

A Hybrid Approach For Air Conditioning Control System With Fuzzy Logic Controller

K.A. Akpado, P. N. Nwankwo, D.A. Onwuzulike, M.N. Orji

Abstract— Today air conditioning systems have been considered by all people as one of welfare requirements in buildings and closed environments. Conventional room air conditioners are controlled by thermostat with targeted temperature and no control over humidity. Fuzzy logic controller (FLC) was developed to maintain temperature and humidity at set conditions. Temperature and humidity are the inputs of the fuzzy logic control and outputs are the compressor and the Fan. ‘ColdAirIn’ and ‘HotAirIn’ represent ‘low and high’ heat of the Fan respectively. The paper presents the algorithm for intelligent air conditioning system. This algorithm is based on fuzzy logic. Fuzzy control is one of the methods which provide a powerful rule and methodology to guarantee Heating Ventilating and Air-Conditioning (HVAC). The designed system consists of two sensors for feedback control: one to monitor temperature and another one to monitor humidity. The logic control was developed to control the operation mode of the air conditioning, and maintain the room set conditions. A fuzzy rule for this controller was formulated by temperature and humidity. The model of the controller was tested using MATLAB simulation. The system has proven to be a reasonable advancement in air conditioning system.

Index Terms— Logic Controller (FLC), Heating Ventilating and Air – Conditioning (HVAC), Fuzzy Inference System (FIS), Air Conditioning System, Membership function, Fuzzy set.

I. INTRODUCTION

Fuzzy logic is a powerful problem solving control system methodology that lends itself to implementation in systems ranging from small, simple, embedded micro-controller, to large networked multi-channel personal computer or work-stations based data acquisition and control system. Fuzzy logic is a soft computing tool for embedding structured human knowledge into workable algorithms. The idea of fuzzy logic was introduced by Dr. Lofti Zadeh of UC/Berkley in 1960’s as a means of model of uncertainty of natural languages (Zadeh 1965). Fuzzy logic is a superset of conventional Boolean logic. In Boolean logic, propositions take a value of either completely true or completely false. Fuzzy logic handles the concept of partial truth. It uses an imprecise but very descriptive language to deal with input data more like the human operator. A fuzzy logic based design control system offers flexibility in system design and implementation, since its implementation uses “if then” logic instead of sophisticated differential or mathematical equations. Fuzzy logic control (FLC) is a

control algorithm based on a linguistic control strategy which tries to account the human’s knowledge about how to control a system without requiring a mathematical model [1]. Fuzzy logic system structure consists of database or prior knowledge that has to be crisp value to allow fuzzification using membership function.

A. PROBLEM STATEMENT

When the air conditioning system is in operation; as time passes, the temperature starts dropping and the metabolic rate of one’s body decreases. If it is during the night, one is expected to wake up from time to time to adjust the cooling temperature. Most people find it difficult to be waking up during the night to adjust the air conditioning cooling level manually. Many lives have been lost as a result of this. So an intelligent system using fuzzy logic controller that put into consideration temperature and humidity was designed to provide high level of intelligence to the air conditioning system.

B. AIM AND OBJECTIVES OF THE PROJECT

The aim of the project is to apply fuzzy logic controller in the control of an air conditioning system taking into account the room temperature and humidity at any point in time.

The objectives of the project are to:

1. Design a Fuzzy logic air conditioning system that takes into account both temperature and humidity.
2. Design an intelligent system that will automatically ‘Heat’ the room when the room temperature is getting ‘Cold’, and ‘Cool’ the room when the room temperature is getting ‘Hot’.
3. Design a closed loop system based on combination of software and hardware.
4. Design a controller using MAT-LAB Fuzzy Logic tool box.

