iNSPiRe

Systemic energy renovation of buildings

D5.1 Report on the Adopted ICT Solutions

Development of Systemic Packages for Deep Energy Renovation of Residential and Tertiary Buildings including Envelope and Systems

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1 Introduction

In this document, the design and development of the distributed monitoring system is described, which was used to establish communication with sensors and monitoring hardware in operation. The aim is to ensure the availability of the required information for a detailed supervision of the building. To achieve this objective the document has been split in:

- Description and general characteristics of monitoring systems
- State of art for general technologies for monitoring
- System Monitoring Devices
- Monitoring systems in the case study

A description about each case study construction characteristics, energy supplies and monitoring systems has been reported. The main systems consuming energy are:

- Heating and cooling
- Domestic hot water.
- Lighting.

The specific objectives of a monitoring campaign are to provide information about the energy performance of the building, the indoor thermal comfort, the efficiency of several energy renovation measures and the efficiency of the HVAC system.

Smart buildings have a set of technologies that increase energy-efficiency and user comfort as well as the monitoring, improving in addition the safety and health of the buildings. Information and Communication Technologies (ICTs) are used in:

- Building management systems for monitoring heating, lighting and ventilation.
- Software packages which automatically switch off devices such as computers and monitors when offices are empty.
- The application of sub and smart metering approaches.

The first step in improving energy management is measuring how, where and when energy is used. While monitoring alone does not save energy, the information from the measurement system can result in significant reductions. Once monitoring information is available, the facility manager can make a comparison with similar or reference buildings using key performance indicators (e.g. kWh/m^2). That information can provide a general sense of whether energy costs at a particular building are higher than the average and, if so, it means that energy-saving opportunities are to be looked for. When a metering system is needed, the right level of detail has to be chosen. Basic metering level (system) is the measurement of energy taken from the grid (e.g. electricity, gas and water meter) for real-time total consumption data or historical statistics.

2 Description and general characteristics of monitoring systems.

Monitoring systems in buildings collect and gather data of systems integrated within a home/building through the Information and Communication Technologies (ICT). Such systems allow decentralizing the monitoring (local and remote) thanks to a number of devices. They are systems relatively new, since the integration of systems at commercial level started in 1980s. At a first moment, such systems were used in the industrial sector, beginning their commercialization in the domestic sector later, coinciding with the evolution and deployment of Internet. In their early days, introduction of technology in homes was only aimed to the improvement of benefits of domestic devices without any desire to develop the capacity of communication between other devices. Currently, these monitoring systems mainly include the use of electricity, electronics, computer systems and different telecommunications devices, including mobile phones and Internet. Some of its main features are: interaction, simplicity of use, remote operation, or driving distance, reliability, and capability of programming and updating.

These applications provide the ability to manage an intelligent system by modifying the parameters of the installation locally or remotely.

Previous to the definition of the monitoring system in each dwelling, the following lines show an overview of the monitoring concept in order to share a better understanding. The use of different systems and different kinds of networks creates the existence of different parameters as the complexity of cabling, speed of transmission, vulnerability, network management, rate of malfunctions, etc.

2.1 Main objectives of a monitoring system.

Objectives of monitoring system are [1]:

- Remote monitoring & metering
- Energy management
- Communication
- Alarming
- Data-logging

The next section describes the main characteristics of each one:

2.1.1 Metering Strategies

Using a well-accepted study, there are four predominant metering strategies to consider, each one with its own level of data activity and estimated savings [2]:

1. Install meters only with software for collecting data

Action:

- Gathering energy data from individual buildings.

Use of Meters/Data:

- Storing of information.

Typical electrical energy savings: Installation of meters: 0-2%.

2. Install meters with data collecting and cost allocation software

Action:

- Accountability for meeting conservation goals.
- Cost allocation for each functional area.

Use of Meters/Data:

- Monthly reports.
- Monthly bills.

Typical electrical energy savings: Installation of meters and bill allocation: 2% to 5%.

