ENERGY SAVING IN BUILDING AUTOMATION USING ZIGBEE WIRELESS NETWORK AND FUZZY CONTROL

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Abstract. This paper presents results of wireless intelligent building automation focusing on the rational use of energy without prejudice to the thermal comfort. The wireless approach, in this work, could better target retro-fitting of buildings still in operation, a great HVAC market share in Brazil. We used split air conditioners, power meters and temperature sensors, forming a ZigBee wireless network of sensors and actuators. A supervisory computer integrates all measurements and command signals. The thermal regulation of a laboratory environment was implemented with Atmel ATmega8 microcontrollers and XBee transceivers. Through the use of information not generally used in building automation (outside temperature, estimation of number of persons in the room and dynamic load sharing between the air conditioners) we could reduce significantly the energy consumption while maintaining the thermal comfort sensation. We compared classical on-off and fuzzy control strategies. The fuzzy system, an expert rule based inference machine, could better take care of the different contexts in the building automation. We verified that both controllers were able to maintain the thermal comfort; however, the fuzzy controller attained it with lower energy consumption (reaching 30% savings in some situations).

Keywords: *Building Automation; Thermal Comfort; Fuzzy Control; Energy Saving; Wireless Network*

1. INTRODUCTION

The consumption of electric energy is increasing gradually in Brazil, being buildings responsible by much of this consumption. Much of this energy is consumed in the maintaining the thermal comfort. Typically between 40% to 70% of total consumption of the building (Bauchspiess et al, 2004). Inadequate architectural project and non-controlled actuators may lead to waste of energy. An example: In most land environments with air-conditioning of the window occurs over-cooling, in other words, in the hours less hot of the day the ambient temperature drops below of the temperature of comfort. After all, do not want to adjust the thermostat of each air-conditioning of the window throughout the day. The temperature going beyond of the comfort point is clearly a waste of energy.

The concessionaires promote programs to encourage the change of the habits of their customers regarding the use of energy stimulating most efficient consume. However the idea of energy efficiency haven't be associated with lack of comfort, therefore, good levels of efficiency energy can be achieved taking simple measures, in other words, the intention isn't deprive people of comfort, but to maintain the same level of comfort with the lesser expense of possible energy (Borduni, et al., 2006).

The building automation develops adequate techniques to implementation of efficient mechanisms that can avoid the unnecessary consumption of energy. According to the thermal comfort ISO 7730, environmental parameters as radiant temperature, air temperature, air humidity and wind speed and individual parameters as metabolism and clothing affect the sensation of thermal comfort and consequently energy consumption. There are projects in the area of rationalization of energy and thermal comfort using since PID controllers until neural controllers, being also verified the use of fuzzy controllers for some authors (Gouda et al, 2001), (Haissig, 1999), (Santos, 2005), (Urzeda, 2006).

This paper presents results on energy saving in the context of Ambient Intelligences. The incorporated use of ZigBee wireless network sensors (WSN) and actuators and information not generally used in building automation (outside temperature, estimation of number of persons in the room and dynamic load sharing between the air conditioners) allow reducing significantly the energy consumption while maintaining the thermal comfort sensation.

In this work, we will consider only the control of temperature as indicative of the thermal comfort. The temperature is, in fact, the predominant factor in the norm of thermal comfort. The relative air humidity has small influence in the usual bands measures in Brasilia (without extreme drought). The speed of the wind is important factor, but it will be considered appropriate. Mean radiating temperature is considered constant, as well as activity level and clothes are assumed as appropriate to the season.

2. THERMAL PROCESS

In the thermal system used in this work, Figure 1, we can observe the provision of air conditioners, that together with power meter and temperature sensors will form a ZigBee network managed by a coordinating computer running a supervisory software. We used two split air conditioners with capacity 22.000 BTU / hr, being each split air conditioners composed of an internal unit, also called evaporator responsible for pumping cold air in the room and the external unit, also called condensing, responsible for cooling the gas that returns from the evaporator unit.

