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 thermal comfort. The wireless approach, in this work, is used for better target retro-fitting of buildings still in operation, a great HVAC (Heating, Ventilating and Air Conditioning) 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 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, buildings are responsible by much of this consumption. Much of this energy is consumed in maintaining thermal comfort. This is typically between 40% to 70% of total energy 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 building environments with air-conditioning for windows over-cooling occurs, in other words, in certain hours of the day the ambient temperature drops below the comfort of temperature. After all, do not want to adjust the thermostat of each air-conditioning for windows 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 hasn't be associated with lack of comfort, therefore, good levels of energy efficiency 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 lesser expense of energy (Borduni, et al., 2006).

The building automation develops adequate techniques of 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 of intelligent building automation, forming a ZigBee wireless network of sensors and actuators. The use of wireless node sensors and actuators, aims in this work to simplify the retrofitting in buildings already in operation, reducing costs of equipment and installation.

A comparative study will be done between the ON-OFF controller (base on control of air conditioners) and the *fuzzy* controller (used in complex dynamic systems), aiming to show which of the controllers is more efficient in maintaining of the thermal comfort of the environment and with the least energy consumption.

In this work, we will consider only the control of temperature as indicative of 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 measured 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 for the season.

2. THERMAL PROCESS

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

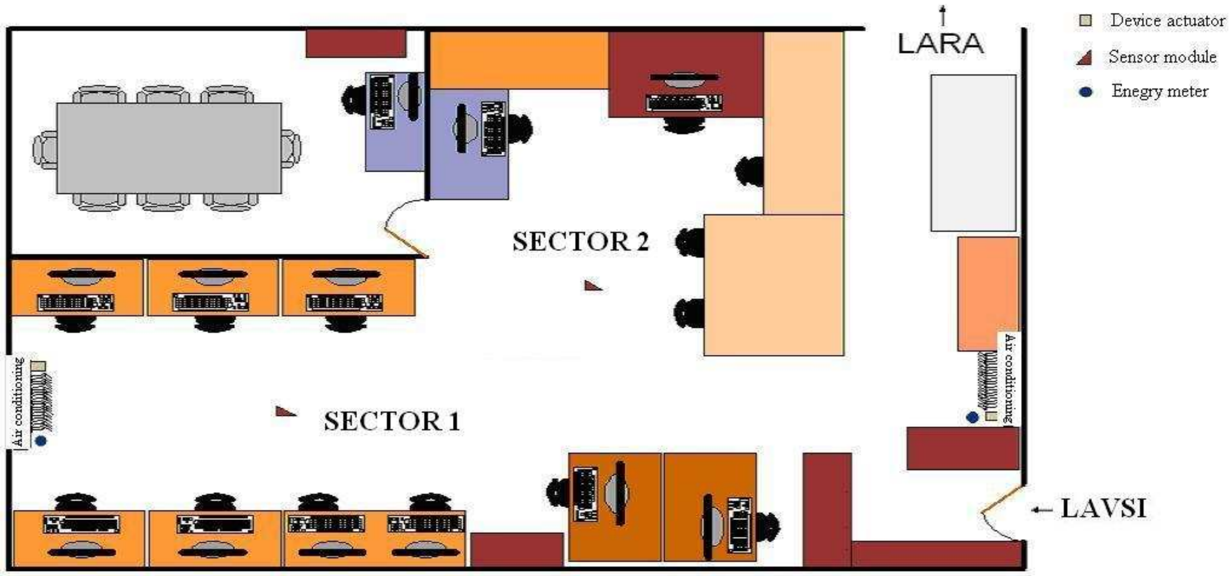

Figure 1. Thermal Systems (Filho and Dias, 2008).

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 network equipment (processors and controllers). For the project in question was used an architecture based on modules from company Digi (previously MaxStream) called XBee. The XBee is a wireless technology designed to meet the standard IEEE 802.15.4, it 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 (100m). Figure 2 shows the topology used.

