



Report
**D 4.5 Guideline for the implementation of
monitoring system**

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Deliverable D4.5 Guideline for the implementation of monitoring system

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0 Abstract

Monitoring and automation systems are one of the main challenges to be addressed in every building because of the context constrains, especially in existing ones, in terms of impact on building functions and users operations. To fill the gap, several standard and open protocols are available in the market, such as LonWorks or BACnet, but also, new approaches such as ZigBee, which solves some typical wireless issues. In particular, cultural heritage presents further peculiar constrains, due to conservation and preservation issues.

Nevertheless, the monitoring system is very important in a retrofitting process because the collection of historical and real-time data are necessary to keep a log of the building behaviour. Thus, the status before and after refurbishment could be measured and compared in order to evaluate the effectiveness of a retrofitting strategy, as well as the achieved energy savings.

The installation of sensors and actuators are not the only question to be faced, being the software another important topic to be considered. Such a software includes, specific applications, monitoring interfaces, databases and other software which supports all the infrastructure and monitoring environment functioning. Commonly, this set of application is known as a Building Management System, including more functionality than only monitoring. It presents the capability of integrating control algorithms for active components and optimizing the performance of generation and distribution systems.

The report presents the requirements of a monitoring system and explains why the building should use this kind of system. Moreover, it presents the constraints and general restrictions to take into account when the monitoring system is set up in a historic building. More concretely, heritage and preservation issues are deeply analysed with a special interest. Furthermore, available protocols in the market which could fulfil the requirements and constraints are detailed. This section is extended with the ZigBee protocol developed in 3ENCULT where the identified restrictions have been coped. Last but not least, the Building Management System features and how to install it in a historic buildings are described.

1 Requirements for the monitoring system

The improvement of energy efficiency of historic buildings, does not only require the search of energy saving measures in compliance with preservation methods, but also the evaluation of the consequences of kind and intensity of the possible use of the buildings. In addition, the level of users required comfort must be carefully analysed and then assessed.

Frequently, the term “monitoring” stands for the collection of measurement data. The logging of measuring data is only a part of the monitoring. On one hand, monitoring is used for systematic collection, observation or controlling of technology systems operation, although the rerunning procedure is a central element of research program aimed at comparison of results. Secondly, another function of the monitoring is to be able to intervene to adjust the building functioning when is requested, providing for example warning when quantitative threshold values are exceeded. Based on this definition of the term "monitoring", the following basic questions have to be clarified before performing or giving away a monitoring task:

- definition of monitoring aims, e. g. pure data collection or data collection with evaluation of the stored data;
- definition of the planned structural measures;
- determination of the assessment criteria with the involved stakeholders;
- verification of the possible interventions on the building structures;
- choice of the monitoring system layout and components (different if only data collection or also control capability);
- description of the measured parameters and selection of the necessary sensors and meters;
- sharing decision among involved stakeholders about measurement points and sensor positions.

Very often only very few information about a building are available. Therefore, the detection of the state before retrofitting of the building is very important. In this context building climate studies taking into account monitoring objectives can be useful and cost-effective. With the help of an actual-state monitoring, damages can be prevented, for example, if the influence of the planned interventions (i.e. conversion, modification, installation of new or different heating systems, integration of interior insulation, window replacement and so on) could be estimated. Predictions on the impact of planned interventions on the energy and/or hygrothermal behaviour of the building structure can be derived from these measurements. Finally, recommendations of specific retrofit measures can be consequent derived from these forecasts.

In a historic building, the installation of a monitoring system permits to collect the relevant parameters and metrics for characterizing the energy behaviour. These information permits to reach the following aims:

- identification of the actual energy and environmental conditions of the building;
- validation of the energy simulations of the building;
- identification of the energy and environmental conditions of the building retrofitted;
- comparison among energy and environmental conditions of the building in the situation pre-interventions and post-interventions.

The main objective of the performed research activities was to identify the actual condition of the building. It is especially important to collect data of, for example, thermal bridges and other critical design details, since the interventions on a historic building can have a large impact on the hygrothermal conditions of the mentioned construction details. The detection of constructive details surface and surrounding (proximity or near-field) temperatures allows assessing the structural interventions in terms of their compatibility with existing constructive elements. For this reason it is already required to install a monitoring system with appropriate sensors to be placed on the affected building components.

The collected data allows the validation of building simulations and can also be used as real boundary parameters for detailed coupled hygrothermal simulations (e.g. FEM or CFD). The scope is therefore, by means of a suitable sensors network, to collect data of all the relevant parameters and metrics for characterizing the energy behaviour of the retrofitted building, the climate situation and comfort level in

the rooms, the climate-related stress on valuable surfaces, moisture and heat transmission, and actual energy consumption.

The implementation of a monitoring system can be useful even after the realization of structural intervention or building use conversion intervention. It is also possible that after the intervention critical not adjustable conditions arise. The outcome of this can be both damages on the building construction elements or historic surfaces as well as low level indoor environmental quality with relative users discomfort. With the help of monitored data, optimization strategies can be developed, which can then drive to the implementation of suitable control algorithms in a possibly existing building management system. Furthermore, technology systems operational modes can be verified and optimized, producing benefits in terms of both energy demand and user comfort.

1.1 Basics of monitoring

To evaluate the energy and hygrothermal behaviour of a historic building, a structural-climate monitoring is necessary. This allows on the one hand, an observation of the building structure, so depending on the kind and intensity of building use, possible threats to the buildings and facilities can be identified. On the other hand monitoring can give important information about the thermal comfort and energy consumption of a room or whole building. A further option consists in optimizing the operation of technological systems for heating, ventilation and air-conditioning.

The aim of monitoring is, therefore, by a suitable sensors network able to measure all relevant parameters and metrics, to characterize the energy performance of the building, the climate situation and the comfort in the rooms, the climate-related stresses on valuable surfaces, the moisture and heat transmission within the original and / or the retrofitting constructions components. To do this, the monitoring system must be objects-based planned and implemented. Table 1 gives an overview of functional measurement parameters.

Table 1: Measurement parameters and target (3EnCult consortium D 4.1)

Monitoring task	Parameter	Evaluation / Control variables
Room climate	<ul style="list-style-type: none"> • Temperature of air • Relative humidity of air • Concentration of CO₂ • Airflow • Solar radiation • Light level • Luminance 	<ul style="list-style-type: none"> • Users' comfort
Historical surfaces	<ul style="list-style-type: none"> • Temperature of air • Relative humidity of air • Air flow microclimate • Surface temperature of building envelope • Solar radiation • Light level 	<ul style="list-style-type: none"> • Occurrence of condensate • Development of mould / dry rot • Climate fluctuations • Phase transformation of salt • Light damage
Building construction	<ul style="list-style-type: none"> • Temperature microclimate • Relative humidity microclimate • Surface temperature of building envelope • Moisture content 	<ul style="list-style-type: none"> • Occurrence of condensate • Development of mould / dry rot
Energy	<ul style="list-style-type: none"> • Heat quantity • Hot water • Heat flux through the building envelope • Electricity 	<ul style="list-style-type: none"> • Energy efficiency • Energy performances

	<ul style="list-style-type: none"> • Lighting consumption • Global solar radiation • Temperature of air • Air infiltration through door/window 	
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With the assessment of all these state variables, an evaluation of the energy and physical behaviour of a building can reliably be evaluated. Furthermore based on this information, an adjustment and optimization of the operation of building services compatible to the demand for energy efficiency and preservation of monuments can be coped with.

The monitoring of buildings can be achieved with the following two tasks:

- monitoring of energy consumption and users' comfort;
- monitoring of conditions of historic construction components, nodes and surfaces.

With these two subtasks of the monitoring of buildings, the real-state behaviour of the historic building can be investigated, depending on the daily and annual ever-changing weather conditions and the internal loads, due to the use of the rooms.

1.2 Development of a monitoring concept in generally

Basis for the creation of a monitoring concept is a so-called basic evaluation of the building. Here, the building constructive details, the existing systems and any historic values findings are worked out. In this context, the following approach is being considered:

- Auditing of the constructive design details, existing constructive and technology components and systems, any existing historic surfaces, constructive details and structure and potential problems such as salt loads, thermal bridges, etc.;
- Collection and elaboration of previously possible measurements of energy consumption (heat meters, costing, energy bills, etc.);
- Collection and elaboration of any existing measurements related to indoor environmental quality, outdoor or surrounding climate, critical nodes and details, in particular related the historic constructive elements;
- Evaluation of existing building investigations, e.g. materials, components or system analyses, performance assessment (certification, mandatory inspections, ...), etc.;
- Definition of possible energy and indoor environmental quality improvements.

After reviewing the provided documents and after connecting with the responsible stakeholder (e.g. cultural heritage preservation, owner, architect), an individually optimized monitoring plan, tailored on specific object, can be designed and implemented. The resulting sensors network should be selected in advance so that the most of installed sensors could be integrated or connected with a possibly existing or foreseen automation system.

1.3 Energy and comfort

Figure 1 shows the sensor and meters positions, for the collection and recording of energy demand, user comfort and user behavior parameters and their location in the building.

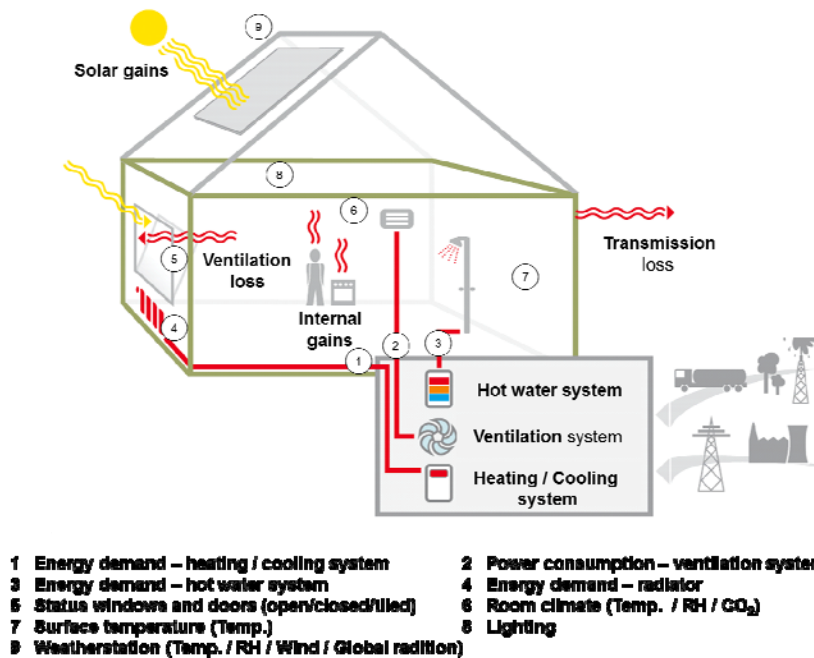


Figure 1: Energy and comfort monitoring

Often, the primary energy consumption of a building as it is, is calculated before the implementation of energy saving measures, by means of planning tools, such as e.g. PHPP (passive house planning package). If monitoring data are available for the purpose to control the energy demand, namely weather conditions, room temperatures, components U-values, as well as users behavior is known, it is possible to calibrate the building model to have results very close to the actual ones. On this basis the influences of the various proposed energy retrofitting, can then very well calculated and evaluated. The collection and recording of data should, if possible, be in relative short time intervals. In this context, the experienced data acquisition frequencies shown in Table 2 were demonstrated as useful.

Table 2: Sampling intervals depending on the measuring task

Measuring task	minimal interval	optimal interval
Energy demand	monthly	4 hours
Comfort/Utilization	5 minutes	1 minute
Outdoor/Indoor climate	5 minutes	1 minute

1.4 Historical surfaces

The possible interaction between external and indoor climate and the historical surfaces are often ignored. Figure 2 shows the required framework of investigations. As a result of an energy retrofitting, risks like critical climate fluctuations can appear in the proximity area of valuable historic surfaces. This can occur due to, e.g. heating, cooling, ventilating, humidify and dehumidify. The installation of active systems for indoor environmental control are not the only measure that could lead to a change in climate conditions in the surfaces (e.g. painted with a fresco) proximity.

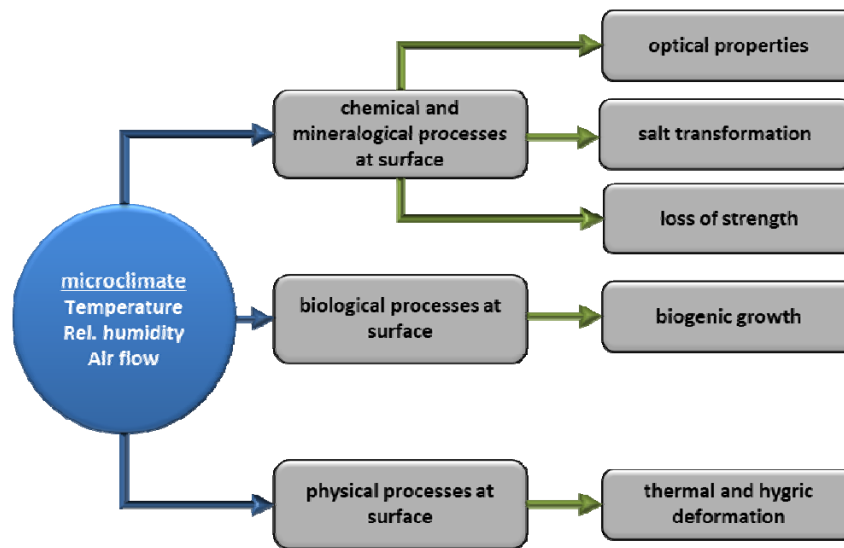


Figure 2: Interaction – Climate and historical surfaces

Energy saving measures such as, for example, the installation of an inside thermal insulation could produce as well some extremely complex transient hygrothermal conditions in the proximity area of inner construction layers. A first assessment of the risks of historically valuable surfaces bring to the need to collect data of the environmental conditions in the proximity of inner construction layers, e.g. by surface temperature sensors, near-field temperature and humidity sensors, with several measurement points effectively distributed in the room to spatially cover all the exposed surfaces. Accurate knowledge of hygrothermal material properties, potential loads to salt crystallization as well as restoration, repair and modernization measures, which were carried out in the past, are mandatory to evaluate near field possible stresses. The assessment criteria required in this context are usually provided by the restorers or the conservation authorities. However, the thresholds identified in Table 3 can be useful as a first assessment basis:

Table 3: Assessment criteria

Parameter	Set-point
Temperature [°C] seasonal	10 - 26
Relative humidity [%] seasonal	40 - 60
Fluctuation relative humidity [%/h]	10 %
Heating- or cooling rate [K/h]	1

1.5 Critical construction details

Another monitoring objective is to record the state of the building as a result of an energy retrofit. Particularly important here is the detection of, for example, thermal bridges, beam ends and other critical design details. Indeed, the retrofitting of the historic building by means of structural measures can have a major influence on the hygro-thermal status of these construction details. The surface temperature and the environmental conditions in the construction details proximity, allow evaluating the structural measures impact and compatibility with existing building components. To this aim it is absolutely necessary to install appropriate sensors to the potentially affected components. Key evaluation criteria at the inner wall surfaces and/or in the layer behind the insulation level are connected to the following phenomena: water condensation, climate conditions favoring biogenic infestation.

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EN ISO standard 13788:2001 11, the Merkblatt of the WTA 6-4:2009-05 "*Innendämmung nach WTA I: Planungsleitfaden* (Inside insulation according to WTA I: Planary guide)" and the corresponding European/National Standards, gives more information on the assessment of the climate conditions in the surrounding of the already mentioned construction details.

2 Monitoring systems

Several and various are the monitoring systems available in the market. A lot of standard, open and proprietary protocols are nowadays installed in the buildings. Nevertheless, the current trend is the deployment of standard and open ones because they are able to communicate in heterogeneous networks and there are a lot of tools for managing and gathering data from the network. Furthermore, they allow the development of ad hoc applications for connecting external software or tools in the sensor network. Some examples of standard and open protocols are BACnet, LonWorks, Modbus, OPC, ZigBee, Z-Wave or EnOcean. With regard to proprietary protocols, Kieback&Peter, Panasonic ECO-I or ANT are a set of instances.

2.1 Available protocols

Within this chapter, some of the main protocols are explained in more detailed, focusing on the advantages and disadvantages of each one in order to bear in mind the possible solutions in the buildings. With this overview, the final decision of the implementation of a specific protocol in the building depends on the features of the protocol and the characteristics of the building. Taking care of these variables, the selection must be done according to a balance between both issues.

2.1.1 LonWorks

LonWorks is defined as a networking platform specifically created to address the needs of control applications (Echelon, Dhingra 2006). “LonWorks is an open networking solution for building automation and control networks that was developed by the American company Echelon. It is designed in such a way that it can be used in centralized building automation controllers as well as in decentralized building control components. LonWorks is a standardized bus system (ANSI/CEA-709.1-B and ISO/IEC DIS 14908) that enables intelligent devices to communicate with each other over a locally operated control network (LON stands for Local Operating Network).” (Echelon) “LON technology has become an integral part of building control. Distributing measurement, monitoring and control functions, among local, de-centrally installed components means that you can customize a variety of comfort solutions for an individual room. For instance, there is a wide range of sensors and actuators on the market for implementing the following functions:

- Heating, cooling and ventilation
- Lighting control
- Shade/blind control
- Security
- Multimedia (Echelon)

On the other hand, LonTalk is the protocol that defines how the LON devices are programmed for different applications and how they communicate with each other as nodes in a network (Echelon, Dhingra 2006). Each network device has a transceiver (short for transmitter and receiver). The transceiver provides a physical communication interface between a LonWorks device and a LonWorks network. The transceiver are usable in different transmission media such as twisted pair, which is the most commonly used, power line, radio frequency and optical fibre.

