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Design of A Room Temperature And Humidity Controller Using Fuzzy Logic

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Abstract: - This research paper describes the design of a room temperature and humidity controller using fuzzy logic. The proposed model consists of two fuzzy logic controllers to control temperature and humidity respectively. The first controller accepts two input values- the current temperature as detected by temperature sensor and its deviation from user set-temperature, and controls the speed of heat-fan and cool-fan accordingly . When the current temperature in the room reaches set point, it serves as one of the input for second fuzzy logic controller that controls the humidity. The ideal relative humidity level for user's set temperature is preset in the system. Current humidity in % as detected by the humidity sensor in the room serves as the second input to the controller. The humidifier and exhaust fan speed is controlled accordingly to maintain the correct humidity level for that temperature. This research work will increase the capability of fuzzy logic control systems in process automation with potential benefits. MATLAB-simulation is used to achieve the designed goal.

Keywords: - *Fuzzy logic, Inference Engine, Matlab Simulation, Rule Selection*

I. INTRODUCTION

A control system is a device, or set of devices, that manages, commands, directs or regulates the behavior of other device(s) or system(s). Industrial control systems are used in industrial production for controlling an equipment or a machine. The control system design, development and implementation need the specification of plants, machines or processes to be controlled. A control system consists of controller and plant, and requires an actuator to interface the plant and controller. The behaviour and performance of a control system depend on the interaction of all the elements. **[2]**

Computational Intelligence (CI) is a field of intelligent information processing related with different branches of computer sciences and engineering. The fuzzy systems are one paradigm of CI. The contemporary technologies in the area of control and autonomous processing are benefited using fuzzy sets. One of the benefits of fuzzy control is that it can be easily implemented on a standard computer.

In contrast with traditional logic theory, where bi- nary sets have two-valued logic: true or false, fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false. Fuzzy logic imitates the logic of human thought, which is much less rigid than the calculations computer generally perform. Intelligent control strategies mostly involve a large number of inputs. The objective of using fuzzy logic has been to make the computer think like people. Fuzzy logic can deal with the vagueness intrinsic to human thinking and natural language and recognize its nature is different from randomness. Using fuzzy logic algorithm, we could enable machines to understand and respond to vague human concept such as hot, cold, large, small, etc. **[1] [2]**

This proposed design work of room temperature and humidity controller can be used in a processing plant to maintain comfortable atmosphere in the environment.

II. BLOCK DIAGRAM OF PROPOSED MODEL:-

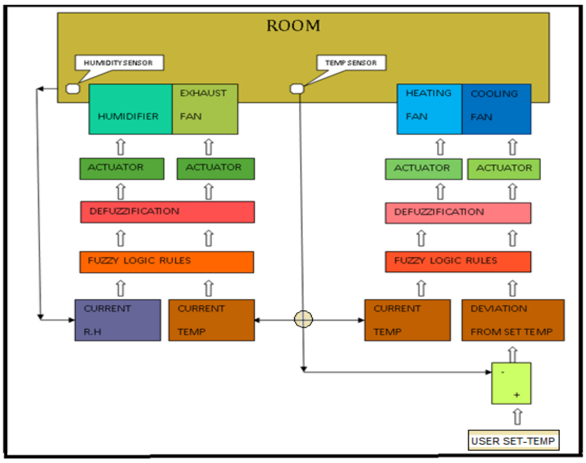
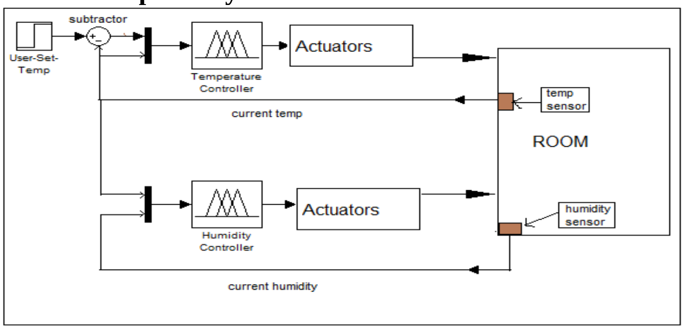


Figure 1: Block Diagram Of Room Temperature And Humidity Controller

The basic model of the proposed structure consists of room temperature and humidity controller with fuzzy logic control system. The room atmosphere controller has a heating fan, a cooling fan to heat or cool the room according to user demand ; a humidifier to release moisture in the air and a exhaust fan to dry out the air if the relative humidity is higher than the needed range. Humidity and temperature sensors used to monitor the environment of room are mounted in the room and are connected with the fuzzifiers of the two fuzzy logic control system.

2.1.Simplified Diagram For The Prposed System:-



III. HOW HEATING AND COOLING IS DONE

The model basically employs the principle of ground water/air source reversible heat pumps which work in either thermal direction to provide heating or cooling to the internal space.

