Developing of a Fuzzy Logic Controller for Air Conditioning System

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ABSTRACT.

Reducing energy consumption and to ensure thermal comfort are two important considerations in designing an air conditioning system. The control strategy proposed is fuzzy logic controller (FLC).This paper describes the development of an algorithm for air condition control system based on fuzzy logic (FL) to provide the conditions necessary for comfort living inside a building.Simulation of the controlling air conditioning system, on which the strategy is adopted, was carried out based on MATLAB This system consists of two sensors for feedback control: one to monitor temperature and another one to monitor humidity. The controller i.e. FLC was developed to control the compressor motor speed and fan speed in order to maintain the room temperature at or close to the setpoint temperature.

Keywords: Fuzzy logic, Heating, Ventilation and Air-conditioning, variable speed compressor.

1. INTRODUCTION

In EU countries, primary energy consumption in buildings represents about 40% of total energy consumption, and depending on the countries, more than a half of this energy is used for indoor climate conditions. On a technological point of view, it is estimated that the consideration of specific technologies like building energy management systems (BEMSs) can save up to 20% of the energy consumption of the building sector, i.e., 8% of the overall community consumption. With this aim, BEMSs are generally applied only to the control of active systems, i.e., heating, ventilating, and air conditioning (HVAC) systems.

HVAC Systems are equipments usually implemented for maintaining satisfactory comfort conditions in buildings. The energy consumption as well as indoor comfort aspects of ventilated and air conditioned buildings are highly dependent on the design, performance and control of their HVAC systems and equipment. The use of knowledge-based systems can represent a more efficient approach to the HVAC System management, providing BEMSs with artificial intelligence (AI). By means of AI, the system is capable of assessing, diagnosing and suggesting the best operation mode. Within the framework of machine learning, some AI techniques could be successfully applied to enhance the HVAC System capabilities or to aid the HVAC System modeling. In this way, the use of appropriate automatic control strategies, as fuzzy logic controllers (FLCs), for HVAC systems control could result in important energy savings when compared to manual control, specially when they explicitly try to minimize the energy consumption [1].

2. FUZZY CONTROL OF HVAC SYSTEM.

From ON/OFF double-position control method occurred in 1960s, automatic control of HVAC has been developed to the Digital Direct Control (DDC), which control algorithm is mainly PID control method, and self-adjusting control method based on the traditional control algorithm.[2]

HVAC system consists of indoor air loop, chilled water loop, refrigerant loop, condenser water loop, and outdoor air loop. In each loop there are many dynamical variables which interact with each other. So the HVAC system is a typical nonlinear time-variable multivariate system with disturbances and uncertainties.

It is very difficult to find a mathematical model to accurately describe the process over wide operating range. The design of controller for HVAC systems is a big challenge for practical engineers. Recently, some complex control strategies based on the classical control concepts have been proposed in attempt to improve the system performance. Among those works, classical control techniques, especially proportional-integral derivative (PID) controllers were still widely used in practice due to easier implementation, low cost and reliable in harsh field conditions. However, under well-tuned PID control, performance is excellent within the narrow operating range within which the plant was tuned as is evident above. Once the plant operating region changes significantly (e.g., as a result of a change in season), then the need for retuning becomes evident. Also, it is not possible to adequately generalize the required parameter specification for different applications – for example a PID controller optimized for the control of heating in a higher thermal capacity space will be sub-optimal and possibly even unstable in a low thermal capacity space. Similar difficulties arise with the wide choice of heating systems that can be applied. One solution is a controller that can respond to this essentially subjective problem with experiential information about plant response and user requirements. A fuzzy logic controller has the potential to meet these needs and can overcome some shortcomings of traditional PID. In addition to these, fuzzy air-conditioning control can as well be implemented in living environment, especially in houses and offices. One of the most outstanding reasons for the use of fuzzy logic in this type of air-conditioning is energy save and human comfort. In this section the basic structure of the fuzzy logic controller applied will be described. More fundamental information can be found in the literatures [3-7] .

3. DESCRIPTION OF THE MODEL.

In the real world, however, it is usually not enough to manage an air conditioning system with temperature control only. We need to control humidity as well. The main idea of an air conditioning system shown in **Fig.(1**) is to maintain an acceptable comfort level in the various areas of the house as needed rather than assume a homogeneous environment and turn the compressor on and off based on the reading of one temperature sensor as is the usual case.