One great advantage of LON technology, as happen with open and standard protocols, is the interoperability that is the capability of communication among different devices from several manufactures to be able to exchange information with each other. It is extremely important because the LonMark Interoperability Association (Echelon) is responsible for defining a device's basic functionality and minimum requirements as well as the standard network variable types. For example a smoke detector could invoke an air conditioning system to switch off and instruct windows to open to extract the smoke.

To sum up, using LON technology in building automation provides benefits such as:

- Comfort and convenience

- Efficiency through energy management functions
- Flexibility through the reprogramming options available
- Security

“In the LonTalk protocol, bus nodes (devices) that have equal access right to the transmission channel use the predictive p-persistent Carrier Sense Multiple Access (CSMA) protocol to communicate with each other.” (Echelon) A physical connection between the LON nodes is a prerequisite to communication. The LON nodes exchange the actual data using network variables, a standardized way to represent data for interoperability. The LonMark Interoperability Association has defined a set of rules so the different network variables could be standardized (known as Standard Network Variable Types, SNVTs). “The following definitions have been defined for the most commonly used variables:

- Area of application
- Name of the network variable type
- The variable’s configuration
- The total length in bytes
- Value range, degree of precision and units” (Echelon)

Considering the historical context of the project, LonWorks presents some advantages as the aforementioned interoperability, the flexibility for installing the devices, the scalability of a current network by integrating new sensors, the simplicity of installation and configuration, as well as the huge range of sensors available which cover the needs in historical buildings. As the main disadvantage, it could be noted that the most common media is twisted pair, which means it is required visible cables in the building or a modification in the structure of the building in order to hide these wires, which is not allowed in a lot of buildings. However, it could be solved by means of using radio frequency channels and devices compliant. Yet, the challenge of wireless sensors is the range of communication and the possibility of requiring the usage of devices as signal repeaters that increases the costs of the installation.

2.1.2 BACnet

“BACnet (Building Automation and Control Network) is a standardized data communication protocol developed by ASHRAE for use in building automation to enable devices and systems to exchange information.” (Newman 2012, ASHRAE) BACnet was developed to cover the need for a standardized data communication protocol that would allow systems from various vendors, such as HVAC, lighting, security and fire systems, to communicate with each other by providing standardized methods for presenting, requesting, interpreting, and transporting information, ensuring interoperability and manufacturer independence (Newman 2012, ASHRAE).

The main goal of BACnet is to provide interoperability between devices, so that devices coming from different vendors or of different generations could work together through the digital exchange of information. This is achieved by dividing the building automation functions in five interoperability areas (IAs):

- Data Sharing
- Alarm and Event Management
- Scheduling
- Trending
- Device and Network Management (Campus21, 2012)

In building automation the distributed system can be depicted using a three layers model (Management level, Automation level and Field level). Field level is responsible for measurements, positioning and metering. Automation level is responsible for measurement, control and regulation processes. Furthermore, monitoring, energy management and operation building management functions belong to Management level. “BACnet can be used at all levels of building automation, but is

particularly suited for management functions. As a result, is preferably used as a superordinate system in larger installations with LonWorks and KNX used in field level even though there is a BACnet implementation for the field level.” (ASHRAE)

On the lower level communication layers (first and second layer according to OSI reference model, ISO 7498), messages can be transported through Ethernet, MS/TP, LONTALK, ARCNET or even point-to-point connections over a telephone line. Wireless communication is also possible through Wireless LAN (WLAN). “BACnet supports Internet Protocol (IP) and therefore enables global networks to be interconnected (BACnet/IP). IP is a network layer protocol and is responsible for routing packets through a complex network.” (ASHRAE) Thus, the capability for integrating the protocol in cultural heritage is as high as happened in LonWorks both in wired environments and wireless ones with the constraints of signal range. (Campus21 2012)

BACnet devices store information, such as the temperature reading from a sensor or a control command, in an object-oriented approach. Objects in BACnet are abstract data structures in which information is stored as object properties. Objects have readable (R) and/or writable (W) properties which can be optional or mandatory for each object type, providing a huge span of available devices and sensors covering the monitoring needs in historical buildings. (Campus21 2012)

2.1.3 KNX

“KNX, formerly known as the European Installation Bus (EIB), is a building control communication technology used to connect devices such as sensors, actuators, controllers, operating terminals and monitors. KNX technology is designed to be used in electrical installations for implementing automated functions and processes in buildings.” (KNX) KNX is approved as an International Standard (ISO/IEC 14543-3) as well as European Standard (CENELEC EN 50090 and CEN EN 13321-1) and Chinese Standard (GB/Z 20965). This makes KNX a worldwide open standard for home and building control. Open, in this context means that devices from different manufacturers can communicate with each other over KNX. (KNX) KNX technology can be implemented with different transmission media for the field network: Twisted-pair cable, power line (KNX.PL), radio frequency (KNX.RF), fibre-optic cable and more, providing the same ability to be integrated in historical buildings. Moreover, it offers the chance of integrating different transmission media in the same network, giving a greater level of flexibility. The more problematic issue arises in the compatibility of old implementations with newer because few changes are required.

“The KNX products listed in the manufacturers catalogues can be classified into four main groups:

- System components (power supply units, accumulators, line couplers, backbone couplers, line repeaters, bus couplers, and RS-232 or USB interfaces)
- Sensors (switch sensors, motion detectors, glass break detectors)
- Actuators (switch, blind or shutter actuators)
- And others devices such as logical components and control panels” (KNX)

2.1.4 1-wire

The 1-Wire bus is a simple signalling scheme that performs half-duplex bidirectional communications between a master controller and one or more slaves sharing a common data line. Both power delivery and data communication take place over this single line, making 1-Wire devices unmatched in their ability to provide key functions to systems where interconnect must be minimized. The 1-Wire products provide combinations of memory, mixed-signal, and secure authentication functions through a single-contact serial interface. Typical applications of 1-Wire devices are:


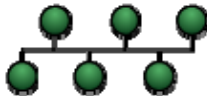



1-wire is the name for a simple and powerful bus system, which is almost arbitrarily expandable. It is suitable particularly for sensors, for control and reporting, as well as for the identification through unique and unchangeable 64 bit serial numbers. In the field of building automation in particular are 1-wire sensors interesting, because of the very low price, easy wiring in particular for measuring temperature, humidity, barometric pressure, air quality, ambient light, capture window contacts, etc..

The optimal function of the 1-wire bus is determined especially of three parameters:

1. Selection of the correct bus master and its control by the software

2. Number of sensors and the sum of the lengths of all lines
3. Used topology (cf. Table 4)

Table 4: Overview of the different topologies for the 1-wire bus

Type of the 1-wire installation	Description	Permissible	Length Number of sensors	Recommended
Line with breakout	Tree structure 	yes	50 – 100 m 10 - 20 Sensors	for small installations
Bus with short breakout (few meters)	Tree structure, short breakout 	yes	up to 100 m	nearly optimal length expansion possible
Sensors are in row	Line 	yes	up to 150 m	optimal installation, maximum range
Sensor lines are combined at a point	Star 	yes	up to 100 m max. 10 Sensors	for small installations
Connecting the end with the beginning	Ring 	no		No function

2.1.5 Z-wave

The Z-Wave protocol is an interoperable wireless RF-based communications technology designed specifically for control, monitoring and status reading applications in residential and light commercial environments.

Z-wave offers the following features:

- Low Powered RF communications technology that supports full mesh networks without the need for a coordinator node;

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- Operates in the sub-1GHz band; impervious to interference from Wi-Fi and other wireless technologies in the 2.4-GHz range (Bluetooth, ZigBee, etc.);
- Designed specifically for control and status apps, supports data rates of up to 100kbps, with AES128 encryption, IPV6, and multi-channel operation;
- The physical and media access layers (MAC and PHY) are described by ITU-T G.9959 specification;
- Full interoperability through layer 5 with backwards compatibility to all versions;
- Successfully bridged and trialed with OpenADR, SEP 1, SEP 1.1 and other Smart Energy protocols;
- Shares the same position in the NIST / SGIP Catalogue of Standards as the IEEE 802.11 and 802.15 and 802.16 families.

Each Z-Wave network may include up to 232 nodes, and consists of two sets of nodes: controllers and slave devices. Nodes may be configured to retransmit the message in order to guarantee connectivity in the multipath environment of a residential house. Average communication range between two nodes is 30.5 m (100 ft), and with message ability to hop up to four times between nodes, this gives enough coverage for most residential houses.

As of 2013, Z-Wave is supported by over 160 manufacturers worldwide that offer more than 900 different products certified by the *Z-Wave Alliance* - <http://www.z-wavealliance.org/>.

Topology and routing

Each Z-Wave network is identified by a Network ID, and each device is further identified by a Node ID. The Network ID is the common identification of all nodes belonging to one logical Z-Wave network and has a length of 4 bytes (32 bits) and is assigned to each device, by the primary controller, when the device is "included" into the Network. Nodes with different Network ID's cannot communicate with each other. The Node ID is the address of a single node in the network and has a length of 1 byte (8 bits). It is not allowed to have two nodes with identical Node ID on a Network.

Z-Wave uses a source-routed mesh network topology, and has one Primary Controller and zero or more Secondary Controllers that control routing and security. Devices can communicate to one another by using intermediate nodes to actively route around and circumvent household obstacles or radio dead spots that might occur. A message from node A to node C can be successfully delivered even if the two nodes are not within range, providing that a third node B can communicate with nodes A and C. If the preferred route is unavailable, the message originator will attempt other routes until a path is found to the C node. Therefore, a Z-Wave network can span much farther than the radio range of a single unit; however, with several of these hops a slight delay may be introduced between the control command and the desired result.

In order for Z-Wave units to be able to route unsolicited messages, they cannot be in sleep mode. Therefore, battery-operated devices are not designed as repeater units. A Z-Wave network can consist of up to 232 devices, with the option of bridging networks if more devices are required.

As a source-routed static network, Z-Wave assumes that all devices in the network remain in their original detected position. Mobile devices, such as remote controls, are therefore excluded from routing. In later versions of Z-Wave, new network discovery mechanisms were introduced. So-called "explorer frames" can be used to heal broken routes caused by devices that have been moved or removed. Explorer frames are broadcast with a pruning algorithm and are therefore supposed to reach the target device, even without further topology knowledge by the transmitter. Explorer frames are used as a last option by the sending device when all other routing attempts have failed.

2.1.6 ZigBee protocol

ZigBee is a specification for a suite of high level communication protocols used to create personal area networks built from small, low-power digital radios. ZigBee is based on an IEEE 802.15 standard. Though low-powered, ZigBee devices can transmit data over long distances by passing data through intermediate devices to reach more distant ones, creating a mesh network; i.e., a network with no centralized control or high-power transmitter/receiver able to reach all of the networked devices. The

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decentralized nature of such wireless ad hoc networks makes them suitable for applications where a central node can't be relied upon.

ZigBee is used in applications that require only a low data rate, long battery life, and secure networking. ZigBee has a defined rate of 250 kbit/s, best suited for periodic or intermittent data or a single signal transmission from a sensor or input device. Applications include wireless light switches, electrical meters with in-home-displays, traffic management systems, and other consumer and industrial equipment that requires short-range wireless transfer of data at relatively low rates. The technology defined by the ZigBee specification is intended to be simpler and less expensive than other WPANs, such as Bluetooth or Wi-Fi.

ZigBee networks are secured by 128 bit symmetric encryption keys. In home automation applications, transmission distances range from 10 to 100 meters line-of-sight, depending on power output and environmental characteristics.

ZigBee was conceived in 1998, standardized in 2003, and revised in 2006. The name refers to the waggle dance of honey bees after their return to the beehive.

ZigBee is a low-cost, low-power, wireless mesh network standard. The low cost allows the technology to be widely deployed in wireless control and monitoring applications. Low power usage allows longer life with smaller batteries. Mesh networking provides high reliability and more extensive range. ZigBee chip vendors typically sell integrated radios and microcontrollers with between 60 KB and 256 KB flash memory.

ZigBee operates in the industrial, scientific and medical (ISM) radio bands: 868 MHz in Europe, 915 MHz in the USA and Australia and 2.4 GHz in most jurisdictions worldwide. Data transmission rates vary from 20 kilobits/second in the 868 MHz frequency band to 250 kilobits/second in the 2.4 GHz frequency band.

The ZigBee network layer natively supports both star (each device is radio connected to the coordinator device) and tree (there are routers devices able to repeat the radio signals coming from other devices and leaves devices that can not repeat radio signal. The network has a tree structure with a parenthood to each device and the root device is called coordinator) typical networks, and generic mesh networks (router devices can repeat the radio signal to other routes without respect the parenthood as in the tree network). Every network must have one coordinator device, tasked with its creation, the control of its parameters and basic maintenance. Within star networks, the coordinator must be the central node. Both trees and meshes allow the use of ZigBee routers to extend communication at the network level.

ZigBee builds upon the physical layer and media access control defined in IEEE standard 802.15.4 (2003 version) for low-rate WPANs. The specification goes on to complete the standard by adding four main components: network layer, application layer, ZigBee device objects (ZDOs) and manufacturer-defined application objects which allow for customization and favor total integration.

Besides adding two high-level network layers to the underlying structure, the most significant improvement is the introduction of ZDOs. These are responsible for a number of tasks, which include keeping of device roles, management of requests to join a network, device discovery and security.

ZigBee is not intended to support powerline networking but to interface with it at least for smart metering and smart appliance purposes.

Because ZigBee nodes can go from sleep to active mode in 30 ms or less, the latency can be low and devices can be responsive, particularly compared to Bluetooth wake-up delays, which are typically around three seconds.[4] Because ZigBee nodes can sleep most of the time, average power consumption can be low, resulting in long battery life.

The application layers are:

- ZigBee Home Automation 1.2
- ZigBee Smart Energy 1.1b
- ZigBee Telecommunication Services 1.0
- ZigBee Health Care 1.0

- ZigBee RF4CE – Remote Control 1.0
- ZigBee RF4CE – Input Device 1.0
- ZigBee Light Link 1.0
- ZigBee IP 1.0
- ZigBee Building Automation 1.0
- ZigBee Gateway 1.0
- ZigBee Green Power 1.0 as optional feature of ZigBee 2012

However the Zigbee protocol does not permit the routers to sleep, so a Tree or Mesh network should have the router always on reducing their operative time with small commercial batteries. In a typical Zigbee network with Tree or Mesh topology, the router and the coordinator are not batteries supplied.

2.1.7 Summary

This chapter summarises the features, advantages and disadvantages of the before described protocols for monitoring systems.

Feature	LonWorks	BACnet	KNX	1-wire	Z-wave	ZigBee
Wire/less	Both	Wire	Wire	Wire	Wireless	Wireless
Standard	Yes	Yes	Yes	No	No	Recommendation
Interoperability	Yes	Yes	Yes	Yes	Yes	Yes
Comfort sensor	Yes	Yes	Yes	Yes	Yes	Yes
Energy sensor	Yes	Yes	Yes	Yes	Extended	Extended
Easy-to-use	No	No	No	Yes	Yes	Yes
Read/Write	Yes	Yes	Yes	Limited	Yes	Limited
Bit rate	High	High	High	Low	High	High
Device size	Medium	Medium	Medium	Small	Small	Small
Energy needs	Always on	Always on	Always on	Always on	Always on	Sleep nodes

Table 5: Summary of the monitoring system protocol features

With all the features gathered, the most appropriate for the 3EnCult requirements is the ZigBee based networks. First of all, historic buildings present constraints and restrictions from the monitoring installation point of view, due to the cultural value. Then, it is forbidden in many cases the installation of wired sensor network in order to avoid both aesthetical damages and structural ones. Another important point is the interoperability because different manufactures could develop devices under the same protocol but without the possibility of communication among them, which is not recommended at all. Moreover, the use of standard protocols allows the integration and replicability of the systems. ZigBee is not a standard but a recommendation, being widely used in the world marketplace. Furthermore, it is easy-to-use, although it presents limited capabilities in the actuation. However, it can be solved by the extension of control devices. Also, it has a high bit rate, permitting the transmission of multiple data-point values in a short period of time. Last but not least, the nodes are able to sleep

saving energy, being one of the most important features because it increases the duration of the batteries for a long time.

2.2 3ENCULTWSN

The 3ENCULT project aimed to realize a new Wireless Sensor Network system targeting the cultural heritage building monitoring for preservation purpose. The System developed, called hereafter 3EncultWSN, is a wireless network able to sense several building climate parameters and collect them in a central server unit. The central unit can exploit the data collected to perform environmental analysis and hazard condition detection. Moreover the data can be used by a building management system in order to perform automatic building HVAC control.

The 3EncultWSN was designed to be easy installable, with small size and reduced building impact, with long last operative time, reduced maintenance, remote configuration, remote management and update and compatibility with other system like web server and HVAC control (3EnCult consortium D4.3).

The 3EncultWSN is a network of small electronic boxes able to collect data from several environmental sensors and send them via radio to the central unit. The electronic boxes are the Wispes W24TH motes (see Figure 3), which have 32bit microcontroller, battery charger, 128kbyte of RAM, IEEE802.15.4 radio transceiver, accelerometer, temperature sensor, humidity sensor, light intensity sensor, gas sensor connector and expansion connector. The W24TH has top of class power management system permitting it to work with 2 AA batteries for years. The mote is enclosed in a 98 x 54 x 29 mm box.

Sensor Specifics:

Temperature: 14bit codification, 0.01°C resolution, ± 0.3 accuracy, -40 to 125°C operative range.

