

Fuzzy Logic Control of Air Conditioners

Amiya Patanaik

Roll number 05EG1008

Department of Electrical Engineering

Indian Institute of Technology, Kharagpur - 721302, India

E-mail: amiyain@gmail.com

Abstract

Air conditioners and air conditioning systems are integral part of almost every institution. They contribute significant part of total energy consumption. Studies suggest that in locations like auditoriums, indoor stadiums and conference halls, air conditioning can contribute as much as 75% of total energy intake. Even in homes and offices, power consumed by air conditioners is significant. In this paper a scheme has been proposed to maintain the temperature and the humidity close to the targeted values, and reduce the electrical energy intake of the AC compressor/Fan while utilizing all available resources in the most efficient manner.

Problem Definition

The task of dehumidification and temperature decrease goes hand in hand in case of conventional AC. Once target temperature is reached AC seizes to function like a dehumidifier. Also complex interactions between user preferences, actual room temperature and humidity level are very difficult to model mathematically. But in this work this limitation has been taken into cogitation and overcome to a great extent using fuzzy logic to represent the intricate influences of all these parameters. The optimal limits of comfort zone, typically marked at a temperature of 25°C and dew point 11°C, are used as the targets. Conventional AC system controls humidity in its own way without giving the users any scope for changing the set point for the targeted humidity unlike the scope it offers to change the set point for the targeted temperature through a thermostat. This causes a significant level of flexibility as well as efficiency loss especially in hot and humid countries like India. For instance at higher humidity level (say at dew point 18°C) an occupant may perceive same comfort level at 22°C as he would perceive at 26°C at dew point 15°C. This translates to huge energy and monetary saving in terms of reduced compressor/fan duty cycle. In the developed scheme, the sensor captured temperature, user temperature preference and humidity readings are fuzzified. These are used to decide the fuzzy qualifier, which is decoded into a crisp value that in turn controls different aspects of the AC. In the problem dew point (Td) temperature is used to measure humidity instead of relative humidity (RH), this is because RH is a function of both temperature and moisture content while Td is a function of moisture content only. Hence it becomes very easy to model comfort level on the basis of Td. Human reaction to different levels of dew point*...

Table1 human reaction to different levels of dew point

<i>Dew Point</i>	<i>Reaction</i>
Above 20C (68F)	Oppressive
18C (64F)	Sticky
16C (61F)	Humid
13C (55F)	Comfortable
10C (50F)	Refreshing
Less than 10C (50F)	Dry

*source: Mark Margarit, WHDH-TV Boston Channel 7 Weather

Details about the Problem

Slight modifications [figure 1] in air circulation method around heat exchangers allow a conventional AC to function anywhere between normal AC mode and Dehumidifier only mode. In dehumidifier only mode chilled air is totally passed through hot side of heat exchanger so that the AC dehumidifies without any change in output temperature. The problem takes three variables into consideration...

- User temperature preference ($18^{\circ}\text{C} \sim 30^{\circ}\text{C}$ continuous control).
- Actual room temperature.
- Room dew point temperature.

User temperature is subtracted from actual room temperature before being sent for fuzzyfication. Fuzzy arithmetic and criterion is applied on these variables and final result is defuzzified to get following crisp results...

- Compressor Speed.
- Fan Speed.
- Mode of operation.
- Fin Direction.