II. CONCEPTS OF THE PROJECT

A. Fuzzy Logic Control

The fuzzy logic system can be used to design intelligent systems on the basis of knowledge expressed in human language. There is practically no area of human activity left untouched by intelligent systems as these systems permits the processing of both symbolic and numerical information. The systems that are designed and developed based on fuzzy logic methods have been proved to be more efficient than those based on conventional approaches. Fuzzy logic has been recently applied in process control, modelling, estimation, identification, stock market prediction, diagnostics, military science, agriculture and so on [2]. The structure of the fuzzy logic controller is shown in figure 1 below.

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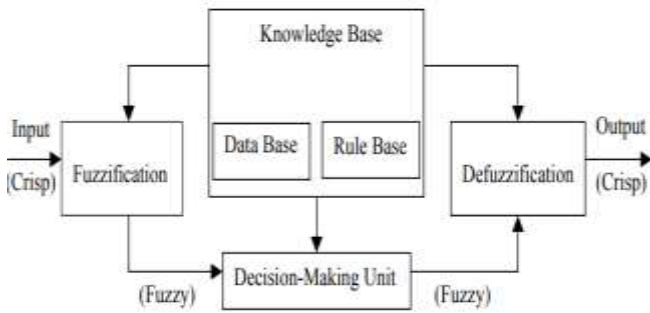


Figure 1: Structure of Fuzzy logic controller

1) Fuzzification:

As the inputs of fuzzy logic controller are from sensors and the data from sensors are crisp in nature, the fuzzy logic controller cannot use this data directly. Hence, there exists the need for converting this data to the form comprehensible to the fuzzy system. Fuzzification is the process of converting a real scalar crisp value into a fuzzy quantity. The data required to change the crisp value to the fuzzy quantity is stored in the knowledge base in the form of membership functions associated with various linguistic fuzzy variables. A membership function defines the degree or extent to which a particular element belongs to the set and spans between 0 and 1. The membership function can be an arbitrary curve that is suitable in terms of simplicity, convenience, speed and efficiency (Kecman 2001, Ross 2005).

2) Knowledge Base:

Knowledge base is a technology used in expert systems to store complex structured and unstructured information used by a system. The knowledge base can be divided into two sub-blocks namely the 'Data Base' and 'Rule Base'. The data base consists of the information required for fuzzifying the crisp input and later defuzzifying the fuzzy outputs to a crisp output. It consists of the membership functions for various fuzzy variables or sets used in the controller design. The rule base consists of a set of rules, which are usually formulated from the expert knowledge of the system. The rules are typically of the form "If..., then..." rules provided by experts. The knowledge base is the heart of fuzzy logic based system. It has to be designed with utmost care and requires a lot of expertise in the knowledge of the system into which fuzzy logic controller is being incorporated [3].

3) Fuzzy Inference Engine:

Fuzzy inference is the process of converting fuzzy input to fuzzy output according to fuzzy rules in the knowledge base. It simulates the human reasoning process by making fuzzy inference on the inputs and IF-THEN rules. The three types of fuzzy inference mechanisms commonly used are; Mamdani-Type Inference, Sugeno-type Inference, and Tsukamoto-Type Inference.

4) Defuzzification

Defuzzification is the process of converting a fuzzified output into a single crisp value with respect to a fuzzy set. The defuzzified value in fuzzy logic controllers represents the action to be taken in controlling the process.

B. Block diagram of the system

The block diagram of the air conditioning control system is shown in figure 2 below.

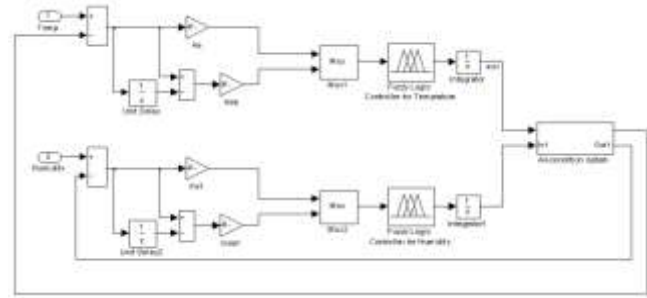


Figure 2: The block diagram of the hybrid air conditioning control system

Two independent fuzzy controllers are assigned to control Temperature and Humidity parameters. Error signal and its derivation are fed to each fuzzy controller. The outputs of fuzzy controllers are assigned as inputs of air conditioner system. The output of the system is feedback to the controllers to form a closed-loop.

