Energy Saving Project for Heating System with ZigBee wireless control network

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Abstract – An energy saving system able to optimize power management and energy efficiency of an home heating plant is proposed. Thanks to an advanced interface and control architecture based on ZigBee wireless devices, a continuous control of temperature is warranted making efficient the heating plant. The system uses a sensor and actuator combination to control and guarantee the desired system parameters; the information is transferred point-by-point using ZigBee communication network and it's sent to a central unit used to check the peripheral devices state and to take appropriate measures in case of failure or alarm.

Keywords - automation, control system, heating system, wireless networks, ZigBee, sensors.

I. INTRODUCTION

One of the greatest challenges in contemporary engineering, regarding automation and control, is to achieve products aimed to increasing energy savings customizable by the user. The customization allows to satisfy different asks, reflecting different ways of viewing life being able to meet community needs (such as energy saving) and individual needs (such as the management of some home or business environmental parameters).

The solution proposed in this work wants offer an actual and innovative technology in integrated electronic which provides wide flexibility, ensures automatic and customizable management of the modules that make up the system. In particular, it has been developed a "smart system" for centralized heating plant which, through the appropriate use of electronic control devices, should be allowed to manage public and private equipment with maximum energy savings, dynamically changing the hot water flow according to actual site requests.

The idea behind this work is related to multiple aspects: environment, technology, economy, society.

Regarding the first, environmental awareness has changed over the years suggesting behavioral and social development patterns more compatible with nature and environment. Intelligent public and private energy management can reduce gas emissions.

In recent years, miniaturization of electronics has allowed the rise of very small large computing capabilities components, enabling development of control units for a "smart" resources management.

The economic is also extremely important and becomes macroscopic if we take into account the energy consumption of a state. Furthermore, due to Kyoto agreements and the more and more stricter environmental regulations, to consume less energy produces a direct gain related to saving on utility bills, but also gain an indirect linked to energy certificates which could be resold to other companies or organizations more energetically ravening.

Finally, not to underestimate the social dimension of the customization of domestic environments, deeply related to personal wellbeing. In fact, a custom environment can be a reason of serenity both at home and in public environments.

Many other researchers have focused their efforts on designing a better heating system and to allow greater savings. Wang J. *et al.* [1] developed a control system with RF modules, but for industrial environment. Naughton R. *et al.* [2] used a PID controller, but only to reduce the boiler ignition time. Chao-Ying Liu *et al.* [3] developed a heating control system based on neural network, but it's only a simulation. Thybo H. *et al.* [4] developed a control heating system for floor plant, but only to increase the heating performance of the system. Yao Y. et al. [5] developed a wireless monitoring system for heating, but only to show the status of each heaters.

II. DEVICES AND METHODS

As mentioned above, the application presented in this work is directed to central heating systems, as shown in Figure 1.

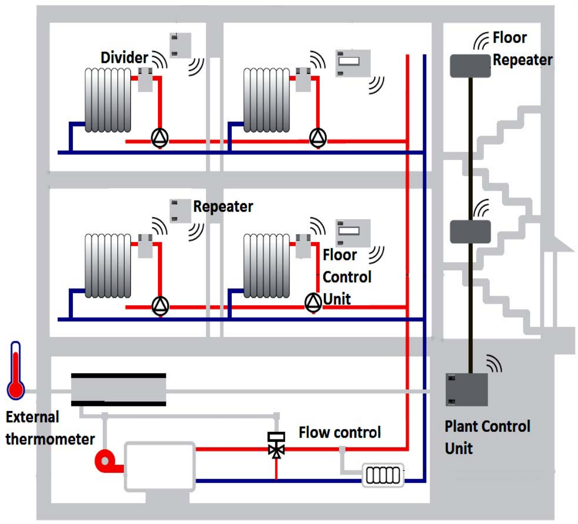

Fig. 1 – System schematic

The system is able to collect data about temperature, both in terms of the building rooms where it's installed and in terms of external environment. According to the collected information, the control unit is able to decide if and how to turn on heating system by the action of control valves which regulates the warm water flow in the plant. This action can be performed on all water column (to activate all the plant) or on some water columns (to activate particular sections of