Three sets of sensor inputs are available to the controller for each zone; relative humidity, temperature, and zone temperature set point. The testing facility consists of a variable speed compressor and fan as well as a cooling coil (evaporator). Temperature and relative humidity from each zone are available on a continuous basis to the control system. The temperature set points for each zone can be programmed manually or can assume default values. Outputs of the controller are compressor motor speed, fan speed, and cooling mode. These input and output parameters have been given reasonable ranges which determine the universe of discourse for the definition of the fuzzy membership functions[8] .

4. DESIGN OF FUZZY CONTROLLER.

There are three inputs and two outputs in the application and experiment of fuzzy control system. The three inputs are the error, the change rate of error (Δe), and relative humidity (*RH)*. The performance measurement is as follows:

e(t) = set point temperature(t)- actual temperature(t)

Δe(t) = e(t) - e(t-1)

The outputs of fuzzy control are compressor motor speed and fan speed. The analogue signal is transferred by the digit/analogue (D/A) transducer. So the digital signal to the (D/A) transducer, *u,* which is the change of digit, is the actual output of fuzzy control.

Fuzzification of the temperature error (*e*): Through many experiments, it was found that the fluctuation bound of the temperature in the building is about ±2^{o}C when the equipments start or stop. Only when the air-conditioning system is stopped and restarts once more, the fluctuation bound of building temperature exceeds ±2^{o}C. In this system, (- 2 ^{o}C, +2 ^{o}C) is the range temperature error. We divided the space -2 < e < 2 into seven intervals. Next we specified the fuzzy-set values of the temperature error **Fig.(2).**

- Fuzzification of the difference of temperature error (Δe): The change rate of temperature error is the difference in a sampling period. In summer work condition, the change rate of temperature is ranges ±2^{o}C per minute through the experience and experiments. The change rate of temperature error is divided to seven fuzzy-set values.
- Fuzzification of the Relative humidity: RH is quantified according to memberships in similar way, like (e) and (Δe).

Using Matlab and draw the appropriate membership functions as shown **Fig.(2)**, the seven fuzzy variables for temperature error (e) input are term as very cold (VC), cold (CD) ,cool (CL),normal (NR),less hot (LH),hot (HT)and lastly very hot (VT).

As for difference temperature error (Δe), the fuzzy variables are negative large (NL), negative medium (NM), negative small (NS), neutral (NU), positive small (PS), positive medium (PM) and positive large (PL) as shown in **Fig.(3)**.

Table(1) show the compressor motor speed rule base which has temperature error (e) as an input as well as difference temperature error (Δe).

From this rule base a fuzzy set denoting compressor motor speed is computed, and defined using the membership functions, to give the required speed level of the compressor in percent of maximum speed. Similarly fan speed is computed from a fan speed rule base and membership functions for actual sensed temperature **Fig.(**4) and relative humidity (RH) . There are seven fuzzy set for temperature: very cold (VC), cold (CD), cool (CL), good(GD), warm(WM), hot(HT), and very hot(VH), This set is illustrated in **Fig.(4)**.

The seven fuzzy set for relative humidity are: dry (VL), not dry (LW), less dry(LCO), comfort(COM), low comfort(LWC), not wet(HG), and wet(VHG), as shown in **Figure** 5.

- Fuzzification of the output: The output is divided to seven fuzzy-set values based on the practical experience of operator to give the required speed level of the compressor motor speed (Δz) and fan speed (Δf) in percent of maximum speed**.** The seven fuzzy set for output variables (the compressor motor speed and fan motor speed) are: very slow(VS), slow(SL), less speed(LS), normal speed(NO), less fast(LF), fast (FT), and very fast (VF). **Fig.(6)** explain the membership function of output fuzzy variable motor speed

5. RESULTS AND DISCUSSION.

For controlling the compressor motor speed the temperature error (e) as an input as well as difference temperature error (Δe) are used as input and for controlling the fan motor speed of the conditioning room temperature and humidity inside this room are used as inputs.