3. Install meters with data collecting and cost allocation software, and conduct operational analysis and building tune-up

Action:

- Accountability for meeting conservation goals;
- Cost allocation;
- Identification of inefficient operations;
- Fine-tuning of building controls.

Use of Meters/Data:

- Monthly reports for each functional area;
- Monthly bills to outside vendors.
- Internal review and adjustment of building operations (time schedules, etc.).

Typical electrical energy savings: Installation of meters, bill allocation, and tune up: 5% to 15%

4. Install meters with data collecting and cost allocation software, and conduct continuous operation analysis and building commissioning

Action:

- Cost allocation to departments and outside vendors;
- Continuous commissioning of energy-using systems;
- Outside review of energy savings goals with staff.

Use of Meters/Data:

- Monthly reports for each functional area;

- Monthly bills to outside vendors;
- Action plan and fine-tuning;
- Review with building staff and outside consultants.

Typical electrical energy savings: Installation of meters, bill allocation, and persistent commissioning: 15% to 45%.

2.1.2 Energy Management

The purpose of energy management is to reduce energy consumption. To reach this objective it can be split into three different aspects.

1. Regulation from the evolution of the energy consumption of building.
2. Programming to set various parameters such as temperature according to schedules, days of the week, month, etc.
3. Optimization to minimize consumption. Harnessing energy and reducing the consumption is one of the most important aspects of control systems since it reverses in the medium and long term in its depreciation as well as is linked to the concept of comfort. Actions aimed at reducing consumption are closely related to the integration of all devices of the housing system.

These actions involve:

- Use of the cheapest time zone rate (for example, using night rates according to schedule).
- Reduction of consumption for air conditioning outside normal working hours.
- Detection of sources of leaks in air conditioning systems (for example, suspension of the operation in rooms when open windows are detected).
- Reduction of consumption for air conditioning or lighting in the absence of people in the rooms through the occupancy sensors.
- Acting on automation blinds for the use of solar light.

2.1.3 Communications.

In communications area, there are many possibilities depending on the type of installation.

This area has become very relevant due to the emergence of searching new technologies in the field of communications and data transmission networks as well as in the dependence of automation systems of advanced domestic network on them, which has encouraged the research and development of new architectures and integration systems. Nowadays there are not integral solutions for all networks and protocols that can be found in a house or building, but we find different technologies that we have to integrate to provide the desired services (see Figure 1). Networks, internal to the installation, are called (Home Area Network) and they involve three types:

- Network home automation (domotic system) or control of home devices, such as appliances, points of light, blinds, switches, etc. They are often used in network protocols as KNX, Lonworks, CEBus, X10, MODBUS, M-BUS etc.

- Data network which are Ethernet, wired or wireless.
- Multimedia network, such as telephony or cable television. Due to the absence of integrated solutions, it makes necessary the use of residential gateways, devices that can interconnect different internal and external networks of housing (see Figure 1).

