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WIRELESS POLYVALENT EQUIPMENT FOR MICROCLIMATE CONDITIONS MONITORING

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Lucrarea prezintă o rețea inteligentă de monitorizare a microclimatului şi calității aerului, folosită pentru a identifica impactul acestora asupra componentelor artistice ale clădirilor istorice, muzeelor şi galeriilor de artă. Rețeaua constă dintr-un set de senzori autonomi inteligenți pentru umiditate relativă şi temperatură care comunică radio cu o unitate centrală care înregistrează, de asemenea, datele de la 6 senzori de gaze poluante. Datele sunt difuzate prin intermediul Internetului. Avantaje importante şi noutăți: diseminarea datelor şi alarmare în timp real, instalare rapidă în clădirile monitorizate, impact vizual foarte scăzut datorită conectivității wireless, uşurința de operare, flexibilitate şi accesibilitate.

The paper relates to an intelligent network for microclimate and air quality monitoring, used to identify their impact on the artistic components of historical buildings, museums and art galleries. The network consists from a set of autonomous intelligent sensors for relative humidity and temperature, communicating wirelessly to a central unit that also records data from 6 polluting gas sensors. Data are disseminated through Internet. Important advantages and novelties: real-time data dissemination and alarming, a quick deploying of sensors within the monitored building, very low visual impact due to the wireless connections, ease of operation, flexibility and accesibility.

Key words: hystorical buildings, museums, microclimate monitoring, real-time, wireless

1. Introduction

The intelligent network for monitoring microclimate and pollutants' concentrations with application in identifying and controlling the effect thereof on the artistic components in historical buildings, museums and art galleries is designed to ensure a flexible and accurate monitoring of microclimate and air quality parameters. It consists in a set of intelligent autonomous, wirelessly connected relative humidity and temperature (RH&T) sensors that are reporting the monitoring data to a central unit (CU), at fixed intervals of time.

While the sensors are measuring the temperature, the relative humidity and other individual functioning parameters, the CU is acquiring information from 6 polluting gas sensors.

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The central unit receives the incoming radio data from sensors which are deployed inside the building, is merging these with data regarding the concentrations of the polluting gases and stores the whole information in a nonvolatile flash memory (SD card).
The central unit is also equipped with a TCP/IP server which allows the data transmission over a local network or over internet.

Data consistency in case of temporary radio communication failure is assured by local memorizing of acquisition results within a flash memory ring buffer.

The industrial, scientific and medical (ISM) radio band chosen for communication uses frequencies around 434MHz, providing a good coverage even within the reinforced concrete buildings.

Microclimate and air quality monitoring has increased important since it is unanimously accepted as compulsory activity for any intervention design and/or conservation strategy. The presented system is one of the most important equipment of the ART4ART Mobile Laboratory, omnipresent on site to all longer applications[1]. The importance of microclimat condition permanent control is also revealed by the quality of analitical investigations' results that are strongly related by laboratory environment or by the on-site experimental conditions [2,5]. Also several categories of interventions, like laser cleaning or enzime cleaning [3]. A particular attention has to be assured for the objects based on organic materials, which are susceptible to accelerated ageing, too. Also, there is a connection between biocontamination dynamics and environmental conditions gradient that request real-time monitoiring in archives, deposits, museums, galleries etc. [4]

Thus, the paper will focus on the following chapters: an overall description of the network, result obtained from the use of this network and conclusions regarding its usefulness and some possible further improvements.

2. Description of the intelligent monitoring network

The intelligent microclimate monitoring network was designed as an alternative to existing stand-alone sensors for temperature and relative humidity measurements. These battery operated sensors store the measurements into their memory, so that the post-factum analysis of their data consists a wittness probe regarding the dynamic of the conservation conditions. There are also sensors operated wirelessly, but they are using usually Bluetooth type connections, at 2.4GHz. Specifications of Bluetooth interface don't allow them to transmit over large distances. Moreover, when the communication takes place into a concrete building, the absorbtion of the electromagnetic waves at that frequency is so high that the real range is of only 10-15 meters, at most. The intelligent monitoring network presents the advantages of a much larger radio communication distance within a building, extended autonomy and real-time data dissemination through internet. A schematic representation of this network is presented in Fig 1.