Let us consider the value *e*= -1.4^{o}C and Δ*e* = -1.2 ^{o}C, that is meant the actual room temperature measured by the sensor is hot and *e* = -1.4^{o}C satisfies two membership functions μ_{VC} and μ_{CD}, while Δe = -1.2^{o}C satisfies two membership function μ_{NL} and μ_{NM} .The inference block accepts four inputs from the fuzzification process. Finally, the output fuzzy set is converted into a numerical solution variable using centroid defuzzification (also called center of area, center of gravity). Therefore, the centroid is obtained as:

$$\Delta Z = \frac{\int \mu_X(z)\cdot zdz}{\int \mu_X(z)dz} \tag{1}$$

The compressor motor speed output should be increased by 80%, and this is reasonable since temperature is high. The whole control procedure is governed by means of the rules shown by a control surface, as reported in **Figures** below. **Fig.(7)** shows an isometric view of the variation of compressor motor speed with respect to temperature error and (Δe). **Fig.(8)** shows the variation of fan speed according to humidity. The addition of extra levels of classification gives a much smoother control surface and by increasing the number of fuzzification levels yet further, a much closer approximation can be obtained.

Fig.(7) clearly indicate the smoothly change of compressor motor speed according to the signal changes of temperature error and difference temperature error (Δe). When the temperature error negatively increases that is mean the room become hot, therefore the FLC will response to this change and the compressor motor speed increase gradually. Also when temperature error positively increases the compressor motor speed reduces gradually and the consumption of energy will be reduce.

Fig.(8) shows the influence of temperature and relative humidity of the room on the fan speed. As the temperature and humidity increase the FLC will response to this change in interior climate and the fan speed will increase smoothly. In the middle of this Figure we can see the comfortable zone (temperature 22-26 ^{o}C and humidity 30-60%),therefore the fan speed will operate with less than half it power, which is mean reduce of power consumption.

6. CONCLUSION.

The application of variable speed control to air conditioning offers the potential for substantial energy savings or energy efficiency. In variable speed control application, the compressor motor speed and fan speed influences various operating and design parameters such as cooling load, power consumption, coefficient of performance COP, volumetric and isentropic efficiency. Variable speed control indicates that space temperature may be controlled simultaneously by the simultaneous operation of compressor motor speed, with the result that operation of compressor speed to adapted of temperature (cooling load) changing.

REFERENCES.

[1] Rafael Alcala´, Jorge Casillas, Oscar Cordon, Antonio Gonzalez, Francisco Herrera, " A genetic rule weighting and selection process for fuzzy control of heating, ventilating and air conditioning systems", Engineering Applications of Artificial Intelligence 18 (2005) 279–296,2005..

[2] Jili Zhang, Yongpan Chen "Advance of Systematic Design Methods on Fuzzy Control" Control Systems for Energy Efficiency and Comfort, Vol. V-2-5, 2006.

[3] Jan jantzen" Design Of Fuzzy Controllers" Technical University of Denmark, Department of Automation, Bldg. 326,DK-2800Lyngby,1998.

[4] James Vernon " Fuzzy Logic Systems"www.control-systems-principles-co.uk.

[5] Robert H. Bishop" THE MECHATRONICS HANDBOOK" CRC PRESS,2002.

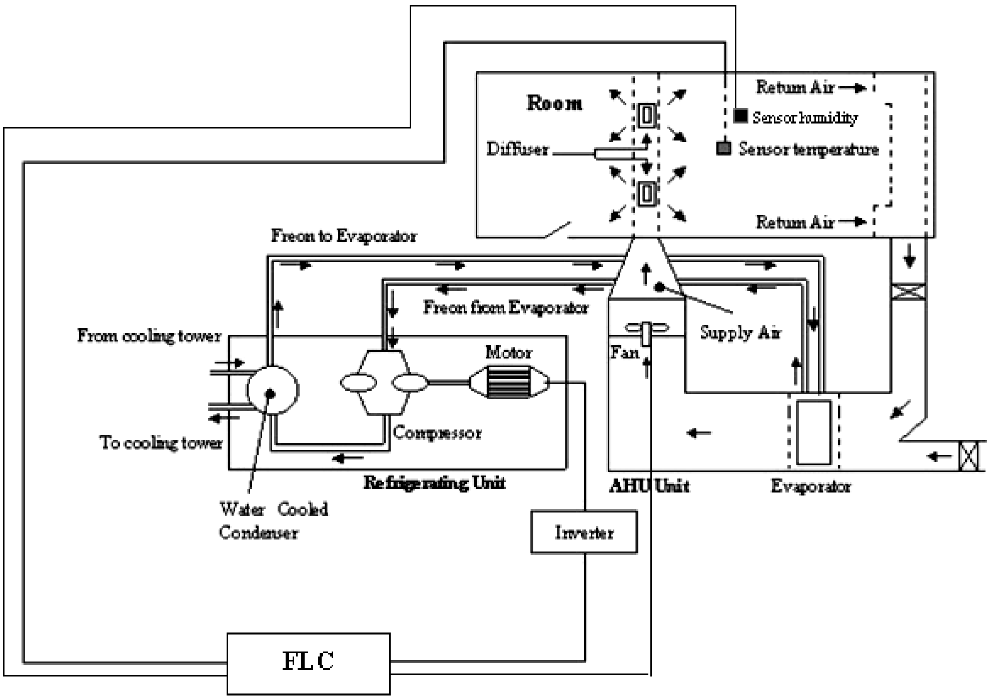
[6] Jia Lei Lv Hongli, Wenjian Cai" Model Predictive Control Based on Fuzzy Linearization Technique For HVAC Systems Temperature Control" IEEE ,2006.

