International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 08, August-2015

Fuzzy Expert Systems to Control the Heating, Ventilating and Air Conditioning (HVAC) Systems

Siham A. M. Almasani[1] Wadeea A. A. Qaid[1] Ahmed Khalid[2] Ibrahim A. A. Alqubati[2]
1. Hodeidah University, Faculty of computer science and engineering, Yemen
2. Najran University, Community College ,Computer Department, KSA

***Abstract* - This paper presents a fuzzy expert system for heating, ventilating and air-Conditioning (HVAC) system to provide a comfortable environment in terms of humidity, temperature and other environmental parameters for the occupants as well as to save energy. The current values of temperature, humidity and oxygen inside the building and the temperature outside the building is used as inputs variables for the introduced system, and the Heat valve, Cold valve, Speed of exhaust motor and Speed of water pump as output variables. Fuzzy logic Toolbox and Simulink in LABVIEW software are used to simulate the proposed system. The system shows good performance in controlling the HVAC system.**

Keywords: Fuzzy Expert System, control, HVAC, Non-linear system, PID, Auto-tuning PID.

1. INTRODUCTION.

Commercial and industrial HVAC systems use electric and mechanical control system to maintain the desired temperature humidity level, and static pressure within a given area or zone [10]. Previous work have established a foundation of process models and control strategies suitable for building HVAC systems. Good results are obtained with application of PID auto-tuning controllers [20], neural network techniques [25], and even genetic algorithms [17]. Although a great deal of research has been conducted to improve the performance of HVAC control system [21, 7, 15]. In [19] Hybrid PID-Cascade Control for HVAC System was proposed. In recent years, researchers have extensively used the fuzzy logic for modeling, identification, and control of highly nonlinear dynamic systems [16,27]. To decrease the energy consumption researchers in the area of thermal comfort [12,6,18] have learned that the required indoor temperature of a building is not a fixed value. In fact, the certain range of temperatures is sufficient to create a comfortable situation. Therefore, the ideal HVAC system works with high efficiency supplying only the amount of heat, cold and air that is necessary to maintain internal conditions at a level providing thermal comfort to room occupants.

Fuzzy logic like human logic has no limits, which based on decision-making methods. Therefore, to make a better decision, controlling the operation is needed which has in turn led to use fuzzy control mechanism that is based on logic [8]. Fuzzy logic controller systems do not require full knowledge of the model, while in another known controller this knowledge is required [9]. The uncertainty tests of fuzzy systems and expert's knowledge are very important as control has become popular and used in many different fields of science [22, 24, 5]. Fuzzy logic gave the best result when it used to control heating system [11].

In this article, we use fuzzy expert system. Fuzzy logic is a branch of artificial intelligence that deals with reasoning algorithms used to emulate human thinking and decision making in machines. FLCs are suitable for control of HVAC system because their inputs and outputs are real-valued variables, mapped with a non-linear function. These kinds of systems achieve an alternative for those applications where classical control strategies do not achieve good results. In many cases, these systems have two characteristics: the need for human operator experience, and a strong non linearity, where it is not possible to obtain a mathematical model [23,14,2].

The basic configuration of the fuzzy logic system consists of four main components: fuzzifier, fuzzy inference engine, fuzzy rule base, and defuzzifier.

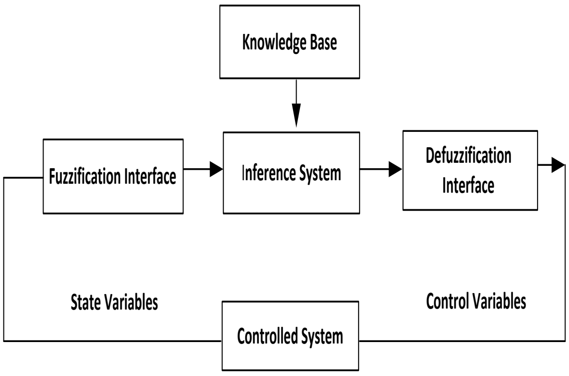

Fig. 1. Generic structure of fuzzy logic controller.