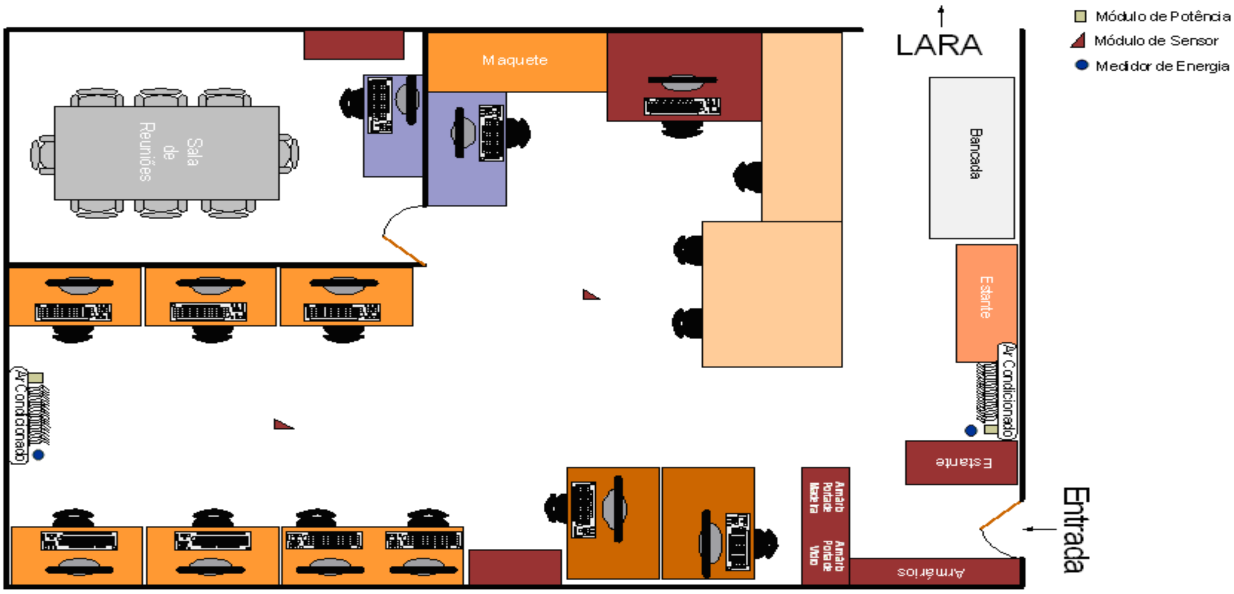


Figure 1. Thermal Systems (Filho and Dias, 2008).

3. USE OF WIRELESS NETWORKS IN BUILDING AUTOMATION

3.1. GENERAL ARCHITECTURE

The architecture of a system of supervision and control (SCADA) of a building is based on a network equipment (processors and controllers). For the project in question was used an architecture based on modules of the company Digi (previously MaxStream) called XBee. The XBee is a wireless technology designed to meet the standard IEEE 802.15.4, operates in a band of frequency of 2.4 GHz with a rate transmission of 250 Kbps and uses radio devices of low power (~ 100mW), low cost and small reach (until 100m). The following topology was used, Figure 2.

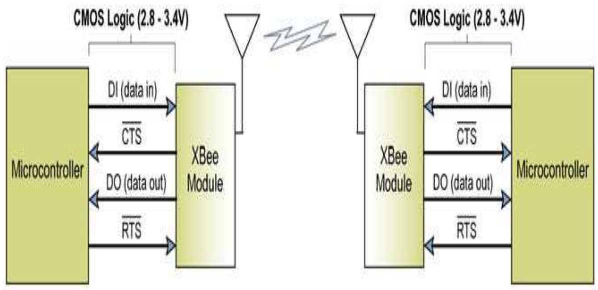


Figure 2. System Data Flow in an environment with UART interface (Oliveira et al 2007), (MaxStream, 2006).

We used two types of devices: The first device that is the coordinator module, responsible for the interconnection between the node End Device and the PC, Figure 3, receiving of the node sensors data relative the temperature of environments and relaying the processed information for the node of the actuators.

Figure 3. Plaque CON-USBEE (Rogercom).

Figure 4. Diagram of the End Device Sensor (Filho and Dias, 2008).

There are also two End Device (two specialized nodes), each responsible for the capture of analog signals relative the temperature read by the sensor, Figure 4, and the other node is responsible for the actuation of the output of the PWM, Figures 5 and 6 .

In Sensor module the functionality of conversion A / D of the module XBee was used, allowing not have to use a microcontroller, also was used a temperature sensor LM35 that operates in the range of -55 ° C to +125 ° C, has a gain of 10mV / ° C, precision of 0.5 ° C and low consumption (active mode = 250 μ A) and an operational amplifier to amplify the signal of the sensor in one another channel A / D of the XBee.

In Figure 5, the end device actuator is composed of a XBee, a microcontroller Atmega 8, interface for a programmer and a serial interface with the possibility of selection through jumpers between the communication PC / XBee, XBee/ATmega8 and PC/ATmega8.

