FUZZY THERMAL CONTROL WITH REMOTE ACCESS FOR BUILDING AUTOMATION

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Abstract: This paper presents the development of a project that aims thermal efficiency in building automation. The internet infrastructure is used to develop a computational system for remote supervision. As building automation involves time-varying, distributed parameter systems we propose the use of fuzzy logic to implement an expert rule based systems that take care of the different contexts of the building management. The implementation of a prototype has been carried out on PIC16F877 microcontrollers.

Keywords: Thermal systems, Fuzzy control, Automation, Microprocessor control.

1. INTRODUCTION

Fuzzy logic, neural networks, genetic algorithms and expert systems are part of a relatively new paradigm known as intelligent systems. These systems were created to supply answers to a great variety of problems which could not be solved by traditional methods, be because of its complexity or the inexistence of a necessary specific tools capable to handle this kind of problem, see (Azevedo, *et al*., 2000). Fuzzy logic looks for to incorporate the human way of thinking in a control system. The produced controller can be applied to complex dynamic systems.

A lot of work has been published in this field. E.g., Mauris (2002) apply fuzzy symbolic to a comfort sensor, taking care of temperature and humidity to obtain "comfort". Haissig (1999) applied adaptive fuzzy in temperature control for hydronic heating systems. Comparison with PI show better results for the intelligent approach. This work aims to develop tools, which based on the use of intelligent algorithms (fuzzy logic), deals with information generally not used by common building facilities as: external temperature, presence of people in the room, luminous intensity in the control environment among others, processing them and adjusting the air conditioning devices to reduce the energy consumption.

2. THERMAL SYSTEM

Thermal systems are systems where the variables are related with the storage and transport (flow) of heat. In these systems, the heat transference can occur by three distinct forms: conduction, convection and radiation. In practice, one of the three forms is predominant. If considering two forms, in general the radiation can be neglected. Thermal processes are inherently distributed parameters systems that means, its variables vary with the localization or distance. To simplify the problem, we admit that the thermal system can be controlled with sufficient precision using only a few measure points. A step farther, for simulation purposes, would be approximate the system by concentrated parameters (thermal resistances and capacitances).

The prototype thermal system used in this work should represent a typical bureaus working place, Fig 1. Five rooms "working places" have doors and windows that can be opened or closed; it simulates the normal operation of the bureaus. Two heat sources should establish the air temperature in the five rooms.

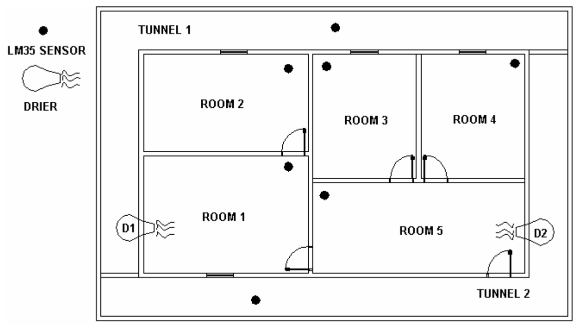

Fig. 1 – Thermal system prototype.

As air heating is much easier to implement than cooling, we used it in our prototype. Heating and cooling are both heat flow problems, with changed sign. So we opted to use heating in our prototype environment. Two 1kW hair driers deliver heat. We expect to obtain preliminary results with heating that can give insights and directions for a later implementation of air conditioning on a real world office environment. The prototype consists of three major areas. The first one is represented by two adjacent rooms (rooms 1 and 2). The larger (room 1) receive heat source D1. The second area comprehends two rooms with half height walls (rooms 3 and 4) and a corridor (room 5), where is the source of heat D2.

These two first areas represent the main part of the prototype, that is, the office. The third area consists of two tunnels (T1 and T2) in which ice bags can be placed to establish different temperatures for inlet D1 and D2. This simulates the effect of the sun on one side and shadow on the other side of a building, which can significantly affect energy efficiency. In each room, corridor and tunnel we installed a temperature sensor to measure the temperatures. A linear, time-invariant analogy of the thermal process can be made by an electrical circuit with capacitors and electrical resistances. In this analogy heat flow is equivalent to electrical current and temperature is equivalent to electrical tension.