The simplified block diagram of the air-conditioning control system is a simple closed loop system as shown in Figure 3 below. Figure 4 shows the structure of the fuzzy control system.

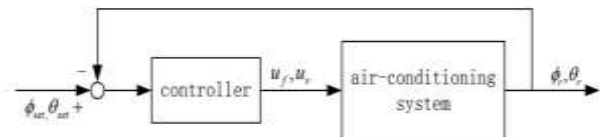


Figure 3: Simplified block diagram of the air – conditioning control system

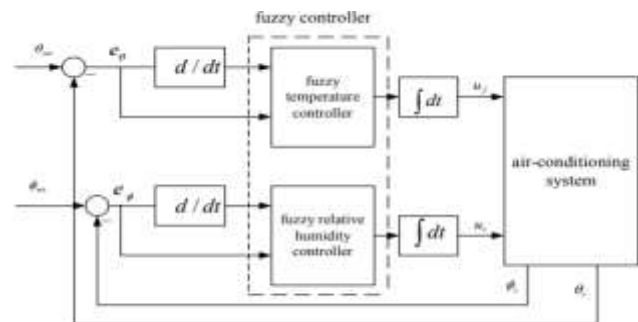


Figure 4: The structure of the fuzzy control system

C. Membership Function:

Membership functions allow one to quantify linguistic term and represent a fuzzy set graphically. A membership function for a fuzzy set A on the universe of discourse X is defined as; $\mu_A: X \rightarrow [0, 1]$. Here, each element of X is mapped to a value between 0 and 1. It is called membership value or degree of membership. It quantifies the degree of membership of the element in X to the fuzzy set A. X-axis represents the universe of discourse, while Y-axis represents the degrees of membership in the [0, 1] interval [4].

III. METHODOLOGY

A. Introduction to System Design:

Air-conditioning involves the delivery of air which can be 'Warmed' or 'Cooled' and have its humidity raised or lowered. It is an apparatus for controlling, especially lowering the temperature and humidity of an enclosed space.

Air-conditioning typically has a Fan which blows, cools, and circulates fresh air. It also has a cooler, and the cooler is under thermostatic control. Generally, the amount of air being compressed is proportional to the ambient temperature.

Consider our air-conditioner which has five control switches: 'COLD', 'COOL', 'PLEASANT', 'WARM' and 'HOT'. The corresponding speeds of the motor controlling the Fan in the air-conditioner have the graduations: 'ColdAirIn', 'LittleColdAirIn', 'NoAirInOut', 'LittleHotAirIn' and 'HotAirIn'.

B. Algorithm:

- Define linguistic variables and terms.
- Construct membership functions for them.
- Construct knowledge base of rules.
- Convert crisp data into fuzzy data sets using membership functions. (Fuzzification).
- Evaluate rules in the rule base. (Inference Engine).
- Combine results from each rule. (Inference Engine).
- Convert output data into non-fuzzy values. (Defuzzification).

1) Define linguistic variables and terms

Linguistic variables are input and output variables in the form of simple words or sentences. For temperature (T): very cold, cold, warm, hot, and very hot, temperature is the linguistic variable, while very cold, cold, etc are the fuzzy variables.

Temperature (t) = {Cold, Cool, Pleasant, Warm, Hot}
Speed (s) = {'ColdAirIn', 'LittleColdAirIn', 'NoAirInOut', 'LittleHotAirIn' and 'HotAirIn'}

Every member of this set is a linguistic term and it can cover some portion of overall temperature and speed values.

2) Construct the membership functions

Table 1 below shows the data according to which the influence of air temperature to Fan speed will be shown through fuzzy logic.