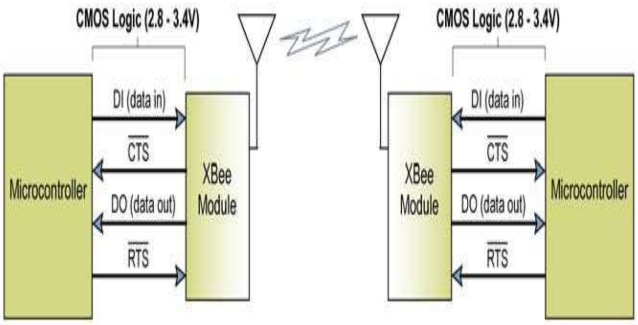

Figure 2. System Data Flow in an environment with UART interface (Oliveira et al 2007), (MaxStream, 2006).

We used two types of devices: The first device, the coordinator module is responsible for the interconnection between the node End Device and the PC, Fig. 3. It receives the node sensors data relate the temperature of environments and relaying the processed information for the node actuator.

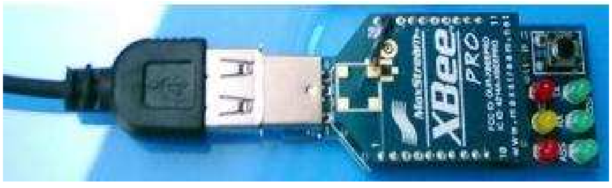

Figure 3. Plaque CON-USBEE (Rogercom).

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

In the sensor module, Figure 4, the functionality of conversion A / D for the XBee module was used. This allows a conversion without the microcontroller. Also a temperature sensor LM35 was used, that operates in the range of -55 ° C to +125 ° C, has a gain of 10mV / ° C, precision of 0.5 ° C, low energy consumption (active mode = 250 μ A) and, an operational amplifier to amplify the signal of the sensor in one of the A / D channel of the XBee.

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

In Figure 5, the end device actuator is composed of a XBee, a microcontroller Atmega 8, an 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.

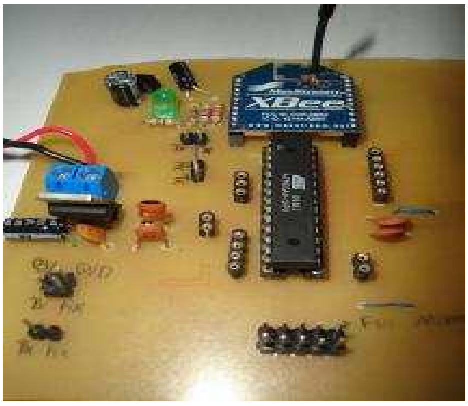

Figure 5. Diagram of the End Device Actuator (Filho and Dias, 2008).

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 to the compressor is of approximately 0.8 A. It is composed 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.

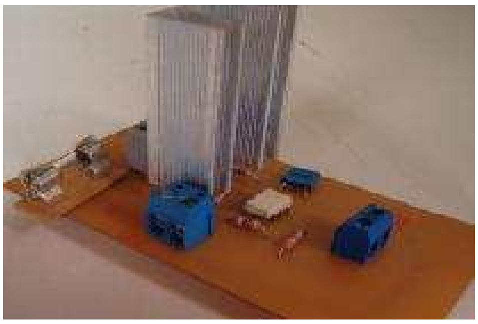

Figure 6. Drive Circuit (Filho and Dias, 2008).

3.2. SUPERVISORY SOFTWARE

The software SCADA is responsible for data acquisition equipment (sensors, actuators, programmable controllers, etc) to the computer, by your organization, use and management, showing to the operator of the system the status of the system 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 in real time, allowing operators to control and monitor all the system (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 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 done in the command mode and the reading of data in API mode of the XBee module. This is also where all information that enters or leaves the module is contained in framed 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).

3.3. MEASUREMENT OF TEMPERATURE

In this work, a network of wireless sensors and actuators was developed. This was done by using a Xbee, that was implemented at the LAVSI laboratory. This was combined together with a fuzzy controller to ensure a thermally comfortable environment and with the least consumption of energy possible.