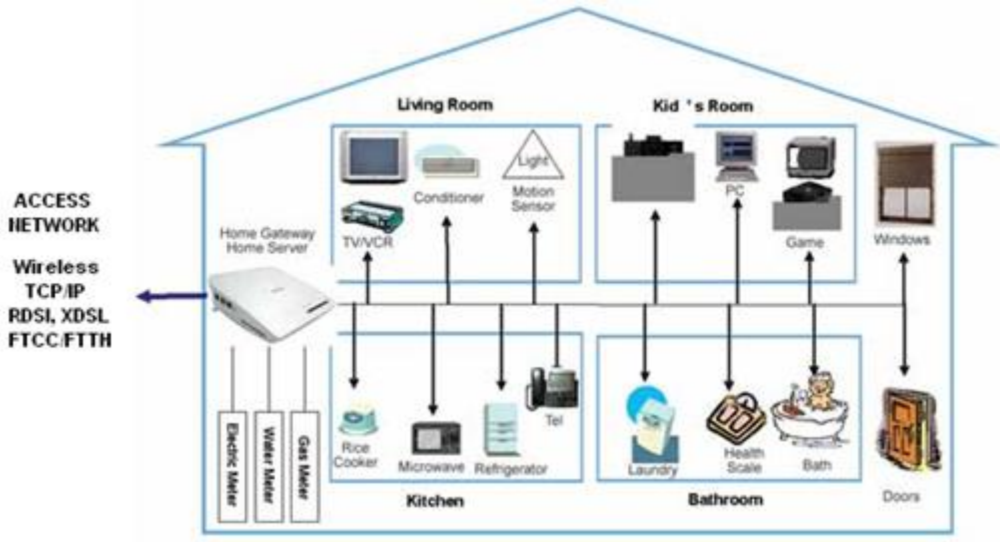


Figure 1 Home Networking.

Possibilities of telecommunications according to the kind of building are:

- Indoor communication system: dissemination of audio & video, intercoms, etc.
- Outdoor communication system: basic telephony, video-conference, email, Internet, digital TV, cable TV, fax, radio, transfer data (X.25, ATM), etc.
- External communications: alarm messages which detect gas, water leak, etc., and remote control of the automation via the line telephone or Internet networks.

Among all of them, from the point of view of contributions of research and implementation of new technologies, the initiatives of tele-control of the domotic system from outside are the most popular in the recent years. In this sense we can highlight works such as:

- Development of the open initiatives for the implementation of domotic services in residential gateways.
- Management of domotic installations using protocol TCP/IP, HTML or applets in the Java language, for the tele-operation and monitoring systems in home automation buildings.
- Control of facilities in home automation networks using mobile devices (mobile phones, PDA, etc.), by service of short messages (SMS, Short Message Service or email), (Wireless Application Protocol WAP) wireless application protocol and other technologies.
- Implementation of encryption and authentication systems in remote access to home automation installations through internet.

- Applying techniques of 'Design for all' to facilitate interaction between domestic environment and ancient people or people with some type of disability.

2.1.4 Alarms

Alarms are a monitoring service in which the system warns of particular event. Therefore they are preventive actions, in which the system acts in a certain way:

- on/off any system
- warning of any behavior

Alarms will be reported through one of the following mechanisms:

- alerts in the monitoring console
- email
- SMS

2.1.5 Data logging

Data Logging is an application used to record data point values and store them to a log file. To use a data logger, the type of log file to store the data point values (historical or cyclical) is chosen firstly, selecting then the data points to be tracked and the method to record data point values (polling and/or event-driven updates). In addition, it is possible to connect the data logger trigger with an alarm.

This service has been traditionally used in the industrial control areas; hence, there are many industrial instruments which support this standard. Currently, it is very common to use data logger in buildings for storing HVAC data, lighting data and electrical consumption for selection of a monitoring system and energy control.

In general, the following points must be considered to select the monitoring and control system, which will depend on the type of building and user:

- **Typology and size:** Typology of the architectural design (flat, attached home, single-family home, building, industry, district) and size.
- **New or built buildings:** If the building has not been built yet, there is a practically complete freedom to incorporate any system, but if the building is already built, civil works associated with different systems and their limitations on possible interventions or changes in the structure of the building must be taken account.
- **Functionality**: The functionality required for monitoring and control systems is usually based on the organization, habits and the use that is made of the building.
- **Integration:** In addition to the equipments and systems that are directly controlled by the management system, others building systems are searched to interact.
- **Interfaces**: There is a large variety of interfaces, such as pushbuttons, touchscreens, voice, presence, mobile, web, etc., to choose and implement. Each one of these systems

has a different interface.

- **Budget:** Cost varies greatly among the different systems and the budget must be balanced with other factors to be fulfilled.
- **Reconfiguration and Maintenance**: It must be taken into mind how easily is the system reconfiguration by the user but also the maintenance and after sales service offered by manufacturers and system integrators.