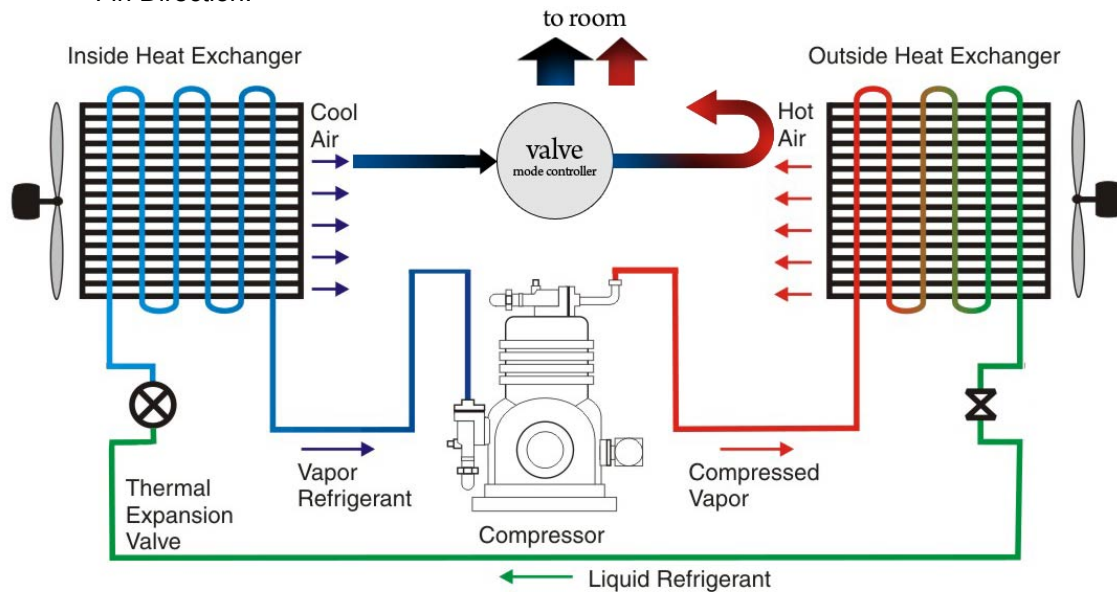


Figure 1 Simplified working diagram of AC

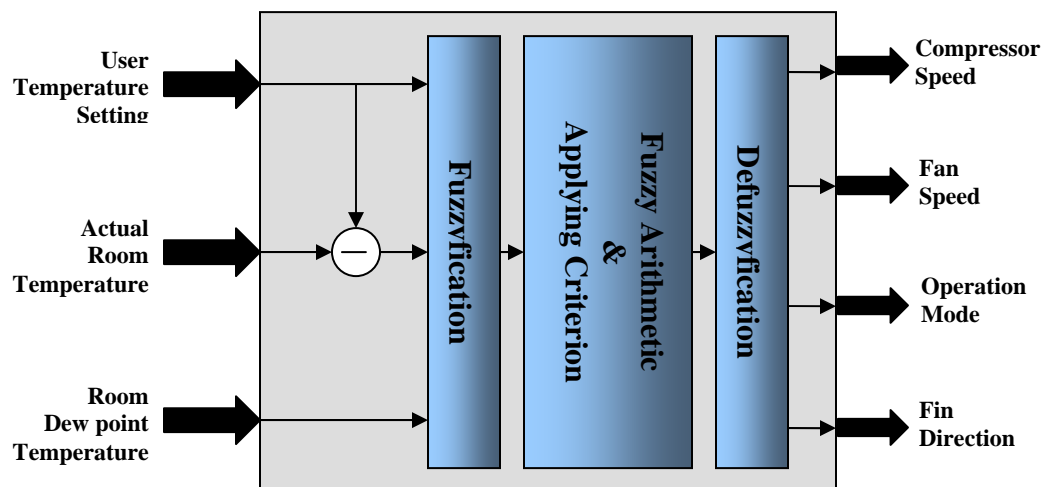


Figure 2: Basic block diagram of controller

Details of set applied and membership function

Range of possible values for the input and output variables are determined. Membership functions are formulated for these variables which map the real world measurement values to the fuzzy values, so that the operations can be applied on them.

Input variables

“User temperature preference” (Ut) holds user’s preferred temperature received by remote/front control unit. The control unit [figure 3] allows user to set temperature on a continuous dial over full range of 18C to 30C. Membership functions for Ut are shown in figure 4.



Figure 3 arrangements to accept user temperature preference (Ut)