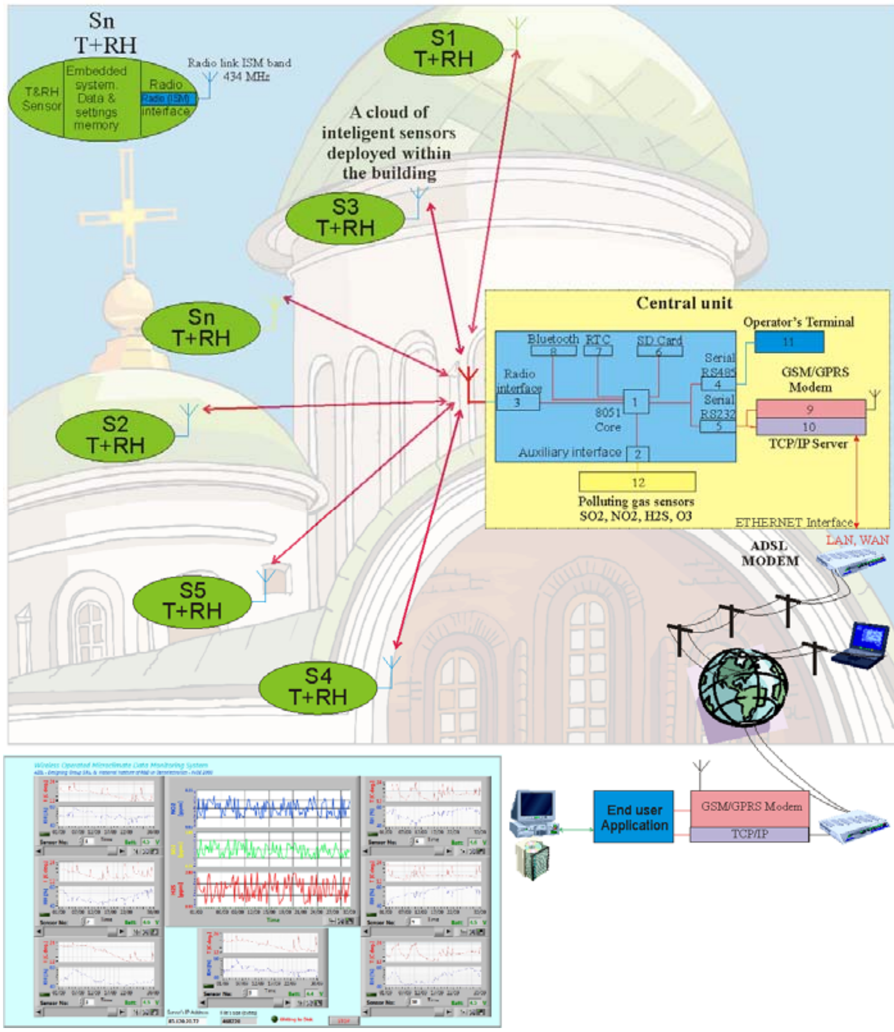

Fig. 1. Schematic representation of the monitoring network

2.1. Sensors

The monitoring network uses sensors equipped with a Texas Instruments microcontroller that is built on a 8051 core - MSC1214Y5. The microcontroller makes use of a serial programmable real-time clock (RTC), a combined sensor which measures the temperature and relative humidity that can be serially accessed through its I2C interface (SHT15), a bank of serial E2PROM's

(4x32KB), a radio transceiver module (RC1240) operating within the ISM band, from 433.05MHz to 434.79MHz.

In Fig. 2 is presented the block diagram of a sensor. Fig. 3 presents a internal view of a sensor and its component parts.