In cooling mode, the inside coil is the evaporator and the outside coil is condensor. The compressor takes away the low pressure vapour from the refrigerant and discharge it as high pressure vapour which thereby enters the condensor where it is cooled and condensed into liquid. After leaving the condensor as high pressure cooler liquid, the refrigerant now enters the evaporator where it changes into vapour coming in contact with low pressure atmosphere. During this evaporative cycle, heat is removed from the air which gets cooler and enters the room. The low pressure refrigerant then routes back to the compressor by suction line to repeat the cooling process.

In heating mode, the inside coil is now condensor and outside coil is evaporator. The compressor sends the high pressure vapour into the reversing valve which routes the vapour to the condenser coil where it is cooled, and condensed into liquid by passing through the coil. The heat removed from the refrigerant is expelled to the inside air by the air movement system. The refrigerant leaves the inside coil as a high pressure liquid. When this liquid enters the low pressure atmosphere of the outside coil (evaporator) it evaporates into vapor. When the evaporative process takes place, heat is removed from the air flowing through the evaporator and the air,which is now cool, is returned to the outside air (ambient). From the evaporator, the low pressure refrigerant vapour returns to the reversing valve which routes the low pressurevapour to the compressor through the suction line to start the heatingprocess again. **[2]**

A heat pump with one extra valve allows the condenser (hotcoil) and evaporator (cold coil) to reverse places in the winter. Figure 2 shows close-ups of this "reversing" valve and where it is located in the heat pump system.

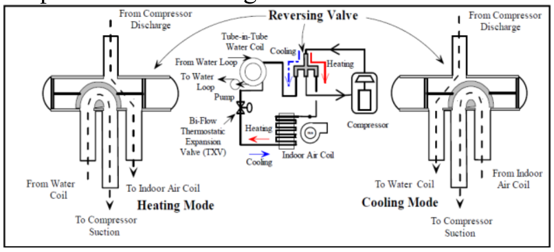


Figure 2:- Reversing Valve That Enables Both Heating And Cooling Processes

IV. DESIGN ALGORITHM OF FUZZY LOGIC FOR ROOM TEMPERATURE & HUMIDITY CONTROLLER

This simplified design algorithm is used to design the fuzzifier, inference engine, rule base and defuzzifier for the room air conditining system according to the control strategy of the processing plant to achieve the quantity and quality of the desire needs to maintain the room environment. The model can operate within 8'C to 44'C temperature range. And user can set any desired temperature from 18 to 26. For any temperature within 18 to 26 both temperature and humidity controlling part of the proposed model performs well to maintain the comfort atmosphere of the user. The humidity comfort level is pre defined and works perfectly within temperature range 18 to 26(^{o}C).

4.1.Fuzzifier:-

4.1.1.Membership Functions And Ranges For The First Fuzzy Logic Controller For Controlling The Desired Temperature

4.1.1.1.Input Variables:-

4.1.1.1.1.Current Temperature:-

It is the current temperature of the room as recorded by the temperature sensor mounted in the room. The sensor range should be wide enough to take care of climatic and regional fluctuations. The proposed model works perfectly at any temperature within range 8^{o}C-44^{o}C

Table 1: Membership Functions For Current-Temperature

MEMBERSHIP FUNCTIONS	RANGE (^{o}C)
COLD	8-14
COOL	13-19
NORMAL	18-22
WARM	21-27
HOT	26-32
VERY-HOT	31-39
EXTR-HOT	38-44

4.1.1.1.2.Deviation From Set Temperature

It gives the difference between the user preferred temperature and current temperature of the room as recorded by the temperature sensor in the room. As this model can work between temperature range 8-44'C and user can set any desired temperature from 18-26'C, so temperature difference between the current and the user preferred temperature can never go beyond -26'C (18'C – 44'C) and 18'C (26'C - 8'C). Thus (-26'C) & (+18'C) are the lower and upper limits of the input variable " deviation from set-temperature").

Table 2: Membership Functions for "Deviation from current temperature"

MEMBERSHIP FUNCTIONS	RANGE(^{o}C)
NE2	-26 to -18.5
NE1	-19.5 to -12
NL	-13 to -6
NS	-7 to 0
O	-2 to 2
PS	1 to 10.5
PL	9 to 18