Humidity: 12bit codification, 0.04% RH resolution, $\pm 2\%$ RH accuracy, 0 to 100% RH operative range.

Ambient light sensor: 0.23 to 100,000 lux operative range, $\pm 15\%$ Accuracy.



Figure 3: Wispes W24TH mote

The 3Encult partner DEI-UNIBO has developed the entire software layers to permit the W24TH to create a network, collect data from multiple sensors and send them to the central unit. The 3EncultWSN is built upon the IEEE802.15.4 radio protocol, permitting the network to be compatible with ZigBee devices.

The new radio layer is able to manage and create both star (each device is radio connected to the coordinator device) and tree (there are routers devices able to repeat the radio signals coming from other devices and leaves devices that can not repeat radio signal. The network has a tree structure with a parenthesis to each device and the root device is called coordinator) topology network where routers can sleep. The capability of the router to sleep is essential to monitoring Cultural Heritage Buildings. In fact the monitoring can be performed for years in a building without electrical current or

Deliverable D4.5 Guideline for the implementation of monitoring system

with reduced current plug. To cover the whole building the network should have a tree structure due to the low radio power of each mote. Moreover having routers able to sleep avoids the realization of leaves devices making the network structure and installation easier. Figure 4 shows the network topology in the Palazzina della Viola as an installation example. The 3EncultWSN has the capability to auto configure the network structure like ZigBee, furthermore gives to the user the possibility to customize the network with manual configuration. The 3EncultWSN provides all the information to analyse the network performance and permit to the user to do the network maintenance and configuration remotely. Respect Zigbee, the new wireless system has a strong time synchronization that avoids data collision and provides better data time stamp. Others functionalities introduced are: remote network management, remote device configuration, over the network firmware update and network clock time.

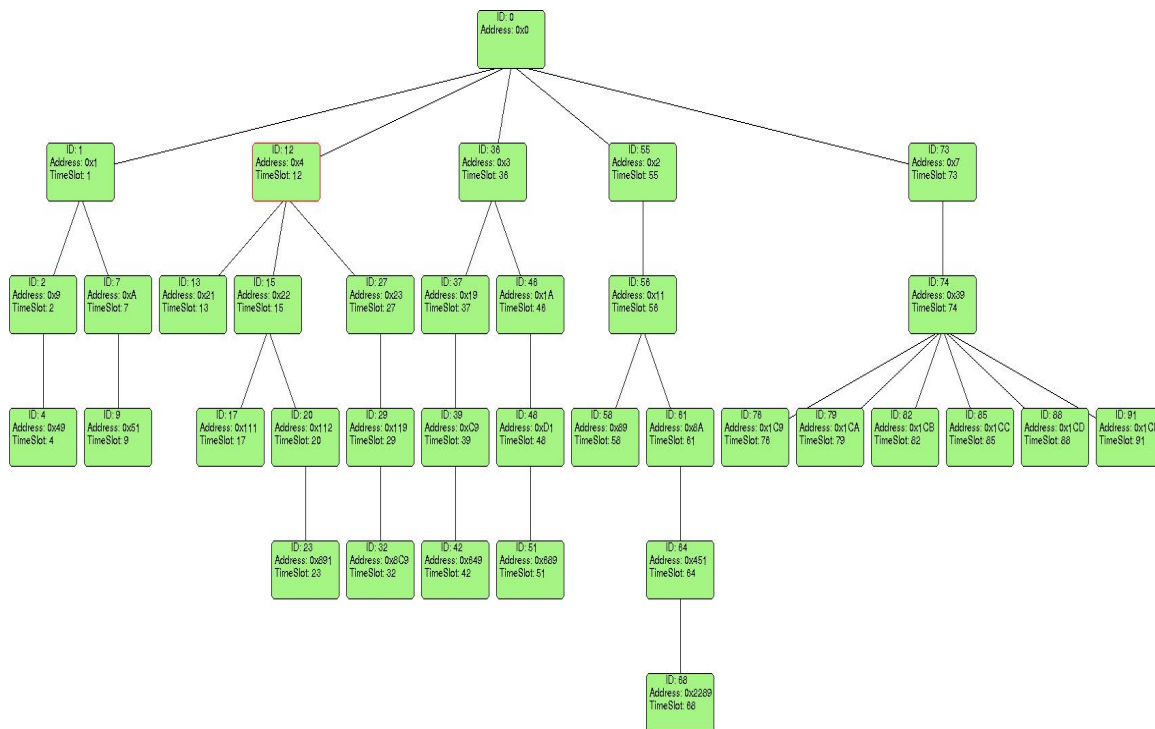


Figure 4: 3EncultWSN Tree network topology deployed in the “Palazzina della Viola”

The users can interact with the 3EncultWSN using the java application “javaTerminal” able to run in several commercial system like, pc, pc board, smartphone and tablet called afterword gateway (see Figure 5).

Deliverable D4.5 Guideline for the implementation of monitoring system

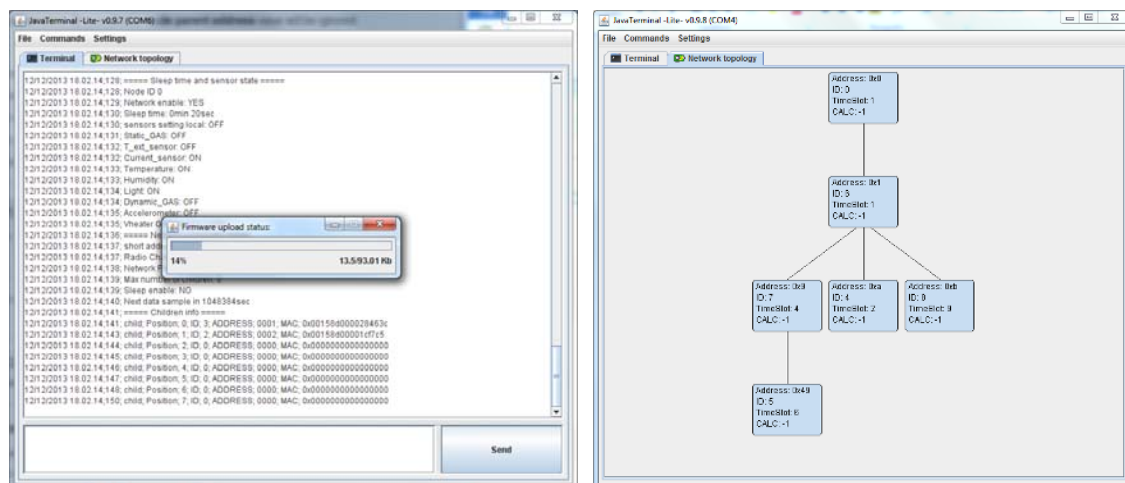


Figure 5: javaTerminal application

With the javaTerminal application the user can: configure a new network; collect and visualize the data; remote control each mote in the network; set the sensors enables; select the time acquisition interval; visualize the network structure; update the system software; send the data to a remote server for internet base application and building management application.

2.2.1 How to deploy the ZigBee sensor network

To install a new network the user has to connect the coordinator mote (which is a W24TH with coordinator firmware inside) to the gateway by USB cable (see Figure 6).



Figure 6: 3EncultWSN installation and test with 100 motes

After that, he/she has to position the others W24THs in the building where he/she would like to collect data (the others W24THs must have the sleepend firmware inside). During the installation, the user has to switch on each mote. Every mote has an ID number that identify the mote physically. The coordinator has ID equal to zero.

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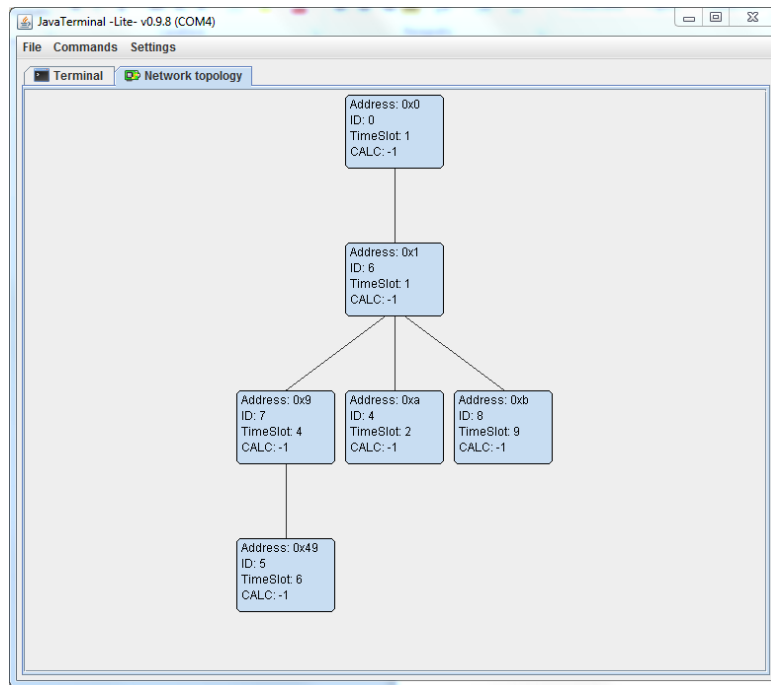


Figure 9: JavaTerminal with the network structure

When each mote is inside the topology, the user has to select “Commands” – “Calculate Time Slot” to set the transmission time of each mote (see Figure 10).

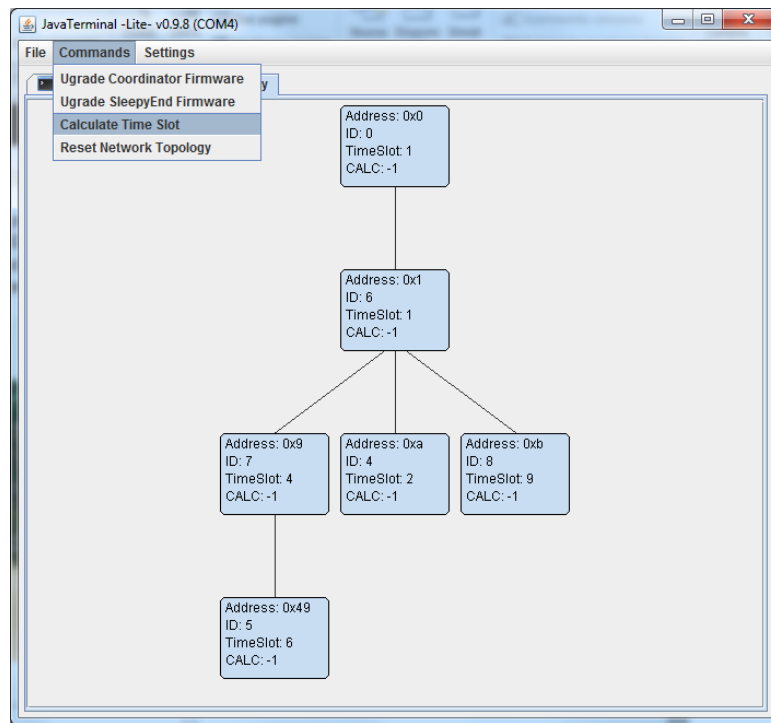


Figure 10: JavaTerminal Commands – Calculate Time Slot selection

Select yes and each mote will be set with the calculated time slot (see Figure 11).

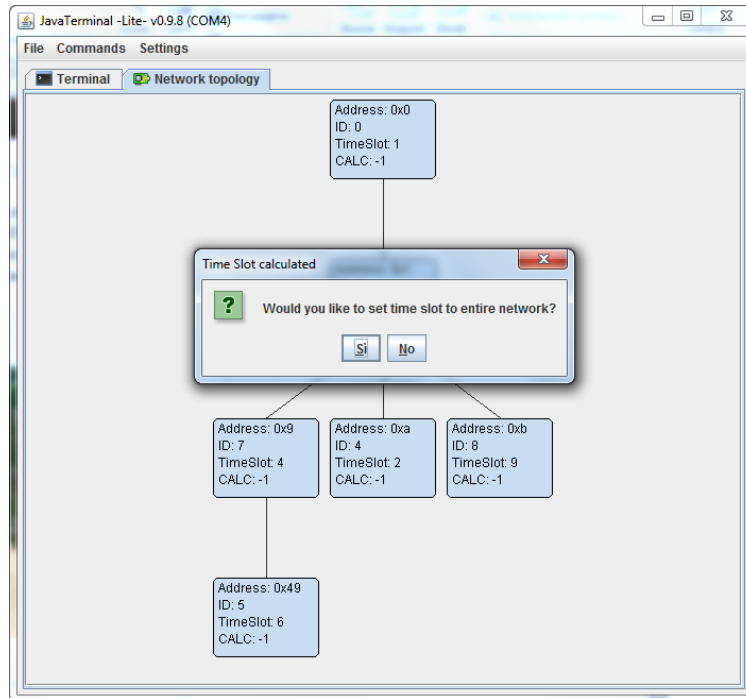


Figure 11: JavaTerminal Time Slot calculation

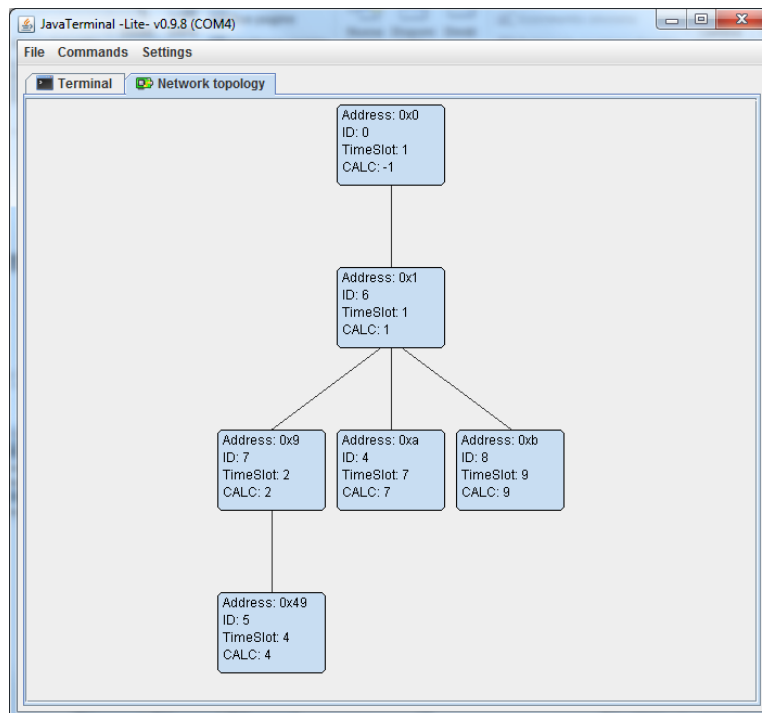


Figure 12: JavaTerminal with network topology with right time slot

Now the network is ready to collect data and the user can set the time sample interval typing $w=60$ to receive a data every minute (see Figure 13).

Deliverable D4.5 Guideline for the implementation of monitoring system

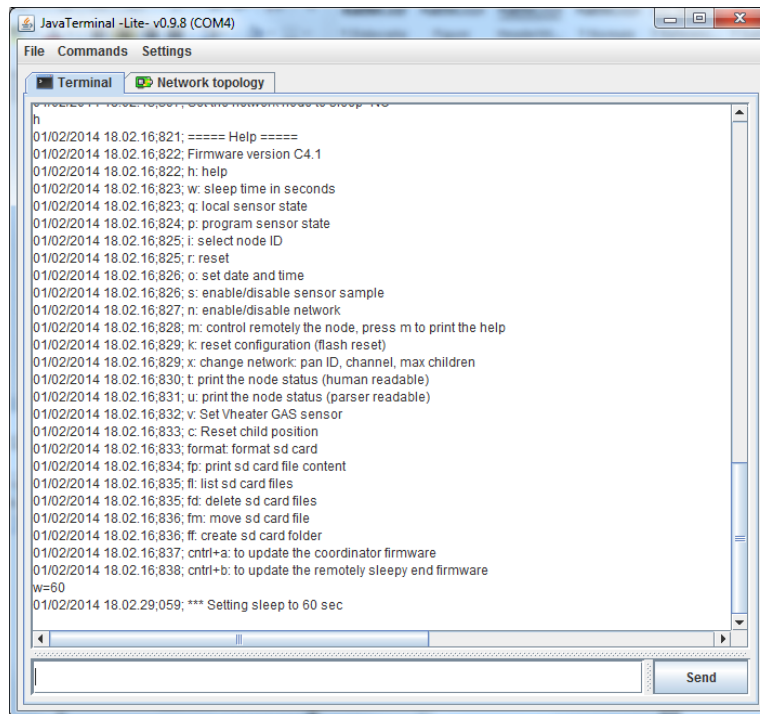


Figure 13: JavaTerminal with command w=60 executed

To start the data sample the user has to type s. The user can stop the data acquisition to perform a network maintenance typing again s (see Figure 14 and Figure 15).