2. HVAC FUZZY EXPERT SYSTEM

Fuzzy logic is one of the methods of Soft Computing. Soft Computing is a computational method that is tolerant to sub-optimality, impreciseness, vagueness and thus giving quick, simple and sufficient good solutions [4]. Fuzzy logic together with the appropriate rules of inference provides a power framework for managing uncertainties pervaded in medical diagnosis and control [13]. Fuzzy logic system take the input which may be imprecise and vague and applied reasoning that is approx., rather than precise and as a result give their decision [1]. There are two concepts within fuzzy expert system that play an important role in its application. The first is the linguistic variable, that is, a variable whose values are words or sentences in a natural synthetic language. The second is a fuzzy if-then rule in which the antecedent and consequent are propositions containing linguistic variables, which exploits the tolerance for imprecision and uncertainty [26]. Fig. 2 represent the HVAC expert system Block Diagram system

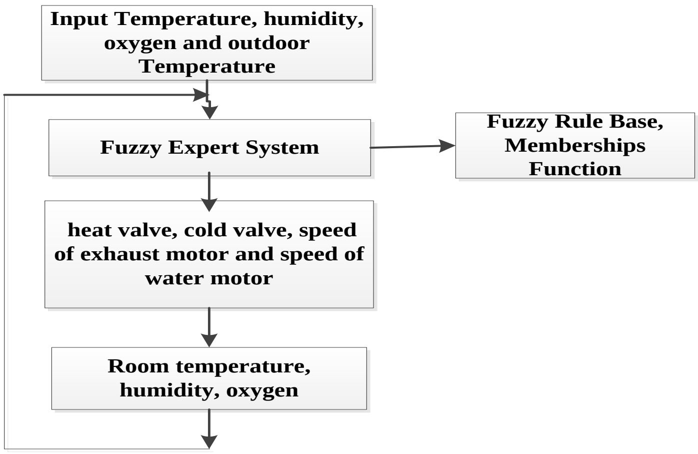

Fig. 2 the Block Diagram of HVAC System

Table 1. Shows the input variables and their linguistic values for the HVAC fuzzy expert system.
Table. 1. The input variables and their linguistic values.

Parameters	Linguistic values
Temperature	Very Low, Low Medium, High, Very High
Humidity	Very Low, Low, Medium, High
Oxygen	Very Low, Low, Medium, High
Outdoor Temp	Cold ,Hot

Table 2. Shows the output variables and their linguistic values for the HVAC fuzzy expert system.
Table.2. The output linguistic variables and their values

Parameters	Linguistic values
Heat valve	Off, Low, Medium, High
Cold valve	Off, Low, Medium, High
Speed of exhaust motor	Low, Medium, High
Speed of water pump	Off, Low, Medium, High

In this paper Mamdani's fuzzy inference method is used to build fuzzy IF-THEN rules because it simple structure for 'min-max' operations [2, 3].

The fuzziness methods for Temperature, Humidity and oxygen is Gaussian and the membership function is shown in equation (1) (Temperature=X, temperature value=x)

$$f\left(X:\sigma,c\right)=e^{\frac{-(x-c)^2}{2\sigma^2}} \tag{1}$$

For heat valve motor, cold valve motor, speed of exhaust motor and speed of water pump the membership function in triangle fuzziness methods as shown in equation (2) (Heat valve =Y, value of speed heat valve =y).

$$f\left(Y:a,b,c\right)=\begin{cases}0, & y\le a\\ \frac{y-a}{b-a} & a\le y\le b\\ \frac{c-y}{c-b} & b\le y\le c\\ 0 & c\le y\end{cases} \tag{2}$$

The parameters *a* is a locating of the "feet" and *c* is a locating of the peak. In the equation (2).
The fuzzy set for the linguistic expressions and membership functions of both input and output are obtain as seen in Fig 6-7.