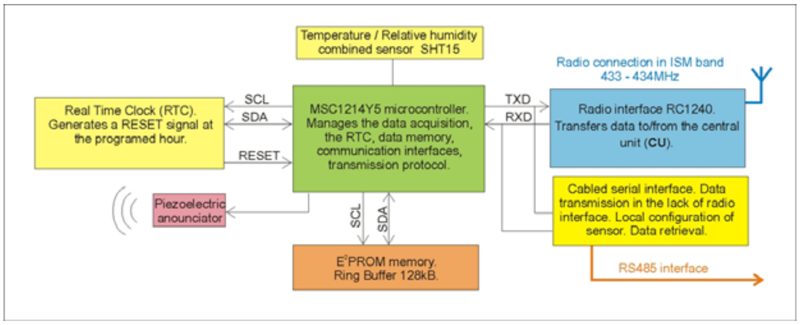

Fig. 2. Block diagram of a wireless RH&T sensor

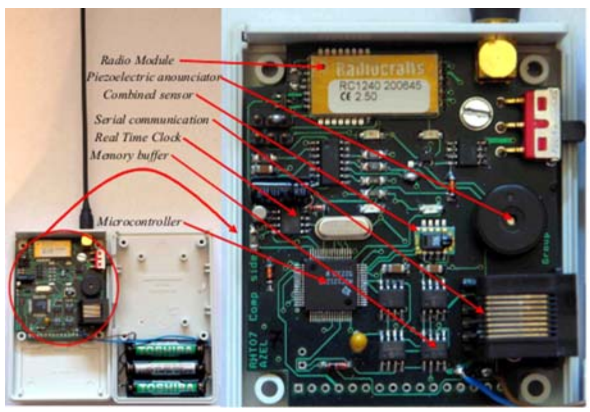

Fig. 3. Internal view of a RH&T sensor

Sensors are powered from 3xAAA batteries and a control circuit provides a continuous reset signal if the supply voltage falls bellow 2.8V, avoiding hardware brown-outs due to insufficient voltage.

Sensors are configurable, as they allow the operator to establish the acquisition period (between 1 minute and 180 minutes), the communication channel and parameters, alarm thresholds for temperature, relative humidity and supply voltage, calibration coefficients, date and time settings. They are provided with two types of communication: radio and cabled (through an RS232 serial interface).

In order to reduce the average current consumption, the microcontroller stays into a power-down mode from which is waked up by a hardware reset provided by the RTC after the established acquisition interval expires. After each reset, the first task of the microcontroller is to reprogram the new time at which it will be awakened by the RTC. After this, the microcontroller reads the temperature and relative humidity values furnished by STH15 sensor, starts a conversion to an internal analog-digital converter in order to determine the value of the supply voltage, reads the RTC, applies a time stamp to this sample, compress the data, stores them into the E2PROM memory and starts a commnunication procedure with the radio module, by transmitting the packet of data to the central unit (CU).

After the transmission, the sensor waits an acknowledgement from the CU. If this aknowledgements doesn't come, then the sensor repeats the transmission for two times more. If a response from the CU doesn't arrive, then the microcontroller enters again into the power-down mode.

In order to manage the radio communications and to avoid radio collisions, there is implemented an addressing protocol, combined with a randomly delayed retransmission procedure.

Each sensor has its own software address. This address serves to identify the sensor within the network and to establish the time-window in which the sensor is allowed to transmit. For instance, the sensor with address 12 will program its RTC to give an alarm signal (reset) at a certain hour and minute, but always at second 12 of that minute. So, the second 12 will represent the time-window in which this sensor will transmit. The sensor with address 13 will transmit at second 13 and so on.

If due to a time shift in the internal RTC, two or more sensors overlap their transmissions, then the CU will not be able to recognize a valid message and it will not provide acnowledgements. The overlapped sensors will then retransmit their messages, but only after randomly established intervals, so that to create a time gap between them.