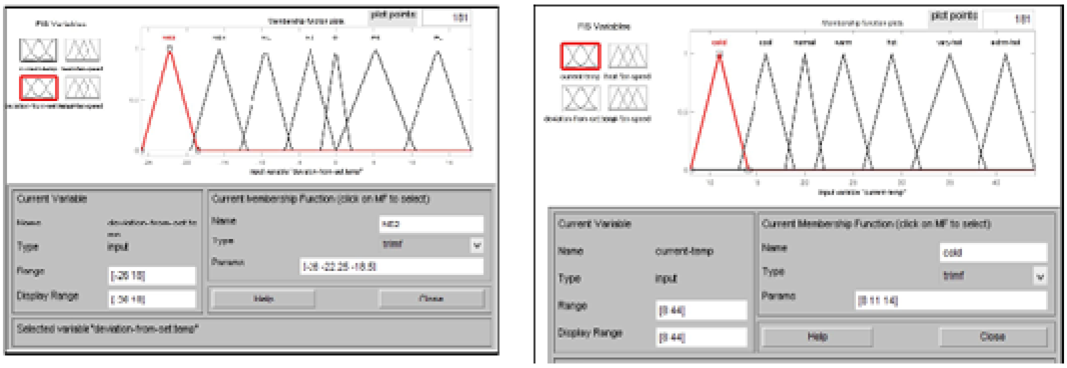


Figure 3:-Plot Of Membership Functions For " Current-Temperature" & "Deviation from current temperature"

4.1.1.2.Output Variables

4.1.1.2.1.Heat-Fan-Speed

The heat fan can either be in ON or OFF state depending on the temperature preference in the room. The heta-fan-speed is catagorised into 1. STOP 2.HEAT-SLOW 3. HEAT-MEDIUM 4. HEAT-FAST.
If the current temperature of the room is below the desired temperature then this fan automatically gets on varies speed according to temperature difference.

Table 3:-Membership Functions For "heat-fan-speed"

MEMBERSHIP FUNCTIONS	RANGE %
STOP	0-5
HEAT-SLOW	0-45
HEAT-MEDIUM	35-65
HEAT-FAST	60-100

4.1.1.2.2.Cool-Fan-Speed

The cool-fan-speed is catagorised into 1. STOP 2.COOL-SLOW 3. COOL-MEDIUM 4. COOL-FAST.
If the current temperature of the room is above the desired temperature then this fan automatically gets on varies speed according to temperature difference.

Table 4:-Membership Function For "cool-fan-speed"

MEMBERSHIP FUNCTIONS	RANGE %
STOP	0-5
COOL-SLOW	0-30
COOL-MEDIUM	25-50
COOL-FAST	45-80
COOL-V.FAST	75-100

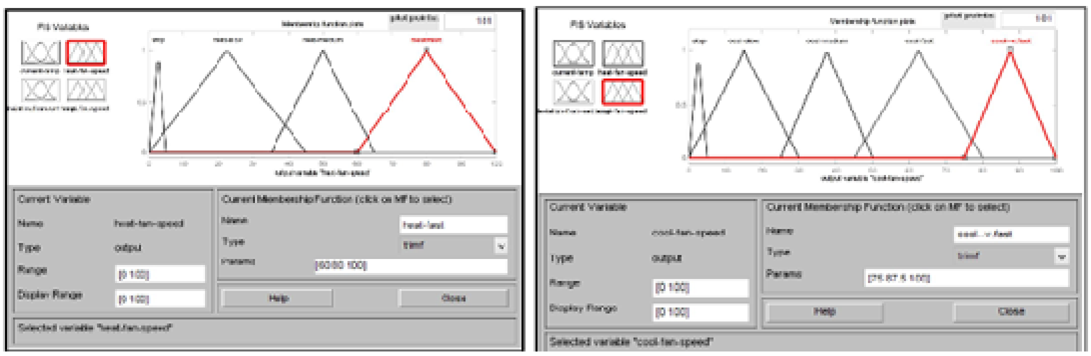


Figure.4:-. Plot Of Membership Function For "heat-fan-speed & cool-fan-speed"

4.1.2.Membership Functions And Ranges For The Second Fuzzy Logic Controller For Controlling The Relative Humidity

4.1.2.1.Input Variables
4.1.2.1.1. Current Temperature
This input variable of the second fuzzy logic controller is dependant entirely on the temperature sensor. As the user is allowed to choose the desired temperature between 18-26’C, so this temperature range is divided into two membership functions.

Table 5:- Membership Function For “current-temperature”

MEMBERSHIP FUNCTIONS	RANGES(^{o}C)
Temp-range-A	16-22.5
Temp-range-B	22-28

4.1.2.1.2.Current-Humidity
Relative Humidity is the percentage of water vapour the air is holding, in relation to the amount it is capable of holding at a given temperature.The Proper Indoor Humidity **[3]** that gives comfortable atmosphere depends on temperatures, as indicated here:

Table 6:- Proper Indoor Humidity

If Outdoor Temperature Is:	Relative Humidity That Should Be Maintained
86’F (30’C)	56%
80.5’F (27’C)	54%
77’F (25’C)	50.5%
71.5’F (22’C)	45%
68’F (20’C)	43.5%
62.5’F (17’C)	40%
59’F (15’C)	35%

The most recent advancement in humidification is a humidifier that automatically delivers the optimum RH without periodic homeowner adjustment.The humidification part is designed in this model in such a way that the user does not have to set any particular humidity. The comfort feeling humidity level within user settable temperature range (18-26C) is pre-set here . from 18(^{o}C) to 22(^{o}C) the ideal comfort RH level is taken as 45%. And from 23-26’C the ideal RH level is taken as 50-54%.