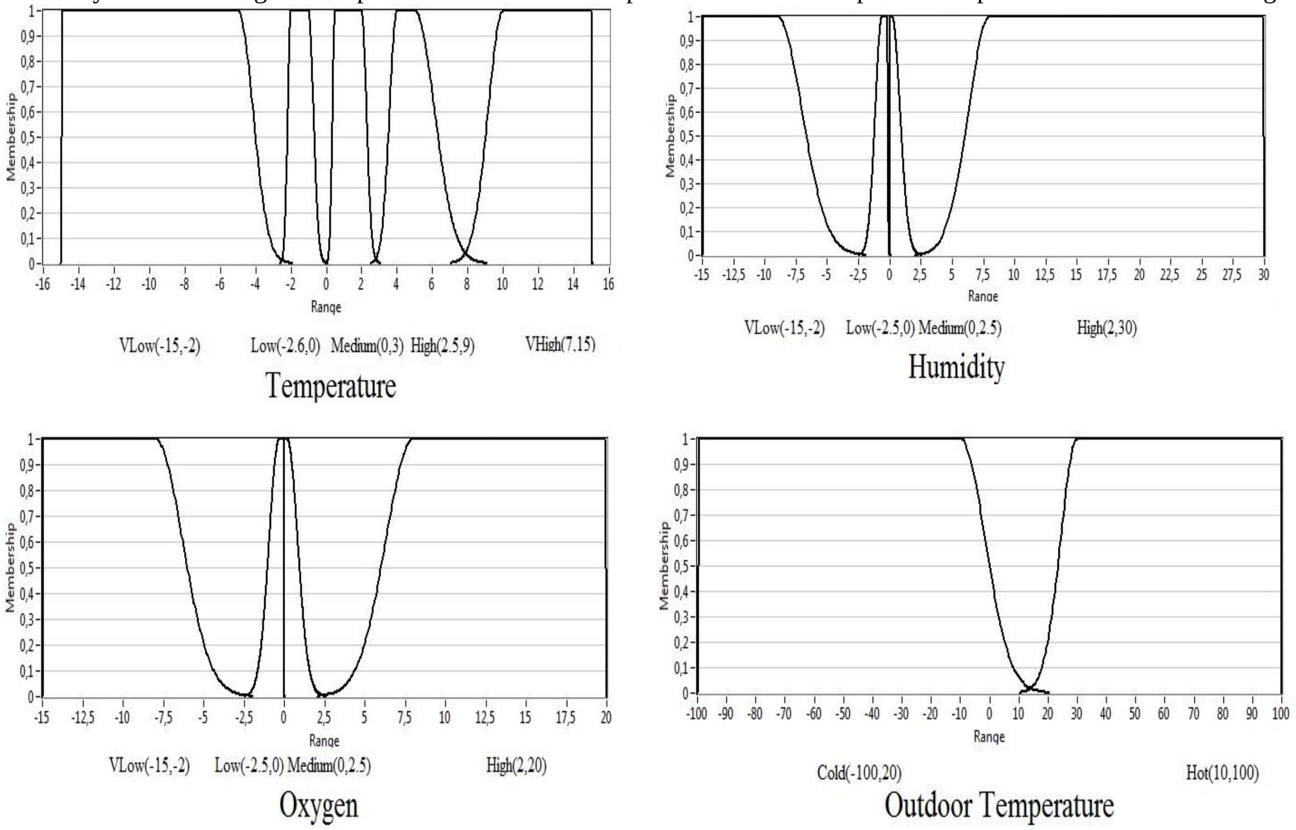

Fig. 3 The fuzzy set for the linguistic expressions and membership functions of input parameters

