. From the three methods were compared, the best method in terms of reduction of electrical energy consumption is Tsukamoto method with average savings of 74.2775%.

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