In order to avoid these inherent time-shifts of RTC's, the CU includes its own time stamp into the acknoledgement response, so that each sensor's clock is resynchronized with the clock of the CU after each transmission.

To ensure the portability of the sensors, all transmitted and received messages are ASCII coded, so that they can be directly visualized with any communication program, like HyperTerminal or RealTerm are.

Sensors can be also used independently, in a configuration that doesn't require a CU. In this case, all data are stored only in the internal, nonvolatile, memory. Data retrieval is done through an RS232 interface, by a serial connection with a PC. All samples are time-stamped and contain the measured values for temperature, relative humidity, supply voltage, and flags that indicate the activation of alarms on limit values exceeding.

Here is an example of the transmitted buffer, with the explanation of the numeric fields:

04.09.2010 12:53:05 005 +28.9 48.8 04.1 V
04.09.2010 12:53:05 .... time and date of the sample;
005 .... address of the sensor within the network;
+28.9 .... measured temperature, in °C;
48.8 .... the percentage value of the relative humidity;
04.1 .... supply voltage, in volts.
V .... flags field - in this case "V" represents the low-voltage alarm, as the supply voltage threshold is established at 4.2V.

2.2. Central Unit (CU)

It is also developed around the MSC1214Y5 microcontroller (Texas Instruments) and is designed for acquiring data provided by the set of wireless RH&T sensors located within a building, but also to acquire signals from a set of 6 polluting gas cabled sensors. The CU ensure the retransmission and storing of the data as well as to a local user and to a dispatching system.

The unit is provided with a series of interface devices, as follows:

- a radio communication module that allows bidirectional data transfer between master and its network of independent sensors;
- Real-Time Clock module, which ensures synchronization with the network of RH&T sensors and attaching of a time stamp to each stored measurement;
- signal conditioning modules for the cabled polluting gas sensors, which provide a primary signal scaling and filtering;
- 6 polluting gas sensors, which are provided with unified signal outputs (4-20mA), representing the gas concentration;
- data storage module, which consists of a SD Card flash memory and its interface;
- Bluetooth module, ensuring the transfer of stored data by a user's laptop;
- a TCP / IP server, which provides a network interface with a local or public network so that the CU can be accessed both locally and remotely;
- local user interface module, which provides man-machine interface through which performs local monitoring and parameterization;
- specific interfaces for multiplexing / demultiplexing communication channels with specific modules.

At present the input channels for polluting gas sensors are equipped with NO2, SO2, H2S, Cl2, CO and ethylene oxide sensors provided by AlphaSense company. The characteristics of these sensors are presented in Table 1.

It was chosen to use sensors with current output interfaces because this type of signal transmission are less susceptible to interferences, providing a good immunity of the signal to noises.

Acquisition of these analogic signals is performed by using the analog/digital converter incorporated in the MSC1214Y5. This converter has an effective resolution of 21bits at a sample rate of 10sps. This gives it a dynamic of more than 125dB, making it suitable for monitoring the sensors at their best achievable resolution.

The CU performs the synchronization of the autonomous sensors by sending back responses to their messages. These responses (aknowledgements) contain the precise time indicated by the embedded RTC module, so that all sensors within the radio network have permanently synchronized clocks.

All acquired data are stored in the SD Card and they are also transmitted to the embedded TCP/IP server, which can accept up to 4 clients. Bellow is an example of the format in which data are stored on the SD Card.

04.09.2010 12:53:03	001	+30.1	44.7				04.4	
04.09.2010 12:53:05	002	+28.9	48.8				04.2	V
04.09.2010 12:53:55	100	+28.9	48.8	00.051	00.315	001.161	14.1	
04.09.2010 12:54:03	001	+30.0	44.8				04.4	

A LabVIEW application is used to receive data from the TCP/IP server and to disseminate them further, by internet.

In Fig. 4 there is presented an internal view of the CU and the LCD screen of the operator's panel.