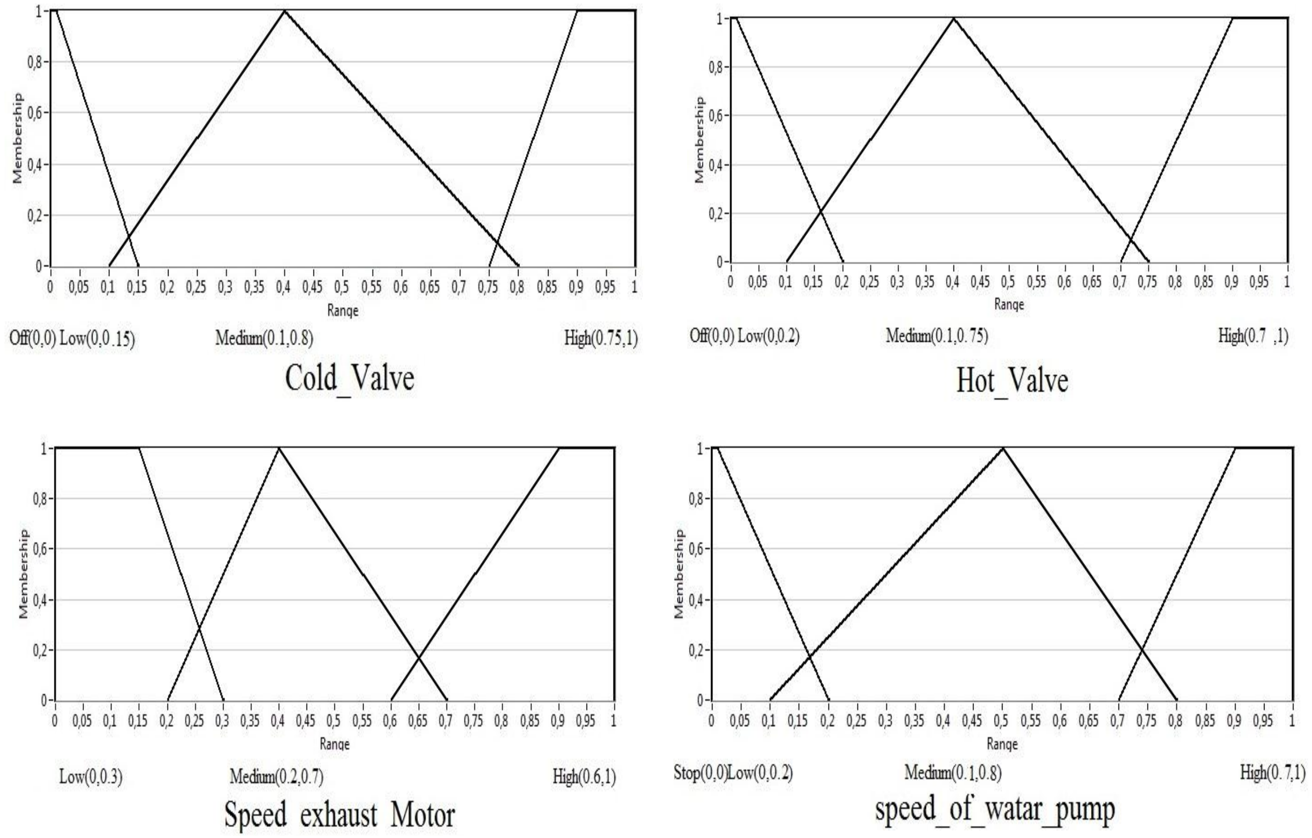

Fig. 4. The fuzzy set of the linguistic expressions and membership functions of the output parameters

The Center of Area Defuzzification method is used in the proposed system to convert the degrees of membership of output linguistic variables into numerical values which is compound with Mamdani's fuzzy inference method as shown in equation (3)

$$CoA = \frac{\int_{x_{\min}}^{x_{\max}} f(x) \cdot x dx}{\int_{x_{\min}}^{x_{\max}} f(x) dx} \qquad (3)$$

Table 3. Shows some of the rules composed by the expert for heating, ventilation and air condition the total of rules for the proposed fuzzy expert system is 100 rules.

Table. 3. Some of the rules for heating, ventilation and air condition

Rules	Temperature	Humidity	Oxygen	Outdoor Temp	Heat valve motor	Cold valve Motor	Water pump speed	Exhaust motor speed
1.if	Low	….	Low	Cold Then	Off	Low	….	High
2.if	Low	Low	Low	Hot Then	High	Off	Low	High
3.if	VLow	…..	Low	Cold Then	Off	Med	….	Med
4.if	VLow	Low	Low	Hot Then	Low	Off	High	High
5.if	Med	…..	Low	Cold Then	Off	High	……	Low
…..	…..	…..	…..	…..	…..	…..	…..	…..
90.if	VHigh	Med	Low	Hot Then	Med	Off	Low	High
91.if	VHigh	High	Low	Hot Then	Med	Off	Med	High
92.if	VHigh	Vlow	VLow	Hot Then	Med	Off	Low	Low
93.if	VHigh	Med	VLow	Hot Then	Med	Off	Low	Low
94.if	VHigh	High	VLow	Hot Then	Med	Off	Med	Low
95.if	VHigh	Vlow	Med	Hot Then	Med	Off	Low	Low
…..	…..	…..	…..	…..	…..	…..	…..	…..

3.2. HVAC expert system Mathematical Model

The mathematical model is very important to understand how the system behaves. Equation 4 through 16 represent the mathematical model for the heating, air conditioning, humidity and ventilation systems.