2.2 Current status of energy management service.

There is a variety of methods, tools and techniques, which develop an energy management service in buildings. To summarize it, the current status is as follows:

- Control, design and integration of solar thermal systems in buildings: The solar systems often use commercial devices and are based on temperature differentials. Rarely, proportional control is utilized, and neither case is used integrated platform control.
- There are many solar systems models used as design tools, however, they are never used as control tools.
- Integration of solar photovoltaic systems in buildings: Energy management systems for buildings do not include the contribution of photovoltaic because they are usually installed as connected photovoltaic grid. From the point of view of energy balance, these facilities are not involved in management applications because they do not provide a controllable service. Hence, there is not any tool which incorporates the solar photovoltaic in its algorithm control. However, it is far from negligible effect because it contributes very significantly to the reduction of emissions and therefore, to the quality of the building's energy generation. So, it is necessary to include photovoltaic plants in an integral management if it is desirable to deep strategies for energy conservation and efficiency. Communication networks and distributed control: There are several commercial solutions to provide buildings of a communications network, seldom focused directly on energy management.
- Digital communication infrastructure is usually utilized for information services in local networks and for providing Internet service. In the global energy management, it is necessary to have the communication infrastructure needed to integrate systems, taking into account that information must be used for the control of parameters such as temperature, flow, valve actuators, start up, etc.
- Building and home automation technology: Until a decade ago, the technological improvements introduced in households consisted mainly of the appearance of new devices and the increase of their utilities, considering them mostly as isolated devices, without any relationship or communication. However, they were only systems of turn off and on devices, without communication between them, expensive, rigid and complex. Nevertheless, in a few years, the situation has become completely different. Companies have done important advances on adapting them to user needs, and in considering from the beginning of design of the components, systems and services, concepts such as ease of use, understanding, customization depending on comfort requirements and tastes of each user, the scalability to adapt systems to new and emerging technologies, ergonomics and usability. Moreover, it must be added that the systems are equipped with a certain capacity for communication among its components, creating homes networks that

interchange data.

- Control environments, comfort: The concept of smart environment is exactly at the gates of the state of technology and many research groups have developed services based on smart environments for managing comfort.
- Statistical theory of short-term prediction: In the field of integrated building management, it is very useful that the techniques can estimate the demand of at least 12 hours, as it was explained in previous sections. There are prediction techniques for very advanced meteorological variables that might be applicable to the prediction of demand and estimation of the availability of renewable energy, solar and geothermal. It is possible thanks to Kalman Filter techniques, neural networks, statistical time series or other more complex techniques such as physical modeling or SVM technology (Support Vector Machines). There are some tools to predict demands but they are inflexible and are not easily integrated into a common platform.
- Advanced modeling of thermal systems: There are many developments in modeling and simulation in the field of thermal energy. In a few cases they have the flexibility to form by themselves part of an integral management system.

  The most useful tools are TRNSYS, which allows modeling based on elements developed and parameterized of almost any thermal systems, including solar, geothermal and conventional systems, with significant levels of detail and flexibility, which it becomes a candidate for the management platform in general terms. Also, Matlab is a remarkable tool for its versatility when deploying advanced controllers.
- Buildings Modeling: TRNSYS tool is accepted by the scientific community for its combination of flexibility and simplicity.
- Currently energy management systems are complex for buildings, and they have these key features:

1. Each company has its solution that is hardly exportable. Some examples are the Honeywell platforms, management systems of "Johnson Controls", or similar.

2. They do not address the overall management of the building, but they are an individual integration of several solutions, some for generation, other for the end use.

3. They do not have any services of advanced character that allows focusing on the building energy management with more ambitious targets, but they present the comfort user as only objective, disconnecting the control power generation with its end-use, and solving this issue with availability strategies that do not lead to optimal efficiency and energy saving.

1. Finally, any energy certification control is required in spite of the method has some short comings.

2.3 Integral systems in building management systems (BMS).

The implantation of a BMS system, which provides information to facilitates, the work of the energy service companies and also maintenance works, have made to emerge a new line of business.

