A ZigBee based building management system for heritage

Historic buildings are a challenge in the energy refurbishment because the special character of such buildings. Thus, 3ENCULT has developed a Building Management System compliant with heritage where the restrictions of heritage have been faced. Thus, wireless monitoring and control is used in combination with passive solutions to improve energy efficiency.

Keywords: 3ENCULT, wireless sensor network, building management system, BMS, monitoring.

JOSÉ HERNÁNDEZ
Cartif technology centre, Energy division, Spain
josher@cartif.es

HARALD GARRECHT, GIACOMO PACI, SIMONE REEB and DANIEL GARCÍA

The research European Project 3ENCULT [1], which is funded by the 7th Framework Programme from the European Commission, aims to establish a methodology for improving the energy efficiency and comfort conditions in European historical buildings.

In the EU-27 context, about 40% of the housing stock was built before the 60s and the other 40% between 1961 and 1990 (Buildings Performance Institute Europe 2011). Therefore, a large proportion of the building stocks are old constructions belonging to the historic heritage which presents a high level of energy consumption and low comfort conditions. Apart from the aesthetics, the heritage and other conservation issues must be borne in mind.

For those heritage values, the full range of solutions is not applicable in a historic building; therefore, the role of the ICT (Information and Communications Technologies) becomes more important. Sometimes, passive solutions such as internal insulation or a wired monitoring system do not comply with conservation concerns. Thus, in order to bridge this existing gap, the development of wireless technologies and the combination of Building Management Systems (BMS) ease the integration of energy efficiency solutions in historic buildings.

In this way, this paper presents an innovative solution utilising a wireless monitoring and control platform. Firstly, a brief state of the art is covered followed by the monitoring concepts tackling the constraints in these buildings and the wireless solutions. Secondly, the description of the Building Management System and its benefits are detailed. Finally, an example with the results achieved is described.

State of the art

Currently, there has been considerable research in heritage for both monitoring and control. An example is shown in [2] where a BMS has been developed for the improvement of the performance in the Archaeological Museum of Thessaloniki integrating multiple communication protocols for a complete management of the electric power, heating, ventilation and microclimate systems. Moreover, in the Firesense project [3] a multi-sensor network is deployed for the protection of cultural heritage areas, including wireless sensor networks.

However, these solutions are not fully compliant with the objectives of 3ENCULT because, in the first case, no wireless systems are integrated and, the second one, it is centred in fire security. Therefore, in the 3ENCULT [1] scope, a solution for the specific building requirements is needed.

Monitoring systems

In order to assess the energy behaviour of a historical building, a monitoring phase is required. This also allows an observation of the valuable basic materials and structure of buildings, so that, depending on the type and intensity of building use, an immediate threat to the valuable buildings and equipment can be detected. The monitoring can also give important information on the thermal comfort of a historical chamber [4].

The aim is therefore, by means of a suitable sensor network, to collect data of all the relevant parameters and metrics in order to characterize the energy behaviour of the building, the climate situation and comfort in the rooms, the climate-related stress on valuable surfaces, moisture and heat situation in the energy upgraded building construction and energy consumption, such as it is shown in the **Figure 1** [5]. With the evaluation of all these state variables, an evaluation of the energetic and physical behaviour of a building can be reliably evaluated. There are several reasons for implementing building monitoring. The essential task is to understand the actual condition of the building.

Heritage constraints

The possible interactions between external and indoor climate and the historical surfaces are often ignored. **Figure 2** [4][5] shows the required framework of the investigations. It is the result of an energy redevelopment whose risks appear in the near field area of valuable historical surfaces, because they are exposed to critical climate fluctuations.