Table 7:-Membership Functions for Current-Humidity

MEMBERSHIP FUNCTIONS	RANGE (%)
DRY	0-21
NOT TOO DRY (NTD)	20-43
SUITABLE-1 (S-1)	42-48
SUITABLE-2 (S-2)	46-54
NOT TOO WET (NTW)	53-75
WET	70-100

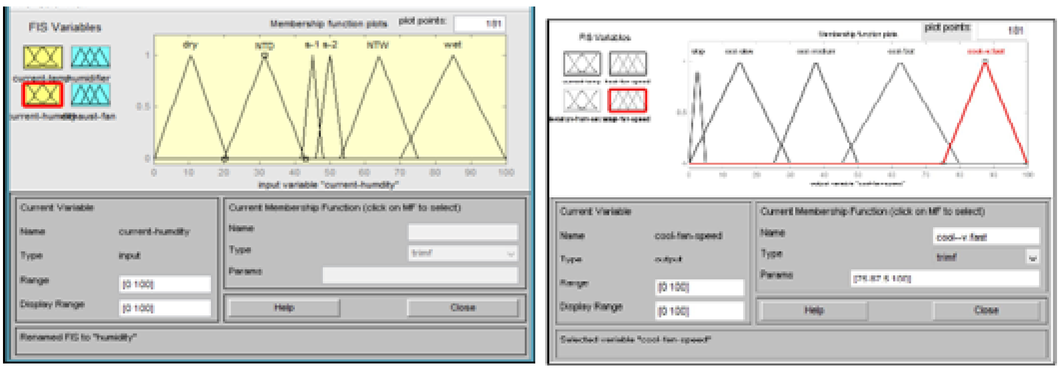


Figure 5:-Plot Of Membership Functions for “Current Temperature” & “Current Humidity”

4.1.2.2.Output Variables

4.1.2.2.1.Humidifier

Table 8:-Membership Functions for Humidifier

MEMBERSHIP FUNCTIONS	RANGE (%)
DRY	0-5
SLOW	4.5-35
MEDIUM	28-62
FAST	60-100

4.1.2.2.2.Exhaust-Fan

Table 9:-Membership Functions for Exhaust-Fan

MEMBERSHIP FUNCTIONS	RANGE(%)
STOP	0-5
SLOW	4.5-35
MEDIUM	28-62
FAST	60-100

Figure 6:- Plot of Membership Functions For “Humidifier” & “Exhaust-fan-speed”

4.2.Rule Base :-

Table 10 :- Rule Base For First Fuzzy Logic Controller

RULE NO	CURRENT-TEMP	DEVIATION FROM SET-TEMP	HEAT-FAN-SPEED	COOL-FAN-SPEED
1.	Cold	PL	Heat-Fast	Stop
2.	Cold	PS	Heat-Medium	Stop
3.	Cool	PL	Heat-Medium	Stop
4.	Cool	PS	Heat-Slow	Stop
5.	Cool	O	Stop	Stop
6.	Cool	NS	Stop	Cool-Slow
7.	Normal	PS	Heat-Slow	Stop
8.	Normal	O	Stop	Stop
9.	Normal	NS	Stop	Cool-Slow
10.	Warm	PS	Heat-Slow	Stop
11.	Warm	O	Stop	Stop
12.	Warm	NS	Stop	Cool-Slow
13.	Warm	NL	Stop	Cool-Medium
14.	Hot	NS	Stop	Cool-Slow
15.	Hot	NL	Stop	Cool-Medium
16.	Hot	NE1	Stop	Cool-Fast
17.	Very-Hot	NS	Stop	Cool-Slow
18.	Very-Hot	NL	Stop	Cool-Medium
19.	Very-Hot	NE1	Stop	Cool-Fast
20.	Very-Hot	NE2	Stop	Cool-V.Fast
21.	Extrm-Hot	NE1	Stop	Cool-Fast
22.	Extrm-Hot	NE2	Stop	Cool-V.Fast

Table 11 :- Rule Base For Second Fuzzy Logic Controller

RULE NO.	CURRENT TEMPERATURE	HUMIDITY	HUMIDIFIER SPEED	EXHAUST FAN SPEED
1	Temp-Range-A	DRY	Fast	Stop
2	Temp-Range-A	NTD	Medium	Stop
3	Temp-Range-A	S-1	Stop	Stop
4	Temp-Range-A	S-2	Stop	Slow
5	Temp-Range-A	NTW	Stop	Medium
6	Temp-Range-A	WET	Stop	Fast
7	Temp-Range-B	DRY	Fast	Stop
8	Temp-Range-B	NTD	Medium	Stop
9	Temp-Range-B	S-1	Slow	Stop
10	Temp-Range-B	S-2	Stop	Stop
11	Temp-Range-B	NTW	Stop	Medium
12	Temp-Range-B	WET	Stop	Fast