The network defined for implementation of this project consists of two nodes sensors, two nodes actuators and one node coordinator connected in a star form, where the sensor and actuator modules possess fixed addresses for sending and collecting of data.

The communication is done in unicast mode, and for this, the supervisory repeatedly changes the personal and destination address of the coordinator node, Fig. 7.

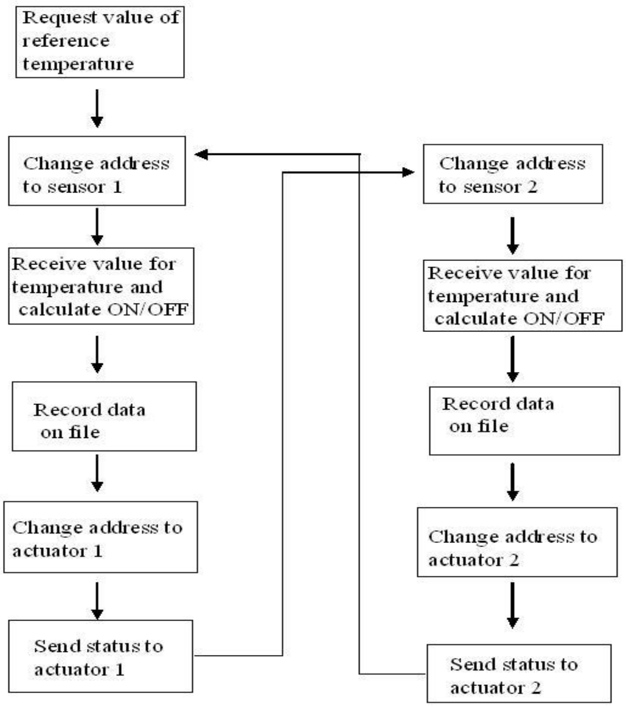

Figure 7. Flowchart of functioning of supervisory software (Filho and Dias, 2008).

The sensor nodes are configured to send three samples of temperature, Fig. 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, the average of 3 read is taken, otherwise, it will be the average of two samples that have a different lesser than or equal to 1, (Filho and Dias, 2008).

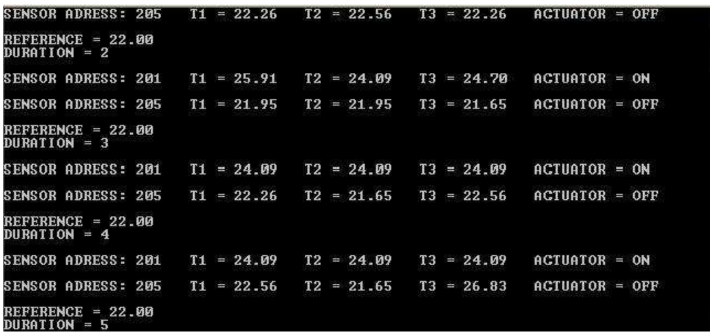

Figure 8. Supervisory.

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, and converts data from serial to USB.

In the supervisory computer occurs the processing of the data and the control of the process done by the software implemented in the modules 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 techniques of control that can be used to control the temperature of building environments are shown.

4.1. ON-OFF CONTROLLER

The on-off controller is one of the simplest controllers to be implemented, being therefore sufficiently used for temperature control in building environments. This is done by the controller, which compares the mean temperature output with the reference value, Eq. 1. 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 closes to its limit point of operation.

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

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 the 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.

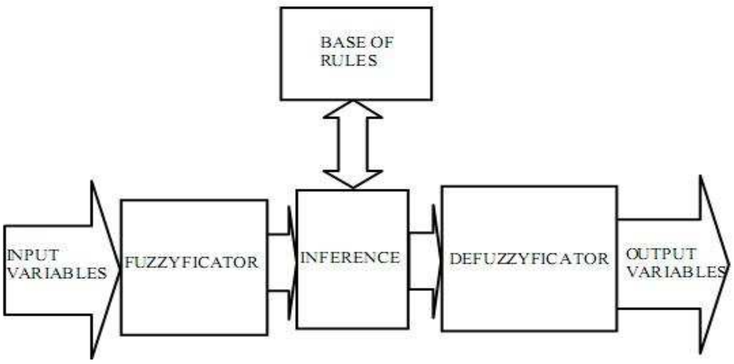

Figure 9. Diagram of a Fuzzy system [12].