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the plant, so to enable a power saving, according to the needed of the environment in which the system works). The collection of data from temperature sensors will be performed with wireless network, implemented by ZigBee technology. This sensors can be battery powered, thanks to the short power consumption assured by ZigBee systems. The field of ZigBee remote sensing and control system is widely present in literature; we can also find ZigBee systems in similar management structure [6-13].

The control unit is able to control the system through a relatively simple algorithm, shown in Figure 2. The information flow is structured according to if-else statements which receive data concerning the various temperature sensors as input and decide the opening or closing (total or partial) of valves, governing the hot water flow. The controller is equipped with a ZigBee radio module able to receive information from temperature sensors and, by identifying the unique ID of the transmitting device, operates on the corresponding valves.

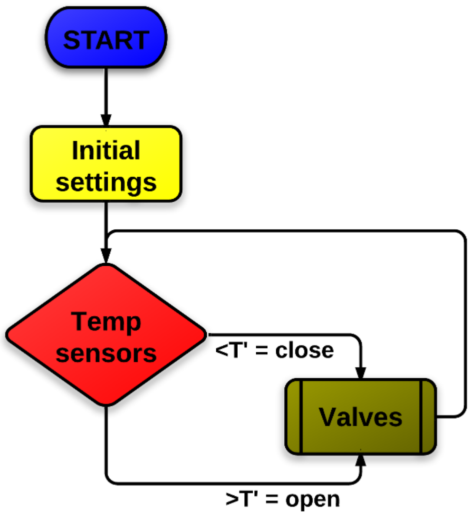

Fig. 2 – System basic algorithm

The system control software doesn't just make a simple comparison of temperature, as a thermostat, but collects and stores data related to environmental conditions and power consumption of the devices to allow a detailed analysis of costs and benefits of the system. This analysis is possible thanks to practical and user-friendly software interface that is made available to the user. The software is designed and developed in Visual Basic and is designed to make easier the communication between the user and the system. In order to allow to the user fast and simply comparisons on consumption, the system provides reports on consumptions in different time slots: instantaneous, daily, weekly, monthly, quarterly. Accounting for consumption is made on the basis of the average gas cost (needed to operate of boiler) and of the exactly operating time collected by system. The GUI used for the software has been designed for touchscreen interaction. Lack of buttons, in fact, makes more flexible (and less expensive) a possible update phase.

The Home screen is sparse of information to prevent confusion and from here the user can access the following screens with a few simple steps. The main window (Figure 3) system provides three buttons that allow to access to different sections.