The heat system mathematical model is determined by relating the heat flow into the room from the heater to the room temperature. The amount of loss of heat air from the heater and the room temperature using the following equations:

$$\frac{dt_{room}}{dt} = \frac{1}{M \cdot c}\left(\frac{dQ_{FlowHeat}}{dt} - \frac{dQ_{losses}}{dt}\right) \tag{4}$$

$$\left(\frac{dQ}{dt}\right)_{Losses} = \frac{T_{room} - T_{outdoor}}{\mathrm{R}_{eq}} \tag{5}$$

Where: M – mass of air inside the house; R_{eq} – equivalent thermal resistance of the house; $dQ_{FlowHeat} / dt$ –heat flow from the Heater; dQ_{losses} / dt – heat losses to the environment.

Now determine the heat flow from the Heater expressed by the equation (6):

$$\frac{dQ}{dt} = (T_{heater} \cdot pv) \cdot M_f \cdot c \tag{6}$$

Where: dQ / dt – heat flow from heater in the room; T_{heater} – largest temperature coming from the heater; pv – the power of heat valve; M_f– air mass flow rate through heater; c – heat capacity of air at constant pressure.

The Air Conditioning mathematical model is determined by relating the cool flow into the room from air condition to the room temperature, the amount of loss of cold air from air condition and the room temperature using the following equations:

$$\frac{dt_{room}}{dt} = \frac{1}{M \cdot c} \cdot \left(\frac{dQ_{FlowCool}}{dt} + \frac{dQ_{losses}}{dt}\right) \tag{7}$$

$$(\frac{dQ}{dt})_{losses} = \frac{T_{outdoor} - T_{room}}{R_{eq}} \qquad (8),$$

Where: M – mass of air inside the house; R_{eq} – equivalent thermal resistance of the house; $dQ_{FlowCool} / dt$ – cool flow from air conditions; $(dQ / dt)_{losses}$ – cool losses to the environment.

Now determine the cool flow from the Air condition expressed by the equation (9):

$$\frac{dQ}{dt} = (T_{Cool} \cdot pv) \cdot M_f \cdot c \qquad (9),$$

Where: dQ / dt – cool flow from air condition in the room; T_{cool} – largest cool degree coming from the air conditioner; pv – the power of cold valve; M_f – air mass flow rate through air conditioner; c – heat capacity of air at constant pressure.

The Humidity mathematical model is determined by relating the flow of steam into the room from humidity to the room humidity, the amount of loss of steam air from humidity and the room humidity using the following equations:

$$\frac{dh_{room}}{dt} = \frac{bs}{1000} \cdot \left(\frac{dQ_{FlowSteam}}{dt} - \frac{dQ_{losses}}{dt}\right) \tag{10}$$

$$(\frac{dQ}{dt})_{losses} = (H_{outdoor} - H_{room}) \cdot R \qquad (11),$$

where: bs– the size of the house (height*width*length); $dQ_{FlowSteam} / dt$ – the amount of steam flow from the humidity for 1000 cubic feet of the size of the place to be moistened; R – equivalent steam leaks of the house; $(dQ / dt)_{losses}$ – steam losses to the environment.

Now determine the steam flow from the humidity is express by the equation (12):

$$\frac{dQ}{dt} = (H_{steam} \cdot pv) \cdot M \qquad (12),$$

where: dQ/dt – steam flow from humidity in the room; H_{steam} – largest steam degree coming from the moisturizer; *pv* – power of steam valve; *M* – steam mass flow rate through moisturizer;

The Ventilation mathematical model is determined by relating the flow of oxygen into the room from ventilation to the room oxygen and the amount of loss of oxygen air from ventilation as following:

$$Sp = \left(\left(\frac{dQ_{FlowOxygen}}{dt} \cdot \frac{1}{dA}\right) - \frac{dQ_{losses}}{dt} \right) \cdot fo \qquad (13)$$

$$\frac{dv_{room}}{dt} = \left(\frac{Sp}{vol \cdot ACH} \right) \cdot 100 \qquad (14)$$

$$\left(\frac{dQ}{dt}\right)_{losses} = FR/1000 \qquad (15),$$

where: *Sp* – the amount of oxygen flow from the ventilation after subtracting the missing oxygen*;* *dA* – density of the Air*;* $dQ_{FlowOxygen}/dt$ – the amount of oxygen flow from ventilation; $(dQ/dt)_{losses}$ – oxygen losses to the environment; *fo* – fraction of oxygen in air, it is equal 0.2095; *vol* – size of the house (height*width*length); *ACH*–the air change rate; *FR*– equivalent oxygen leaks of the house.