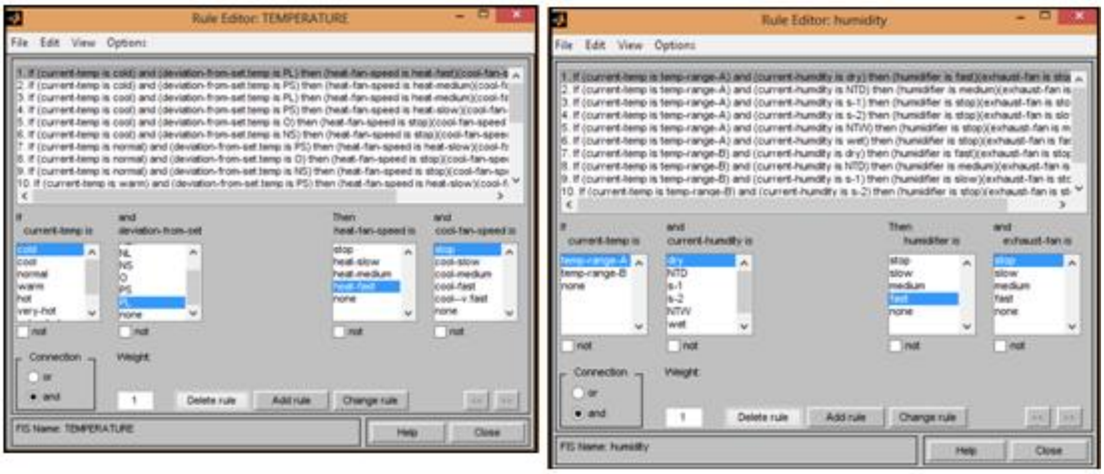


Figure 7:-Matlab Rule Editor for temperature & humidity controller

4.3.Fuzzification:-

We select two random values of input variables from first fuzzy logic controller to demonstrate how fuzzification is done in both the fuzzy logic controller used in this system.

In the first fuzzy logic controller, the signal value of current-Temperature=13C intersects with fuzzy variables "Cold" and "cool", where "cold" is taken as the first fuzzy variable f[0] and "Cool" is the second fuzzy variable, f[1]. The f[0] maps to the membership function value of 0.86 while f[l] maps to the value of 0.13. Similarly, for the input value of “deviation-from current-temperature”=+10,the corresponding intersection of fuzzy variables are "PS" as the second active fuzzy variable f[2] and "PL" as the first active fuzzy variable f[3]. The f[2] will thereby map to the membership function value of 0.04 while f[3] corresponds to 0.96.

Table 12 :- Results Of Fuzzification:-

INPUT VARIABLES	VALUES	REGION SELECTION	FUZZY SET CALCULATION
CURRENT TEMPERATURE	13	0<13<15	f1=(15-13)/15=0.13 f0=1-0.13=0.86
DEVIATION-FROM-SET-TEMPERATURE	+10	0<10<10.5	f3=(10.5-10)/10.5=0.04 f2=0.96

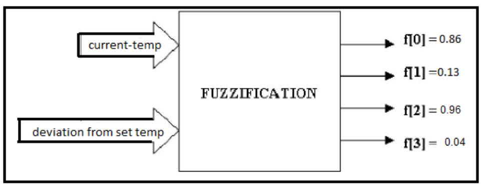


Figure 8:- Block Diagram Of Fuzzification Model

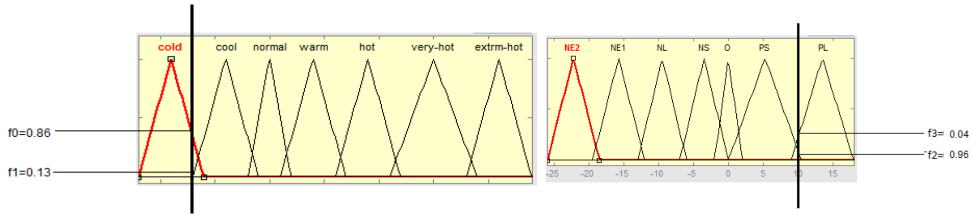


Figure 9:- Fuzzification Of Crisp Input, “Current-Temperature” = 13C. & “Deviation-From-Set-Temperature” = +10

4.4.Inference Engine:-

The inference block accepts four inputs from the Fuzzification process and the inputs of the inference would be f[O], f[l], f[2] and f[3]. The min-max inference method uses the min operator between the two inputs (rule's antecedent) resulting from rule conditions and the rules are finally combined by using OR operator and interpreted as the max operation for each possible value of the output variable. Hence four outputs RO, RI, R2, and R3 will be generated. The values of f[O], f[l], f[2] and f[3] are 0.86, 0.13, 0.96 and 0.04 respectively. Applying the max-min composition, f[O] and f[l] will perform the operation with f[2] and f[3] to output the R values as follows:

RO=f(0) ^ f(2) = f(0) AND f(2) =0.86 AND 0.96 = 0.86
R1= f(0) ^ f(3) = f(0) AND f(3) = 0.86 AND 0.04 =0.04
R2= f(1) ^ f(2) = f(1) AND f(2) = 0.13 AND 0.96 = 0.13
R3= f(1) ^ f(3) = f(1) AND f(3) = 0.13 AND 0.04 = 0.04

Note that the sign ^ indicates that a minimum value will be taken between the two membership function values. Also, in Mamdani-min, minimum is also interpreted as ANDing the two membership function values. However, it is important to note that this is not a logical ANDing. Rather, it is the comparison to obtain the minimum between the two membership functions. The inference model example of its input and outputs are shown in Fig . 10.

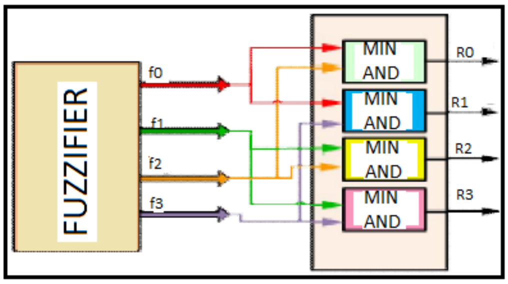


Figure 10:-Block Diagram Of Inference Engine

4.5.Rule Selector:-

The rule selector receives two crisp values of temperature and humidity. It gives singleton values of output functions under algorithm rules applied on design model. For two variables, four rules are needed to find the corresponding singleton values S1, S2, S3 and S4 for each variable according to these rules are listed in TABLE 13. The rule base accepts two crisp input values, distributes the universe of discourse into regions with each region containing two fuzzy variables, fires the rules, and gives the output singleton values corresponding to each output variable. Fig. 11 shows the main block diagram of the Rule Base.

Table 13:-Illustration Of Rules For The Applied Model

RULE	INPUTS		SINGLETON VALUES OF OUTPUTS		SINGLETON
NO.	CURRENT TEMP	DEVIATION FROM SET-TEMP	HEAT-FAN-SPEED	COOL-FAN-SPPED	VALUES
1.	COLD	PL	HEAT-FAST=0.8	STOP=0.025	S0
2.	COLD	PS	HEAT-MEDIUM=0.5	STOP=0.025	S1
3.	COOL	PL	HEAT-MEDIUM=0.5	STOP=0.025	S2
4.	COOL	PS	HEAT-SLOW=0.22	STOP=0.025	S3

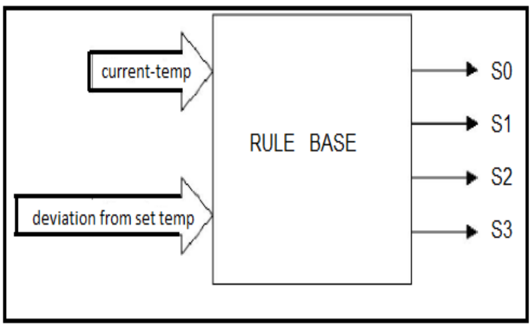


Figure 11:- Block Diagram Of Rule Base

This process is achieved by dividing the universe of discourse into six regions; with each region containing only two fuzzy variables. The illustrations of the region divisions are shown in Fig 12.

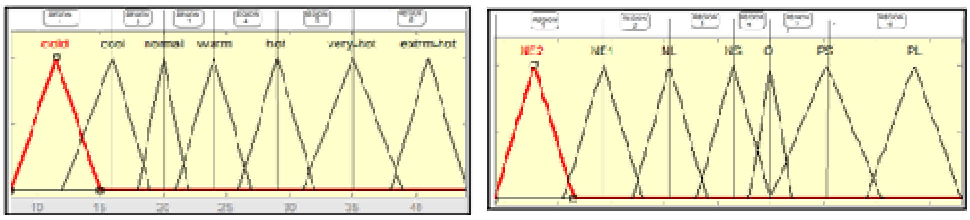


Figure 12:-Illustration of Region Deivisions

Table 14:- Division Of Regions For Current Temperature And Deviation From Set-Temperature

INPUTS	REGIONS	RANGE OF VALUES
CURRENT-TEMPERATURE	1.	8-16
	2	16-20
	3	20-24
	4	24-29
	5	29-35
	6	35-44
DEVIATION FROM SET-TEMPERATURE	1	-26 to -15.75
	2	-15.75 to -9.5
	3	-9.5 to -3.5
	4	-3.5 to 0
	5	0 to 5.25
	6	5.25 to 18

4.6.Deffuzifier:-

In this system, four defuzzifiers control the actuators; heat-fan-speed, cool-fan-speed, humidifier and exhaust-fan-speed. The defuzzification process provides the crisp value outputs after estimating its inputs **[1].** But as we are citing an example of how the defuzzification is done, we select only 2 defuzzifiers that control the heat-fan and cool-fan-speeds in correspondence to the current-temperature=+13 & deviation=+10. So 8 inputs are given to each of two defuzzifiers, four values of R0, R1, R2, R3 from the outputs of inference engine and four values S0, S1, S2, S3 from the rule selector .