The interface of fuzzification takes the values of input variables, make a scaling for conditioning 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). These 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, scaling toward compatible normalized values from the previous step with the values of the universes of discourse of real variables (Barg 2002).

In the implementation of the fuzzy controller the following input variables were defined: 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. 25 rules were used in the database, as shown in Tab. 1 below.

Table 1. Rules Fuzzy

Erro x T_ref	VERY LOW	LOW	MEDIUM	HIGH	VERY HIGH
NEGATIVE	VERY LOW	VERY LOW	VERY HIGH	VERY HIGH	VERY HIGH
LOW NEGATIVE	VERY LOW	VERY LOW	MEDIUM	VERY HIGH	VERY HIGH
ZERO	VERY LOW	VERY LOW	VERY LOW	HIGH	VERY HIGH
LOW POSITIVE	VERY LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW
POSITIVE	VERY LOW	VERY LOW	VERY LOW	VERY LOW	VERY LOW

4.3. ANALYSIS OF RESULTS

This stage consists in verify the results of the implementation. If the system developed takes care of the main objective, which is to use energy rationally while gradually reducing its consumption. Then the controllers will act in a form that allows that the temperature of the room to be maintained around the reference signal.

The energy saving will done by the using of an expert system based on fuzzy rules, which take care of the different contexts in building management, which will cause a decrease in the time of operation of air conditioners, and the amount of times in which it is activated.

During the experiments, besides the temperature of the room was registered the consumption in Wh of air conditioners were used. The monitoring of energy consumption of air conditioners was done 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.

To maintain the thermal comfort of the environment a maximum variation of the temperature of 2 ° C, range usually accepted for climatization was used (Gouda et al 2001). Two tests were done. In the first test the controller worked with a fix reference. The results obtained in the first test can be viewed in the Fig. 10 and 11.