Now determine the oxygen flow from ventilation expressed by the equation (16):

$$\frac{dQ}{dt} = (V_{oxygen} \cdot pv) \qquad (16),$$

Where: dQ/dt – oxygen flow from ventilation in the room; V_{oxygen} – largest oxygen degree coming from the ventilation; *pv* – power of speed of ventilation.

4. RESULTS AND DISCUSSION

Fuzzy logic Toolbox and Simulink in LABVIEW software used to design a simulation system of HVAC fuzzy expert system controller for heating, ventilation and Air Condition control System. Fig.5 shows the interface for the proposed system.

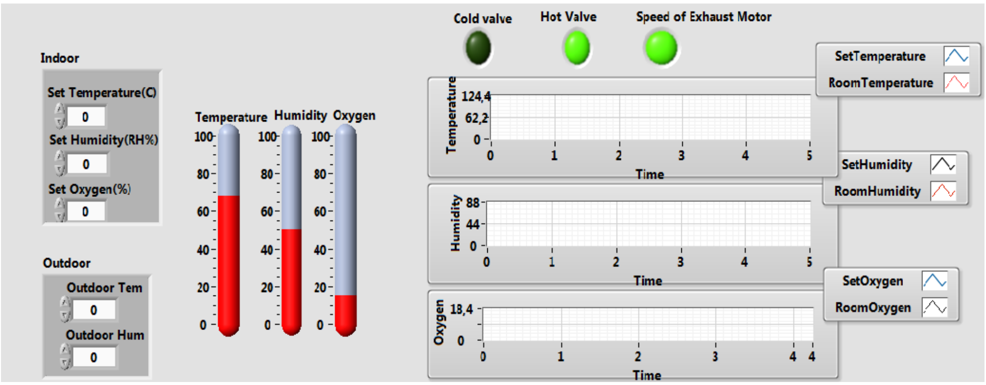

Fig.5 HVAC fuzzy expert system Interface

Fig. 6 shows the results when the temperature = 70°F, humidity=50%, oxygen=20%, outdoor humidity=20 and outdoor temperature = 45°F

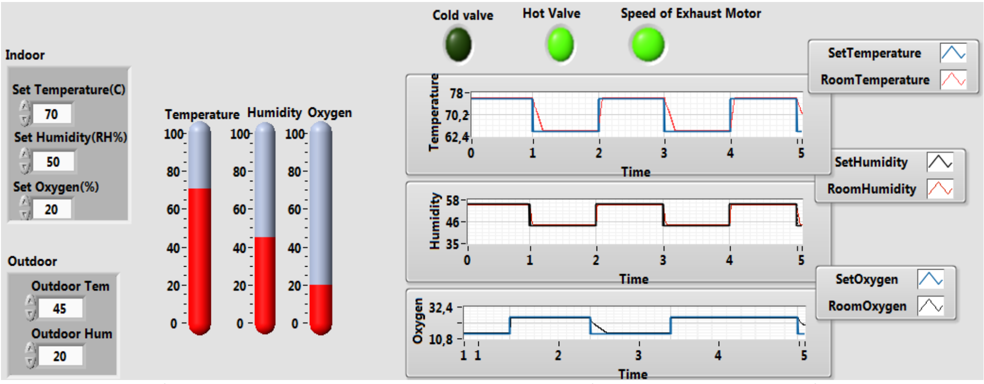

Fig. 6. A result of using Fuzzy Expert Controller In the condition of working heating, humidifier and ventilation

From Fig.6, we see the outdoor temperature is lower than the desired temperature; the system will open the heat valve to heat the place and close the cold valve. As long as the required humidity is greater than the outdoor humidity the humidifier will be open and the exhaust motor is operating, so the system is working to give us the required comfort without overshoot.

Fig. 7 shows the results when the temperature = 70°F; set humidity=60%, set oxygen=25%, outdoor humidity=30 and outdoor temperature = 100°F.