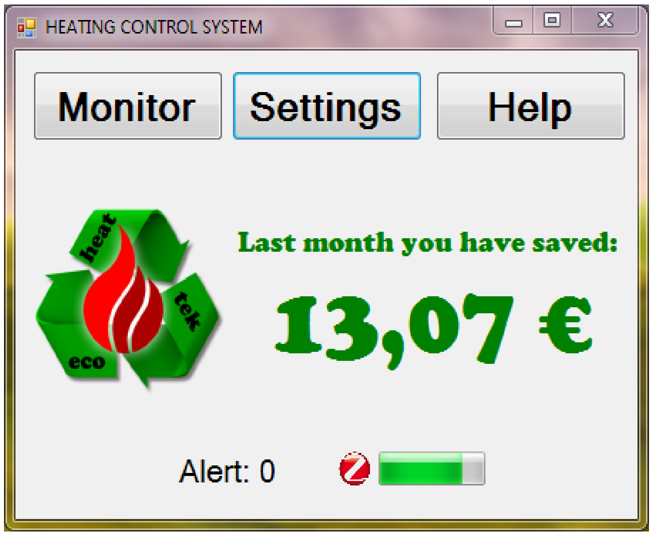

Fig. 3 – Software Home screen

The Monitor button allows to access to the screen that presents the user environment, i.e. statistics, graphs, consumption. The Settings button allows to access the different configuration of the controller. The Help button gives access to the support with which operators can be contacted in order to solve problems of different nature. From here you can also access a user guide that accompanies to firsts steps in the use of the system. The software also provides information on the received ZigBee signal power and possible alarms detected. At screen center, in addition to the system logo, it's shown an information about the savings achieved in the last month thanks to our smart system, calculated respect to the use of a normal centralized system which is always on in a certain time slot. As will be explained below, this savings are achieved by the action of our system that can enable and disable the radiators of the various rooms, on the basis of settings specified at installation. This solution may be adopted at any home heating system, but it would require a user manual action for opening/closing the radiators' valves. In this last case, the savings would be delegated to user action, whereas with our system this laborious procedure is automatic.

In the monitor screen (Figure 4) is possible to view the status of the various heaters (on / off) and the temperatures currently detected in the various environments.

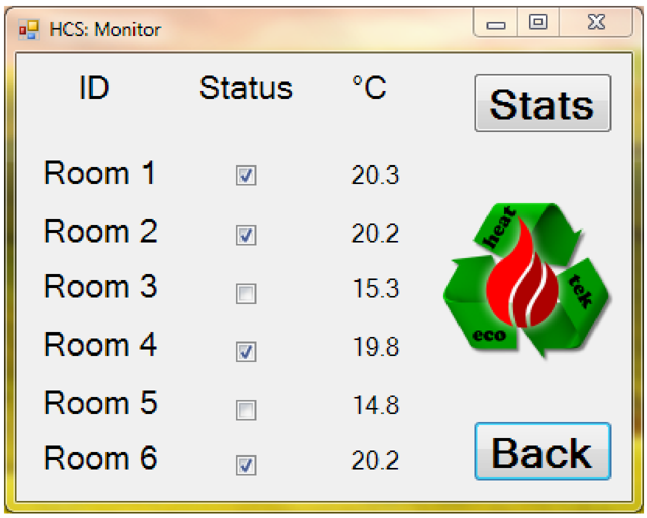

Fig. 4 – Software Monitor screen

This software section is called "environmental management" and it is useful to perform the initial configuration of the system (operating temperature, ignition timing, heated rooms).

The stats button gives the possibility to access to statistics on consumption. This section is called "user environment" and shows information user requests (statistics, power consumption, operating status). Access to the first section is password protected, so as to prevent novice users can make changes that might cause problems or faults.

The Stats screen allows you to select wanted heater and interest time window, in order to observe the fuel consumption, working time, eventual malfunction or loss of connection, by selecting the type of data to show.

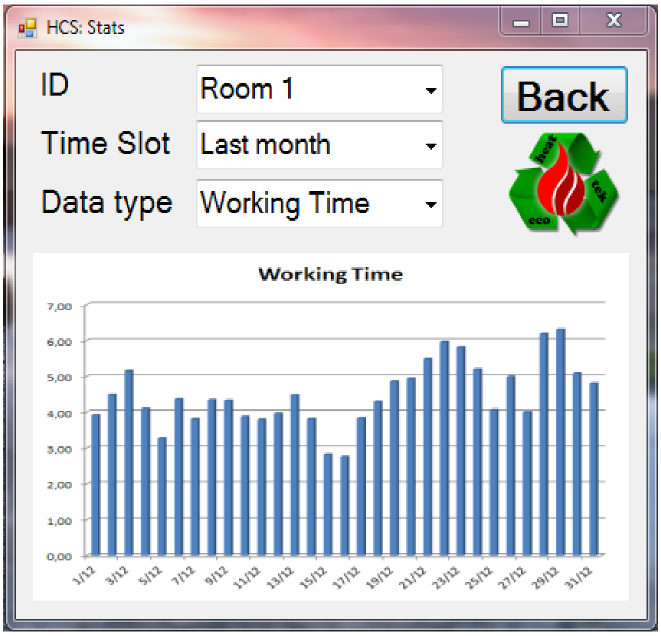

Fig. 5 – Software Stats screen

The Settings screen allows to set the start time of the various heaters and set their operating temperature.