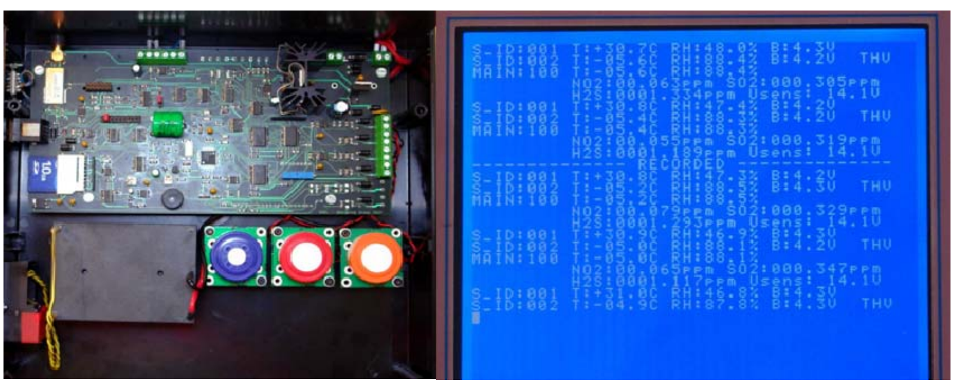

Fig. 4. Internal view of the **CU** and the view of the operator's panel.

A screenshot of the main LabVIEW application, monitoring 3 RH&T wireless sensors and 3 polluting gas sensors is presented in Fig. 5.

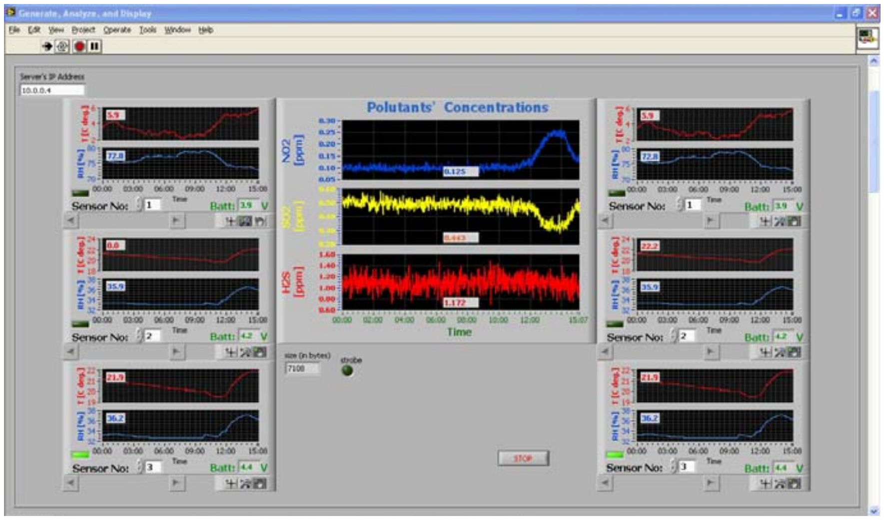

Fig. 5. Screenshot of the main panel of the LabVIEW application.

3. Results

Sensor tests were performed on large and medium term, in real working conditions. Sensors were installed both outside and inside buildings, to check their resistance to environmental factors. With this opportunity, a check of batteries behavior depending on temperature was also performed.

One application was to monitor temperature and relative humidity outside the towers of The Episcopal Church "Manole" - Arges.

The monitoring results show that batteries have discharged from the initial voltage of 4.7V to 4.5V, after 3 months of operation. For this initial experiment we have used medium-quality batteries (GP - Alkaline), and the sampling interval was set at 15 minutes. The discharging degree of the batteries were not altered significantly by the conditions under which the sensors were operated (both sample batch and the sensors instaled in open air have produced the same results, within the limits of the initial voltage spreading: 4.6V ± 0.1V).

Estimates show that the same set of batteries could operate for at least 90 more days. These estimates are based on the decreasing of sensors sampling interval from 15 minutes to 1 minute, to speed up the discharging process.