Table 1: Temperature and Fan Speed operating range

| Air Temperature | | Fan Speed | |
|-----------------|----------|-----------|-----------------|
| 0 - 10 | Cold | 0 - 30 | ColdAirIn |
| 0 - 20 | Cool | 10 - 50 | LittleColdAirIn |
| 10 - 30 | Pleasant | 40 - 60 | NoAirInOut |
| 20 - 40 | Warm | 50 - 90 | LittleHotAirIn |
| 30 - Above | Hot | 80 - 100 | HotAirIn |

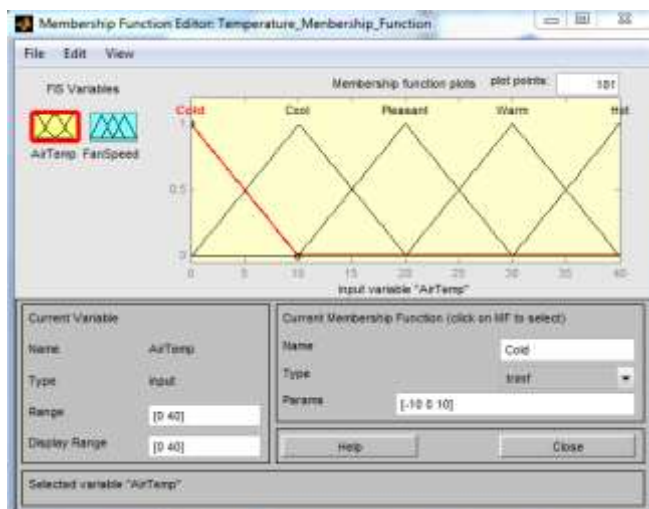


Figure 9(a): Membership function for Air Temperature

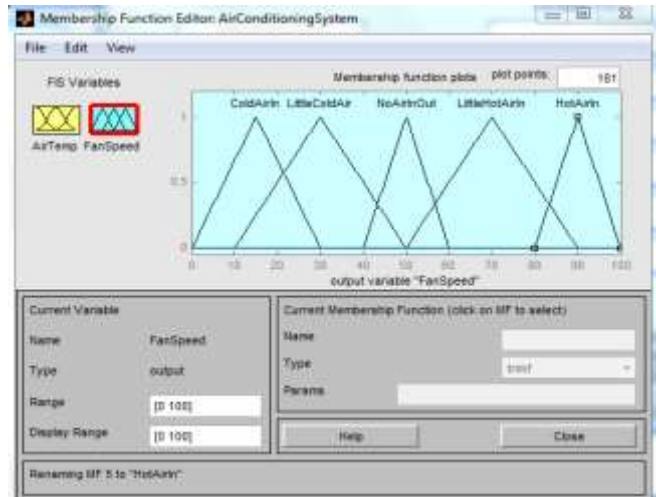


Figure 9(b): Membership Function for Fan Speed

3) Construct knowledge base of rules for the system

For the fuzzy controller for both temperature and humidity, we have 49 rules to have smooth control surface for heating, ventilating, and air – conditioning (HVAC) control. Rule base of this controller is defined in table 2. Table 3 assigns values to the rule base, while table 4 explains the rule base terms. In table 3, it can be seen that the largest positive control action occurs in the upper left cell when both are NL (interception of row and column). It is logical, for example: to increase the supply air Fan speed by the largest amount if the room temperature is much higher than the set point and it is still increasing rapidly. For example (table 2):

If the room temperature error is NL and its rate of change is NL, then supply air Fan speed is PL or If the room humidity error is NL and its rate of change is NL, then chilled water valve opening is PL.