The time constant of each room is related with the value of the thermal resistances R of each wall and thermal capacitances C of each room. In a system that involves a capacitance and a resistance in series, the time constant is RC. This time constant can be found experimentally isolating the involved rooms and measuring the time interval to reach 67% of the step response. Calling the heat flow input variable as q and the output temperature variable as T, the model for one room can be represented by the transfer function:

$$\frac{T(s)}{q(s)} = \frac{K}{RCs+1} \qquad (1)$$

Where q(s) and T(s) are the heat flow and environment temperature Laplace transforms, respectively, see (Ogata, 1997).

3. MICROCONTROLLER

The microcontroller used in this project is a PIC16F877 which has the following main characteristics: high performance RISC CPU; EEPROM memory with 368 bytes; two pulse width modulation modules; 14 interruptions available; program memory of 8k x14 words; three timers (2x8 bits and 1x16 bits); 8 A/D conversion channels (10 bits); serial communication: synchronous and asynchronous, see (Souza, 2001).

4. MEASUREMENT OF TEMPERATURE

The temperature sensor LM35 used in this project is an integrated circuit that generates an output voltage proportional to the measured temperature, in Celsius degrees. It uses semiconductor properties as measurement principle. It is not necessary to calibrate the sensor. Precision of 0,5ºC at 25°C and low current drain, near 60 mA are some advantages of this sensor.

Table 1 - Relevant specifications of the LM35.

Characteristics	Value
Scale factor	10 mV/ºC
Operation range	-55 ºC to 150 ºC
Precision	0,5 ºC (at 25 ºC)
Current consume	< 60 μA
Supply	4 to 20 V

For the measure of the temperature a ten bit A/D (Analogic/Digital) converter of the microcontroller was used. A successive approximation approach is used, with maximum reference input equal to five volts; see (Souza, 2002). In this conversion type, the two less significant bits are usually discarded. The sensor output signal is amplified to have a range of tension from zero to five volts in the amplifier output, representing a range of temperature from zero to 127.5ºC. So, a bit variation in the recorder called ADRESH (0 the 255 in decimal) represents a 0.5ºC temperature variation, so, the precision of the sensor is preserved by the A/D conversion.

5. POWER DRIVER

The signal that carries out the control action on the system is a PWM signal with amplitude of five volts. With this amplitude, the signal is not able to supply the necessary energy to the hair drier. It is necessary, then, a power driver which can transform this low power input signal into an output signal with sufficient power. The following circuit was developed:

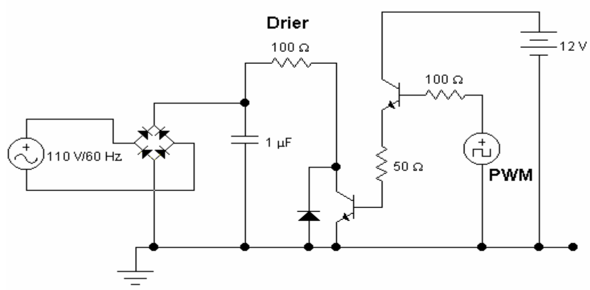

Fig. 2 - Power driver circuit.

The circuit has a first low power transistor BC547, which receives the PWM signal on its base, supplying a tension from 12 volts source to a second high power transistor TIP31C. This second transistor is driven by an 110V AC source, delivering the amount of current required by the hair drier. The two transistors operate in the switched mode; therefore the intensity of the output signal (in the drier) depends on the PWM duty cycle.

6. FUZZY LOGIC

The human creative capacity of inexact reasoning, uncertain or diffuse, contrasts with the computers and machines operation form, driven by binary logic. If these machines lose its “reasoning” restrictions, they would become eventually intelligent, being able to reason by an inexact form. This form of reasoning is known as Fuzzy Logic; see (Wang, 1997).

Fuzzy logic tries to incorporate the human way of thinking in computational systems. When this technique is applied to control loops, it's usual to call it Fuzzy Control. This type of control is generally used with complex dynamic systems.

The Fuzzy technology has an immense practical field, in which it is possible to include human operator's experience (control of processes and industrial plants, computerized controls), making possible decision strategies for complex problems.

Fuzzy systems are relatively easy to understand and use, and the mathematical manipulations of these systems are not so complex as it seems to be in the first sight, however, the fuzzy controller designer needs a deep understanding about doubts and uncertainties that occur in processes and industrial plants, how it affects the usual applications of the modern control theory, making possible the gauging of the relevance and trustworthiness of the gotten results through the application of the Fuzzy logic theory, see (Nascimento, 2000).