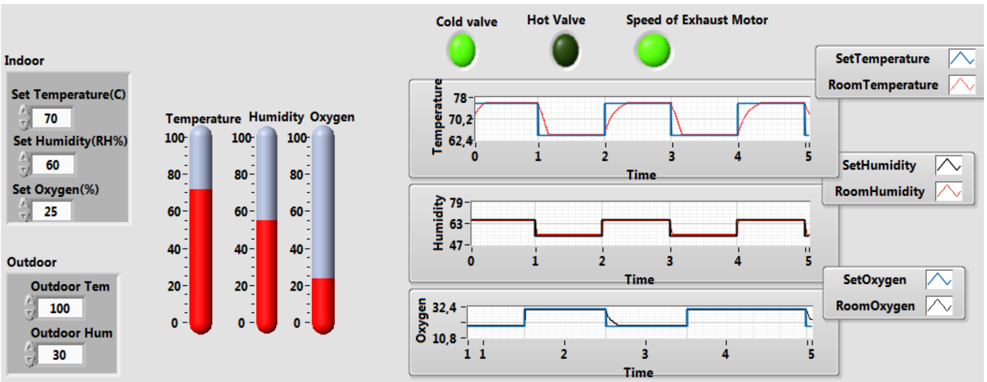

Fig. 7. A result of using Fuzzy Expert Controller in the condition of working air condition, humidifier and ventilation

From Fig.7 we see the outdoor temperature is higher than the desired temperature, the system will open the cold valve to cool the place and close the heat valve, also the required humidity is greater than the outdoor humidity thus the humidifier and exhaust motor is working, so we note that the system is working and also gives us the required comfort without overshoot.

From above results, the simulation provided good performance in terms of oscillations and overshoot in the absence of prediction mechanism.

The result of using the fuzzy expert system has reduced overshoot and steady state error and significant improvement in maintaining performance over the widely, compared with traditional control like PID control, auto tuning PID control and on/off control the fuzzy expert system is the best.

In the result of examining the robustness of these controllers with respect to external disturbances, the fuzzy controller shows better control performance than PID controller in terms of settling time, overshoot and rise time as shown in table 4

Table. 4. Performance characteristics of HVAC system with Fuzzy and PID controllers

Controller	Overshoot	Rise time	Settling Time
PID	8.5	0.009	43.33
Fuzzy	2.25	0.001	2.28

6. CONCLUSION

In this paper, the real time implementation results show that the approach of using the fuzzy logic control with the expert system is the best way to control system and gives good results, the maximum overshoot of the system is 2.25% but in the conventional controller like PID control the maximum overshoot of the system is higher. Therefore, the performance of fuzzy expert controller is better than of conventional algorithm.

We found that the heating, ventilation and air condition system with the Fuzzy expert controller provides the accurate control. The fuzzy controller response in all experimental conditions is quite as expected, and it does not exceed the maximum and minimum for required limit. The FLC algorithm adapts quickly to longer time delays, provides a stable response and can give more attention to various parameters, such as time of response, error of steadying and overshoot.