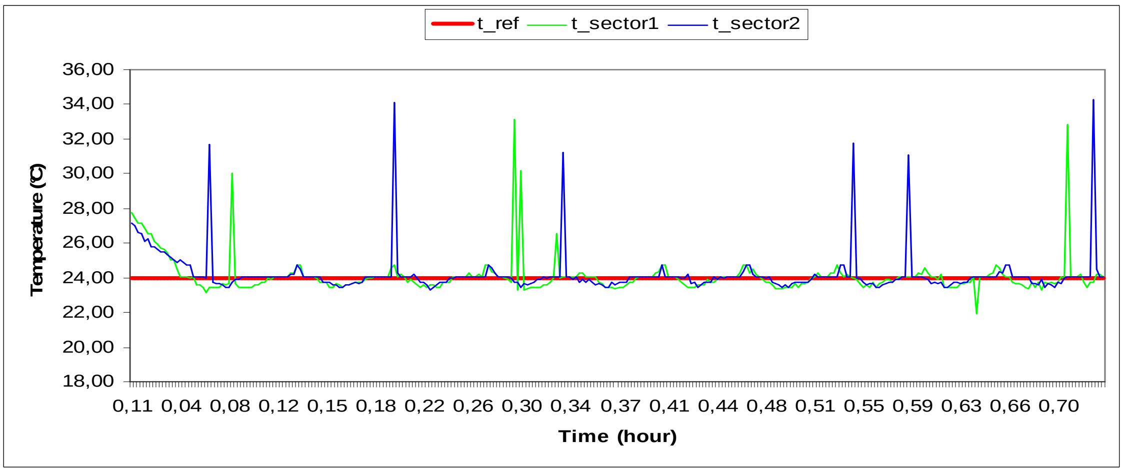

Figure 10. Fuzzy controller – first test

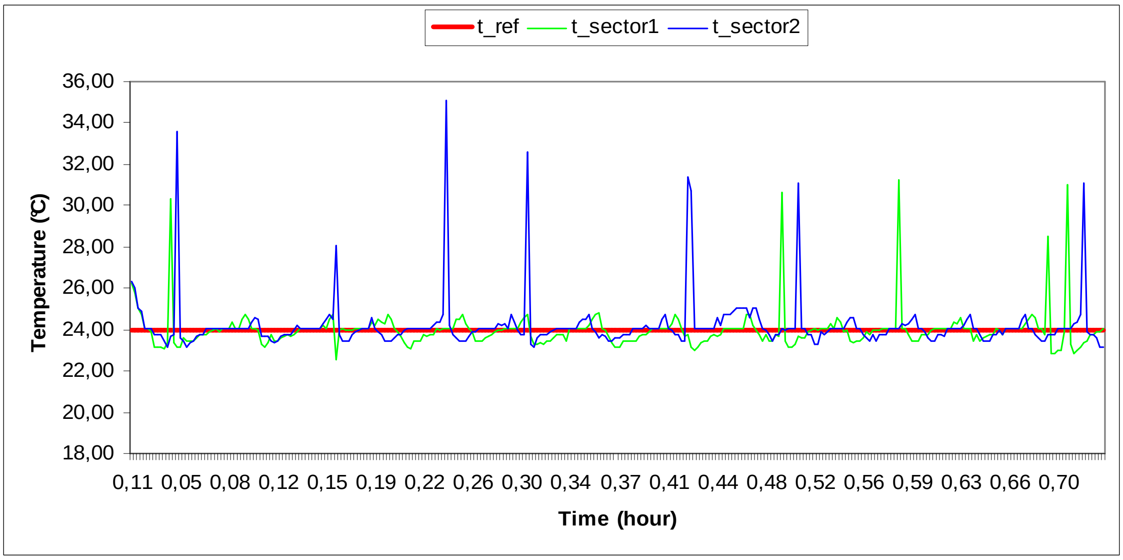

Figure 11. On-off controller – first test

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, which is a 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 of less than 1 ° C. Through the signal of the actuators it 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 compared to the on-off controller. This fact contributes directly in the consumption of energy and the useful life of the equipment.

This fact can be demonstrated through Tab. 2 which shows the consumption of energy for the controllers where if can be verified 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 a change in the values of the reference temperature was done to observe the transient behavior of controllers. The results obtained in the second test is visualized in the Fig. 12 and 13.