A system based on Fuzzy logic has its behaviour schematized for the following set of variables and actions: Input variables, fuzzyficator, inference, base of rules, defuzzyficator and output variables.

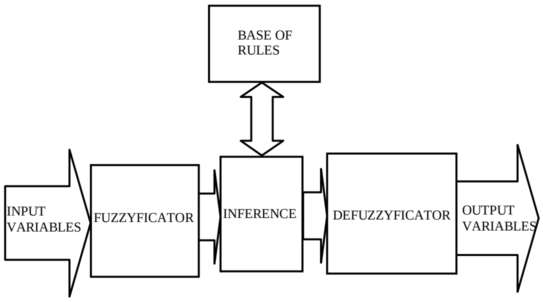

Fig. 3 – Fuzzy system diagram

The fuzzificator is responsible for mapping the numerical inputs in Fuzzy sets (linguistic variables). The fuzzyfication interface is created to receive and treat the numerical data, which came from sensors or computerized input devices, see (Shaw, 1999).

The fuzzification interface use membership functions contained in the knowledge base, converting the input signals into values in the interval [0,1] that are associated to linguistic labels.

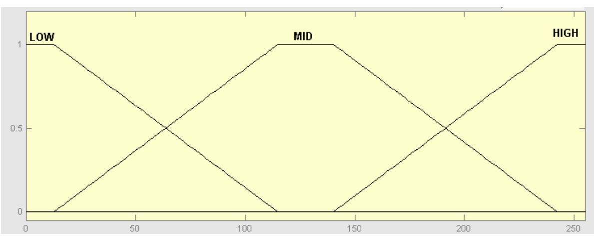

Fig. 4 – Example of membership function.

The inference is made mapping the linguistic input values into linguistic output values using the rules. Fuzzy implication is used to simulate the human decision process, generating control actions, called consequences, from a set of input conditions called antecedents. The knowledge base corresponds to a model of the system to be controlled, consisting in a data base (membership functions) and a base of linguistic fuzzy rules (characterizing the controller targets and the used strategy).

The defuzzificador maps linguistic values in numerical output values. This function is realized by a defuzzification interface, generating a discrete value that can be used in a "real world" control action. As previously said, fuzzy logic emulates the expert operator reaction to process disturbs, as if the operator were operating manually. This form can have a faster reply to disturbances then a conventional PID controller, reducing the overshoot and allowing adjusting the reaction according to the process knowledge.

An interesting potential application of fuzzy logic is the control of air conditioning systems. An example is: A fuzzy controller produces reference signals for the cold and hot water valves, and the humidity control water valve. The control strategy can use different variables, as internal and external temperatures and humidity to determine the operation of the air conditioning system for energy conservation. This is clearly a multivariable controller, with capacity to take care of interdependent variables.

For example, when the temperature increases, the air relative humidity diminishes. This can be explored, through the coordination of the temperature control loop and the humidity subsystem. The humidity controller can actuate before detecting the temperature modification in its sensor. This type of behaviour could improve the quality of this system in terms of predictive behaviour, being able to generate a considerable energy economy, between 10% to 30% (Staefa, 2003). In crisis times in the energy sector (rain shortage, for example) this would represent a considerable amount of saved energy.

In terms of intelligent control on the market we have today fuzzy controlled "window" air conditioning systems. The idea is to use fuzzy logic to implement fuzzy controllers and with them make an intelligent control of temperature and humidity, aiming at to reduce the consumption of the electric energy (economic operation) and providing comfort for the people who work in an office, for example.

For our thermal system, two regions are controlled independently. The first region is represented by rooms 1 and 2 and second for rooms 3, 4 and 5. The tunnels T1 and T2 simulate the external temperature. The same control algorithm is used for both control regions. Such algorithm is recorded individually in distinct microcontrollers PIC16F877A, where each one is responsible for one actuator control (hair drying). The algorithm deals with two input variables: internal and external temperatures and one output variable PWM duty cycle.

First we determined that the system would have three input variables: Reference temperature (to each controlled region), local room temperature and external environment temperature. And one output variable: PWM output (to each controlled hair dryer). All this variables are associated with linguistic variables by pertinence functions. In this project we used 5 membership functions to each input variable and 6 functions for the output variable. We tried to keep the superposition between functions near 50 percent, which seems to be reasonable, as demonstrated by Shaw, 1999.