The drive circuit, Figure 6 is composed for a TRIAC TIC246D that supports voltages of up to 400V and works with current of up to 16 A, although the current that passes for the compressor is of approximately 0.8 A, for a optoacoplador MOC3081 that beyond isolate the control circuit of the power circuit has a device zero detector, guaranteeing that the actuation of TRIAC only occur when the mains voltage passes for value zero and also contains a fuse.

Figure 5. Diagram of the End Device Actuator (Filho and Dias, 2008).

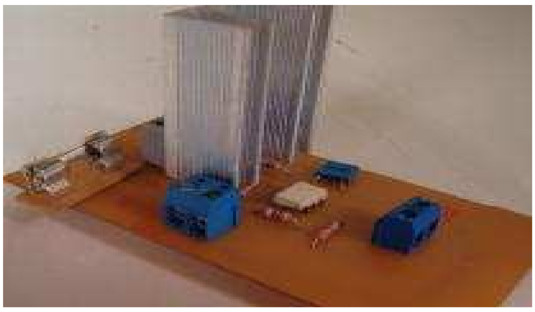


Figure 6. Drive Circuit (Filho and Dias, 2008).

3.2. SUPERVISORY SOFTWARE

Software SCADA are responsible for the acquisition of the data of functioning of the circuits to the computer, for your organization, use and management, showing to the operator of the system the status of the circuits in real time.

The variables of the process must be clearly presented to the operator through specific screens that can be visualized during the navigation in the module real time, allowing operators to control and monitor all the plant (Galo and Ribeiro, 2007).

In this work, the supervisory system was developed in language C, being that, all the flow of data in the network is done through of coordinator node. He modifies the personal address and of destination of coordinator so that it receives / sends the data to the indicators node, saving in a file the referring data of the reference temperature, nodes temperature and actuators status, allowing the generation of reports and graphs with the data collected. The operations of configuration are realized in the command mode and the reading of data in API mode of the XBee module, where all information that enters or leaves the module is contained in frames composites in sequence by a party that delimits the begin of the frame, one that informs its size, the part where if find the data and the checksum (which if verify the integrity of the frame) (Filho and Dias, 2008).

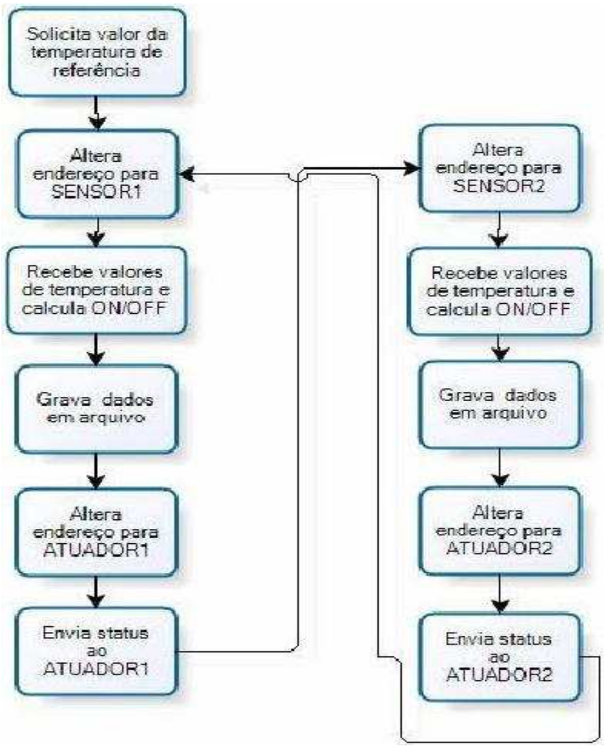


Figure 7. Flowchart of functioning of supervisory software (Filho and Dias, 2008).

3.3. MEASUREMENT OF TEMPERATURE

In this work, it was developed a network of wireless sensors and actuators, through Xbee, implemented on LAVSI laboratory, guaranteeing the "thermal comfort" in this environment with the biggest saving of possible energy. The network defined for implementation of this project consists of two nodes sensors, two nodes actuators and one node coordinator connected in star form, where the sensor and actuator modules possess fixed address for sending and collection of data.

The communication is done in unicast mode, and for this, the supervisory repeatedly change the personal address and of sending of the coordinator node, Figure 7. The sensor nodes are configured to send three samples of temperature, Figure 8, being that the data are sent inside of a package API. If the pair to pair absolute difference between the three read are lesser or equal to 1, or all are bigger than 1, is make the average of 3 read, otherwise, will be the average of two samples that have different lesser or equal 1, (Filho and Dias, 2008).