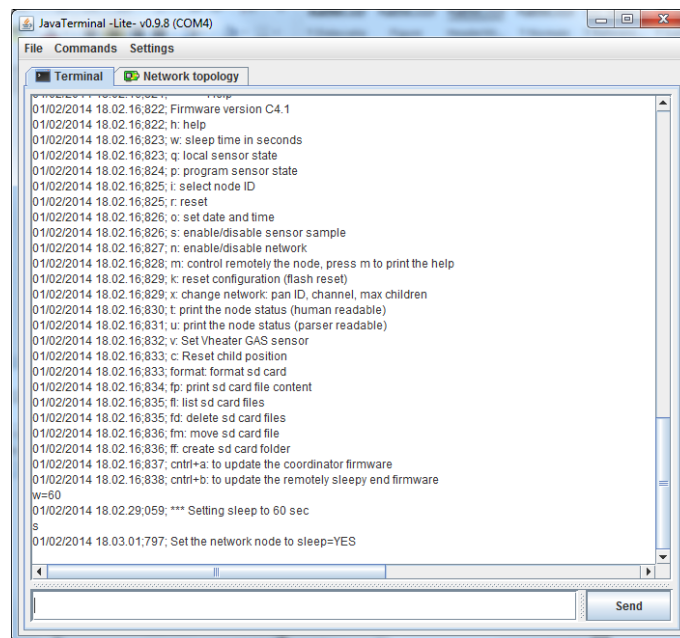


Figure 14: JavaTerminal with command s executed

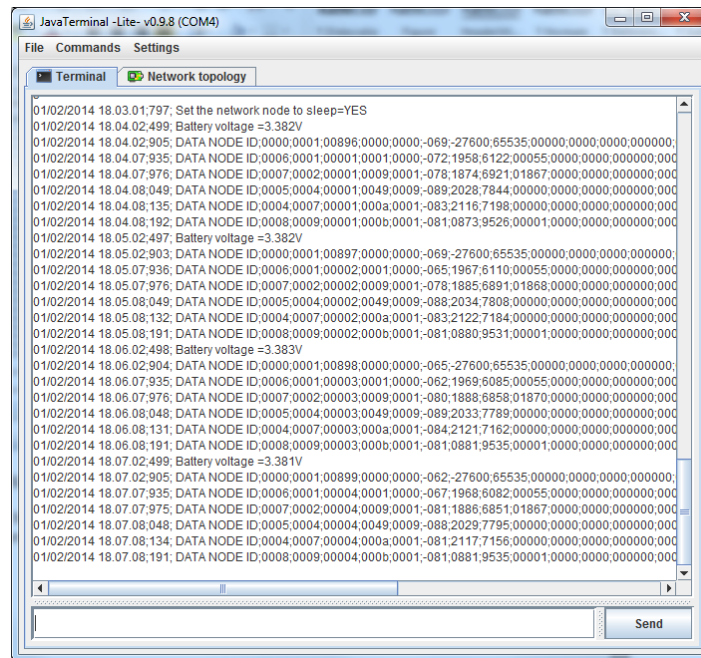


Figure 15: JavaTerminal with incoming data

The user can select to store the data incoming locally in a text file, or and remotely to a FTP server. The FTP server configuration is inside the file ftp.xml that must be in the same directory of the javaTerminal (see Figure 16).

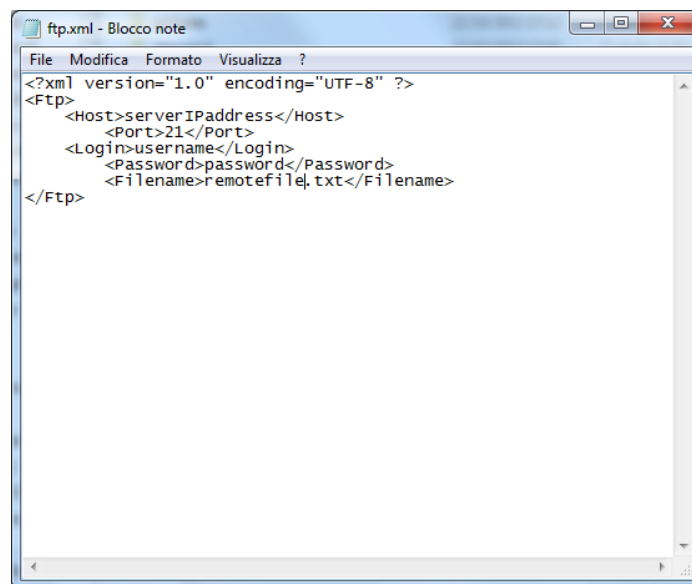


Figure 16: ftp.xml file opened with windows block notes

In the ftp.xml file the user has to set the FTP server url, user name and password and the name of the remote file that will be update with the new sensors' data collected.

To activate both local and remote data logging the user has to select the menu "Setting" – "Log" as shown in Figure 17.

Deliverable D4.5 Guideline for the implementation of monitoring system

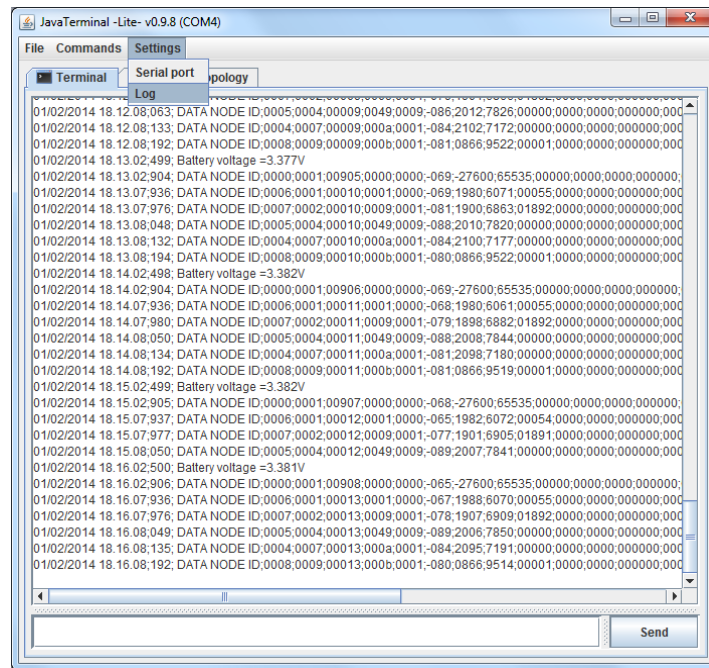


Figure 17: JavaTerminal Setting – Log selection

In the “Log setting” window the user checks the automatically log to file and FTP, moreover the user can select every kbyte the log will be performed (see Figure 40). To have a fast log select 1 kbyte, whereas if the user have a slow internet connection or connection not available every time, the user can choose to log data with higher interval like 100 kbytes.

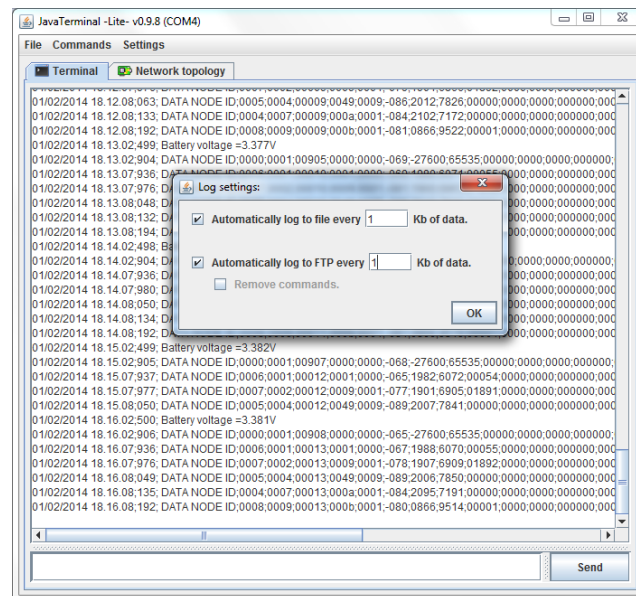
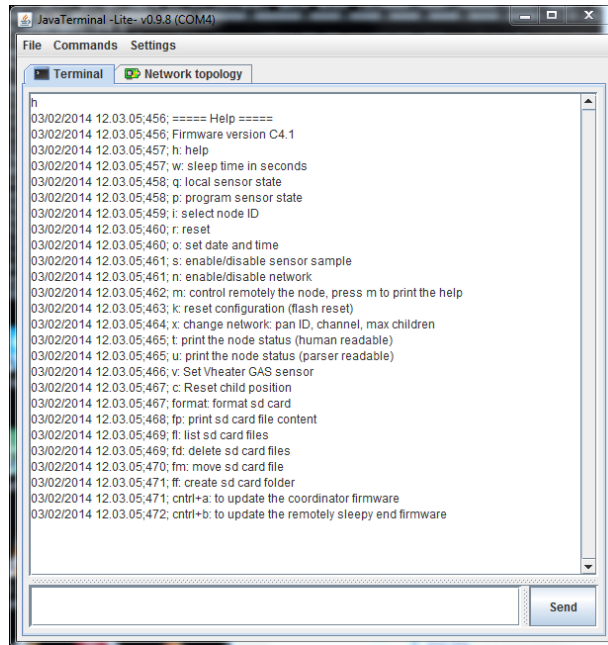


Figure 18: JavaTerminal log setting

Deliverable D4.5 Guideline for the implementation of monitoring system

The javaTerminal has also a built-in help viewable typing h. With the set of commands present in the system, the user can customize the whole network to reach the desired performance and configuration.



The screenshot shows a JavaTerminal window titled "JavaTerminal -Lite- v0.9.8 (COM4)". The window has a menu bar with "File", "Commands", and "Settings". Below the menu bar are two tabs: "Terminal" (selected) and "Network topology". The main area of the window displays a list of commands and their descriptions, each preceded by a timestamp. The commands listed are: h (help), w (sleep time in seconds), q (local sensor state), p (program sensor state), i (select node ID), r (reset), o (set date and time), s (enable/disable sensor sample), n (enable/disable network), m (control remotely the node, press m to print the help), k (reset configuration (flash reset)), x (change network: pan ID, channel, max children), t (print the node status (human readable)), u (print the node status (parser readable)), v (Set Vheater GAS sensor), c (Reset child position), format (format sd card), fp (print sd card file content), fl (list sd card files), fd (delete sd card files), fm (move sd card file), ff (create sd card folder), cntrl+a (to update the coordinator firmware), and cntrl+b (to update the remotely sleepy end firmware). A "Send" button is located at the bottom right of the window.

```
h
03/02/2014 12.03.05:456; ===== Help =====
03/02/2014 12.03.05:456; Firmware version C4.1
03/02/2014 12.03.05:457; h: help
03/02/2014 12.03.05:457; w: sleep time in seconds
03/02/2014 12.03.05:458; q: local sensor state
03/02/2014 12.03.05:458; p: program sensor state
03/02/2014 12.03.05:459; i: select node ID
03/02/2014 12.03.05:460; r: reset
03/02/2014 12.03.05:460; o: set date and time
03/02/2014 12.03.05:461; s: enable/disable sensor sample
03/02/2014 12.03.05:461; n: enable/disable network
03/02/2014 12.03.05:462; m: control remotely the node, press m to print the help
03/02/2014 12.03.05:463; k: reset configuration (flash reset)
03/02/2014 12.03.05:464; x: change network: pan ID, channel, max children
03/02/2014 12.03.05:465; t: print the node status (human readable)
03/02/2014 12.03.05:465; u: print the node status (parser readable)
03/02/2014 12.03.05:466; v: Set Vheater GAS sensor
03/02/2014 12.03.05:467; c: Reset child position
03/02/2014 12.03.05:467; format: format sd card
03/02/2014 12.03.05:468; fp: print sd card file content
03/02/2014 12.03.05:469; fl: list sd card files
03/02/2014 12.03.05:469; fd: delete sd card files
03/02/2014 12.03.05:470; fm: move sd card file
03/02/2014 12.03.05:471; ff: create sd card folder
03/02/2014 12.03.05:471; cntrl+a: to update the coordinator firmware
03/02/2014 12.03.05:472; cntrl+b: to update the remotely sleepy end firmware
```

Figure 19: JavaTerminal help view

3 Building Management System

3.1 What is a BMS?

A Building Management System (BMS) is a high-technology computer-based system which is installed in buildings for monitoring and controlling the equipment and facilities (3EnCult consortium D 4.4). Some examples for the equipment to be added in the BMS are the following:

- air handling and cooling plant systems,
- lighting,
- power systems,
- fire systems, and
- security systems.

A BMS is a complex, multi-level, multi-objective, integrated, interrelated and complete intelligent design management information system (3EnCult 2014b) which mixes software and hardware. The software is the entity in charge of the communication with the physical network, integrating the driver for the communication through specific protocols (ZigBee, LonWorks, BACnet...), and the intelligence to control the connected building components. Finally, the BMS also includes the internet connectivity and the internal operation (control algorithms, database connection...) setting up an “all in one solution” (Hernandez et al 2013).

On the other hand the hardware is the physical environment, including devices, sensors, actuators and the environment or facilities where the devices are placed.

The purpose of a Building Management System (BMS) is to automate and take control of these operations in the most effective way, in terms of inhabitants comfort, energy saving, peak shaving, etc., within the constraints of the installed technology systems (3EnCult 2014b). Usually, a BMS is monitoring and controlling the building's internal environment, but it is sometimes also linked to access control (turnstiles and access doors, controlling who is allowed access to and exit from the building), such as closed-circuit television (CCTV) and motion detectors. Finally, fire alarm systems and elevators can be connected too.

The BMS has four basic functions:

- Controlling: control algorithms to manage the building systems functioning.
- Monitoring: continuous monitoring through sensors of performance indicators status.
- Optimizing: looking for the best performance of the building systems.
- Reporting: Documentation of the intermediate and final results. (Hernandez et al 2013)

Currently, Building Management Systems are commonly implemented in buildings for the management of energy usage and they can lead to a high percentage of energy savings. **Although the gains and losses control and renewable energy resources seem to be the most meaningful issues for energy savings, the Building Management Systems can be one of the most important building component.** That includes cultural heritage buildings such as the museum of Thessaloniki (Karolidis 2009) where a BMS has been implemented, allowing to achieve low operative costs, considerable energy and time savings, as well as high safety and control levels.

3.2 Implementation of a BMS

The Building Management System is designed and developed according to plug&play features. Moreover, the BMS is thought as a single server with multiple entities interworking in a distributed environment in the same machine, as Figure 20 shows. Nevertheless, it is not possible to simply implement the whole system, but a tailored configuration depending on the building is required. For

such a reason, the BMS could implemented as an almost plug&play system, whose configuration should follow the steps described in the following sub-chapters.

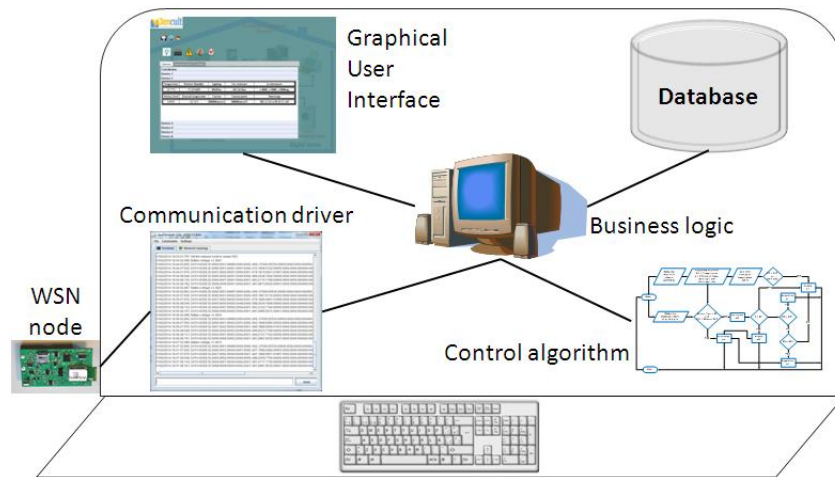


Figure 20: BMS server entities

3.2.1 Installation of PostgreSQL database in the server

The machine where the Building Management System is going to be implemented must have an instance of a PostgreSQL database already installed. The latest version of the database is available in the official Web page (PostgreSQL) of the manufacturer. The installer files are multi-platform in order to be able to install the database in a Linux, Windows or Mac computer. The installation is easy for any user following the steps in the installation guide. First of all, it is requested the directory for the installation, the directory where the data will be stored (in PostgreSQL format), the password for the user “postgres”, which will be necessary afterwards for the connection and configuration, and the first important parameter, the listener port, that must be set to “5432” (Figure 21). It is configurable, but the current status is using the default port. In the next steps of the installation it is enough to choose the default options.

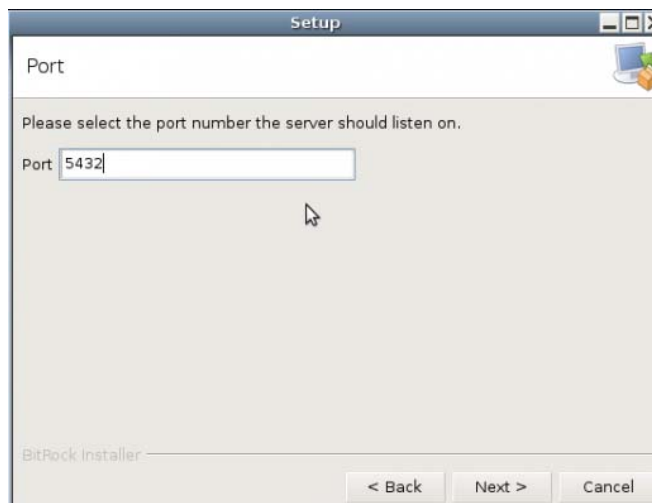


Figure 21: Selection of the port number for the PostgreSQL instance (Source: PostgreSQL)

3.2.2 Configuration of the initial database (SQL script)

Once the database instance is completely installed, there is an application for the management of the database named “PgAdminIII”. The user should run it, access with the aforementioned “postgres” user

and the associated password, and then a screen such as in Figure 22 should be displayed. Afterwards, there are two needs to be fulfilled before running the SQL script delivered with the BMS platform. First of all, the creation of a login role, accessible through the “Login roles” shortcut, shown in red in Figure 22, by right clicking and “New login role”. After that, a pop-up screen is launched like Figure 23 where the name of the role must be “3encult” and the same password (right side of the snapshot). There are other options in the configurations which are not required and only recommended for database administrators. The second needed action is the creation of a new database by right clicking in the “Databases”, blue ellipse in Figure 22, firing off a new screen (see Figure 24). The name of the database has to be “3encult” and the owner the **user created** before (i.e. “3encult” role). Other features are only recommended for advanced users or administrators. Finally, selecting the new database generated and the “SQL” button (see Figure 25), it appears a new screen for running SQL queries. The sql file enclosed with the BMS should be opened and afterwards run. Thus, the database configuration is finished.