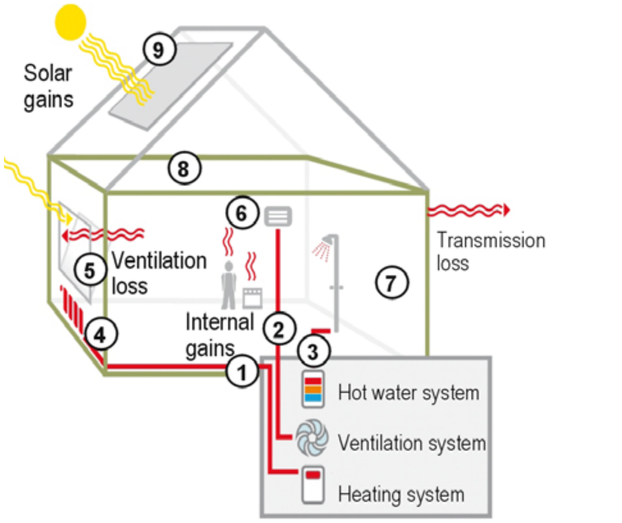
A first assessment of the risk of historically significant surfaces is needed to collect data on the climatic near field conditions, e.g. by surface temperature sensors and temperature and humidity sensors in the near field of historical surfaces in sufficient numbers and distributed in the room.

Other concerns to take into account are related to conservation issues of historical buildings such as aesthetic or conservation aspects. With regard to the aesthetics, wired sensors are forbidden in several cases because it is not possible to modify the visual aspect by making use of cables, therefore the wireless sensor network is used for solving this issue. On the other hand, conservation aspects mean it is necessary to avoid the modification of anything in, the building structure and this is sometimes a problem for the power supply of the sensors. Both concerns define a challenge which has to be faced before implementing the sensor network.

ZigBee based wireless sensor network

For bridging the aforementioned gap, agile, low-cost, ultra-low power wireless networks of sensors, which collect a huge amount of critical information from the environment, become essential tools for building automation. Such wirelessly connected microsystems are defined as Wireless Sensor Networks (WSN) and typically incorporate both sensors and communication functions.

However, the current wireless commercial systems do not provide any ability to create interoperability between new applications and pre-existing subsystems. Thus, a new flexible WSN for the real-time monitoring targeted



1 Thermal demand general – heating system (kWh); Alternatively: temperature flow and return line
2 Power demand ventilation system – ventilation system (kWh); Flow rate – ventilation system (m³/h)
3 Flow rate – hot water system (m³/h); Temperature – hot water system (°C)
4 Thermal demand each radiator – heating system (kWh); Alternatively: temperature flow and return line
5 Contact – window open/close/tiled
6 Room clima – temperature and relative humidity (°C/%)
7 Surface temperature (°C)
8 Lighting (lux)
9 Weatherstation (Temperature, relative humidity, rain, wind, radiation)

Figure 1. Energy and comfort monitoring.

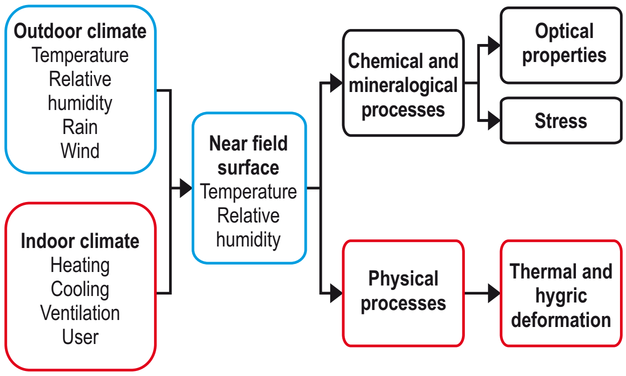


Figure 2. Framework of the monitoring concept.

for historical buildings needs to be designed and its performance optimized, with particular attention to the autonomy and reliability of the whole network [6]. Specific objectives can be formulated as follows:

- Physical node size of the WSN not exceeding a few cubic centimetres.
- Sensors lifetime from several years to tens of years.
- The node should be field-configurable and the WSN be modular, have dynamic deployable capabilities, and be easy extensible.
- Wireless actuators will also be considered which can reduce installation effort considerably in historical building, where existing distributed autonomous components have to work together.

Complying with these requirements, the Wispes W24TH nodes (**Figure 3**) were selected as basis of the adaptation for the sensor network. All these motes are compliant with ZigBee Pro protocol where there are three types of sensors: coordinator, router or end-device.

The core of the system is a 32bit microcontroller with a 2.4 GHz radio transceiver and 32 MHz CPU clock that permits the development of complex applications and distributed data processing [6]. The system is provided with a series of on-board sensors:

- Temperature sensor;
- Humidity sensor;
- 3-axis Accelerometer sensor;
- Ambient light sensor;
- Mox gas sensor (VOC, CO_2...).