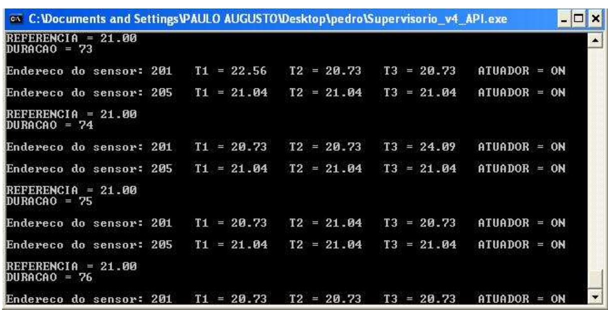


Figure 8. Supervisory.

The software implemented in the sensors module makes the read of the temperature and send to the supervisory computer through the Coordinator module, which is connected to the computer through a USB port, converting data from serial to USB protocol.

In the supervisory computer occurs the processing of the data and the control of the process done by the software implemented in the module of the actuators that trigger the condenser unit through a PWM signal sent by the coordinator node.

4. CASE STUDY: STUDY OF WIRELESS DEVICES IN BUILDING AUTOMATION

In this section are shown techniques of control that can be used to control the temperature of building environments.

4.1. ON-OFF CONTROLLER

The on-off controller is one of the controllers simplest of be implemented, being therefore sufficiently used for the control temperature in building environments. At work in question, the controller compares the mean temperature output with the reference value, and if the reference temperature is higher than the mean temperature and if the difference between them is 0.5 ° C above, the control signal is zero. If the reference temperature is lower than the mean temperature and if the difference between them is 0.5 ° C below, the actuator acts close to its limit point of operation.

$$u=\begin{cases} \text{low} & \text{if } t_{ref} > t_{mean} \text{ e } t_{ref} - t_{mean} > 0{,}5 \\ \text{high} & \text{if } t_{ref} < t_{mean} \text{ e } t_{ref} - t_{mean} < -0{,}5 \end{cases} \quad (1)$$

4.2 FUZZY CONTROLLER

A fuzzy controller has as principle model a specialist, which is well able to control the process. Instead of dealing with a mathematical formulation of the process, imitate the specialist. For the construction of a model based on knowledge of the actions of control of a specialist, there is a necessity of an appropriate mathematical structure (Urzeda, 2006). Figure 9 shows the block diagram with the stages of processing the fuzzy control.

The interface of fuzzification takes the values of input variables, make a scaling for condition the values to universes of normalized discourse and fuzzify the values, transforming numbers in fuzzy sets, in way that can become instances of linguistic variables (Gomide and Gudwin, 1994). The rules characterize the strategies of control and their objectives. The inference procedure acts on the data fuzzy input, together with the rules to infer the actions of fuzzy control, using the fuzzy implication operator and the rules of inference of fuzzy logic. The defuzzifier acts on the actions of fuzzy control inferred, transforming them in action of non-fuzzy control, making then a scaling to compatible the normalized values from the previous step with the values of the universes of discourse of the real variables (Barg 2002).

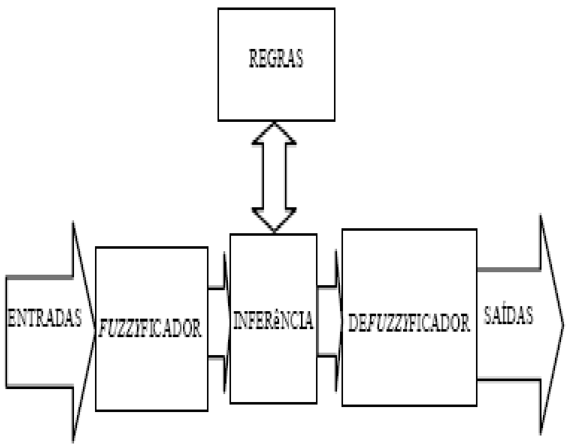


Figure 9. Diagram of a Fuzzy system [12].

In the implementation of the fuzzy controller were defined the following input variables: error and setpoint and one output variable: PWM output. Through error is possible to verify how far from the desired value is the temperature of the controlled room, setpoint adds the output a gain proportional the variation of reference, contributing to maintenance of the error in permanent regimen for any value of temperature (Santos, 2005). The output variable was formed by five triangular functions of relevance: very low, low, medium, high and very high. Were used 11 rules in the database, as shown in table 1 below.