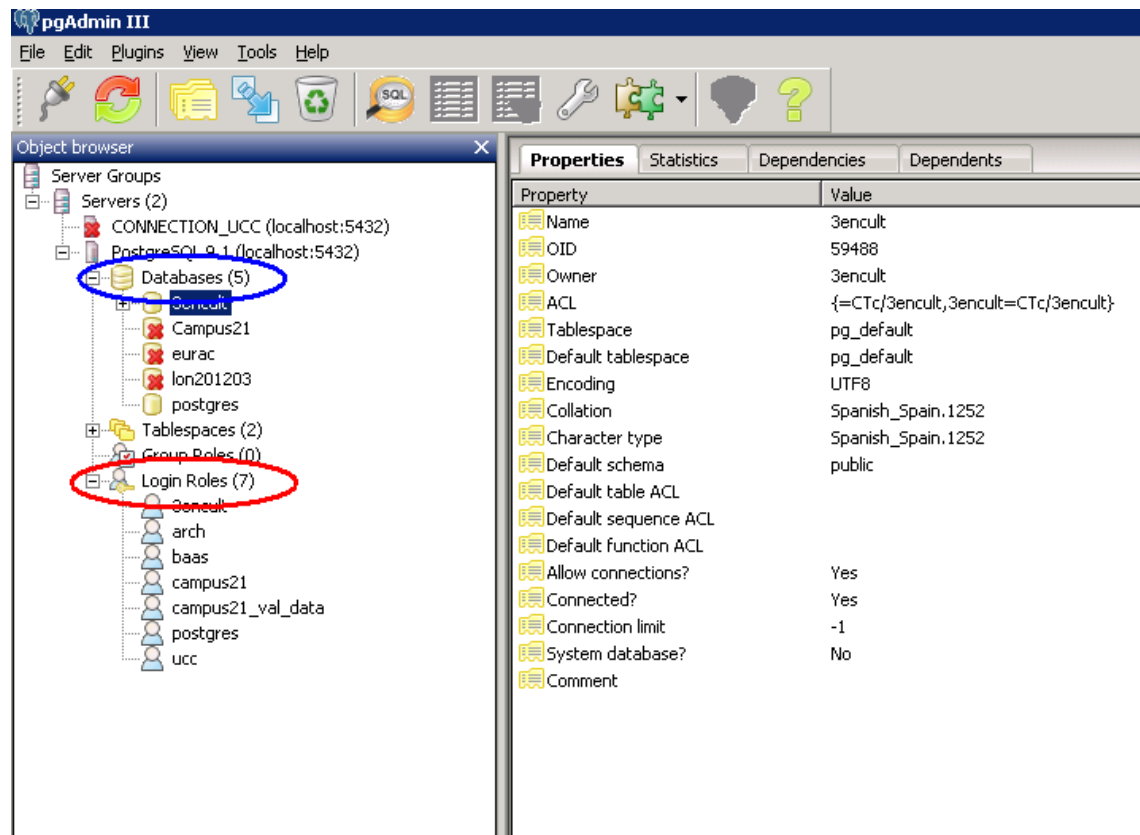


Figure 22: Configuration of the PostgreSQL database

Deliverable D4.5 Guideline for the implementation of monitoring system

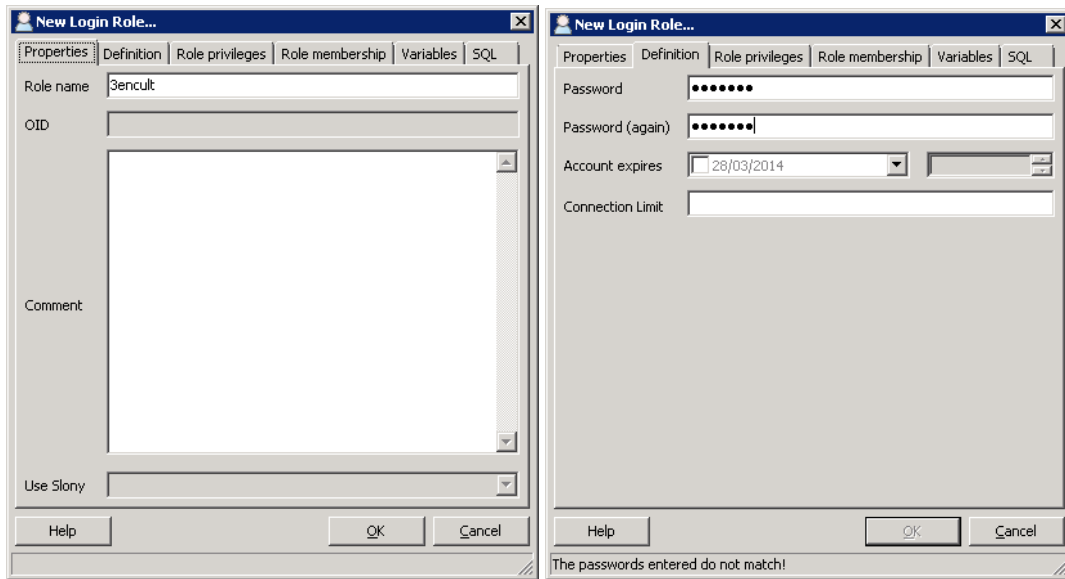


Figure 23: Creation of a new user role

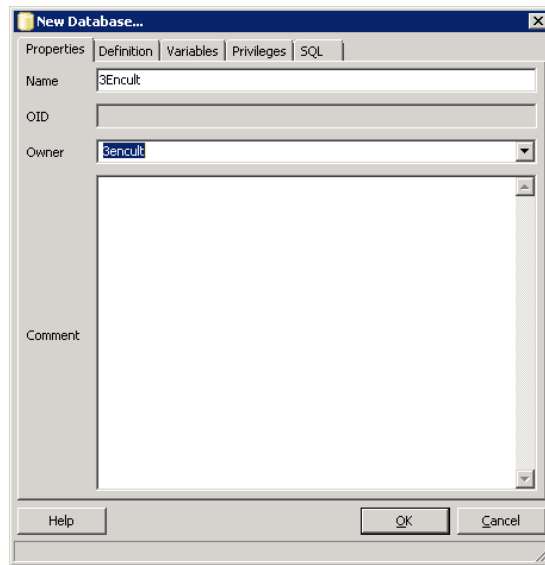


Figure 24: Creation of a new database

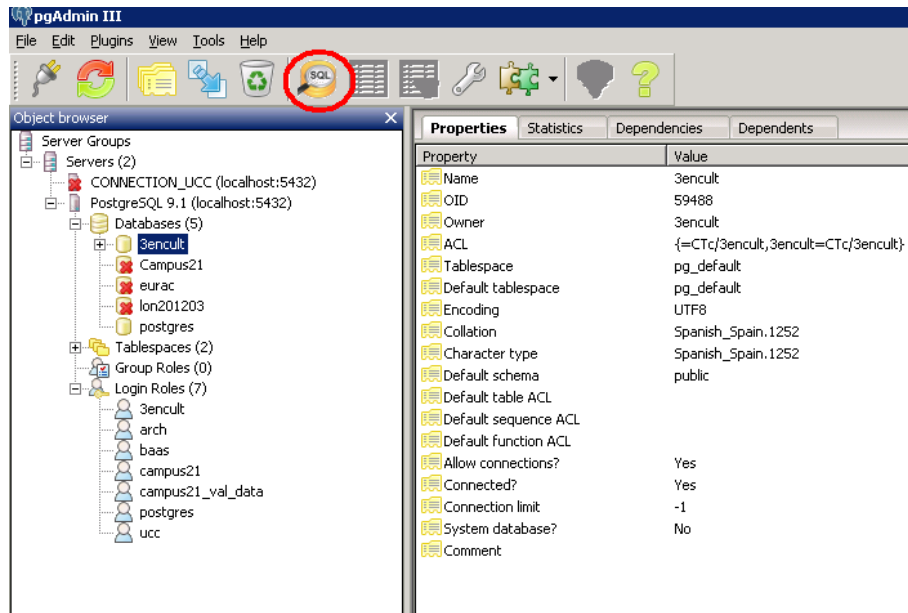


Figure 25: Running the initial insertion of data script

Following steps should then be defined:

1. Connection of USB dongle in any USB port

USB dongle is the coordinator of the ZigBee network to be connected to any USB port of the machine setting up the server for the BMS. Once done, the drivers of the USB device are installed automatically (plug&play). The user only has to check the installation has been completed successfully.

2. Configuration of the ZigBee network

Following the instructions reported in chapter 2, the network should be configured for the collection of the data streams through the USB communication with the coordinator. It is important to note that all the applications which could lock the USB port for the communication must be closed. For example, the putty software for the USB connectivity blocks the communication of other software trying to access the ports. Here, it is important to note that the BMS is able to work independently to the Java terminal interface used for the configuration of the wireless sensor network. However, it does not exclude the usage of such interface if required for the configuration, but it generates a duplicate record of data (i.e. the BMS stores the information into a database meanwhile the Java terminal records the data streams into a log file). The recommendation for the BMS perspective is only using the BMS interface, which is able to read and manage the data streams from the sensors. In case of using the Java terminal, an external connector must be used to interface the files and the database as it was done in the Central Server (see D4.4 (3EnCult, 2014b)). In fact, the Java terminal is able to log the data readings in files, but the BMS is storing all this information in the persistent database.

3. Double click and run

The distribution of the BMS platform contains several folders with the plug-ins, components, configuration files and other. However, in the root folder, there is a file called "equinox_start" for running the application with several file extensions to fit with several different possible platforms (cmd for Windows, sh for Linux). In the case of Windows, with double-click, the BMS starts and in the case of Linux a new console and type 'sh equinox_start.sh' are defined. After some seconds, the Web application could be accessed in any browser through the URL <http://localhost:8115/Gateway>.

4 Monitoring concepts

In the following sub-chapters some example of monitoring system implementation in historic buildings are presented. The monitoring concept (objectives, layout and components, data analysis) were defined after basic evaluation of the context and (see Chapter 1.2) in compliance with steps described in the following. This means that monitoring concept does not depend only on kind of data to be acquired and elaborated, but it is also a question of the object to be monitored and/or context constrains, as well as specific developed algorithms to be implemented (3EnCult consortium D4.2). The monitoring approach used in all examples presented below, is based on the five-step procedure illustrated in Figure 26.



Figure 26: Development of a monitoring and control system in five steps

4.1 Behaviour of construction elements – Strickbau, Appenzell

The energy retrofit approach based on internal insulation is the main focus of the monitoring concept. The user comfort and energy efficiency are not neglected, but they are subordinate to the building construction and insulation requirements and relative retrofitting measure. Table 6 gives a synthetic overview of the building, existing and possible new equipments, in the context of energy retrofitting.

Table 6: Description of the Strickbau, Appenzell building and the building equipment

Building	Log house build in the 17 th century
Utilization	Residential building
Building equipment present	<ul style="list-style-type: none"> • Wood stove • Warm water (flow heater)
Building equipment optionally possible	<ul style="list-style-type: none"> • Heaters (electrical or water based) • Air ventilation (air ventilation using old wood stove or by window or installing small air ducts with decentralized fans) • Heating cable (electrical)
Top priority for control	<ol style="list-style-type: none"> 1. Behaviour of construction elements 2. User comfort 3. Energy saving

After establishing of control priorities, a second step consisted in building zoning, that means the creation of different use zones and relative requested room environmental conditions profile. Figure 27 shows the developed useful profile under the assumption that the building will be used for residential purposes also after the retrofitting.

	Zone 1 Living	Zone 2 Sleeping	Zone 3 Bath	Zone 4 Entrance Staircase
Set point	Temperature day mode = 23 °C night mode = 18 °C	Temperature mode = 18 °C	Temperature day mode = 23 °C night mode = 18 °C	Temperature mode = 14 °C
Time schedule	Weekday day mode 5.30 – 9.00 5.00 – 11.00	Weekday mode 24 h	Weekday day mode 5.30 – 8.00 17.00 – 20.00	Weekday mode 24 h
	Weekend day mode 8.00 – 23.00	Weekend mode 24 h	Weekend day mode 8.00 – 10.00 17.00 – 22.00	Weekend mode 24 h

Figure 27: Requirements for indoor environment at the different building zones

Based on the monitoring priorities, the preliminary basic evaluation and the hypothesis for energy retrofitting measures, a list of critical parameters, damage mechanisms and necessary countermeasures, was developed. The necessary actuators, the type and location of sensors, as well as the resulting control factors can be derived from such a list. Figure 28 shows as an example, an overview preliminary building analysis in terms of critical points and relative possible damages, as well as the resulting monitoring and control variables.

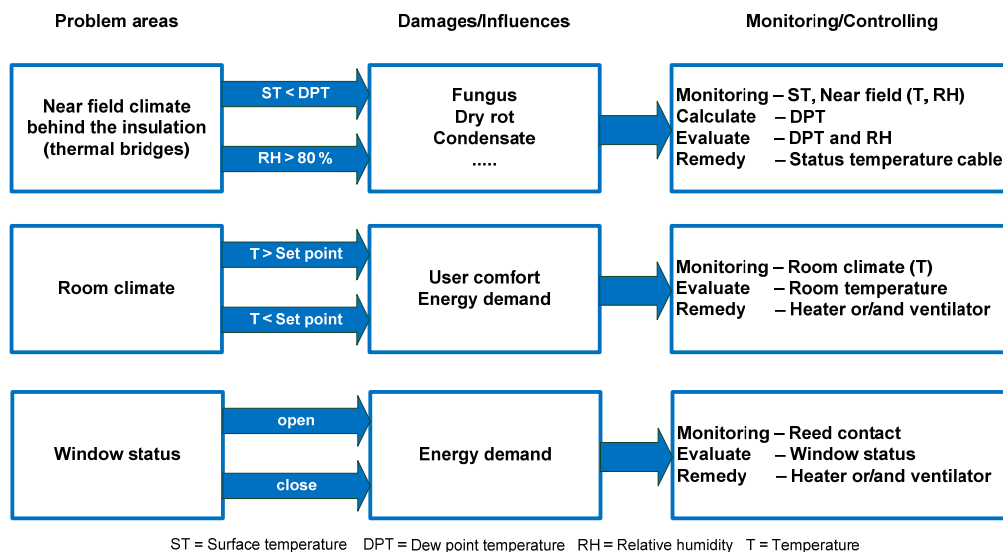


Figure 28: Critical alarms and requirements of construction elements, user comfort and energy demand

The sensor and actuator networks shown in Figure 29 was developed starting with the above mentioned preliminary building analysis. Since the former type of heat generation in the building (individual heating in the living room) does not match current use standards, there is a need to install in every room, a well sized radiator, that could be controlled via the MCR system (measuring, control and regulating system). In addition, decentralized forced ventilation, which can be used during warm weather periods for night-time cooling or to reduce critical room humidity, should be implemented. To protect the construction in the areas of thermal bridges a so-called heating cable is to be placed, on the one hand, facing the risk of condensation by raising the surface temperature and then counteracting critical near field environmental conditions.

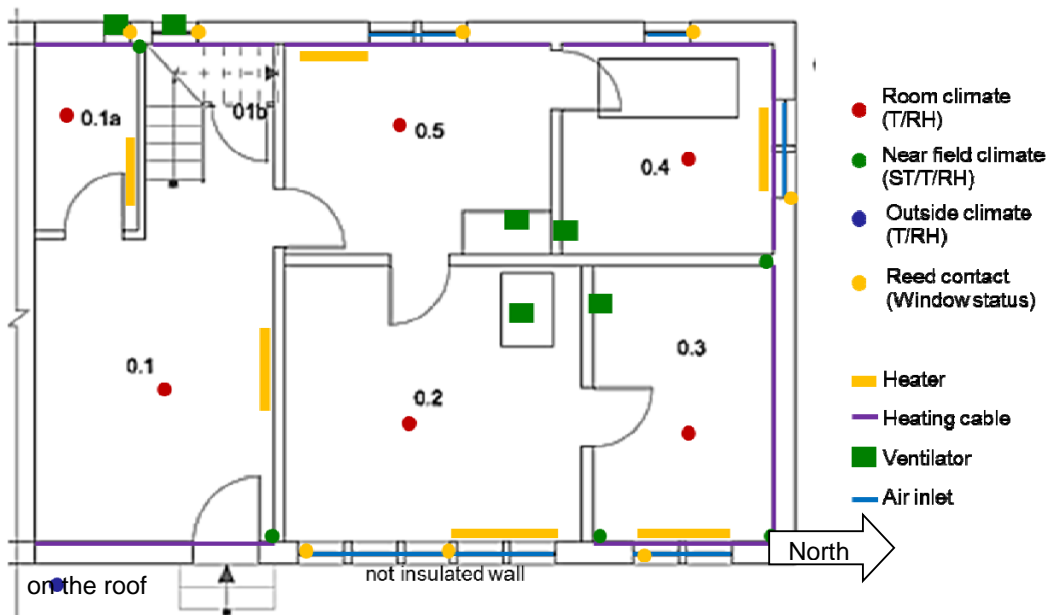


Figure 29: Monitoring and controlling system

Another important component of the control system is the monitoring of the status of the window. With the help of so-called reed contacts, the status of the windows can be detected (open / closed) and thus, taking into account the weather conditions, allowing energy saving results, regulating the heating and ventilation systems components. Figure 30 shows the control algorithm for a room in the building as a result from the various requirements. Here it is clear that the control algorithm is divided into a use-end energy-specific and construction-specific part. This division allows a needs-based energy-efficient control of heat and air distribution systems used while protecting the structure.