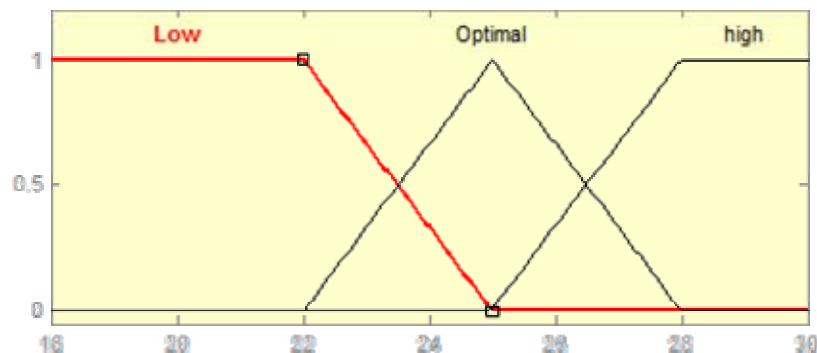


Figure 4 user temperature preference (Ut) membership functions

“Temperature difference” (Tdiff) gives information on difference between actual room temperature as received by electronic thermostat and Ut. The thermostat range should be wide enough to take care of climatic and regional fluctuation. In this case range is taken to be 17C to 45C, which constraints Tdiff between -1C to 27C. Please note that the AC in consideration *cannot* reverse its operation and act like a heat pump, so once Tdiff goes out of range AC is switched off. Memberships functions for Tdiff is partly shown below; note that membership function “large” continues with value 1 from 2C to 27C.

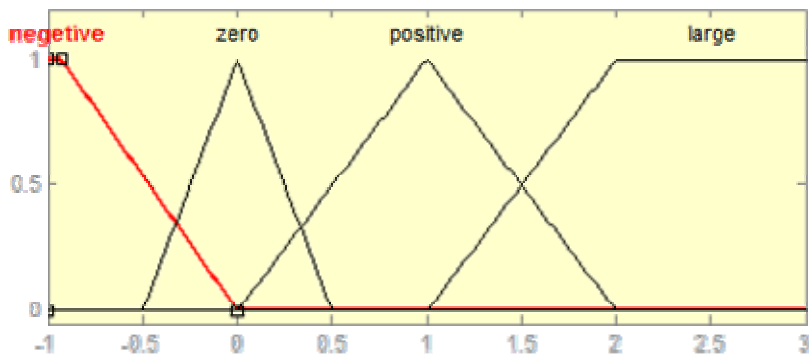


Figure 5 Temperature difference (Tdiff) membership functions

“Dew point” (Td) gives information about dew point temperature inside the room as received by electronic dew point sensor. Dew point is a direct measure of moisture content of air and is independent of temperature. Taking into account information in table 1 membership functions are formed as shown below. In case Td goes out of range it is forced to nearest boundary value. For instance if Td is 5C it will be passed on to fuzzy logic controller as 10C.

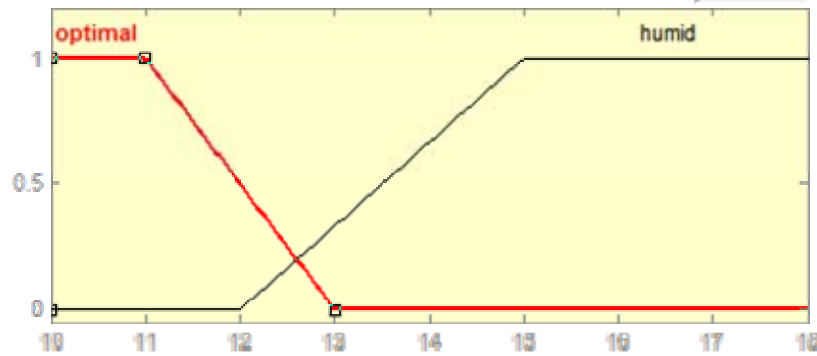


Figure 6 Dew point temperature (Td) membership functions

Output variables

“Compressor speed (Sc) and Fan speed (Sf)” can be either off or can be varied between 30 to 100%. Both will have similar membership functions as shown below.