Each defuzzifier estimates the crisp value output according to the center of average (C.O.A) method using the mathematical expression $\sum S[i]*R[i] / \sum R[i]$, where i = 1 to 4. Each. output variable membership function plot consists of five functions with the same range values for simplification

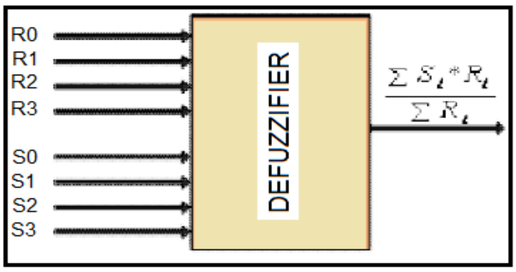


Figure 13:- Block Diagram Of Defuzzifier

V. RESULTS AND DISCUSSION

According to the results of inference engine$\sum R[i]$=R0+R1+R2+R3= 0.86+0.04+0.13+0.04=1.07

Table 15:- Designed Value For Heat-Fan-Speed

Si	Ri	Si*Ri
0.8	0.86	0.688
0.5	0.04	0.02
0.5	0.13	0.06
0.22	0.04	0.008

∑S[i]*R[i] =0.688 + 0.02 + 0.06 + 0.008 = 0.776 ; ∑R[i]=1.07 ; so ∑S[i]*R[i] / ∑R[i]= 0.776/1.07 =0.725 =72.5%

Table 16:- Designed Value For Cool-Fan-Speed

Si	Ri	Si*Ri
0.025	0.86	0.0215
0.025	0.04	0.001
0.025	0.13	0.00325
0.025	0.04	0.001

∑S[i]*R[i] =0.0215 + 0.001 + 0.003 + 0.001 =0.02675 ; ∑R[i]=1.07 =1.07.
So ∑S[i]*R[i] / ∑R[i]= 0.02675/1.07 =0.025 = 2.5%

Using the above mathematical expression the crisp values for output variables were determined and the results were found according to the MATLAB simulation as shown in Fig.14. These results are compared in TABLE 17 and found correct according to the design model. MATLAB simulation was adapted according to the arrangement of membership functions for four rules as given in TABLE 13.

In Fig. 14 the same values of input variables, Current-Temperature=13, and Deviation from set-temperature=+10 are shown. Various values of input and output variables match the dependency scheme of the system design. When the temperature reaches the set value (13+10=23'C),the humidifying controller gives the correct output as designed .

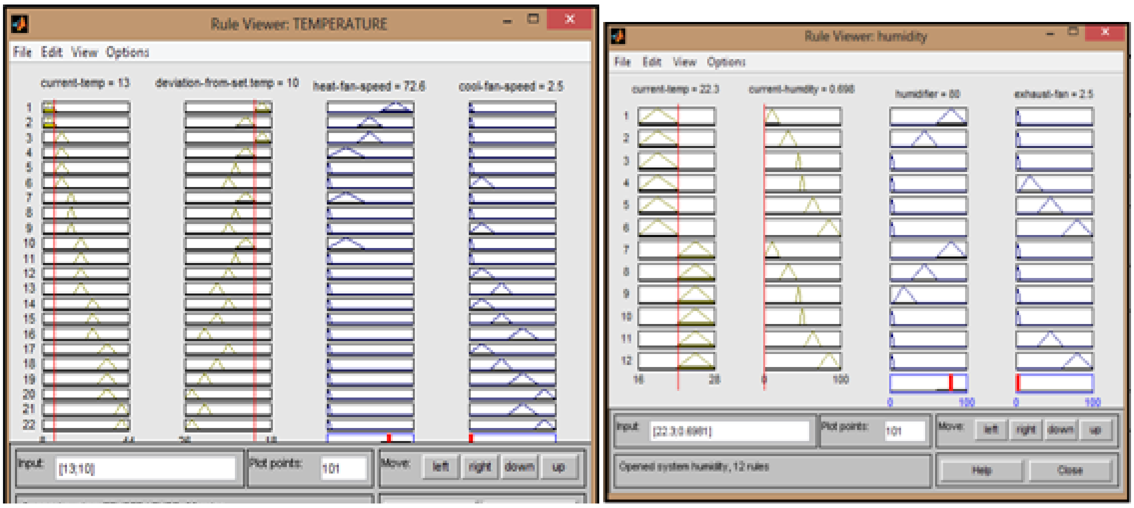


Figure 14:-Matlab Rule Viewer

The correctness of results shows the validity of the simplified design work for processing system using fuzzy control system.