Downloaded data are consistent (no interruptions and no erroneous recordings were observed). The group of sensors placed on open air worked in good conditions, despite being subjected to relatively large variations in temperature and humidity. Installation of these sensors has been done on the exterior walls, in order to observe the stress faced by these areas. Records made by an external sensor are presented graphically in Fig. 6.

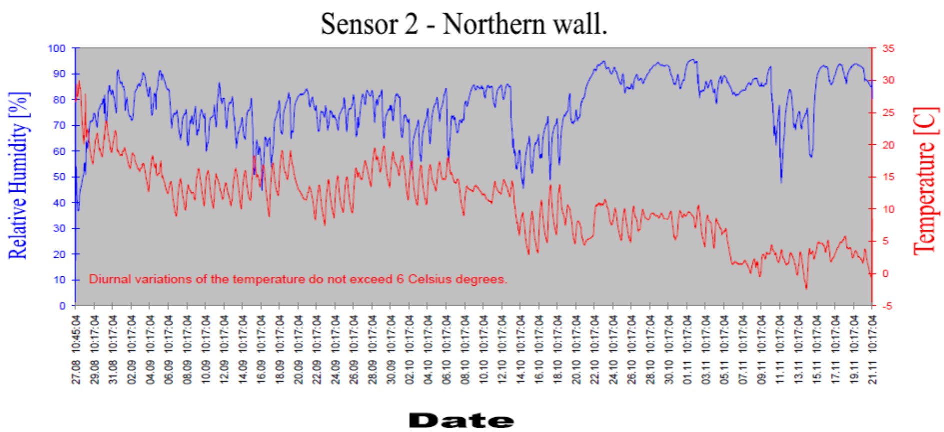

Fig. 6. Records made by an outside sensor

In Fig. 7 there are presented the parameters acquired by a sensor over a period of 182 days. Large periods of time in which the supply voltage is almost constant can be observed. It should be noted that the starting operating voltage is 4.3V. After 182 days the voltage drops with only 0.2V.

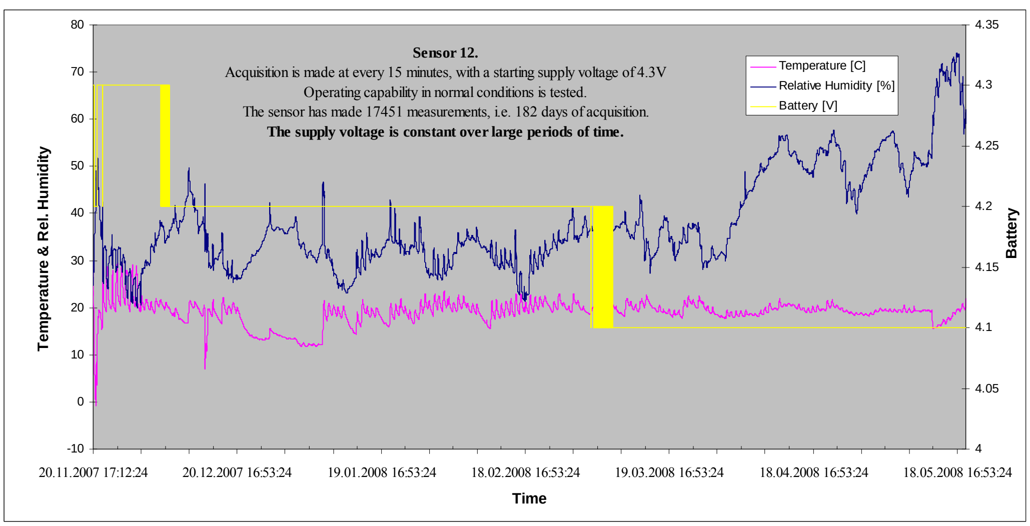

Fig. 7. Parameters acquired by a sensor over a period of 182 days.