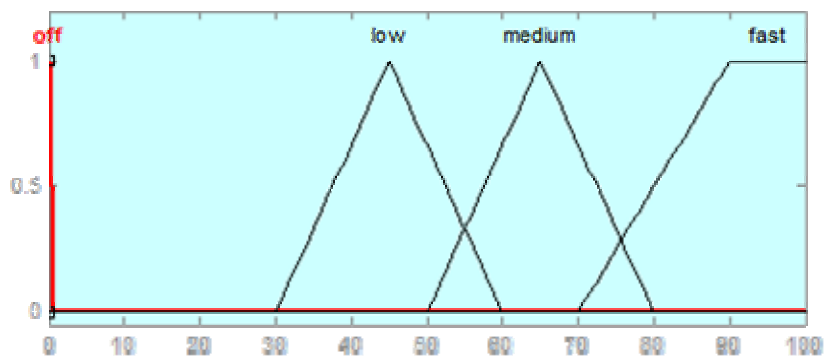


Figure 7 Fan and compressor speed (Sf and Sc) membership functions

“Mode of operation” (Mo) decides whether AC works like a dehumidifier only or normal AC. The control valve shown in figure 1 illustrates that the AC can work anywhere between these two modes. Naturally when AC acts like a dehumidifier only, it won't cause any change in temperature. Membership functions for Mo is shown below

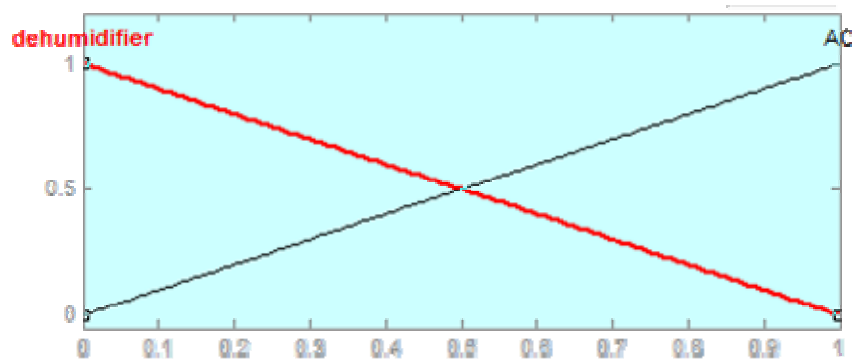


Figure 8 Operation mode (Mo) membership functions

“Fin direction” (Fn) directs air from the AC towards or away from occupants. Assuming top mounted AC, $\theta = 0^\circ$ can be considered as towards and $\theta = 90^\circ$ as away from occupant [figure 9a]. Membership functions for Fn are shown below [figure 9b]

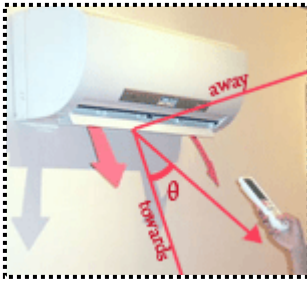


Figure 9a θ =fin direction

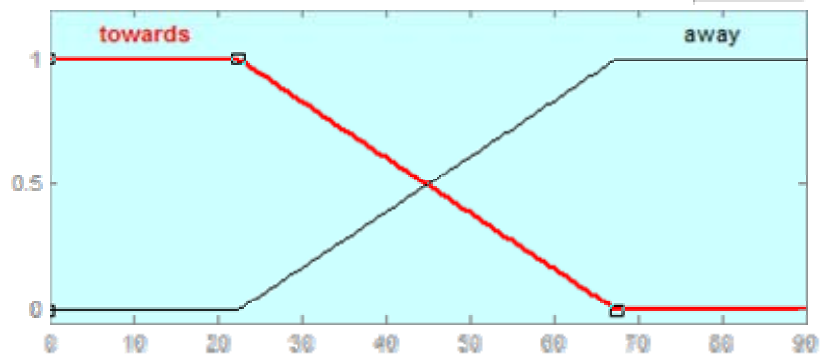


Figure 9b Fin direction (Fn) membership functions

The rule base

Rules are formed keeping in mind intuitive relationship between input and output parameters. Ut having three fuzzy ranges – low, optimal and high, Tdiff with four fuzzy ranges – negative, zero, positive and large and finally Td with two fuzzy ranges optimal and humid give a rule base matrix with size $3 \times 4 \times 2 = 24$ cells. Every cell has four outputs, each for compressor speed, fan speed, mode of operation and fin direction. This equates to total of 24 IF-THEN statements. For simplicity of understanding rule base output matrix is show below instead of IF-THEN statements.