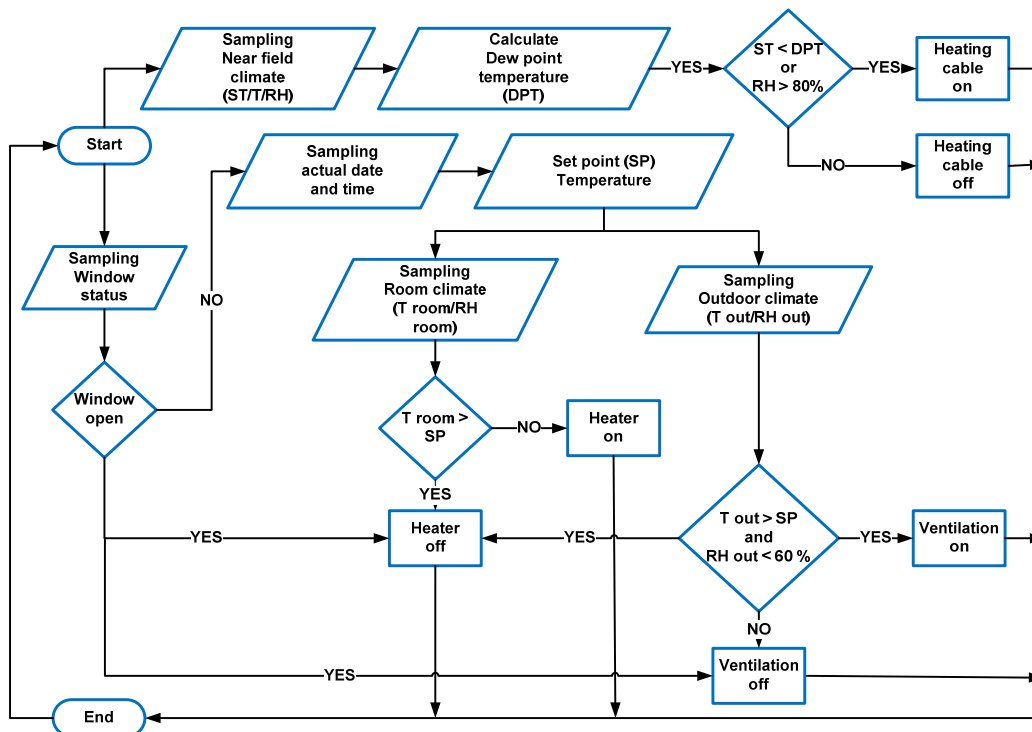


Figure 30: Exemplary implemented control algorithm for one room of the Strickbau, Appenzell building

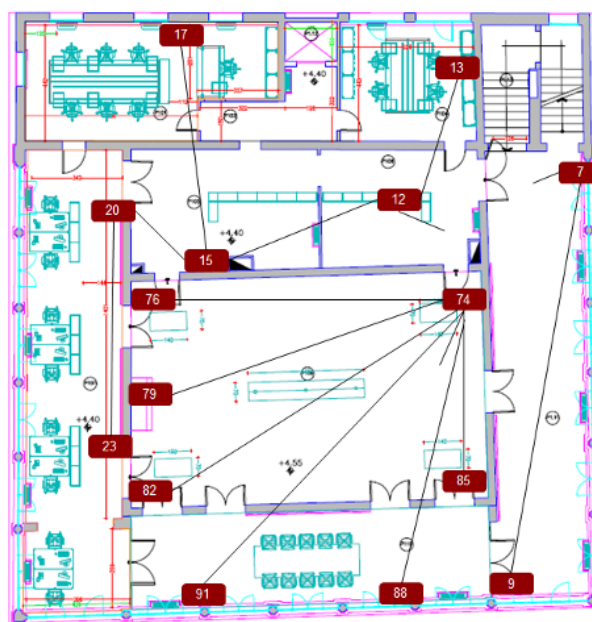
4.2 Protection historical surfaces – Palazzina della Viola

The Palazzina della Viola, a 15th-century building, has historic ceiling paintings scattered throughout the building, in addition, a large room has historical wall paintings. For this reason, the focus of the monitoring was on protecting and preserving the valuable paintings. Also for this case study both user comfort and energy efficiency were taken into account in the development of control system, while considering the previously mentioned requirements on painting conservation. Table 7 gives a synthetic overview of the building, existing and possible new equipments, in the context of energy retrofitting..

Table 7: Description of the building and the building equipment

Building	15 th century building renewed in 2011. The building is a unique architecture structure presenting Fresco and ceiling painting.
Utilization	Head quarter of DIRI, international relationship department of University of Bologna. The building has offices and meeting rooms
Building equipment present	<ul style="list-style-type: none"> • Wireless Sensor Network for cultural heritage building • HVAC composes with fan coil units and electric heater units, controlled by a central system
Building equipment optionally possible	<ul style="list-style-type: none"> • Building Management System BMA • Remote Building Management System • Humidifier system
Top priority for control	<ol style="list-style-type: none"> 1. Historical surfaces 2. Users comfort 3. Energy saving

The building has been monitored by a Wireless Sensor Network before and during refurbishment and the monitoring system used 3EncultWSN component, since its utilization after renewed (Figure 31). The aim of monitoring is to analyse the building environment in order to find hazard condition for fresco, discomfort for the users and energy waste.



First floor

Figure 31: Monitoring system (Fresco room – mid)

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The 3EncullWSN sent the collected data to a web server that allows to the users to visualize them. The web system has several user types that can have a restricted data access or complete data access. The reader can access to a restricted session to the url <http://137.204.213.210> user: guest password: guest. The data has been used to analyse the building climate condition during the entire monitoring period. The analysis has involved the plot of humidity and temperature maps and graphs to underling critical condition in order to find better HVAC scheduling and utilization.

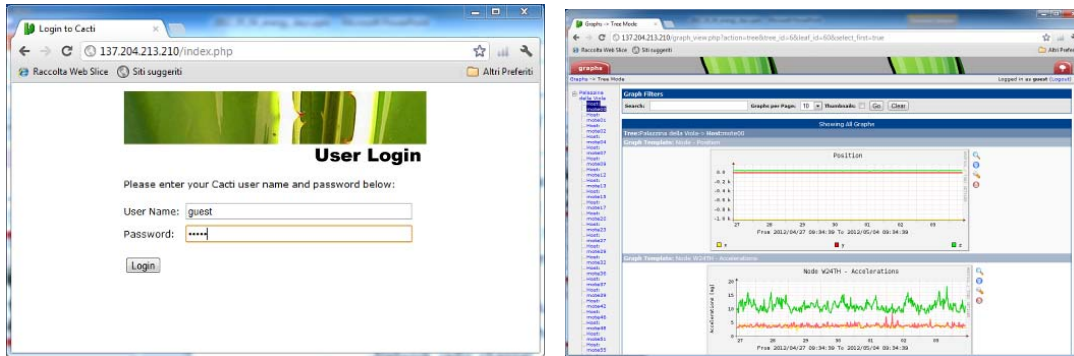


Figure 32: Web data visualizer interface

Figure 33 shows the requirements of historic preservation office for the room environmental conditions. However, after the energy retrofit the detected room climates corresponds rarely with the requirements of the historic preservation office.

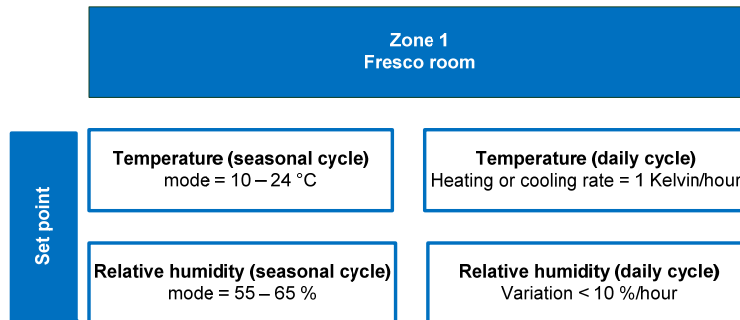


Figure 33: Requirements for indoor environment at the building zone

The evaluation of indoor environmental conditions of a whole seasonal cycle shows that in the room with the precious wall paintings for about 95% of the time, relative humidity is below 50%. From time to time during cold winter periods and due to the heating of the room this falls off even to levels below 25% RH. This suggests that the existing building or the regulation of the heating system only rarely allowed to match the paintings conservation requirements.

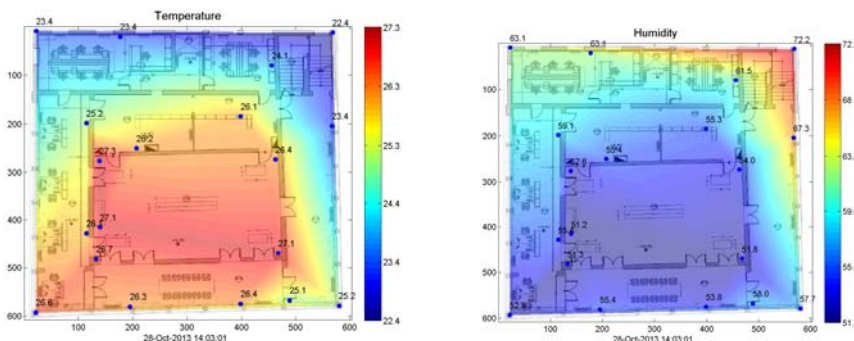


Figure 34: Temperature and Humidity maps at 28-Oct-2013 14:03

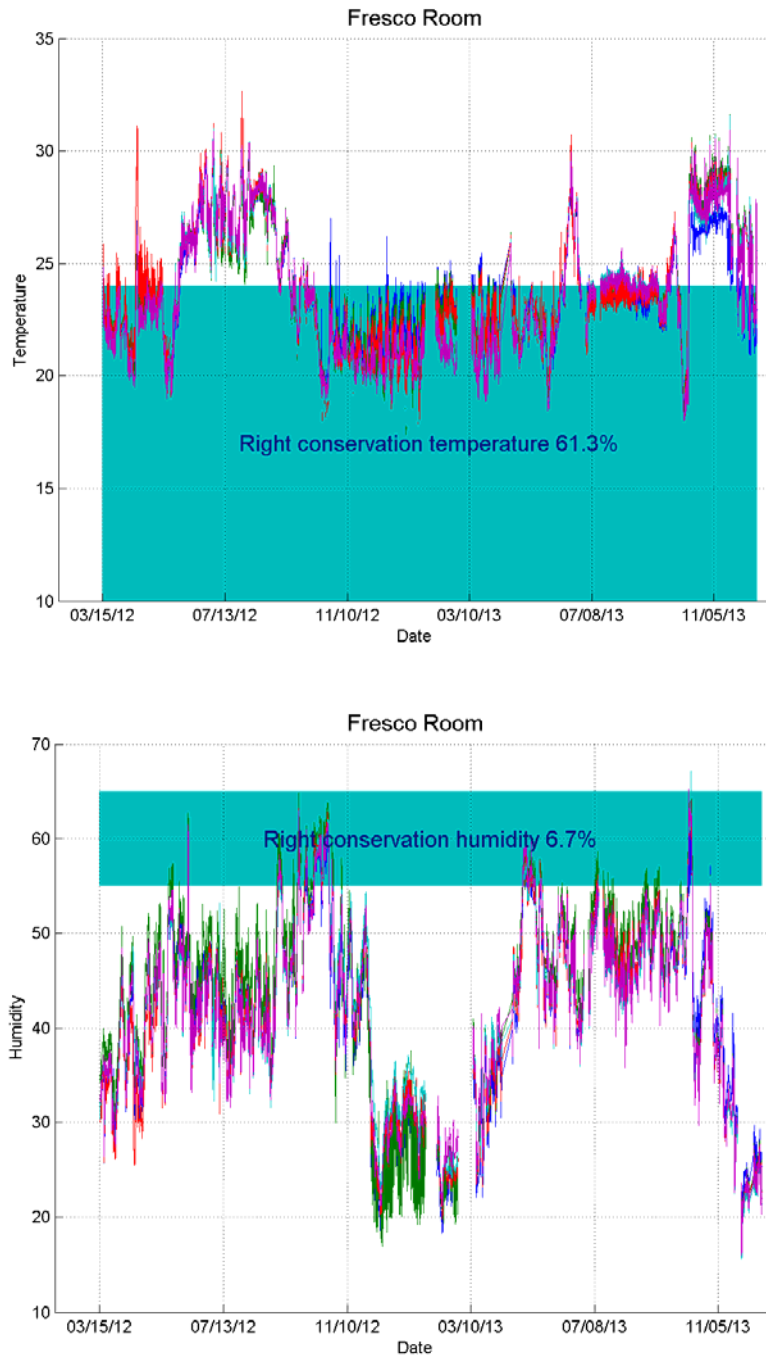


Figure 35: Fresco room – temperature (above) and relative humidity (below) seasonal after refurbishment (red line = node nr. 82; green line = node nr. 85; pink line = node nr. 76; blue line = node nr. 74)

Based on the conservation specifications and existing data from monitoring, they can be derived not only the damage mechanisms critical parameters, the necessary control variables as well as relative sensor types and positions, but also the necessary additional equipment. These are shown in Figure 36, representing the room with the historic wall paintings, where, due to the aforementioned low relative humidity, there is a need of humidifiers.

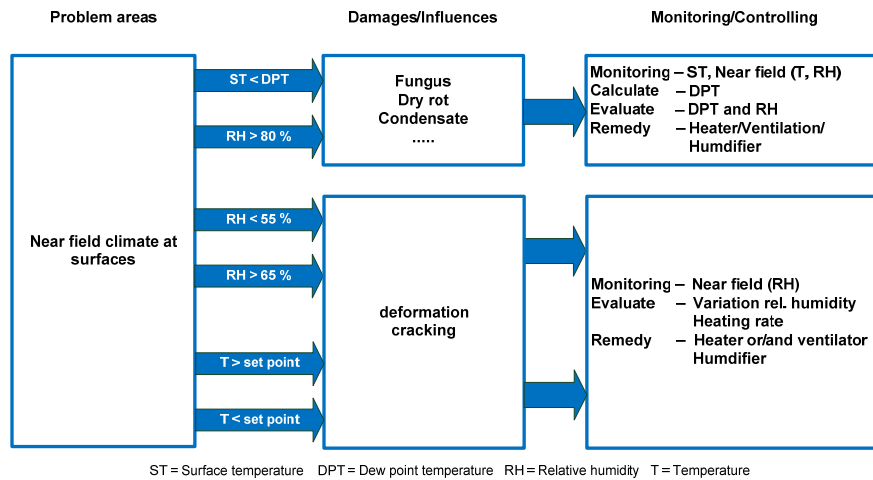


Figure 36: Critical alarms and requirements at historical surfaces, user comfort and energy demand

Figure 31 shows the original sensor network that needs to be extended for further measurement and control tasks in the area of the wall paintings, including not only the near-field climate, but also the surface temperatures, that can be detected at various heights. Furthermore, it is necessary to install several humidifiers in the room that can be controlled by means of a future building management system based on the near-field climate.

The algorithms shown in Figure 37, as in the previous example, consist of two basic operating control scenarios working together. Common point to both scenarios is that they are based on the environmental conditions in the near-field of the historic surfaces. The first scenario consists of adapted and energy-efficient operation of the ventilation system, depending on indoor environment requirements. The second scenario takes into account the active control of indoor relative humidity both with heater and humidifier, the heating is not turned off, if the requested temperature has not been reached, but an increase in the relative humidity produce an effect on the operation of mobile humidifiers.

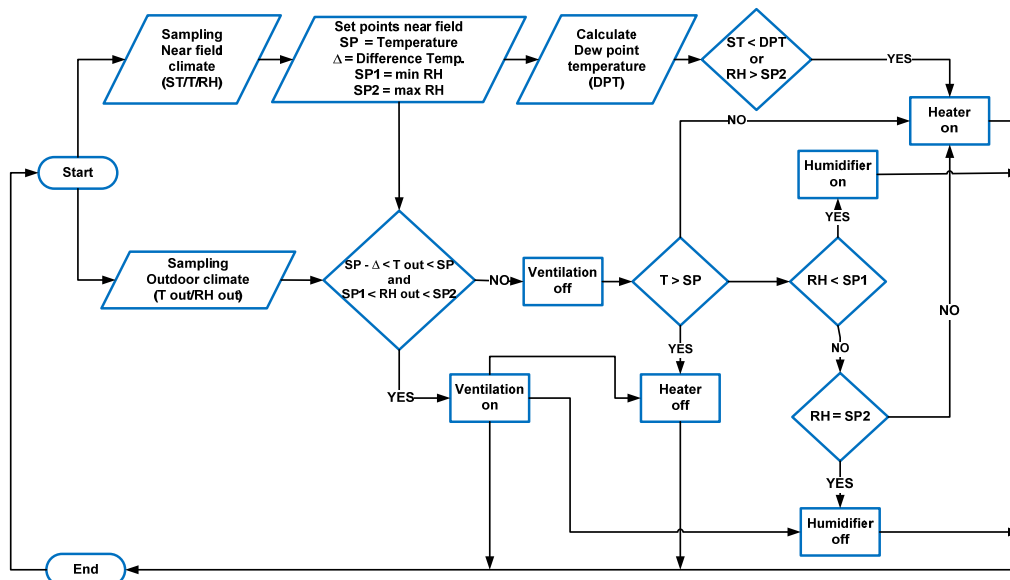


Figure 37: Exemplary implemented control algorithm for the fresco room in the Palazzina della Viola

4.3 User comfort by CO₂-concentration – Monumental School, Innsbruck

The “NMS Hötting” in Innsbruck, a listed four-story school building (Table 8), was an example of a building from early modernism. For demonstration and verification of energy efficient solutions two classrooms of the building have been renovated and provided with a monitoring and BMS system (for artificial- and daylight control as well as ventilation).