In Figure 2 a schematic of an advanced energy management system of a dwelling is shown, giving an idea of the possible functionality of a BMS.

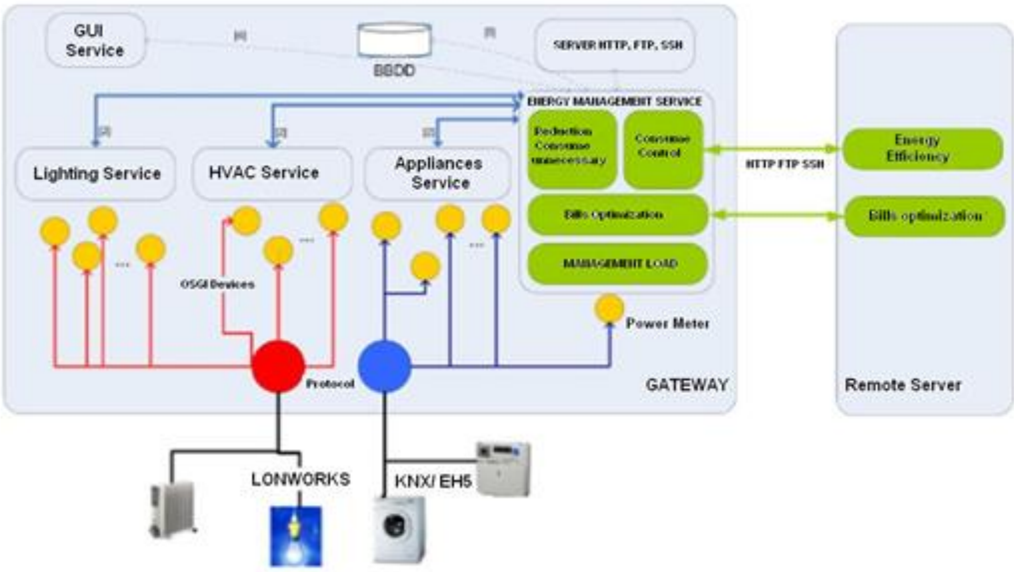


Figure 2 Dwelling management energy system.

An integral management platform can be implemented like a pyramid structure, where the base is linked to the management of the various subsystems of generation and consumption of a building and its top is full integration of energy management. Thus, between the base and the top, there are two intermediate levels. The first level is the integration among thermal generation, electric generation, both electric and thermal consumption; the second level would be the integration between electric generation and its use. Figure 3 shows the described system.