REFERENCES

[1] Anjali Baghel1, Tilotma Sharma2, Survey on Fuzzy Expert System, International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 12, December 2013.
[2] Bolata, F., Nowr, A. From fuzzy linguistic specifications to fuzzy controllers using evolution strategies, IEEE International Conf. on Fuzzy Systems, pp.1089-1094. 1995
[3] Bova, S., Codara, P., Maccari, D., Marra, V. A., logical analysis of Mamdani-type fuzzy inference, I theoretical bases, IEEE International Conference on Fuzzy Systems, Barcelona, pp. 1-8, 2010
[4] Chen, C.L. and Chen, W.C., "Fuzzy Controller Design by Using Neural Network Techniques". IEEE Transactions on Fuzzy Systems. 2(3):235-244, 1994.
[5] Hagras, H., Callaghan, V., Colley, M., Clarke, G., A., hierarchical fuzzy–genetic multi-agent architecture for intelligent buildings online learning, adaptation and control. Elsevier, Information Sciences, pp. 33-57, 2003.
[6] Hamdi, M., Lachiver, G., A fuzzy control system based on the human sensation of thermal comfort. IEEE, International Conf. on Fuzzy System, Washington DC., USA, pp. 4-9, 1998.
[7] Hartman, Thomas, "New horizons for HVAC control", Heating Piping Air Conditioning, Vol. 67, No. 3, 1995, pp. 33-41.
[8] Herrod, R.A.; Papas, B.C., Industrial applications of artificial intelligence. IEEE, Pulp and Paper Industry Technical Conference, pp. 86-90., 1989.
[9] Jian, W., Wenjian, C., Development of an adaptive neuro-fuzzy method for supply air pressure control in HVAC system. IEEE, International Conf. on Systems, Man, and Cybernetics, vol. 5, pp.3806–3809., 2000.
[10] Jianbo Bai, "Development an Adaptive Incremental Fuzzy PI Controller for a HVAC System", INT J Computer, Communication and Control, IDDN 1841-9836 8(5), pp. 654-661, 2013
[11] Kobersi, I.S., Finaev, V.I., Almasani, S.A., Kaid, W.A.A., Control of the Heating System with Fuzzy Logic, World Applied Sciences Journal 23 (11): 1441-1447, 2013ISSN 1818-4952, 2013.
[12] Liang, J., Du, R., Design of intelligent comfort control system with human learning and minimum power control strategies, Elsevier Science, Energy Conversion and Management, vol. 49, pp. 517-528, 2008.
[13] Ludmila, I.K. and Steimann F., Fuzzy Medical Diagnosis. School of Mathematics, University of Wales: Banggor, UK. 2008.
[14] Mamdani, E.H., Applications of fuzzy algorithms for control a simple dynamic plant, in Proc. of the IEEE, vol. 121, no. 12,pp. 1585–1588, 1974.
[15] Mulcahy, Robert W, "New developments in HVAC control systems and the impact ofdirect digital control technology", Australian refrigeration, Air conditioning and heating, Vol. 38, No. 12, 1984, pp. 24-19.
[16] Nguyen, H. T., Prasad, N. R., Walker, C. L., and Walker, E. A., A First Course in Fuzzy and Neural Control, USA: Chapman & Hall/ CRC, 2003.
[17] N. NASSIF, S. KAJL and R. SABOURIN: Evolutionary algorithms for multiobjective optimization in HVAC system control strategy. In IEEE Annual Meeting of the North American Fuzzy Information Processing Society - NAFIPS, 2004., 1 (2004), 51-56
[18] Nowak, M., Urbaniak, A., Utilization of intelligent control algorithms for thermal comfort optimization and energy saving. IEEE, Carpathian Control Conf. (ICCC), pp. 270-274, 2011.
[19] Raad Z. Homod, Khairul Salleh Mohamed Sahari, Haider A. F. Mohamed, Farrukh Nagi, "Hybrid PID-Cascade Control for HVAC System", International Journal of Systems Control (Vol.1-2010/Iss.4), pp. 170-175.
[20] Q.-G. WANG, C.-C. HANG Y. ZHANG and Q. BI: Multivariable controller autotuning with its application in HVAC systems. In Proc. of the American Control Conference, 1999, San Diego, California, USA, 6 (1999), 4353-4357.
[21] Soyguder Servet, Karakose Mehmet, Alli Hasan, Design and simulation of self-tuning PID-type fuzzy ada`ptive control for an expert HVAC system", Expert Systems with Applications, Vol. 36, No. 3, 2009, pp. 4566-4573.
[22] Wakami, N., Araki, S., Nomura, H., Recent applications of fuzzy logic to home appliances. In Proceedings of the IECON'93. International conference on industrial electronics, Vol. 1, pp. 155–160., 1993.
[23] Wang, H.O., Tanaka, K., Griffin, M.F., An approach to fuzzy control of nonlinear systems: stability and design issues, IEEE, Fuzzy Systems, pp. 14-23, 1996
[24] Wong, J.K.W., Li, H., Wang, S.W., Intelligent building research: a review. Elsevier, Automation in Construction. 14:pp. 143– 159, 2005.
[25] Y. CHEN and Z. CHEN: A neural-network-based experimental technique for determining Z-transfer function coefficients of a building envelope. Building and Environment, 35(3), 2000, 181-189.
[26] ZADEH, L.A.: 'Outline of the new approach to the analysis of complex systems and decision processes', IEEE Trans. Syst., Man Cybern., Jan. 1973, 3, (l), pp. 28-44.
[27] Z. Kovaciˇ c, Bogdan, S., Crnošija, P., An automated fuzzy ´ controller design for high-order systems, Automatika-Ltd., vol. 2, no. 3, pp. 37-40, 1996.