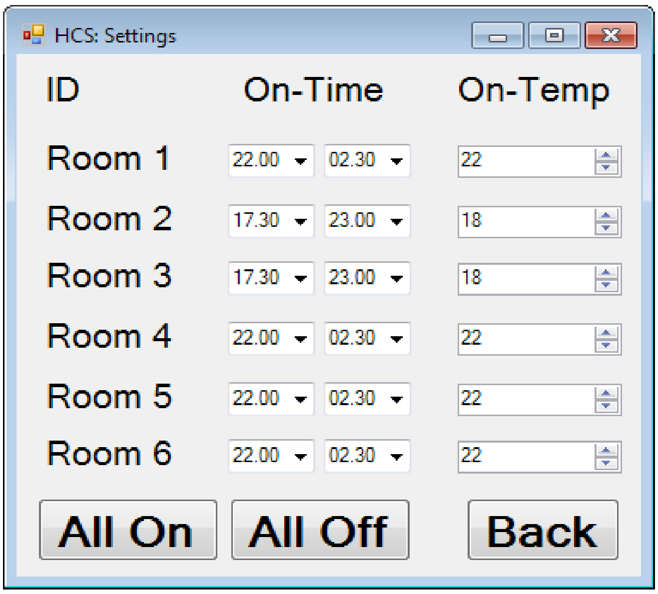

Fig. 6 – Software Settings screen

Furthermore it is possible to turn on and off all the heaters. When the current time is included within the set up time slot, the system will themselves keep the temperature at pre-set value like a normal thermostat. In a more recent version of software you can add more advanced temporal schedules, such as the weekly planning, the power on only with the presence at home or in according to the state of windows (the verification of the latter two conditions is made by crossing data with an alarm system that, for this feature, must be present in environments where the system is installed).

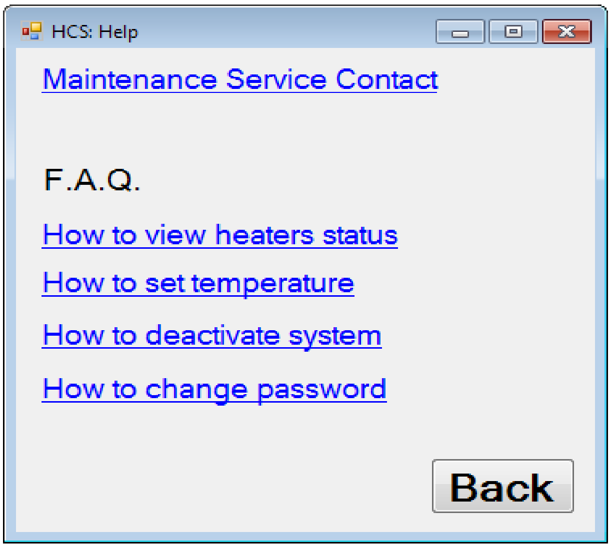

Fig. 7 – Software Help screen

In the help screen the user accesses to some useful references for the use and maintenance of the system. The customer service contacts provide the user with a quick solution to any problem, while some FAQs allowing to learn how to perform the most basic functions.

B. Temperature Sensors

Temperature sensor used in this work is the LM35 semiconductor sensor manufactured by National Semiconductor. The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 doesn't require any external calibration or trimming. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1°C in still air.

This is used for internal environments. For external, we've used the N120 manufactured by Coster. This is designed to be installed on a North or North-West wall of the building, as far away as possible from chimneys, windows and sources of heat in general.