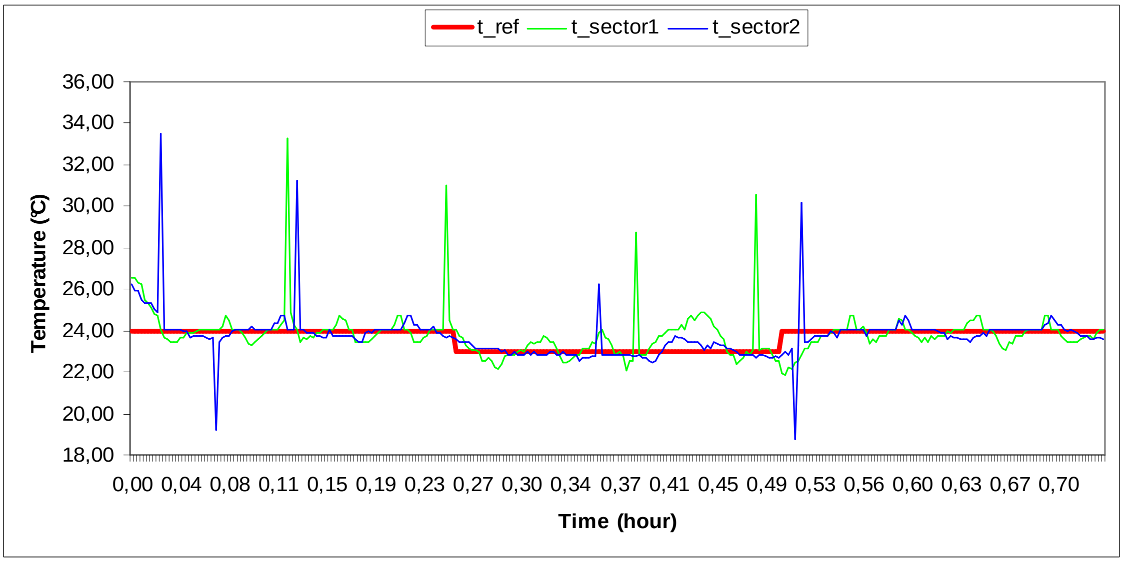

Figure 12. Fuzzy controller – second test

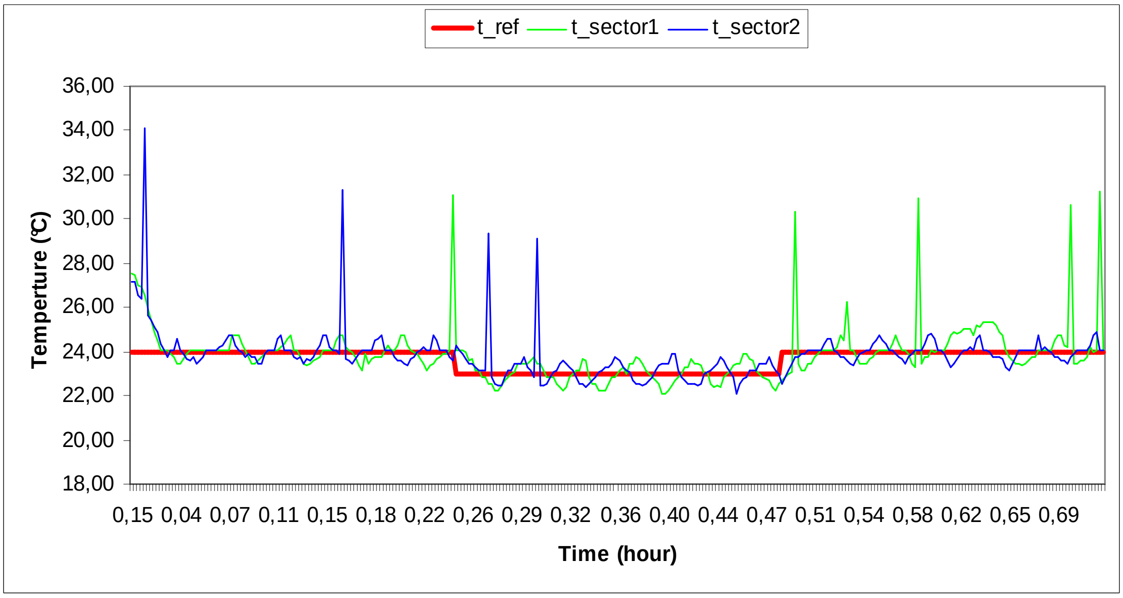

Figure 13. On-off controller – second test

As in the first test, we can observe that both controllers were able to maintain the temperature inside the limits of thermal comfort Furthermore, using the fuzzy controller energy consumption dropped dramatically, Tab. 3. 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 done 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.

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 specialized system based on fuzzy rules, that take into account the different contexts of building management.

Through experiments, we can observe that besides maintaining thermal comfort of the environment there was a saving of 19.97% and 22.94% respectively in energy consumption with the use of fuzzy controller compared with ON-OFF controller that is the base of control of air conditioners. The reduction in energy consumption was due to use of an appropriate conjunct of rules, which ensured a decrease in the time of operation of equipment and the amount of times they were actuated.

The use of ZigBee wireless communication occasionally showed missed packets that were detected by the transmission of temperature equal to zero, requiring the forwarding of them. The implementation of a protocol for communication, e.g. BACNet should identify such situations and request the forward of lost data while ensuring greater reliability in data traffic.

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.

The use of API mode for the operations of configuration makes the total time spent in reading of the data of all sensors and actuators 6 seconds approximately, allowing a larger sample data for analysis.

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

A better analysis must be made using other types of controllers, but also increasing the time of the simulation experiments, allowing a greater improvement of the controller used for the type of application desired.

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