Table 8: Description of the building and building equipment

Building	NMS Höttinger (New Middle School). Year of construction 1929/30. Innsbruck, Austria.
Utilization	School building
Building equipment present	<ul style="list-style-type: none"> • Radiators (water based) • Active overflow ventilation system with central heat recovery • Daylight redirection and shading lamellas (classroom 1) • Shading screen (classroom 2) • LED lighting system (classroom 1) • Luminescent screen tubes lighting system (classroom 2)
Building equipment optionally possible	<ul style="list-style-type: none"> • Centralised or decentralised heat recovery system • Shading lamellas
Top priority for control	<ol style="list-style-type: none"> 1. User comfort (CO₂) 2. Energy saving 3. User friendliness

Besides the reduction of thermal losses and reduction of electrical consumption for artificial light, a special focus is on adaptation and optimisation of the ventilation system which is controlled by means of CO₂-concentration sensors and presence sensors. Criteria used for the control system are shown in Figure 38.

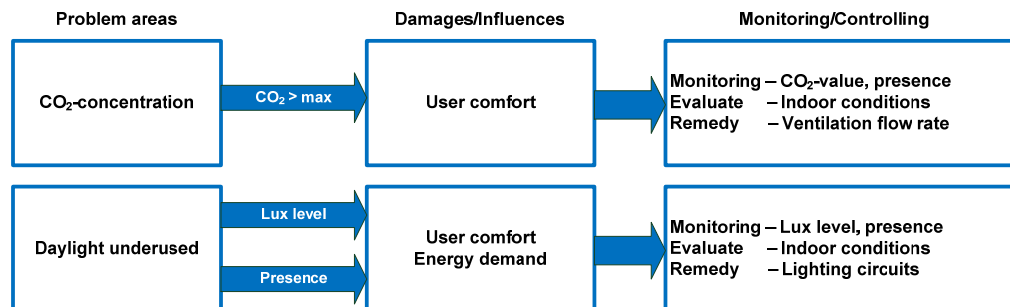


Figure 38: Critical alarms and requirements of user comfort and energy demand

As ventilation system, the active overflow principle was transferred to school buildings. In this case the high flow rate (~ 700 m³/h) calls for a dedicated air distribution system to avoid draft risk and excessive airborne noise. In order to minimise the ductwork within the building an active overflow system takes the air from the corridor to the class room and vents the extract air back to it. A central heat recovery system ventilates the staircase and the corridors with preheated fresh air (Figure 39).

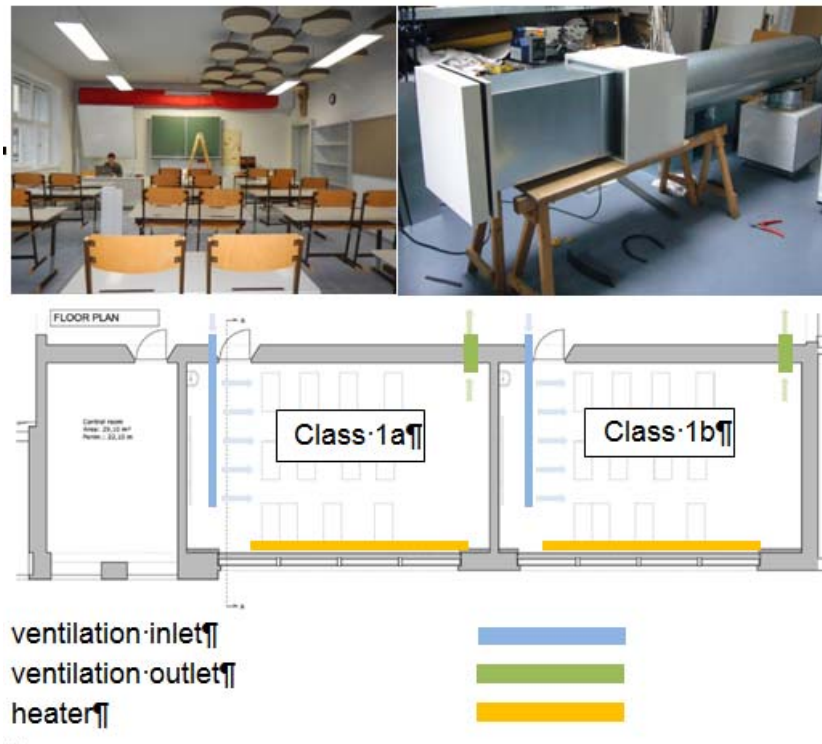


Figure 39: Test-classroom (upper left); Active overflow prototypes with active overflow and silencer manufactured by ATREA (upper right); Ventilation schema (bottom)

Two different control strategies for the ventilation system were considered. The first one is based on the use of time schedules for the control of the fans (Figure 40). This strategy presents low installation costs, since no sensor is necessary, but it is not flexible in terms of changes related to the real occupation and the time schedules.

	Zone 1 class room 1a	Zone 2 classroom 1b
Set point	CO ₂ -level mode = 1000-1400 ppm	CO ₂ -level mode = 1000-1400 ppm
Time schedule	Weekday mode Monday 07.45 – 12.25 Tuesday 07.45 – 11.30 Tuesday 14.30 – 17.10 Wednesday 07.45 – 11.30 Thursday 07.45 – 09.30 Thursday 10.40 – 13.20 Friday 07.45 – 08.35 Friday 09.35 – 12.25	Weekday mode Monday 07.45 – 11.30 Tuesday 07.45 – 11.30 Wednesday 07.45 – 11.30 Thursday 07.45 – 13.20 Friday 07.45 – 12.25
	Weekend mode off	Weekend mode off

Figure 40: Occupation time schedules for the prototype class rooms

For this reason a second strategy was considered, based on monitoring of the CO₂ concentration. The indoor air quality is categorised according to EN 13799 (Table 9) in 4 classes, IDA 2 is rated as good and IDA 3 as moderate air quality. If a CO₂-Sensor would be installed in each classroom, the active overflow fans could be controlled according to a given set point (e.g. IDA 3).

Table 9: Occupation time schedules and Requirements for indoor CO₂ concentration according to EN 13799

CO ₂ -class name	Max. value above ambient concentration	Max. absolute value with 400 ppm ambient concentration
IDA 1	<= 400 ppm	<= 800 ppm
IDA 2	400 - 600 ppm	800 -1000 ppm
IDA 3	600 - 1000 ppm	1000 – 1400 ppm
IDA 4	>1000 ppm	>1400 ppm

This control strategy enables the most efficient demand control for each of the active overflow fans, especially if the number of pupils varies a lot. The drawback however is the high costs for investment and maintenance (re-calibration and substitution). As shown in Figure 41 the flow rate of the central fans are controlled via CO₂-sensors in the corridor.

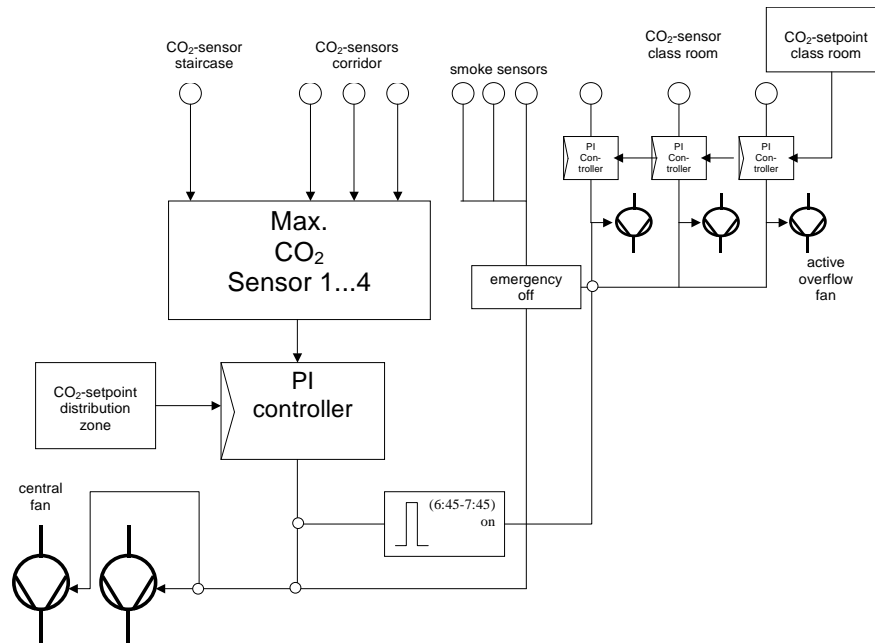


Figure 41: Control scheme for central fans and active overflow fans in case of CO₂-measurement in each class room

The third (most simple, cost effective and robust) control strategy is to measure the CO₂-concentration in the corridors or in the staircase only. The central fans can be controlled via a Proportional-Integral controller (PI) to a set point of e.g. 600 ppm in order to keep high air quality in the staircase and corridor zone as a fresh air reservoir for ventilation of the classrooms. The concentration in the corridors will vary according to the occupation of the adjacent classrooms. Hence at least one CO₂-sensor per corridor should be installed.

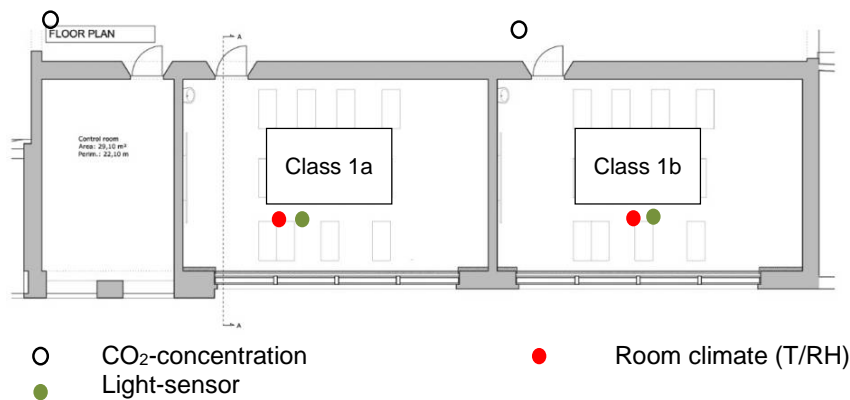


Figure 42: Optimized monitoring system

In case of this simplified control strategy, only the flow rate of the central fans are controlled via the CO₂-sensor whereas the active overflow sensors in the classrooms are controlled via time schedule (on-signal one hour before the start of the lessons) and via presence control sensors (off-signal with 45 min. delay). The disadvantage of this strategy is a lower saving potential, if the number of pupils varies within a wide range, because the on/off-control will always provide the flow rate necessary for the maximum number of pupils.

The artificial light as well as the shading and daylight redirection lamellas is controlled via light-sensors on top of the roof and in the classrooms. A peculiar BMS-system was installed especially for this purpose, enabling also an adaptive control of the colour-temperature of the artificial light according to the daylight.

4.4 User comfort by lighting – Industrial Engineering School, Bejar

Table 10 shows general information of the building as-it-is. The building was built in 1968 for academic purposes and all the facilities are heated making use of diesel boilers through radiators. Moreover, the cooling system foresees as terminal units fan-coils in cooling mode. Thank coils are not used in heating mode to support radiators, even if it would be possible. Furthermore, all the luminaires in the building are controlled all together for lighting purposes. Also, there are extractors for air ventilation, buy they are not usually used, except only rarely and manually.

Table 10: Description of the building and building equipment

Building	University building built in 20th century
Utilization	Academic building
Building equipment present	<ul style="list-style-type: none"> • Diesel boilers • Radiators for heating • Fan-coils for cooling • Luminaires for lighting
Building equipment optionally possible	<ul style="list-style-type: none"> • Extractors and air ventilation • Heaters by using fan-coils in heating mode
Top priority for control	<ol style="list-style-type: none"> 1. User comfort 2. Energy saving

The building works according to the behaviour described in the Figure 43 where three zones are determined, the two tests rooms and the boilers room. Regarding, the test rooms, the control system acts on lighting system where the set-point is 500 luxes following a Spanish rule for indoor conditions (EN 12464-1:2011) and on HVAC system in the library where the set-points are established by

university building manager to ensure the indoor conditions. Generally, the controls are scheduled and set up depending on the building opening timetable apart from physics laboratory where it is not needed because a timer is in charge of switching off the luminaires when the room is empty.

	Zone 1 Physicslab	Zone 2 Library	Zone 3 Boilers room
Set point	Light level mode = 500 lux	Temperature min T = 21,5 °C max T = 26,0 C	Temperature mode unknown
Time schedule	Weekday mode 24 h	Weekday mode 7.00 – 22.00	Weekday mode 7.00 – 22.00
	Weekend mode off	Weekend mode off	Weekend mode off

Figure 43: Requirements for indoor environment at the different building zones

The aforementioned requirements are translated into a set of alarms, shown in Figure 44. Thus, the problems detected are the discomfort in some of the rooms of the building, as well as the underuse of the daylight. In such way, through the monitoring of indoor parameters, as temperature, lighting level or user presence detection, these points could be improved by means of controlling the HVAC and lighting systems.

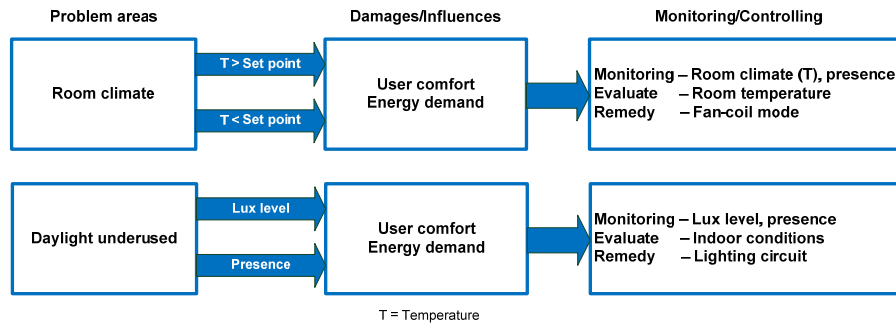


Figure 44: Critical alarms and requirements of construction elements, user comfort and energy demand

One of the test rooms (a physics laboratory) in the building where the monitoring system is implemented is displayed in Figure 45. The monitoring system in the test room measures user comfort related parameters in order to determine the conditions inside the laboratory. In such way, the occupancy in several points, indoor temperature and lighting level, as well as the air quality, are the variables chosen as input for the developed control algorithms. On the other hand, the electrical consumption is measured in the electrical boxes placed on the corridors. Finally, the thermal consumption is also monitored in the boilers room making use of temperature and pressure sensors where the pumps are. Thus, knowing the pressure before and after the pump, the temperature and the pump performance curving, it is possible to calculate the value for the energy flow in every single distribution circuit, that is the thermal consumption.

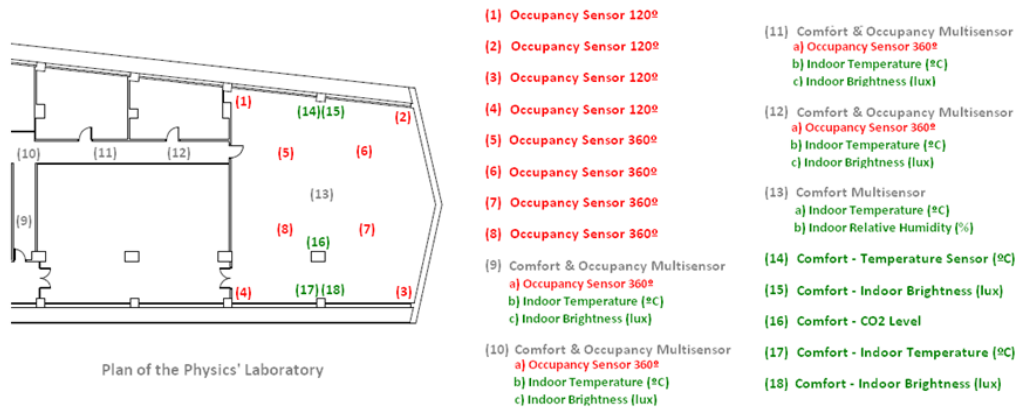


Figure 45: Optimized monitoring system

With regard to the elements involved in the control implementation, Figure 46 shows the facilities used. First of all, the control algorithm is based on the occupancy patterns and the indoor lighting condition; therefore the sensors related to these variables are implemented. Moreover, the lighting system itself as device to be actuated, the controller where the algorithm is programmed and the cable for the communication through the network.