Td -> optimal						
Ut \ Tdiff	Low		Optimal		High	
	O	A	O	A	O	A
Negative	O	A	O	A	O	A
	AC	O	AC	O	AC	O
Zero	O	T	O	T	O	A
	AC	F	AC	M	AC	L
positive	F	T	M	T	M	T
	AC	F	AC	M	AC	M
large	F	T	F	T	F	T
	AC	F	AC	F	AC	F

Compressor speed(Sc) and fan speed(Sf)

O OFF **L** LOW

M MEDIUM **F** FAST

Fin angle(Fn)

A AWAY **T** TOWARDS

Mode (Mo)

AC AC **D** DEHUMIDIFIER

Sc Fn

O	A
D	F

Mo Sf

Figure 10 Rule matrix between Ut and Tdiff when Td is optimal

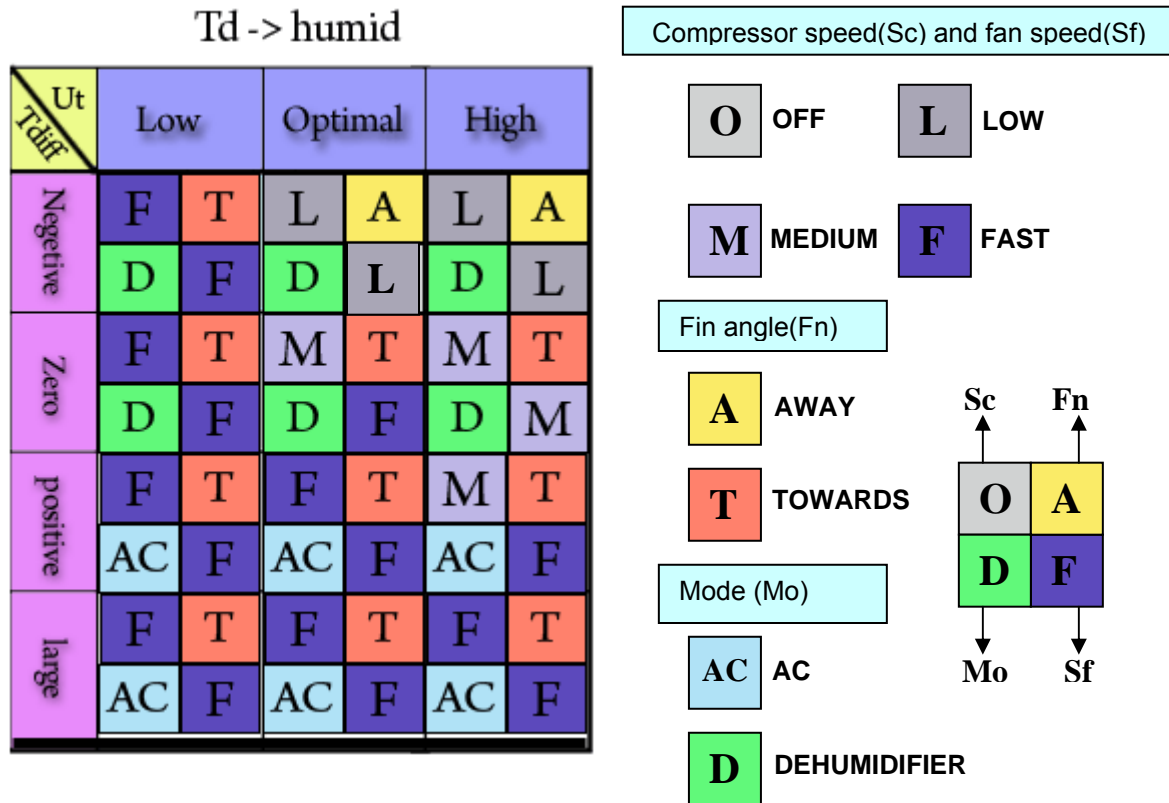


Figure 11 Rule matrix between Ut and Tdiff when Td is humid.

Note that Ut is bound to be within range, but actual room temperature (Tact), Tdiff and Td can surely go out of range. To tackle this problem when Tdiff or Tact goes out of range AC simply switches off and when Td goes out of range it is forced to nearest boundary point. This ensures correct operation over very wide range of climatic conditions. Moreover this ensures AC protection from overheating when room temperature is above working range (45C in this case). Again note that AC cannot reverse its operation and act like a heat pump nor can it act like a humidifier. Figure 12 below shows response curves for Ut fixed at 25C.