5.1.Comparison Between Calculated & Simulated Result:-

Table :-17

RESULT	HEAT-FAN-SPEED	COOL-FAN-SPEED
Design values	72.6	2.5
Calculated values	72.5	2.5
% error	0.13	0

VI. SIMULATED GRAPH DISCUSSION:-

This system was simulated for the given range of input variables. In this design model, the speed of heat-fan and cool-fan depends upon the selected value of temperature sensor, whereas humidifier and exhaust fan speeds depend on the value of both humidity and temperature sensors . The simulated and calculated results are according to the reliance scheme.

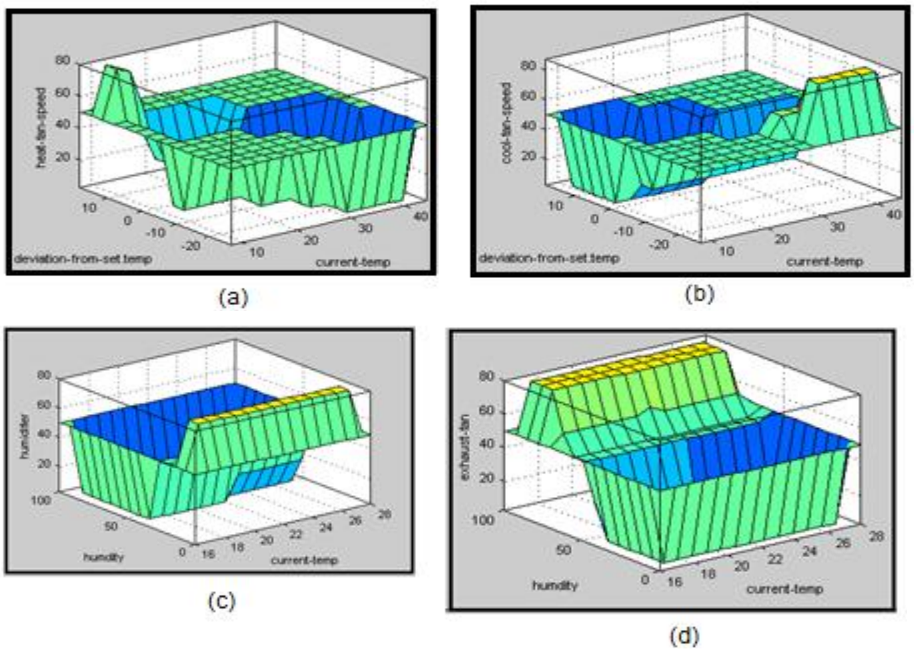


Figure 15 :- 3d Plots Between (a)Current Temperature & Deviation With Heat Fan Speed ; (b) Current Temperature & Deviation With Cool-Fan-Speed ; (c) Current Temperature & Current Humidity With Humidifier ; (d) Current Temperature & Current Humidity With Exhaust-Fan-Speed

VII. SOME SPECIAL CHARACTERISCTICS OF OUR PROPOSED MODEL

(a).The proposed room temperature and humidity controller works perfectly over a wider range of temperature 8-44 ^{0}C.

(b).There are two controllers in this system which measures temperature and humidity respectively. Both are designed using fuzzy logic. After the user sets a desired room temperature, the temperature controller starts immediately to bring back the room temperature to desired value in much shorter time. And when the current temperature is close to to desired value, the humidity controller starts working the get the ideal relative humidity for that temperature.

(c).The number of membership functions of input and output variables of both temperature and humidity controllers are more while difference between upper and lower limits of each range is reduced. This improves the accuracy and sensitivity of the controllers.

(d).The output of each of the controllers is calculation adaptive and is sensitive to small variation of temperatures.

(e).The efficiency of this model is very high as %error between calculated and measured value for a given temperature is approximately close to 0.15 only (shown in the paper).

VIII. CONCLUSION

The algorithmic design approach makes the system efficient and absolutely under control. The analysis clearly maps out advantage of fuzzy logic in dealing with problems that are difficult to study analytically yet are easy to solve intuitively in terms of linguistic variables. In case of the Air-Conditioning system, fuzzy logic helped solve a complex problem without getting involved in intricate relationships between physical variables. Intuitive knowledge about input and output parameters was enough to design an optimally performing system. The utility of the proposed system in processing plants is being carried out and in future it will help to design the advanced control system for the various industrial applications in environment monitoring and management systems.

IX. FUTURE WORK

I. Designing a powerful ground source reversible pumps using fuzzy logic controller which can handle a wider range of temperature and can heat and cool more sensitively and simultaneously.

II. Adding more intelligence to the room condition controller like occupancy, auto human detector and adjusting itself according to outdoor temperature and humidity at various times a day and all round the year.

III. In future we will come up with a device that implements the Fuzzy Logic controller in an embedded system which can be used for increasing the efficiency of Room Air Conditioners.

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