Table 1. Rules Fuzzy

If (error = zero) then (PWM is very low)
If (error = negative) and (ref = high) then (PWM is high)
If (error = negative) and (ref = very high) then (PWM is very high)
If (error = positive) and (ref = low) then (PWM is very low)
If (error = positive) and (ref = very low) then (PWM is very low)
If (error = low positive) and (ref = medium) then (PWM is very low)
If (error = low positive) and (ref = low) then (PWM is very low)
If (error = low positive) and (ref = very low) then (PWM is very low)
If (error = low negative) and (ref = medium) then (PWM is very low)
If (error = low negative) and (ref = high) then (PWM is high)
If (error = low negative) and (ref = very high) then (PWM is very high)

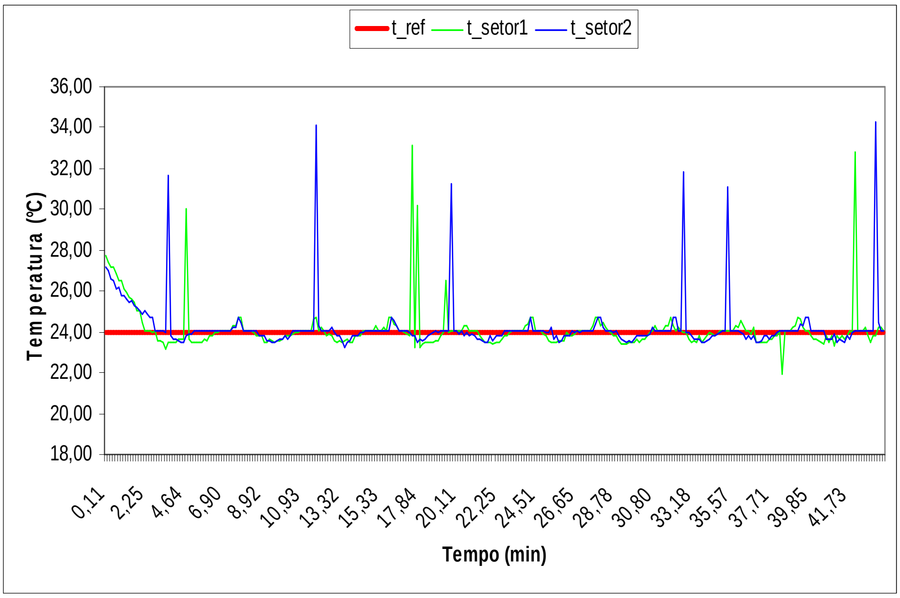
4.3. ANALYSIS OF RESULTS

This stage consists in verify the results of the implementation, if the system projected takes care to the main objective that is to use energy rationally, gradually reducing the consumption. The controllers acted in the control signal of form that the temperature of the room if maintained around the reference signal.

During the experiments, besides the temperature of the room was registered the consumption in Wh of air conditioners used. The monitoring of energy consumption of air conditioners was realized by the meter Landis & Gyr model ZMD-128, being the communication with the two meter made through of an optical connector and the values of consumption visualized by software of the manufacturer.

For maintenance of the thermal comfort of the environment was considered a maximum variation of the temperature of 2 ° C, range usually accepted for climatization (Gouda et al 2001). Two tests were realized. In the first test the controller worked with a fix reference. The results obtained in the first test can be viewed in the figures below.

It can be verified in fuzzy control that the temperature of the room remained around 24.5 ° C, with errors less than 1 º C, value that is inside of the standard of thermal comfort. In the on-off control, the temperature of the room also remained around 24.5 ° C, with errors less than 1 ° C. Through the signal of the actuators can be verified that the time that the air conditioning is activated and the amount of switching to trigger it is lower in the fuzzy controller if compared to the on-off controller. This fact contributes directly in the consumption of energy and the useful life of the equipment.