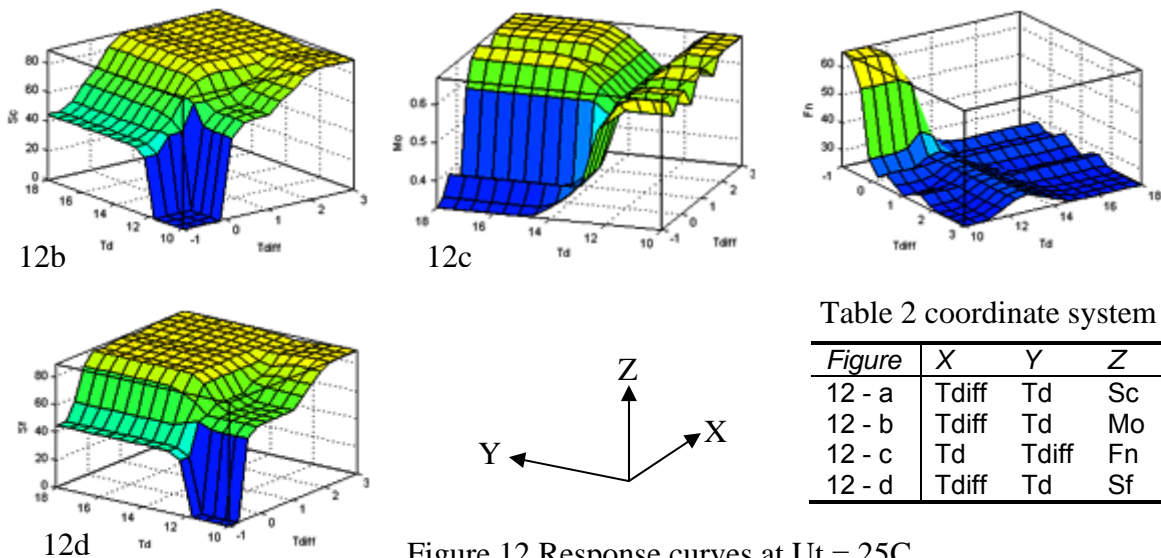


Figure 12 Response curves at Ut = 25C

Computer realization

The problem is realized on a computer which allows realtime response to different sets of input and helps better understand/fine tune its working. Fuzzy logic is written in fuzzy control language (FCL) that complies with IEC ([International Electrotechnical Commission](#)) 61131-7 standard. This ensures portability to different platforms. Software to make use of these logic (FCL) files is written in C++ using Free Fuzzy Logic Library (FFLL), an open source fuzzy logic class library and API. Simulation is also done in MATLAB®. All source code, FCL files and executable are attached with this document. Please note that the C++ code is not completely free of bugs.