C. Control Valves

In this work we've used the M860 spherical regulating valves manufactured by Coster. These valves are pressure independent and ensure a constant flow adjustment. The valves are used to regulate the flow of water in the heating system, guaranteeing working even at high pressure. Obviously, they are needed of appropriate servomotors chosen according to the size of the valve itself. CVLR and

CVSR servomotors, able to work with water temperatures from 5 to 120 °C, were used both.

D. ZigBee Network

ZigBee is wireless communication technology based on IEEE 802.15.4 standard for communication among multiple devices in a WPAN (Wireless Personal Area Network). ZigBee is designed to be more affordable than other WPANs (such as, for example, Bluetooth) in terms of costs and, above all, of consumption of energy. The typical distance of a ZigBee transmission range, depending on the environment conditions and the transmission power, shifts from tens to hundreds of meters, because the transmission power is deliberately kept as low as possible (in the order of a few mW) to maintain the lowest energy consumption. Distances of 1.5 km can be achieved in more advanced devices with slightly higher transmitting power [9-14].

In the proposed system, the network is built to transfer information from the temperature sensors to the control unit. Information is transferred point by point and each sensor has a unique address in the system which uniquely identifies the sensor and therefore the environment who originates the data.

ZigBee wireless communication network has been implemented with the use of radio frequency modules produced by Digi-MaxStream XBee module [15]. XBee is a device compatible with the ZigBee / IEEE 802.15.4 standards [16] that enables to build a network at a low cost and with low power consumption, designed for the use with sensors. The modules are simple to use, require very low power and are a reliable solution for data transmission. Moreover, the very compact dimensions allow considerable savings in terms of physical space used. XBee operates in the ISM band at the frequency of 2.4 GHz and is available in Standard and Pro versions (pin-to-pin compatible).

The receiver has a very high sensitivity and a low probability of receiving bad packets (less than 1%). The modules should be supplied by 3V DC source; the current consumption is in the order of 50 mA (for XBee) and 150-200 mA (for XBee PRO) in uplink and in the order of 50 mA in downlink (identical for both versions). Xbee modules support a sleep mode where consumption is less than 10 µA. The XBee modules are distributed in three versions of antennas: with on-chip antenna, wire antenna and with integrated connector for external antenna.

E. Build-up

Fig. 8 shows the PCB 3D-model of the circuit. This has been realized in SMD technology to reduce the overall dimensions.

In the system, the most important elements are:

- U1 and U3 the voltage controllers which power to all other devices
- U2, placed under the Xbee module, is the microcontroller (Microchip PIC 16f688) which manages the system where the firmware is uploaded
- U20 is the XBee module
- Connectors for programming the pic (ProgPort), for optional serial TTL, for an external reference voltage, necessary for the correct activity of the PIC Analog to Digital converter, and for the I/O ports.

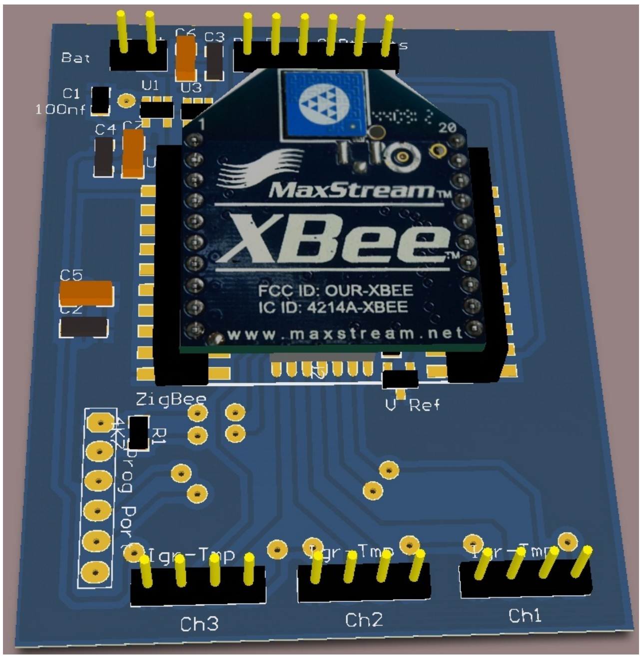

Fig. 8 – PCB 3D-model

Fig. 9 shows the realized prototype inserted in its box ready for tests. This is the prototype tested in real-life conditions.