[7] Jiang Wang Dawei and Cheng Zhi Lou" Application of Fuzzy-PID Controller in Heating Ventilating and Air-Conditioning System" Proceedings of the 2006 IEEE International Conference on Mechatronics and Automation June 25 - 28, Luoyang, China, 2006.

[8] Robert N. Lea, Edgar Dohman,Wayne Prebilsky Yashvant Jan "An HVAC Fuzzy Logic Zone Control System and Performance Results" IEEE 1996.

Table (1): Rules of fuzzy control.

		e						
		VC	CD	CL	NR	LH	HT	VH
	NL	VS	VS	SL	LS	LS	NO	LF
	NM	SL	SL	LS	LS	NO	LF	LF
	NS	SL	LS	LS	NO	NO	LF	LF
Δe	NU	LS	LS	NO	NO	LF	LF	FT
	PS	LS	NO	LF	LF	LF	FT	FT
	PM	NO	LF	LF	LF	LF	FT	VF
	PL	LF	LF	LF	LF	FT	VF	VF



Figure(1): Air conditioning system.

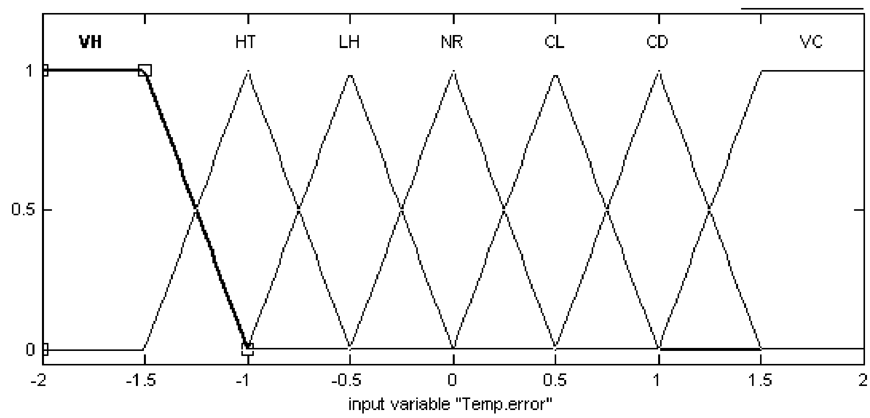


Figure (2): Membership function of input fuzzy variable "temperature error".

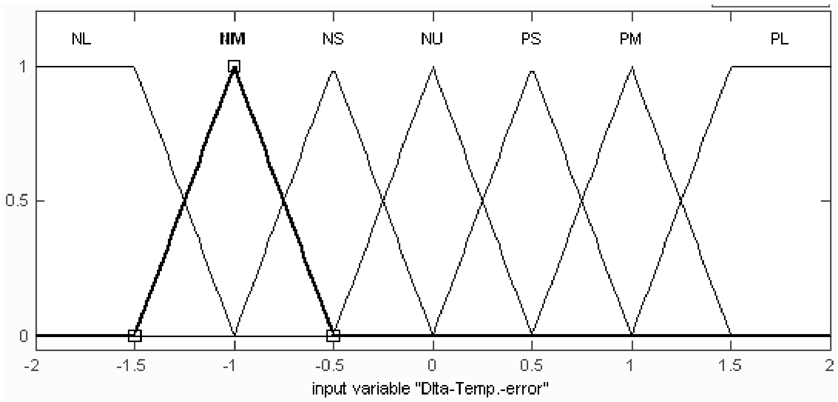


Figure (3): Membership function of input fuzzy variable "difference temperature error".