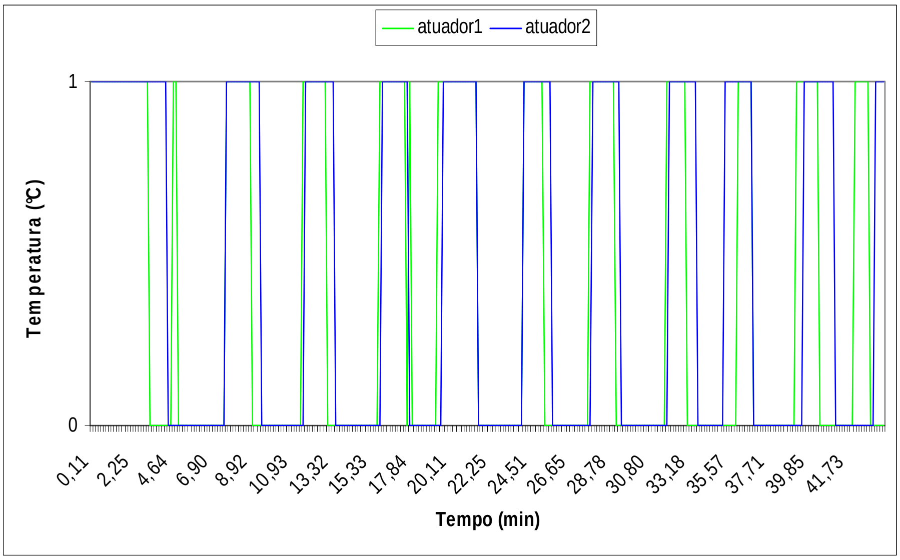


Figure 10. Fuzzy controller – first test

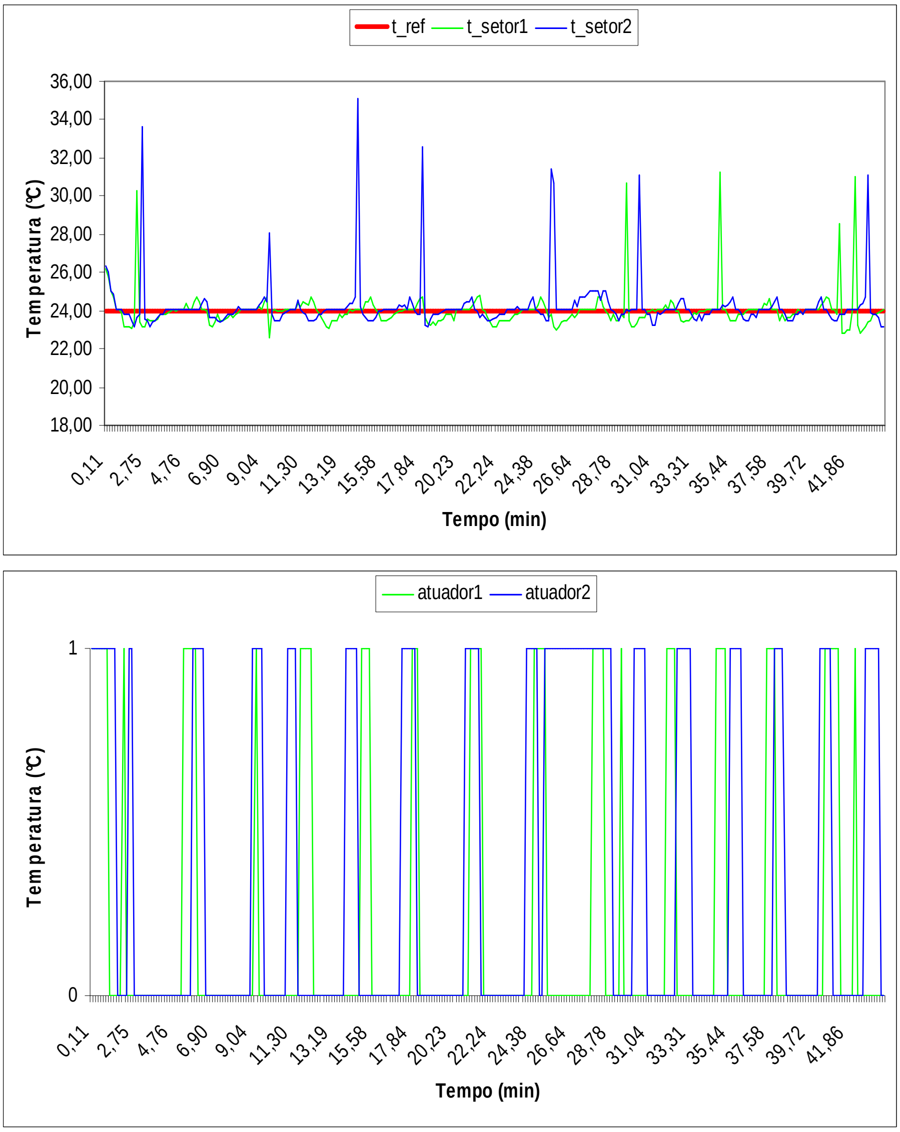


Figure 11. On-off controller – first test

This fact can be demonstrated through table 2 which shows the consumption of energy for the controllers where if can verify that the consumption of energy in the on-off control, which is practically the same during all the experiment, is bigger than the consumption in fuzzy control.