Command-driven driver

For the communication and collection of sensed data from the sensors, a command-driven driver has been designed [6][7]. Thus, based on commands through the USB (Universal Serial Bus) interface, available on any computer, the information is compiled and stored in a persistent database. Several commands are currently implemented in the latest version of the nodes which allow the application layer to interact with the sensors in order to retrieve the information and/or configure the network. In summary, the most important commands are:

- s – Enable/disable sensor samples
- p – Change the on board sensors on/off. It means enable or disable sensor measurements in a concrete device by sending, for instance, p001100. The example deactivates the two first sensors and the last two sensors, meanwhile the two intermediate sensors are enabled.
- r – Reset the network.
- w – Set up the sleep time in the nodes. For example, sending w=600 means the sleep time in the nodes is established to 10 minutes.

Building Management System

A Building Management System (BMS) is a software high-technology computer-based system which is installed on buildings for monitoring and controlling the equipment and facilities [7][8]. 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.

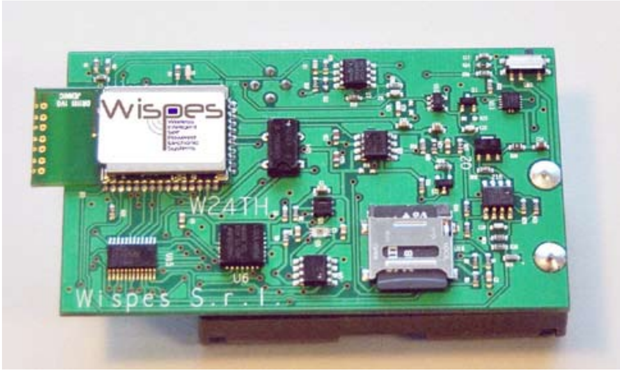


Figure 3. Wireless sensor nodes.

A BMS is a complex, multi-level, multi-objective, integrated, interrelated and complete intelligent design management information system [7][9] which mixes software and hardware.

The purpose of a Building Management System (BMS) is to automate and take control of the operations of the facilities and actuators in the most efficient way possible for the occupiers/business, within the constraints of the installed plant [8].

Architecture

The design of the BMS in the 3ENCULT context is a multi-layer Service Oriented Architecture (see **Figure 4**) based on OSGi (Open Services Gateway initiative) specification.

Thus, the architecture is set up by multiple layers so as to develop a more modular, scalable and replicable system. Lower layers represent the OSGi framework

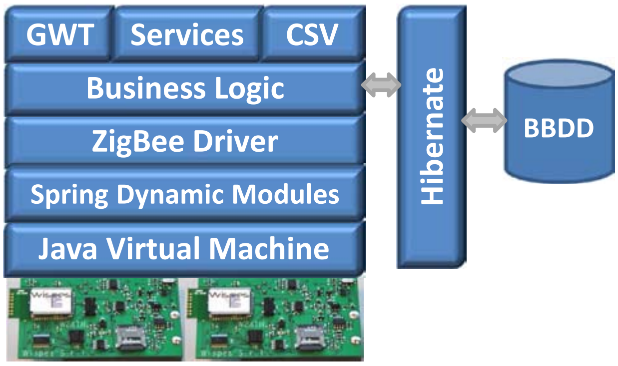


Figure 4. BMS architecture.

(Java Virtual Machine and Spring Dynamic Modules), whereas the ZigBee driver is the implementation of the communication driver described before. Finally, the Business Logic establishes the algorithms and functions for collecting data, performing internal management and rendering control algorithms, and the upper layer is related to the user services and applications.

Technologies

Within the greater novelties, the integration of new technologies is one of the most important. Thus, the main technologies are Spring Dynamic Modules, Google Web Toolkit and Hibernate. The integration of all these technologies has not been realised in the current status of BMSs. First of all, Spring Dynamic Modules provides an OSGi release 4 framework which eases the development of services by means of dependency injection property. This feature mainly manages by itself the services dependencies among services avoiding the need for taking care of these dependencies by Java code. Furthermore, Google Web Toolkit offers a framework for the implementation of Graphical User Interfaces in building and optimizing complex browser-based applications, with wide documentation. Last but not least, Hibernate brings the mapping among object-oriented programming languages and relational databases, so that the developer could manage objects in a natural way without caring the database manufacturer.