Table 2: Rule base for the hybrid air – conditioning control system

| | NL | NM | NS | Z | PS | PM | PL |
|----|----|----|----|----|----|----|----|
| NL | PL | PL | PM | PM | PS | PS | NS |
| NM | PL | PL | PM | PS | PS | NS | NS |
| NS | PM | PS | PS | PS | NS | NS | NM |
| Z | PM | PM | PS | Z | NS | NM | NM |
| PS | PM | PS | PS | NS | NS | NM | NM |
| PM | PS | PS | NS | NS | NM | NL | NL |
| PL | PS | NS | NS | NM | NM | NL | NL |

Table 3: Voltage level for the rule base

| | NL | NM | NS | Z | PS | PM | PL |
|----|----|----|----|-----|-----|-----|-----|
| NL | 30 | 22 | 16 | 10 | 6 | 2 | -4 |
| NM | 24 | 18 | 12 | 6 | 2 | -4 | -8 |
| NS | 20 | 12 | 6 | 2 | -2 | -8 | -14 |
| Z | 17 | 10 | 4 | 0 | -4 | -10 | -17 |
| PS | 14 | 8 | 2 | -2 | -6 | -12 | -20 |
| PM | 8 | 4 | -2 | -6 | -12 | -18 | -24 |
| PL | 4 | -2 | -6 | -10 | -16 | -22 | -30 |

Table 4: Rule base terms

| | | |
|---|----|-----------------|
| 1 | NL | Negative Large |
| 2 | NM | Negative Medium |
| 3 | NS | Negative Small |
| 4 | Z | Zero |
| 5 | PS | Positive Small |
| 6 | PM | Positive Medium |
| 7 | PL | Positive Large |

To interpret table 3: Take for example the upper leftmost rule: If the room temperature error is NL and its rate of change is NL, then increase the supply air fan speed by 30%. Or If the room RH error is NL and its rate of change is NL, then increase the chilled water valve opening by 30%.

Build a set of rules into the knowledge base in the form of IF-THEN-ELSE structures

They are five If- then- else rules built into the knowledge base of the designed systems. The If – then – else rule is an integral part of the knowledge base. It relates input to output. So with respect to our designed system: air temperature (AirTemp) is the input, while Fan speed (Fanspeed) is the output. Altogether, we have five If – then – else rules for our system:

Fuzzy Relationship: The rules governing the air-conditioner are as follows:

- RULE#1: IF TEMP is 'COLD' THEN SPEED is 'HOTAIRIN'
- RULE#2: IF TEMP is 'COOL' THEN SPEED is 'LITTLEHOTAIRIN'
- RULE#3: IF TEMP is 'PLEASANT' THEN SPEED is 'NOAIRINOUT'
- RULE#4: IF TEMP is 'WARM' THEN SPEED is 'LITTLECOLDAIRIN'
- RULE#5: IF TEMP is 'HOT' THEN SPEED is 'COLDAIRIN'

4) Obtain the Fuzzy Value (Fuzzification)

The rules can be expressed as a cross product: CONTROL = TEMP × SPEED

WHERE: TEMP = {COLD, COOL, PLEASANT, WARM, HOT}
 SPEED: {COLDAIRIN, LITTLECOLDAIRIN, NOAIRINOUT, LITTLEHOTAIRIN, HOTAIRIN}

$$\mu_{Control}(T, V) = \min[\mu_{Temp}(T), \mu_{Speed}(V)]$$

Rule#1: IF $0 \leq T \leq 10^\circ\text{C}$ & $80 \leq V \leq 100$
 $\mu_{Control}(T, V) = \min[\mu_{Temp}(T), \mu_{Speed}(V)]$

Rule#2: IF $0 \leq T \leq 20^\circ\text{C}$ & $50 \leq V \leq 90$
 $\mu_{Control}(T, V) = \min[\mu_{Temp}(T), \mu_{Speed}(V)]$

Rule#3: IF $10 \leq T \leq 30^\circ\text{C}$ & $40 \leq V \leq 60$
 $\mu_{Control}(T, V) = \min[\mu_{Temp}(T), \mu_{Speed}(V)]$