Fig. 9 – Prototypes

Fig. 10 shows prototypes plant of our system. In this picture you can see two devices applied to a standard radiator. The unit on the wall is the system of transmission / reception that communicates with the control unit, through the ZigBee module. This unit is powered from the mains supply as well as the electric valve. This latter is applied to tap of the radiator and allows hot water flow adjustments by controlling openness level.

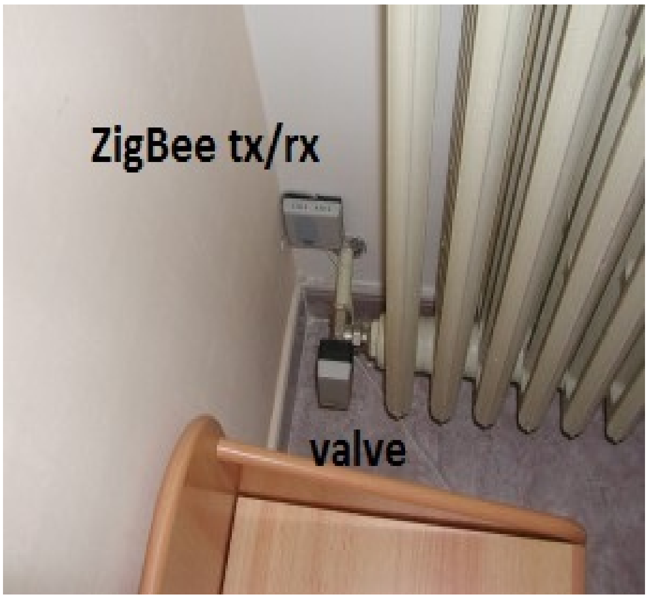

Fig. 10 – Prototypes plant

III. Communications Tests

The prototype has been tested in variable real-life conditions to verify the overall functionality and identify weak points, to finalize improvement and optimization. The measurements collected during the test phase allow to calculate energy saving and economic advantages.

A. Range tests

The first tests on the Xbee modules performance were done to test the reliability of the communication between two or more ZigBee modules in indoor condition; tests have been conducted considering one or more walls between the transmitter and the receiver. Tests were carried out using different types of Xbee modules, Standard and Pro, each one with three different types of antennas (patch, wire, external) provided by the manufacturer. 10,000 transmission tests were done, using an appropriate adapter to simulate the retransmission.

Test cases were designed to check the network in various real-life operating conditions, such as proximity of electrical or electronic devices possibly interfering with the transmission (as a WiFi Access Point).

To check the reliability of the Zigbee transmission, we used the X-CTU software, provided by Digi-MaxStream. X-CTU tool, using a terminal connected to an XBee module, sends a packet through the network and verifies that the data has correctly returned back from the XBee module which has received the packet. The given results using the minimum transmission power available, are very satisfactory: all packets arrive to their destination and are correctly returned. The obtained average reliability was of 99.99%.

TABLE I
ZigBee Reliability Tests

XBEE STANDARD - Indoors (>10m from WiFi AP)			
	1 Wall	2 Walls	3 Walls
Patch Antenna	100%	99,98%	99,96%
Wire Antenna	100%	100%	99,98%
External Antenna	100%	100%	100%
XBEE STANDARD - Indoors (<10 m from WiFi AP)			
	1 Wall	2 Walls	3 Walls
Patch Antenna	99,98%	99,88%	99,96%
Wired Antenna	100%	99,95%	99,87%
External Antenna	100%	100%	99,98%

The same tests were done on the Xbee Pro modules and the percentage of reliability was 100% in each case.