BMS Services

The upper level of the system architecture represents the user applications, which includes a set of services for the performance of the platform. These have been defined for the ZigBee sensors developed in the project, but they could be extended, if required, because of the advantages of the service-oriented design. The list of services deployed is the following [7]:

- Monitoring service: This is the fundamental service that contains the list of sensors and their measurements classified by sensor and application field.
- Lighting service: It displays the latest value related to the lighting system for each device in the network, as well as, the trend during the time slot defined by the user.
- HVAC service: Similar to lighting, it is able to show the latest values and trend for variables associated to HVAC (Temperature, relative humidity and air quality).
- Energy service: This service calculates the costs of the energy consumption, when a probe is available onto the sensors. Also, it prints the energy in order to compare consumption and costs.
- Alarms service: The alarm service allows the configuration of the set-point for raising alarms and it sends a mail to the administrator when any set-point is reneged on.
- Download data: The latest service permits the downloading of historical records of data based on user filters, in "csv" format.

Viability in historic buildings

The Building Management System and the complementary Wireless sensor network are compliant with heritage as far as they obey to the constraints and restrictions. With regard to the wireless sensor, it avoids the use of cables applying with aesthetic premises and possible structural damages in the installation. About the BMS itself, it is able to define set-points and actuate according these values so as to keep the conditions needed in the historical buildings regarding both indoor comfort conditions and energy performance. Moreover, it does not require any additional installation that could damage the building.

Performance parameters

For the evaluation of the platform, some performance parameters have been evaluated which define the capabilities of the software. Thus, the following features [7] are applicable in this case:

- Reliability: The Equinox server provides almost 100% of service working availability.
- Interoperability: Owing to the SOA, the capability of communicating services is transparent thank to the well-established interfaces.
- Scalability: SOA provides loosely-coupled services, which allows the integration of new services in the platform, increasing the number of them. About the scalability of the sensor network, the number is limited by the ZigBee sensors, as far as the BMS is able to manage large data streams.
- Replicability: The development of the BMS has been done through open software and standards, therefore, the BMS could be replicated in any other building.

Deployment in the Industrial Engineering School of Béjar, Salamanca (Spain)

During the test phase, the Industrial Engineering School of Bejar has been used, which is a case study within the project. There, a small ZigBee sensor network has been deployed (see **Figure 5**) in order to measure information in a test room in combination to the current LonWorks network so that the control algorithm could actuate directly in the system because the wireless nodes do not offer control commands until now.

The platform has been working since 28th of October 2013, when the ZigBee based network was deployed and the measurements are feeding the control algorithm in order to control the facilities of the building, improving the comfort levels in this test room, meanwhile the energy consumption has been conserved.

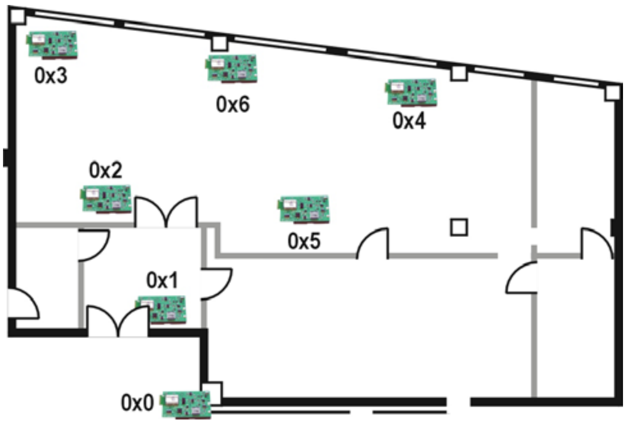


Figure 5. Sensor network in the test room.

Conclusions and future lines

The present article describes the development of a novel Building Management System compliant with historical buildings. As yet, the study of heritage is an open issue with some restrictions and constraints which are not fully covered by the current developments. Thus, the gap between the passive solutions and ICT systems can be fulfilled by integrating the presented technologies.

As open points for future development, the implementation of control commands in the sensor nodes is a key factor instead of using several systems. Last but not least, the BMS is compliant with the ZigBee based network and it is able the integration of other communication protocols, such as LonWorks, BACnet and so on. ■

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