The rule base was designed with 35 rules, considering only the most relevant process aspects. The target is to minimize energy consumption (each controller, in this case, has a different set of rules). The algorithm has a function that calculates the membership value for a given input signal. Four points are used to define this function: two points represents the minimum points of the trapezoidal membership function, two others, the maximum points of this function. The output value represents the control value for the temperature signal or PWM duty cycle. Moreover, fuzzy functions were implemented: the OR (composition) and AND (aggregation) (inference max-min) and the defuzzyfication function of the MoM type, where the output is calculated by means of the average values that represent the maximum values of pertinence. The algorithm needs ~500 words of program memory, where each word is represented by 14 bits.

One innovative aspect in this project is the use of fuzzy controllers that intercommunicate among them by means of a supervisory computer, which receives the information from all local microcontrollers and manage this. This architecture allows each net device to have its own rule base and consequently fine tune of the air conditioning system. The supervisory computer implements also the interface between the controlled processes and the user (if desired, by a www connection). The key point in energy saving are properly tuned rules that can care adequately with the time-varying, non-linear nature of buildings.

7. ARCHITECTURE FOR REMOTE ACCESS

Remote systems can have one or more customers on-line, monitoring or configuring the same module in any instant, given that it has access granted. Such a system is represented through the next figure. The different types of processes to be interconnected show the necessity to consider a portable remote architecture, or either, compatible with different hardware platforms. This model uses one web server. Obviously, the number of processes is limited by the capacity of the web server, and the net bandwidth.

To implementation the remote system two subsystems have to be implemented. One is the communication between the computer that publishes the pages in the internet and the processes; the other concerns the interaction with remote users.

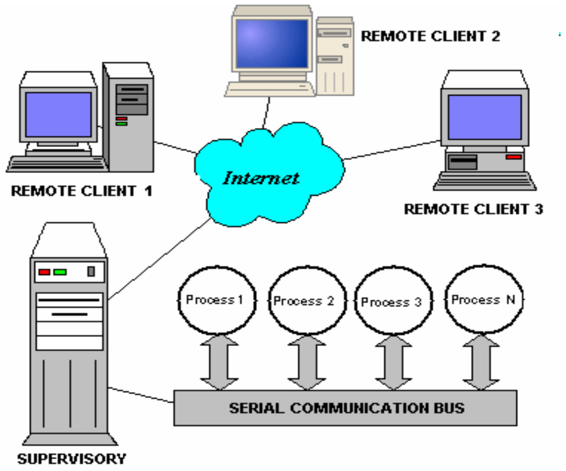

Fig. 5 - Remote supervisory architecture

7.1 Communication between supervisory PC and processes

The standard RS-232 communication interface defines a point-to-point operation; see (Zelenovsky, 2001). However, it is possible to construct a RS-232 bus in which some devices can be connected, and then to share the same set of wires to transmit or receive data.

This implementation is feasible since that having only one master device (supervisory), which can transmit and also make solicitations of data to other devices (PIC microcontrollers).

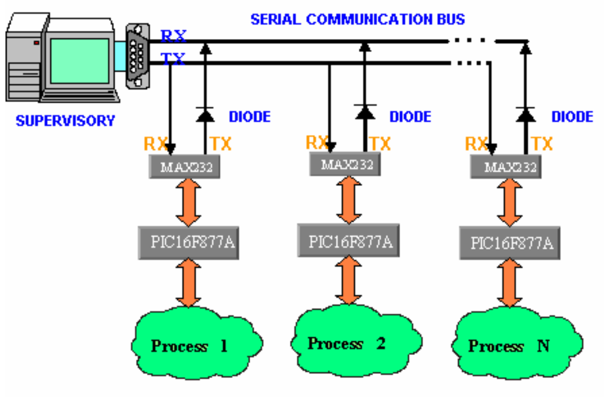

Fig. 6 – Multipoint serial communication.

In the above figure, it is necessary that each slave device has a blocking diode in its transmission line. This electronic element is necessary for the proper operation of the RS-232C standard, which defines the tension of -15V for the transmission lines when these are not active. In this way when a process device starts to transmit data to the supervisory it prevents that the current reaches other slave devices and in this way do not harm the communication drivers between transmitter and receiver.