Rule#4: IF $20 \leq T \leq 40^\circ\text{C}$ & $10 \leq V \leq 50$
 $\mu_{Control}(T, V) = \min[\mu_{Temp}(T), \mu_{Speed}(V)]$

Rule#5: IF $30 \leq T \leq 40^\circ\text{C}$ & $0 \leq V \leq 30$
 $\mu_{Control}(T, V) = \min[\mu_{Temp}(T), \mu_{Speed}(V)]$

5) Inference Engine (Evaluation and combination of result)

The inference engine is the component of our system that applies logical rules to the knowledge base to deduce new information. Figure 6 below shows the structure of fuzzy inference for input variable - air temperature and for output variable - fan speed. Figure 7 shows the fuzzy inference system (FIS) rules. Figure 8 and 9 shows the inference diagram at room temperature 20°C and 30.9°C respectively.

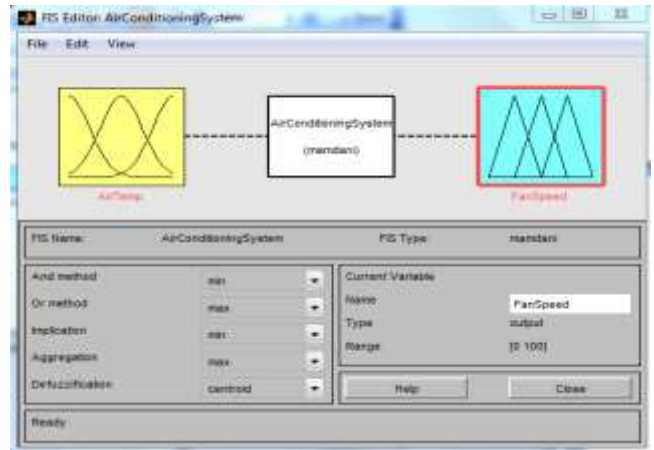


Figure 6: Structure of fuzzy inference mechanism

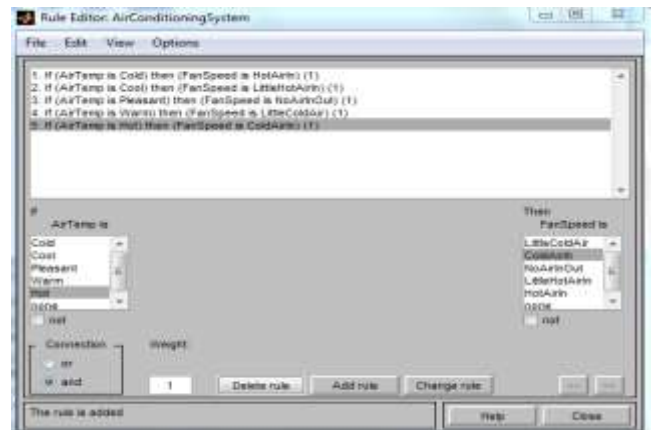


Figure 7: Fuzzy Inference System (FIS) Rules

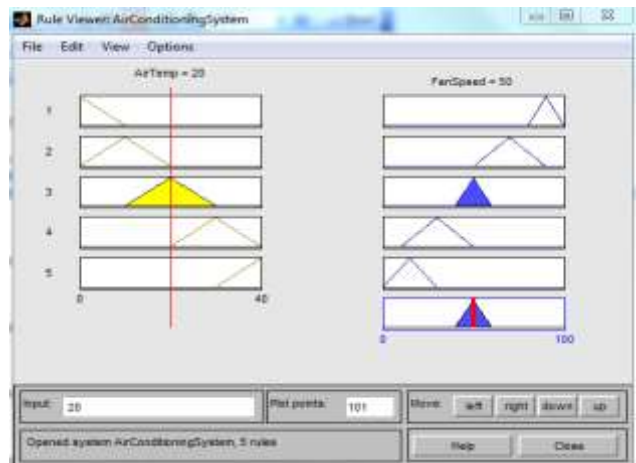


Figure 8: Inference Diagram at room temperature 20°C

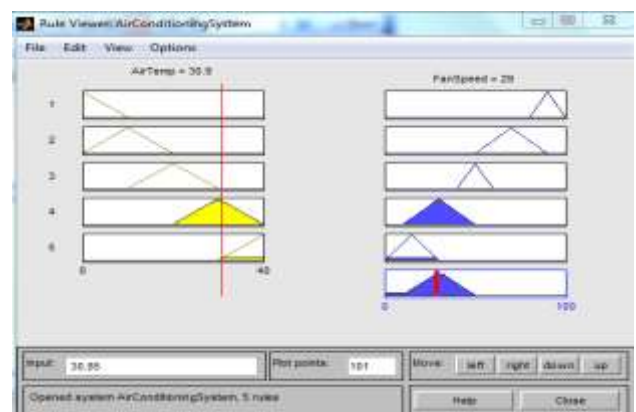


Figure 9: Inference diagram at room temperature 30.9°C

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According to the inference diagram represented in figure 8 above, it is visible that air room temperature matches the average Fan speed. At air temperature 20° , the Fan speed is 50 matching the interval of 'LittleColdAirIn'. In figure 9 above, at air temperature 30.9° , the Fan speed is 29, matching the interval of 'ColdAirIn'.

Figure 10 shows the response function of Fan speed estimation for input parameter 'temperature'. This response function satisfies the rules of the system.

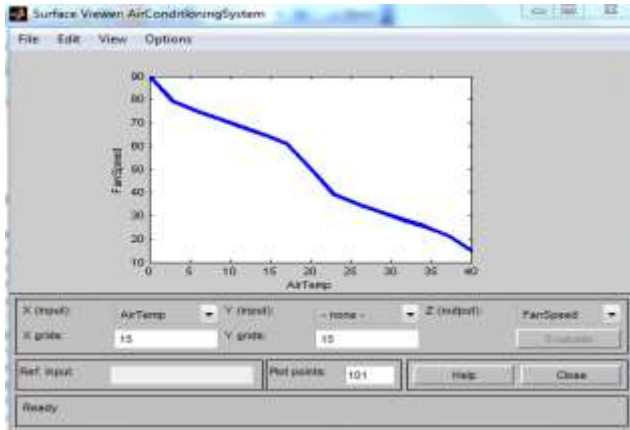


Figure 10: Influence of air temperature to the fan speed

6) Defuzzification of the system