From the point of view of the radio operating distance, the obtained results show that sensors and the CU equipped with a $\lambda/4$ whip antenna can communicate over larger distances than it was expected. In open field, the CU communicates in good conditions (no repeated transmissions) with sensors situated at over 300m.

Inside a reinforced concrete building, with same antennas, stable radio connections could be established between 4 floors (on vertical) and about 40 meters on horizontal.

In real operating conditions, medium quality batteries ensure a functioning period of about 12 months, for a sampling interval of 15 minutes. For this duty factor, the average current consumed by a sensor is of 50μA. The minimal voltage at which the sensors are still working is of 3.4V.

4. Tabels

Tabel 1

Main technical characteristics of the polluting gas sensors

Polluting Gas	NO2-B1	SO2-BF	H2S - BE	CL2 - B1	CO - BX	ETO - A1
Operating range (ppm)	0 to 20	0 to 100	0 to 2,000	0 to 20	0 to 2,000	0 to 100
Sensitivity (nA/ppm)	-600 to -1100	300 to 440	80 to 115	-600 to -950	70 to 120	1,600 to 3,200
Resolution (ppm, 33 ohm load resistor)	< 0.02	< 0.1	< 0.5	< 0.02	< 0.5	< 0.1
Response time (t90) (s)	< 60	< 30	< 35	< 60	< 40	< 75
Zero current (ppm equivalent @ 20°C)	< ± 0.2	< ± 0.5	< ± 0.7	± 0.2	< ± 2	± 0.2
Overgas Limit (ppm)	100	500	10,000	60	5,000	200
Operating life (months)	>24	> 24	>24	>24	>24	> 24
Temperature range (°C)	-30 to 50	-30 to 50	-30 to 50	-20 to 50	-30 to 50	-30 to 50
Pressure range (kPa)	80 to 120	80 to 120	80 to 120	80 to 120	80 to 120	80 to 120
Humidity range (%RH)	15 to 90	15 to 90	15 to 90	15 to 90	15 to 90	15 to 90
Load resistor (ohm) recommended	33	10 to 47	10 to 47	33	10 to 47	10 to 47

5. Conclusions

The intelligent network for microclimate and polluting gas monitoring is a flexible and modern sollution toward an accurate monitoring of sites in which cabled sensors can not be implemented because of conservation and aesthetic related reasons.

The radio connections established between the RH&T sensors and the CU are stable over large distances, covering a very large palette of applications, such as the microclimate monitoring of hystorical buildings, museums and art galleries.

Principal advantages of this equipment are:

- the radio interface used by sensors to transmit and receive data to and from the central unit is using the ISM license-free band at 434MHz. At these frequencies, the propagation within a building is better than it is at higher frequencies (e.g. 2.4GHz) which is used by most wireless sensors.

- intelligent sensors are using a message-based command set which allows the permanent reconfiguration of their important settings - alarm thresholds for temperature, relative humidity, battery voltage and sampling interval.

- the monitoring data are both wirelessly transmitted and stored into an internal nonvolatile memory with a capacity of 65000 data.

- the monitoring data are disseminated through internet, in real time, to authorized users.

- the CU can be accessed remotely, not only by internet, but also through a BlueTooth connection, providing a useful method to download data without entering the site if that is situated in a zone that can't be reached by mobile telephony operators. In this case, the operator can download data without opening the site, if this is an issue.

- if a communication link is available at the investigated site, such as internet, or a GSM network, then the central unit is capable of providing alarm e-mails or SMS messages to a number of authorized users.

Further improvements regard the possibility to send back-commands from final user to each sensor, in order to modify the acquisition parameters and the improvement of the LabVIEW application so that to act as a client/server node, able to disseminate data to a large number of third-party clients. Also, there is envisaged the redesign of the sensors, so that to dramatically diminish their production cost. This can be achieved by changing the microcontroller with a Completely new one, which has an embedded radio section, operating in the same ISM band.

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