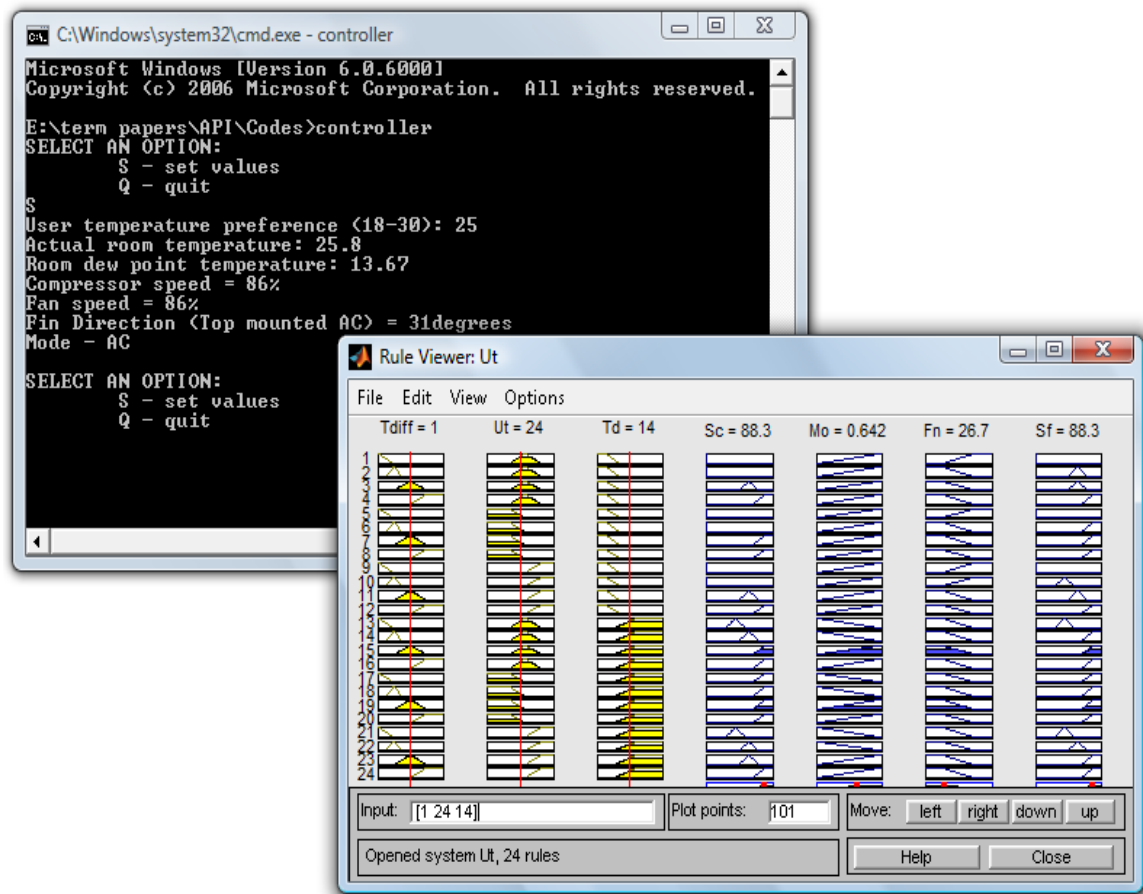


Figure 13. Shows both MATLAB® and C++ implementation of the problem

Results and summary

The performance of the controller was very good as observed from MATLAB® and C++ simulations. 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. Although the analysis in this paper neglected many finer details, but it clearly maps out advantage of fuzzy logic in dealing with problem that are difficult to study analytically yet are easy to solve intuitively in terms of linguistic variables. With most of the problems encountered in day to day life falling in this category, fuzzy logic is sure to make a great impact in human life.

Future directions

The paper simplified the problem by not allowing AC to reverse operation and act like a heat pump and humidifier. By eliminating these restrictions we can go for an all weather AC that would work in almost any part of the world. Also by adding infra red sensors to detect presence of occupants we can go one step ahead in user satisfaction. These sensors can aggregate data such as occupant location and body temperature. These data can further help control temperature, humidity and fan direction automatically for maximum comfort while reducing energy consumption. Application of neural networks and genetic algorithm will allow the controller to adapt to individual user, room environment and weather. An AC that will be “intelligent” in true sense!

Attachments

All files are zipped into a single file “attachement.zip” and attached with this pdf file. This zip file includes following files...

- compressor.fcl, fan.fcl, fin.fcl and mode.fcl : Fuzzy control language files with logic to control each of the four output parameters.
- matlab.fis : Matlab fuzzy toolbox file can be used to simulate the problem on Matlab®.
- controller.cpp : C++ code for the problem. Can be compiled on gcc on linux or MinGW on windows.
- controller.exe : Compiled windows executable for C++ code.
- fflapi.lib, fflapi.dll, FFLAPI.H : Free fuzzy control language class library and API.

References

- US Patent – 5,921,099; Air conditioner temperature control apparatus; Inventor: Seon Woo Lee; Assignee: Samsung Electronics Co., Ltd. Issue date: Jul 13, 1999
- US Patent – 5,148,977; control system for air conditioner; Inventors: Yozo Hibino, Susumu Nakayama, Hiromu Yasuda, Kensaku Oguni, Kenji Tokusa; Assignee: Hitachi, Ltd. Issue date: Sep 22, 1992
- Technical case studies and articles on fuzzy logic and fuzzy logic based control systems www.sciencedirect.com, <http://en.wikipedia.org> and <http://www.aptronix.com/>
- Fuzzy control language specification [International Electrotechnical Commission](http://www.iec.ch) (IEC) 61131-7 standard.