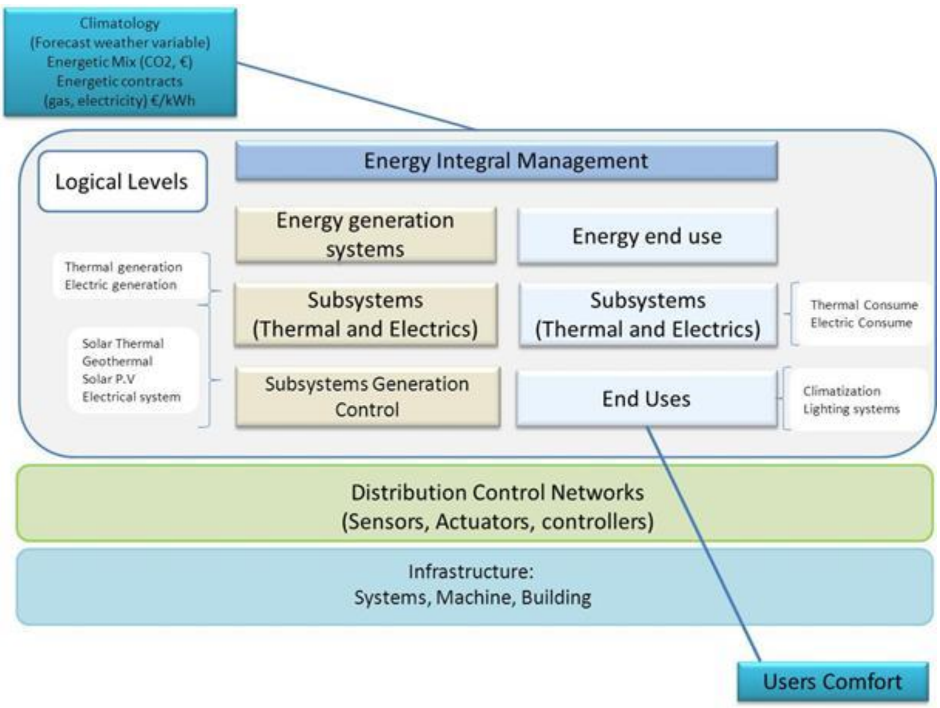


Figure 3 Integral energy management structure.

Figure 4 presents an example of integrated system represented by power manager modules, as management services which may be part of a platform. The main feature of this approach is its opening, which means that adding new services is always possible if they are adapted to the architecture described. The interrelationships among management services are reflected in two columns that represent generation and end use, and external modules give horizontally service to whole the system, some from the lowest level, closest to the building and other high-level, close to the energy manager.

In generation column, there are several services which manage different parts of the system. The service power generation defines amounts of demand and characteristics of the requested energy at lower levels. The management of electrical and thermal services defines the strategic for the distribution of generation among different systems. Each facility has its own service management that determines the optimal way to generate based on the requirements defined by manager.

In the column of end energy use, there are HVAC management systems starting with the both thermal load and lighting of the building. In this way it is calculated the thermal energy demand and electrical energy demand and then the generation systems is managed integrally. Each one of these services has its own identity and an established development structure.

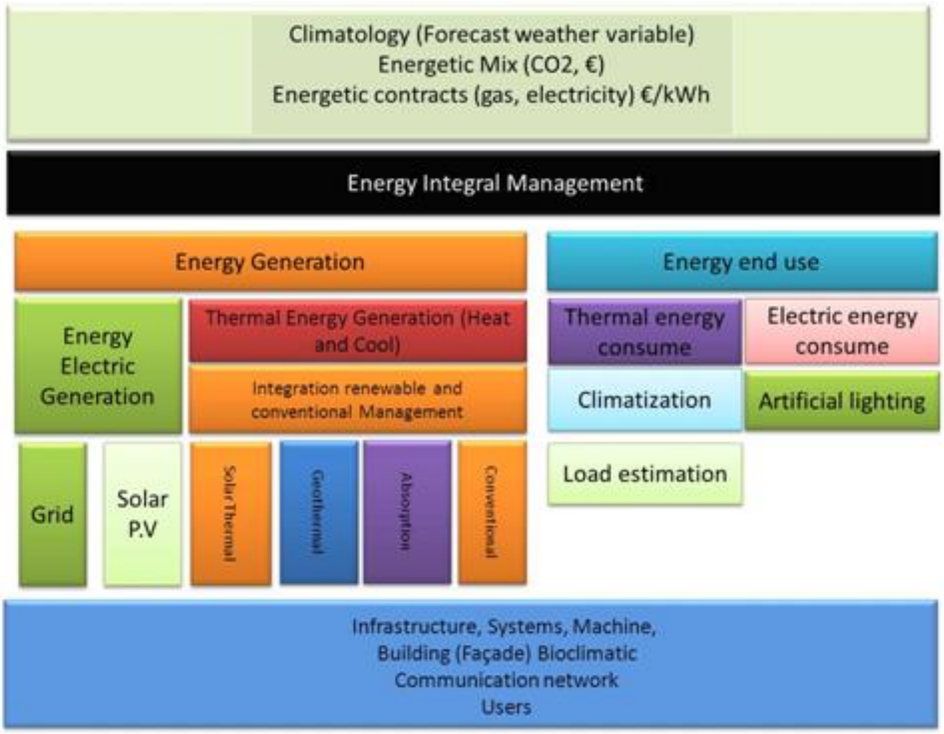


Figure 4. Platform management service modules.