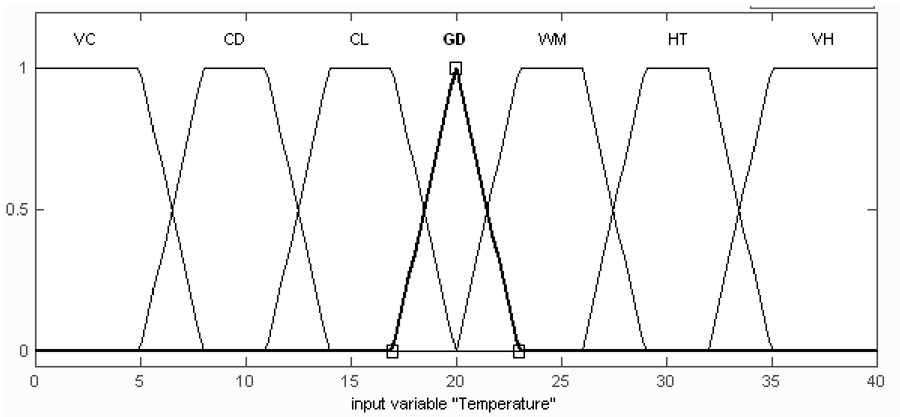


Figure (4): Membership function of input fuzzy variable temperature.

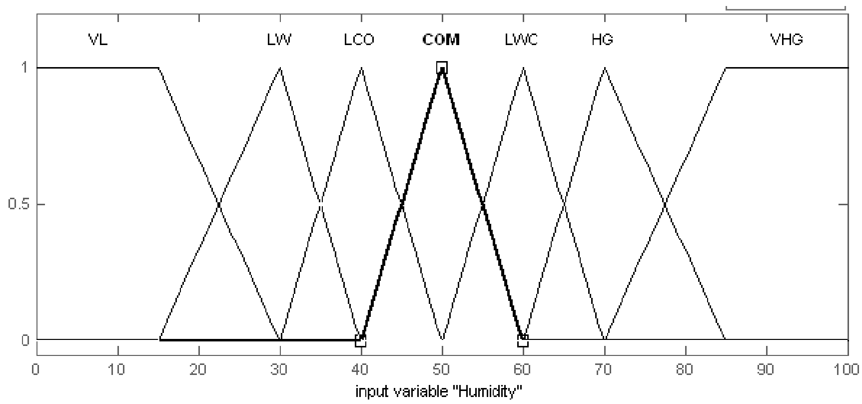


Figure (5): Membership function of intput fuzzy variable relative humidity.

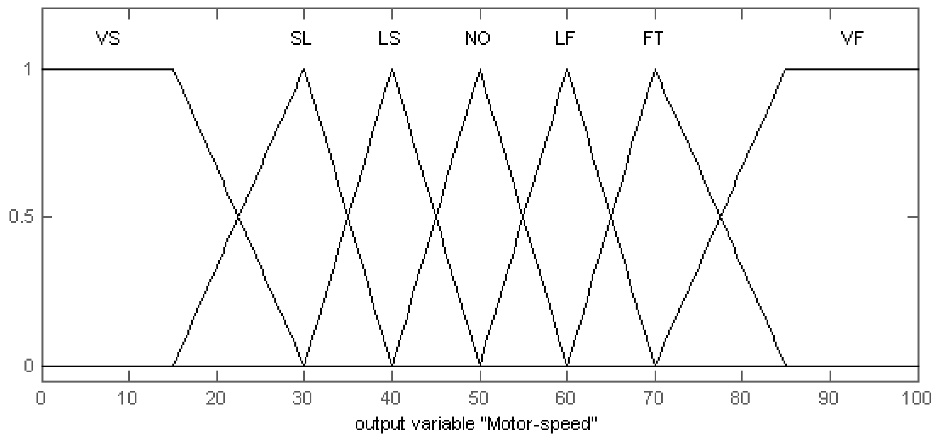


Figure (6): Membership function of output fuzzy variable motor speed.