Table 2. Total consumption of the controller in the first test

Tipe controller	consumption first test (KWh)
On-Off	1,64
Fuzzy	1,36

For the second test was realized a change in the values of reference temperature during the test, to observe the transient behavior of controllers. The results obtained in the second test can be visualized in the figures to follow.

As in the first test, we can observe that both controllers were able to maintain the temperature inside of the limits of thermal comfort, though the fuzzy controller to achieved the objective with a bigger economy of energy. While conducting the tests were also verified the influence in the results and in energy consumption when they are conducted without the presence of people in the environment and the part of the morning where the external temperature is lower. When tests are realized in the morning or without the presence of people the consumption of energy and drive of the air-conditioning to maintain the temperature inside of the limits of thermal comfort is lower.

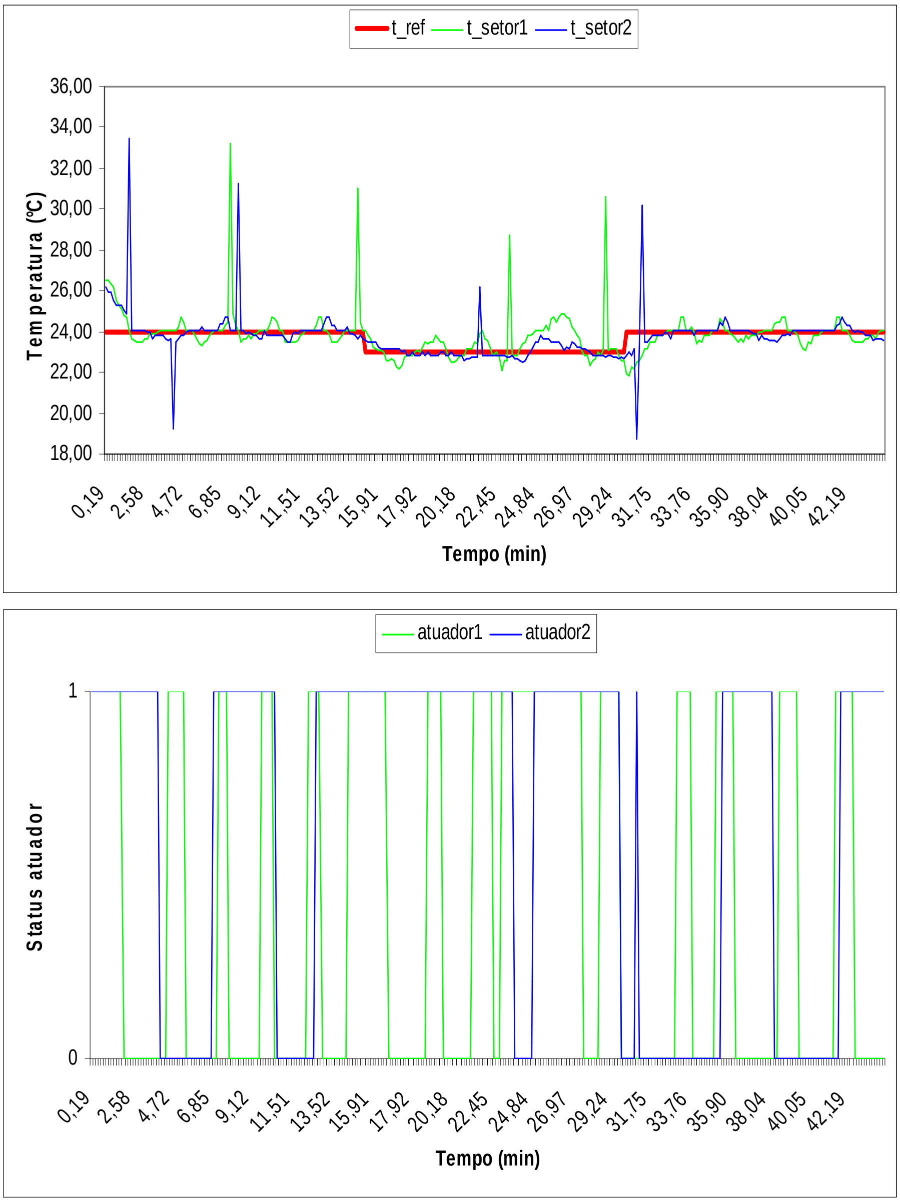


Figure 12. Fuzzy controller – second test

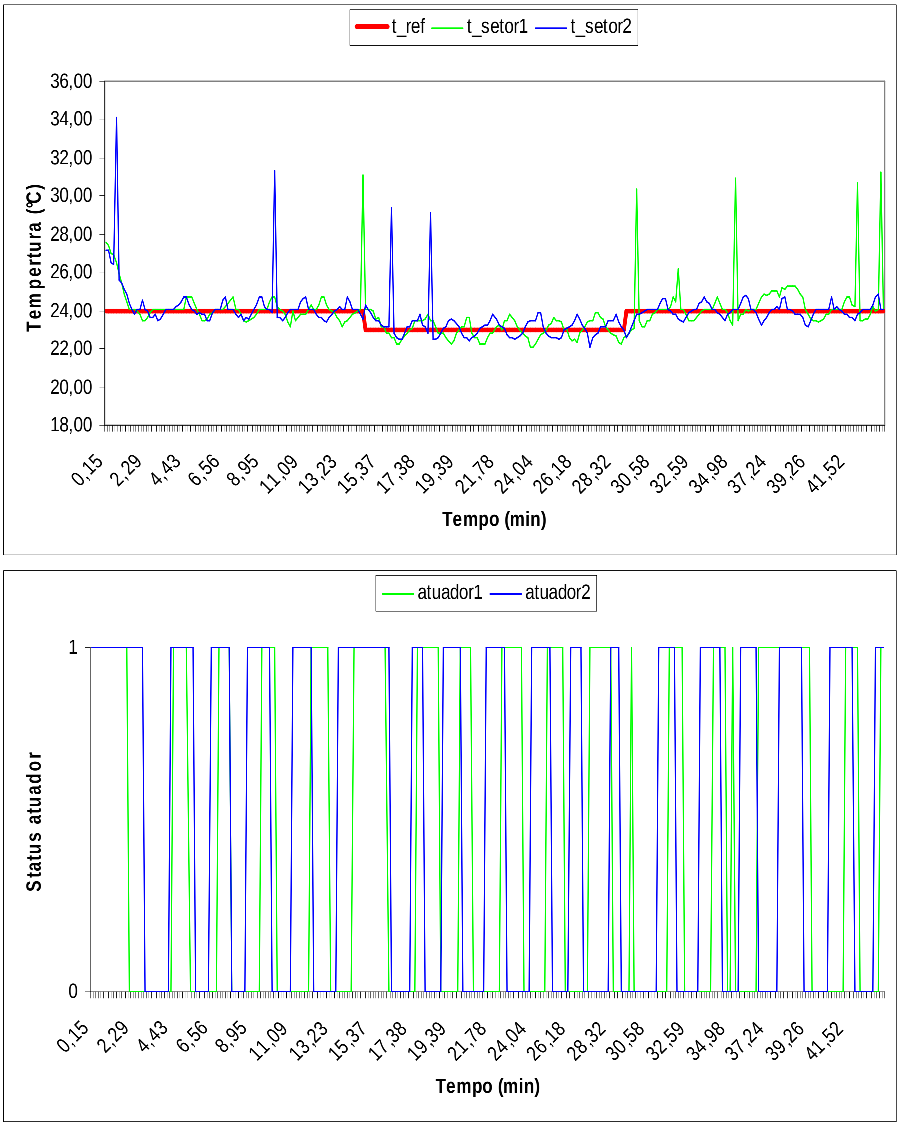


Figure 13. On-off controller – second test

Table 3. Total consumption of the controller in the second test

Type controller	consumption second test (KWh)
On-Off	1,80
Fuzzy	1,51

5. CONCLUSION

This project had as objective to show how the intelligent building automation can contribute to the reduction of energy consumption in air conditioning systems. The energy saving can be achieved by a specialist system based on fuzzy rules, that take in account the different contexts of building management.

The fuzzy controller is applicable to systems where yet doesn't have a adequate methodology to control, due, for example, the difficult or unviability to obtain a mathematical model that describes satisfactorily (Bilobrovec et al 2004).

Through experiments, it was observed that there was a saving of 20,59% and 19,21% respectively in energy consumption and with the maintenance of the thermal comfort of the environment.

The implementation of a protocol of communication, e.g BACNet and the monitoring system of remote form, through the Internet, would be a great improvement to the system, guaranteeing a bigger reliability in the traffic of the data and allowing the operator to monitor to follow the process from anywhere, just for this is connected to the network.

The use of API mode for the operations of configuration makes with that the total time spent in reading of the data of all sensors and actuators lasted 6 seconds approximately, time this that is increased for approximately 30 second case if uses the command mode.

The flexibility to deploy wireless sensors of temperature, humidity, air speed, etc. freely in the environment, allows to control of the temperature that effectively interests the user of the environment and not the usual temperature of the return of the air conditioners of window.

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