Defuzzification is the process of producing a quantifiable result in Crisp logic, given fuzzy sets and corresponding membership degrees. It is the process that maps a fuzzy set to a crisp set. It is typically needed in fuzzy control systems. It will have a number of rules that transform a number of variables into a fuzzy result. A common and useful defuzzification technique is 'centre of gravity'. First, the results of the rules must be added together in some way. The most typical fuzzy set membership function has the graph of a 'triangle'. Now, if this triangle were to be cut in a straight horizontal line somewhere between the top and the bottom, and the top portion were to be removed, the remaining portion forms a 'trapezoid'. The first step of defuzzification typically "chops off" parts of the graphs to form trapezoids or other shapes if the initial shapes were not triangles. In the most common technique, all of these trapezoids are then superimposed one upon another, forming a single 'geometric shape'. Then, the 'centroid' of this shape, called the fuzzy centroid, is calculated. The 'x' coordinate of the centroid is the 'defuzzified' value. [5][6].

IV. CONCLUSION

In this paper, fuzzy logic was used to analyze the problem of conventional air conditioning system which is controlled by thermostat with targeted temperature and no control over humidity. Rules within fuzzy inference mechanism are established in order to register the changes of the parameters through the help of program tool Matlab. From the graphical display of air temperature influence to Fan speed, it can be concluded that room temperature matches average value of Fan speed. Through inference diagram (Fig. 8 and Fig. 9), also in program package Matlab, it is shown that changes in input parameters influence the value of output parameter, which complies with the measured data in table 1.