Based on the above described scheme of communication an electronic circuit was designed to implement the communication between the supervisory PC and four PIC microcontrollers, which are represented by the following schematic:

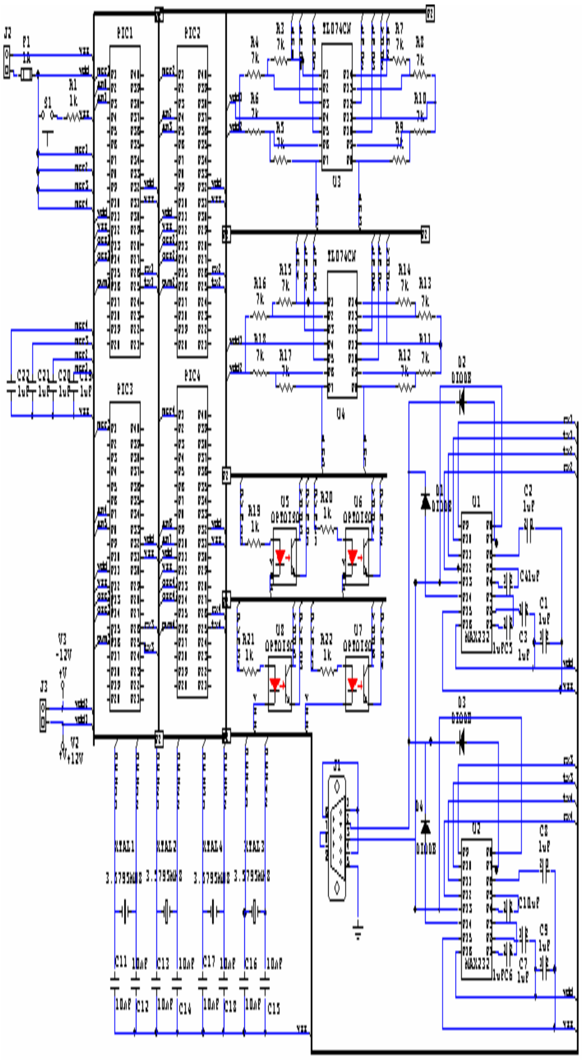

Fig. 7 – Fuzzy control schematic.

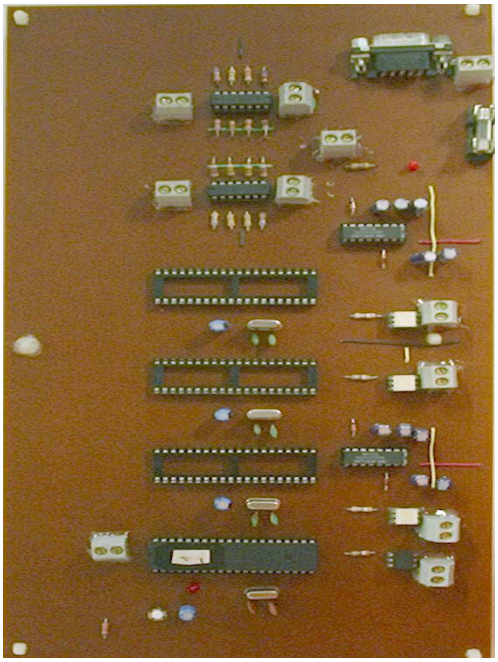

Fig. 8 – Fuzzy control circuit implementation.

Starting from a first design, and after some tests, in order to prevent the typical implementation problems of electronic circuits on protoboards, the circuit in Fig. 7 was assembled on a printed circuit board.

7.2 Supervisory PC and operators Communication

The communication architecture is based on the client/server model and was developed in Java. The operator can access the supervisory system using any operating system that supports a web browser with virtual Java machine. All relatively recent web browsers came with this virtual machine.

The Java language has favourable features for the development of client software as well as the tools necessary to establish communication in real time in a client/server architecture. It is a highly portable language, vastly registered, has mathematical libraries and it is freeware. In general, Java applets (software executed by web browsers) are used in the client machines to establish communication in real time with the Java server software running in the web server (supervisory). From the security point of view the applets offer great advantages because these do not have access permission to the local data (of the client), so, are not able to view/modify any information on the client computer without the initiative of the client himself.

Locally, the web browser is the interface for the system, it downloads the client software in the format of Java applets from the web server and then executes the applet. The web server provides the HTML page and the Java applet. Currently, it is common to find pages developed using languages like PHP (Pre-Hypertext-Processor), ASP (Active Server Page) and JavaScript, where the advantages of these tools are to offer the possibilities of analysis and processing of the data. PHP and ASP execute its scripts in proper web servers, and sending only the results of the requested operation for the client. By this way the necessary processing power on the client computer is reduced.