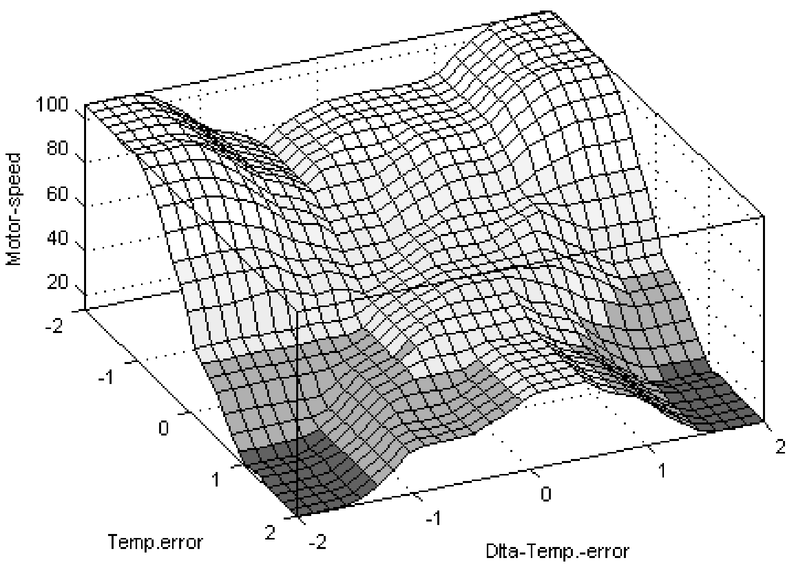


Figure (7): Variation of compressor motor speed.

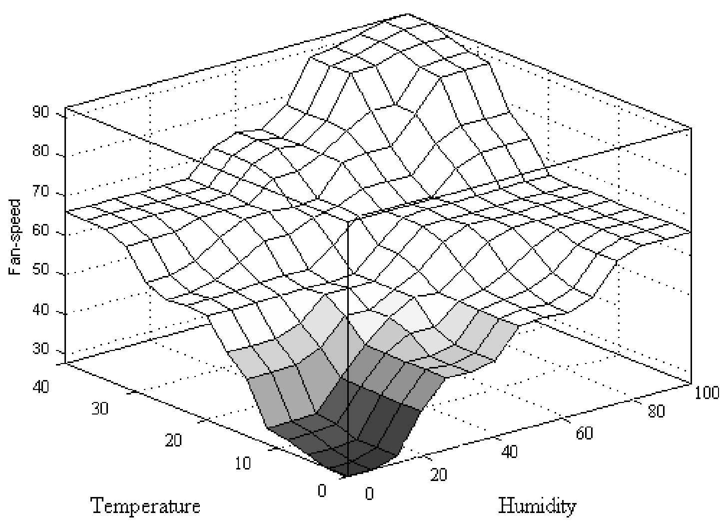


Figure (8): Variation of fan speed.

تطوير نظام تحكم منطقي غامض للسيطرة على نظم تكييف الهواء

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الخلاصة.

تقليل إستهلاك الطاقة وضمان الراحة الحرارية هما من الإعتبارات المهمة في تصميم نظام تكييف الهواء .إستراتيجية السيطرة المقترحة هو إستخدام نظام تحكم منطقي غامض. تم في هذا البحث تطوير خوارزمية ونظام السيطرة لجهاز تكييف الهواء على أساس المنطق الغامض، لتوفير الظروف اللازمة للشعور بالراحة داخل المبنى. عملية محاكاة النظام تمت بإستخدام برنامج ماتلاب.هذا النظام يتكون من اثنين من أجهزة الإستشعار لمراقبة ردود الفعل : أحدهما لقياس درجة الحرارة والآخر لقياس الرطوبة النسبية، وقد وضعت وحدة التحكم للسيطرة على سرعة محرك الضاغط وسرعة المروحة من أجل الحفاظ على درجة حرارة الغرفة أو في درجة حرارة قريبة من نقطة التحديد.

الكلمات الرئيسة: سيطرة، نظام تحكم منطقي غامض، تكييف الهواء والتبريد،ضاغط متغير السرعة.