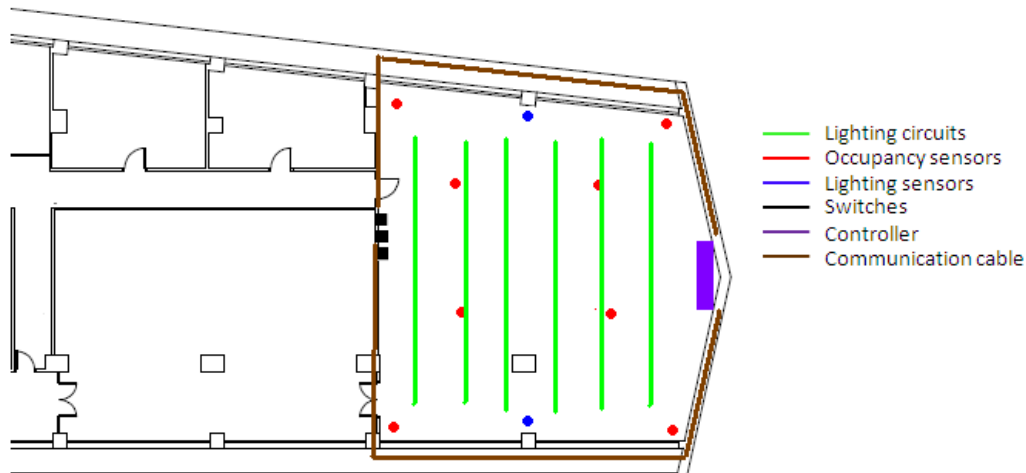


Figure 46: Define existing or possible actors

Figure 47 describes the control algorithm for the physics laboratory in order to control the lighting system. First of all, it is detected the users presence in the room, in order to switch off the luminaires if no one is inside. In case of presence, a timer is turned on, to avoid the hold of the luminaires in case the users are no more in the room (when the timer expires, the lights are turned off). Moreover, the comfort conditions are checked through the indoor lighting levels due to daylight. If the comfort level conditions is achieved, the lights are switched off, but if someone is working, the luminaires can be turned on. Furthermore, it is allowed and prioritized the manual control through the switches. Thus, if the switch associated to the circuit is pressed first time, the luminaires are instantaneously on. Second time pressed, luminaires are immediately off. Note that the switch has only two possible positions, therefore, two states (first and second press).

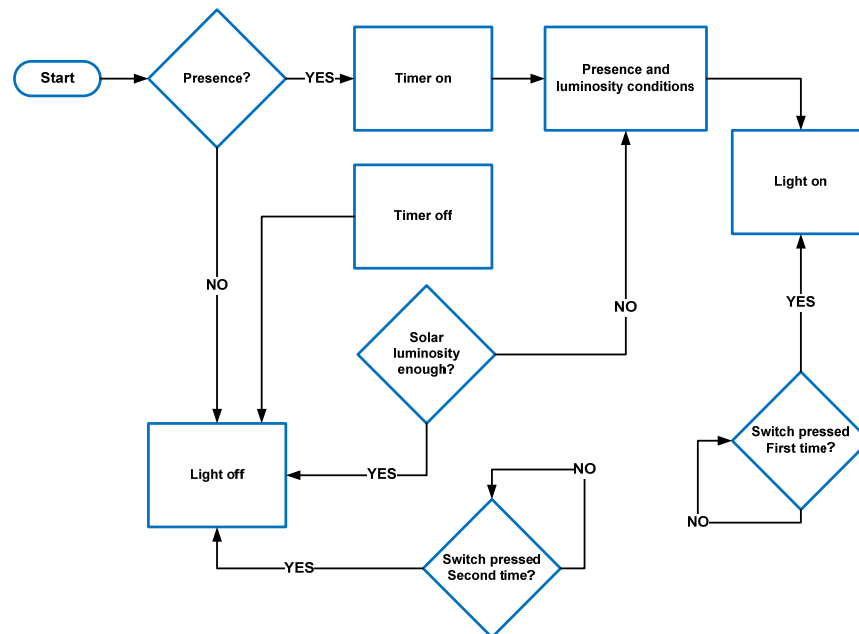


Figure 47: Exemplary implemented control algorithm for one room of the building

4.5 User comfort and artwork preservation – Palazzo D’Accursio, Bologna

Local Authority wanted integer energy retrofitting with extremely necessary non-ordinary maintenance intervention of “Urbana” room (or “Coats and Arms” room) hosting the Bologna Municipal Collection within Palazzo D’Accursio. The non-ordinary intervention was vital to resolve the ceiling’s frescos decay due to the rainwater infiltrations through the deteriorated roof covering. The energy refurbishment interventions had to properly respond to the double requirement of improving room internal comfort – where there is no air conditioning – during the winter and summer period, while protecting the fresco decorations on the walls and ceiling from direct sunlight by reducing massively the ultraviolet radiations and providing protection from the infrareds. In the realization of these maintenance operations, the aspect of energy saving, has been introduced, which normally would not be applied to historic buildings protected by the Cultural Heritage Preservation Authority. Design objectives included the application of the legal requirements that prevent building components and envelope from energy losses. After evaluating singularly of the conservative refurbishment together with energy retrofit, an effective energy analysis through dynamic simulations has been carried out, evaluating alternative solutions and the relative impact in the building.

The works realized in the Urban Room were the following:

1. Roof refurbishment: the substitution of the existing roof and the adoption of a ventilated roof. Insulation of the roof is realized with an insulating packet 9,9 cm thick, made of a double layer of insulating panels in wood fiber “Pavatherm” (4+4 cm) and a layer of wood fiber “Natur isolant” (1,9 cm).
2. Punctual seismic improvement: through consolidation perimeter, integrating new bricks because in many places there were ancient chimneys that weakened the structure and reinforcement with metal edgbanding. Wooden truss was consolidated with insertion of metal bars and epoxy resins.
3. Windows replacement: application of wooden/aluminium window frames, associated to double insulating glass system type based on stratification glass with argon inside (4 + 4be/16argon/4 + 4 (Ug=1W/m2K and g=26). The chosen glass system is selective (in the winter periods retain the heat and in the summer periods reflect it) in such a way as to avoid the UV rays which produce the bleaching effect of the frescoes, thus limiting the solar gain and bright.

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4. Automation and control of the Urban Room: with domotic system that control automatically the windows and the curtains opening and adjusting light intensity in relation to the uses. The domotic system is realized with Konnex standard.
5. Plaster remaking: replacement of the present external plaster layer with a traditional lime-based plaster.
6. Frescoed ceiling renovation: insertion of an insulation layer at the extrados of the frescoed ceiling, using adjustable light intensity in relation to the uses. Pre consolidation of the paint surface with Japanese paper and subsequent cleaning.
7. Artificial lighting: refurbishment of the artificial lighting with a LED wall washer system with improved efficiency.

Table 11: Description of the building and the building equipment

Building	<p>Deposit for the storage of corn at first place; since XIVth century hosted city Government and then Papal Legation. The construction type has been layered across different historical phases.</p> <p>The used materials are:</p> <ul style="list-style-type: none"> • Brick for the wall structure; • Marble and sandstone for the decoration; • - Wood for roof structure, tiles and copper plates for the covering of it.
Utilization	Municipality Head Offices – Town Hall
Building equipment present	<p>D’Accursio Palace, including the nearby Stock Room, is provided with two heating power stations (called “Palace Power Station”, and ”Stock Room Power Station”) and an autonomous generator, with a distinct location than the others (informally called “CALDAIETTA”, ”small boiler”). No Mechanical Ventilation system is installed for control the quality of the air. There is not a system of controlled natural ventilation, the windows are opened directly by the workers according to the their needs.</p>
Building equipment optionally possible	<ul style="list-style-type: none"> • Walls surfaces cannot be altered by insulation or any other coating for protection constraints. • The only surfaces coatings that can be modified by philological renovation interventions are East and South facing vertical enclosures directly bordering the exterior that are at present covered with a layer of strongly deteriorated plaster, made of a mixture of a concrete base of the 30s, therefore with non-philological procedures that would instead entail a lime based mixture. <p>As regards specifically “Sala Urbana”</p> <ul style="list-style-type: none"> • No space available for solar technologies installations, also for constraint given by existing legal regulation codes for historic buildings. • Principles of protection given by the Authority for Cultural Heritage state that the opening of slots or skylights in the roof is not allowed. • No application of insulation layers can be done on the inner surface. The application of new insulation in wood fiber layers has been already studied and carried out in the implementation of the roof refurbishment intervention. No possibility of further elevation.
Top priority for control	<ol style="list-style-type: none"> 1. Maintaining a safe environment for frescoes in the Sala Urbana 2. Increase comfort in winter and summer

WSN monitoring: Two different networks have been tested in Sala Urbana, based on MEMSIC (a Chinese owned US Company) and I.Co. (an Italian Company) products; both networks work at 2.4 GHz supporting the IEEE 802.15.4/ZigBee standard and store data in a SQL database, the former using the PostgreSQL version, the latter the MySQL implementation. However, in the course of the Project the product of MEMSIC have been used only for some preliminary network installations. Connection to the WEB has been implemented by a USB 3G modem linked to the host PC; a contract for a 24 hrs connection with a monthly 1 GB data allowance has been signed with a national mobile provider, so that data can be downloaded at any time without any interruption. One relevant technical issue, that is quite common in places where Internet connection will be provided only via a USB modem, is represented by the fact that the host PC is accessible through a NAT - Network address translation, so the host PC is completely invisible from the outside, because its IP is not its own but is shared with a number of PCs managed by the ISP; even using dynamic DNS locator services is useless, because they cannot trace a PC that is "NAT-ted". In this situation the PC can send data to servers, but cannot be, for example, requested to send data and its databases cannot be remotely queried; however, using remote desktop control services, like TeamViewer - <http://www.teamviewer.com/it/index.aspx>, it is still possible to manually dump data to any external server and do any operation on the host PC, because this services create a "bridge" between any two PCs using Internet, so it is of no importance if one or both of them are behind a NAT or a router or even a firewall. Another important technical issue regards the fact that CARTIF explicitly required data to be sent in PostgreSQL format, and any translation from MySQL would imply writing code in XML or PHP, so a different simpler solution had to be implemented.

Due to the afore mentioned difficulties, it has been decided to send data to an FTP server in Bejar, and that data had to be sent as a plain tab separated text (ASCII) file, so that they had not to be translated from MySQL to PostgreSQL.

The implemented solution is described here below:

- Data are acquired in the WSN and transferred to the MySQL database in the host PC; the software controlling the WSN is implemented in JAVA to guarantee full compatibility with practically all operating systems and software platforms;
- A DOS batch file (CS2-DATA-DUMP.BAT) has been written and is able to dump the MySQL database to a standard TXT tab separated file, compress it as a ZIP file and send it to the server in Bejar;
- The execution of the CS2-DATA-DUMP.BAT file is automated by the use of the "Task Scheduler" function of Windows XP (the OS of the host PC).
 - To manage the USB modem a free German software has been utilized, MWconn - <http://mwconn.net/index.html>.

Using the afore mentioned WSN and server connection, Sala Urbana has been monitored during the periods August 2011-April 2012 and October 2013-March 2014, so results pre/post intervention may be compared to verify the effects of the renovation works, especially of the installation of the new high performance windows.

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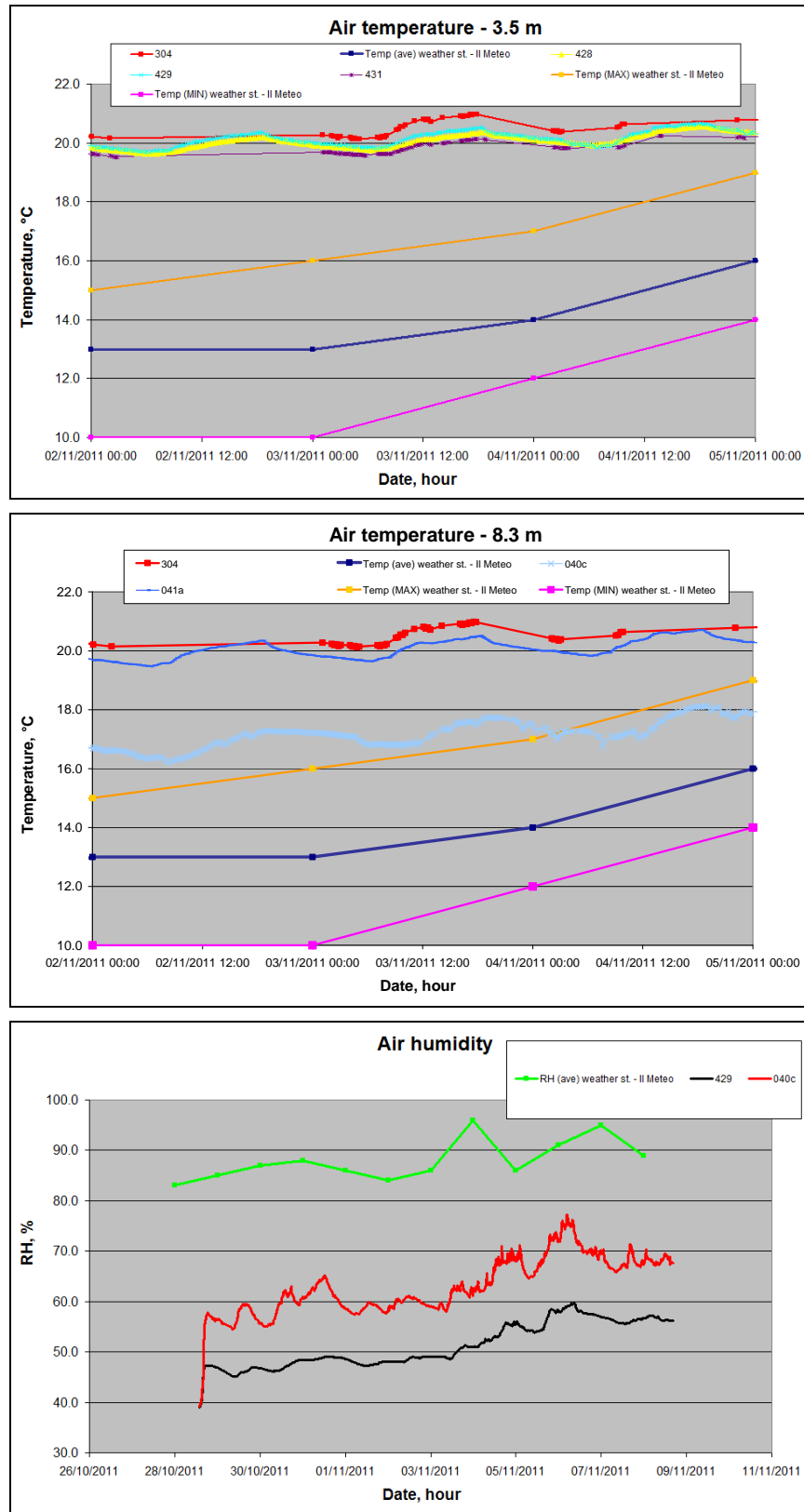


Figure 48: Graph of air temperature and RH, before intervention (temperature at two different heights)

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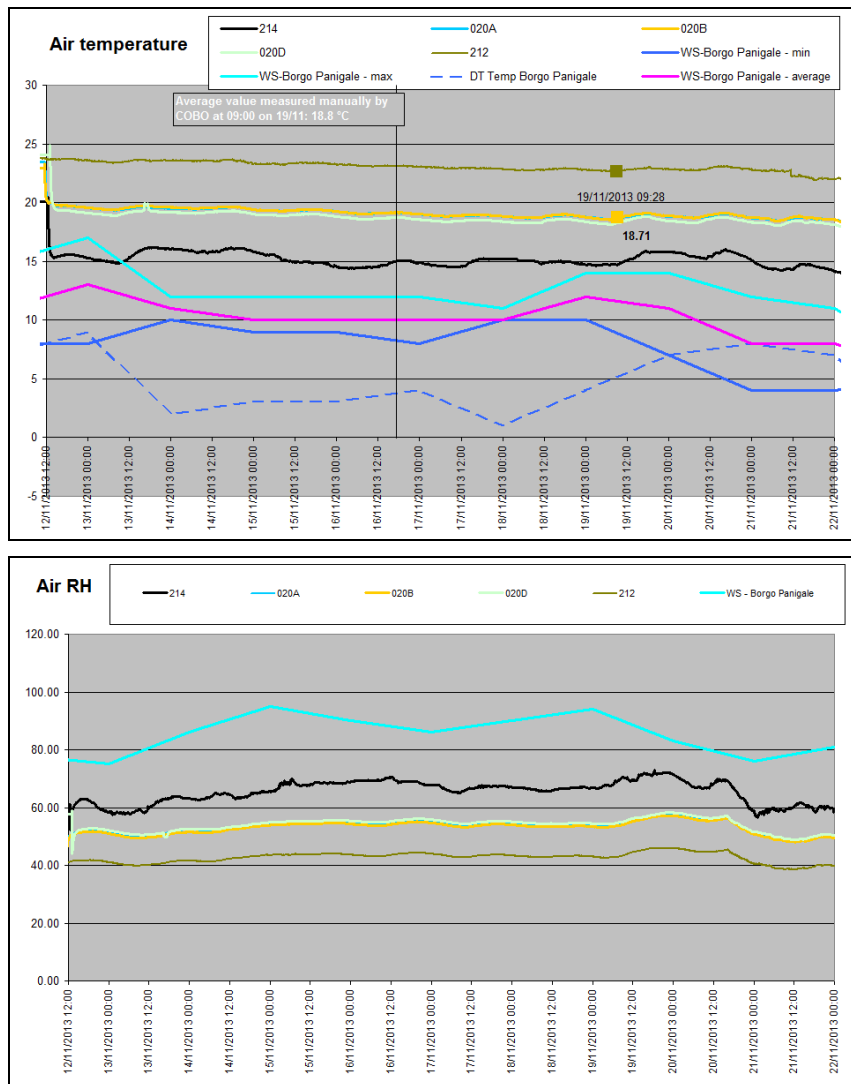


Figure 49: Graph of air temperature and RH, after intervention

As a result from this monitoring session we can state that after the installation of the new windows and the construction of the new roof, daily oscillations are reduced and internal microclimate dynamic is less related to the external conditions, thus obtaining a more stable environment.

Installation of automation devices for internal climate control is still ongoing and so the efficacy of these systems could not be evaluated in the time frame of the 3ENCULT project.

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