Java applets are easily updated, a new download lead automatically to read fresh from the web server. Consequently, from the user point or view, no programming and/or installation of software are necessary to update the system.

Through the Java applet the client can configure the thermal process controller, defining its priorities, monitoring the diverse process variables as well as the controller action on the actuator. Based on these ideas the Java applet shown in next figure was build.

Fig. 9 shows the client interface when remotely operating the temperature control of the thermal process prototype. In the below middle a picture of the prototype is depicted. Right below the current temperature in each room, acquired by a LM35 sensor, is shown. A plot of the temperature over time can be chosen checking the correspondent box in the left below. Each curve as a different colour assigned, to simplify the identification of each signal. All the data is collected in a file that can be downloaded by the user, if required.

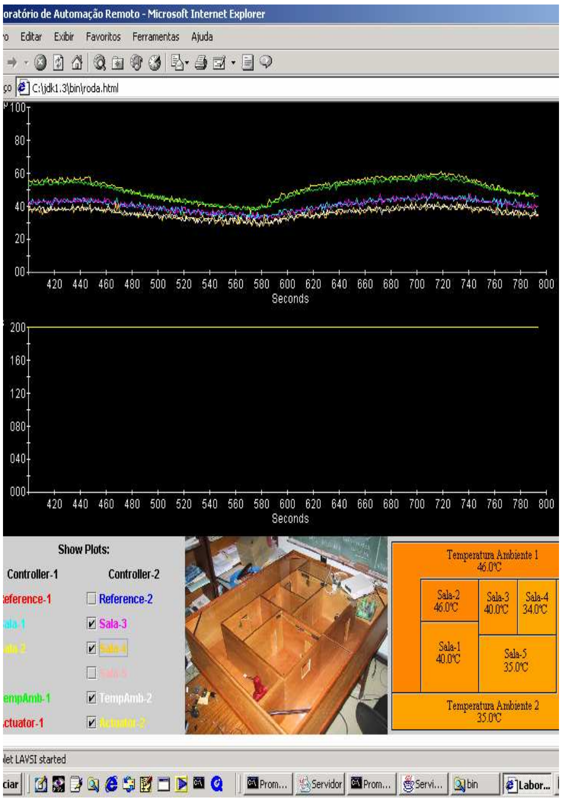

Fig. 9 – Client/server supervisory Java applet.

First experiments with PID control showed that the thermal process is strongly non-linear. For small reference steps (~50°C) we obtained settling times of the order of some minutes. For larger reference steps (~90°C) we obtained settling times of more than three hours. The power of two 1kW hair dryers was clearly insufficient to counterpart the hot loss through the walls of our prototype process.

The fuzzy control of the temperature showed significantly better results than the PID for a fixed set point. Due to specific rules the system converged faster to the set point but, as expected for fuzzy control, some noise was still persistent in steady state. The rule base of the fuzzy control was adjusted empirically until a satisfactory response has been obtained. This is a very important point being investigated. If a practice near approach is to be proposed, it must simplify the acquisition of knowledge necessary to tune each specific building automation. From an expert system is expected to allow the easy commissioning in building automation. Area of each room, disposition and size of the windows, relative position of the room with respect to the sun along a day and along the year, expected use (office, CPD, meeting room etc.), number and position of each air conditioning unit could be used to tune the rules for each temperature control. The presence sensors should “overwrite” the information obtained from the seasonal rules: the normal working day schedule would be *to maintain the comfort temperature (24°C) between 8-12h and 14-18h*. If the presence sensor detects that nobody is in the room for more than 30 min, then an energy saving sate is activated.

8. CONCLUSIONS

In terms of the microcontroller implementation of fuzzy control of thermal processes, it is expected that it offers the necessary hardware/software features for real-time execution of the algorithms. The main considered features were: sufficient memory and necessary functional modules for implementation of the intelligent controller. These until the moment had satisfied the project necessities completely.

The available intelligent controllers on the market have a high cost, therefore, low accessibility. It is expected to develop equipment with minimum costs and good acceptance in building and industrial environment, being able to generate economies of energy for its users, justifying its project, implementation and posterior commercialization. The performance of the intelligent controller must be better, in general terms, of that of conventional PID controllers. This will be observed by the comparison of performance parameters as: settling time and error in permanent regime.

The remote access by the internet must provide control, configuration and monitoring of the building system beyond storage of data for future statistical evaluation and improvements.

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