IV. Costs Saving Estimation

For the Italian law [17], Italy is divided in zone depending by the latitude [18], for each zone a time interval for the heating is fixed, so, e.g., in Rome zone the heating must be turn on at November 1st until April 15th. The only possible variation is the switch on time during the day, fixed by join owners meeting. The temperature inside the apartment is fixed at 20 °C ± 2°C.

Always for this law, in case of centralized heating plant, which are very usual in this area both for public buildings and in domestic ones, the turn on or off of the heating system have to be managed by qualified personnel. Normally who manages the heating plant sells also the fuel for the plant.

This produce an interests conflict that does not allow an intelligent management of the heating plant. In fact, even if the temperature inside the building higher than 20 °C the heating system always works in the daily fixed time interval wasting lots of energy and so money. This is particularly true for those countries or cities typically hot as South of Italy or city as Rome.

On the other hand non qualified personnel can't act on the heating system because is not authorized for safety reasons. The heating control system developed can help to saving costs.

In order to quantify the savings in terms of energy and money that can be obtained with our system, consider the following example: a Roman standard apartment block which uses the pool central heating for the winter season; this, according with Italian laws n.10/91, 412/93 [19] and following, is turned on for up to 12 hours a day, from November 1 to April 15, with an operating temperature which can vary from 18 to 22 °C. With these conventional systems, a room of normal size (12 m^2) and volume of 30 m^3 (3 X 4 X 2.5 m) with walls made of brick and lime, two versus the external side of the building, is heated on average 8 hours a day at a temperature of 20 °C. This implies a fuel consumption (in this calculus we used oil) of about 150 liters, for a money cost of about 187.5 € per year (with a fuel cost of about 1.25 €/l). Considering methane the cost is obviously less.

With our system, according to tests carried out in December on an apartment, the system activates the heating with an average of four hours a day, with a saving of about 50%!

At this stage of our analysis (February the 10th) the system is working, but we have analyzed data only for the month of December. Probably this is a case extremely lucky, but it is reasonable that in some months like November, December, March and April is reachable, while will be surely less in January and February.

V. CONCLUSIONS

This paper describes a new intelligent centralized heating system which integrates new technologies available on the market to offer higher efficiency and considerable savings.

Another advantage obtained by the control system is the intelligent management of the plant obtained sending data to a central station by ZigBee wireless communication network. The system maintenance can be easily and efficiently planned from the central station allowing additional savings. For the time, the control unit consists of a computer equipped with a ZigBee radio module, but it is already working to integrate the solution through ARM platform by writing a control program in C. Furthermore, the control algorithm presented at Figure 2 is based on conditional statements; currently, we are implementing two adaptive control systems, one based on fuzzy logic and one based on neural networks. With these types of control, the system will be able to better meet user needs.

Information collected can be processed on site by the controller accessible only by the customers or by authorized workers. This control unit will send summarized data and eventual alarm messages to a central server, monitored by maintenance staff. The summary information can be submitted over Ethernet, or in case of need, using GPRS. For reporting alarms and emergency, is scheduled to use pre-recorded phone calls (or the sending of text messages to mobile phones). In addition, the unit is equipped with self-diagnostic function, based on the detection of voltage, current and temperature to allow monitoring of correct operation.

The proposed system is particularly suitable for heating system in urban residential or working building. The proposed data transmission technology allows the use of wireless technology for the management and control system, facilitating the maintenance. The system is flexible, extendable at any time and fully adjustable to user needs.

The simplicity of ZigBee, the reliability of electronic components, the feature of the sensor network, the processing speed, the reduced costs and the ease of installation are the features that characterize the proposed system, which presents itself as an interesting engineering and commercial solution.

The firsts tests seem to show the validity of our project.

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