3 State of art for general technologies for monitoring

3.1 Installation architecture.

Monitoring system architecture specifies the connection between different components of the installation: sensors, actuators and controllers.

The use of diverse kinds of networks makes possible the existence of different parameters as the complexity of cabling, speed of transmission, vulnerability, network management, rate of malfunctions, etc. Main architectures are centralized, decentralized, distributed and hybrid/mixed.

3.1.1 Centralized architecture.

In this type of architectures, all information regarding detection and performance is processed in a single point. The centralized controller receives information from multiple sensors, then the main controller processes this information and sends appropriated commands to actuators, interfaces, settings, sensors, systems and users as it is shown in Figure 5.

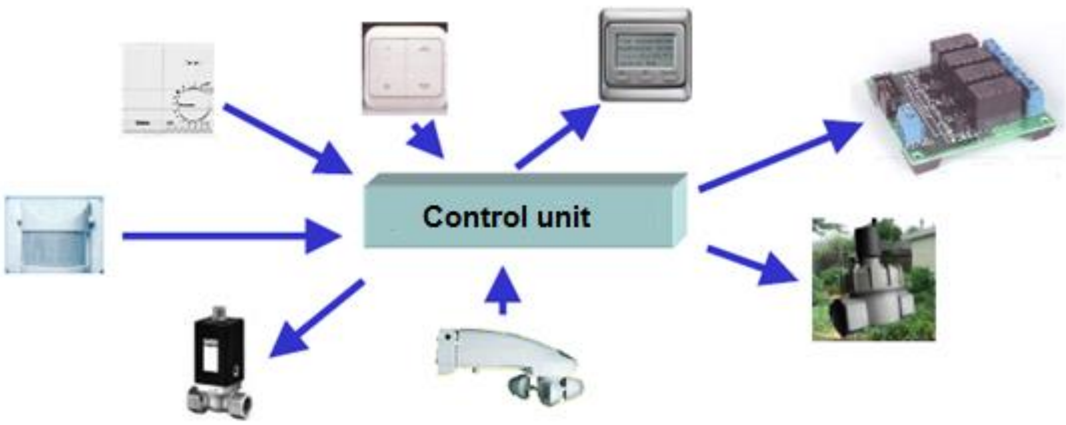


Figure 5 Centralized architecture.

The wiring frequently used in these cases follows a structure in star whose center is the central control unit and there is no communication between sensors and actuators.

Main advantages include:

- Low cost since items do not need special modules or interfaces to different buses.
- Simple installation and possibility of using a wide variety of commercial elements.
- Minimum requirements.

Disadvantages:

- Limited flexibility because of reconfigurations are costly.
- It is not reliable due to if central module falls, the system falls.
- Longer length of wiring given the topology, which increases the installation cost and limits

its use in large facilities. System does not run, in case of controller malfunction.

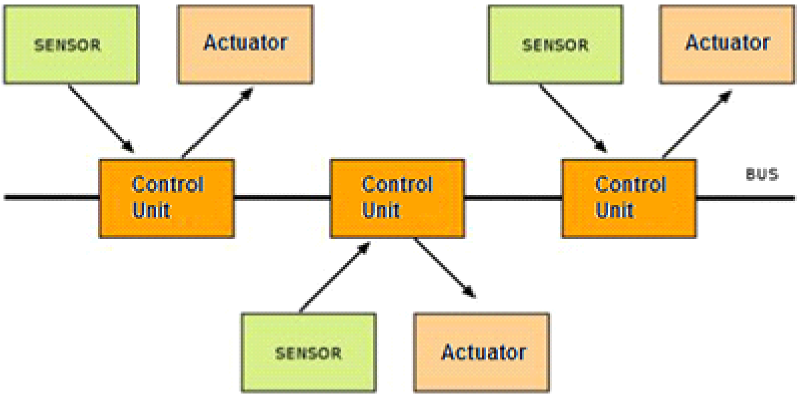


Figure 6 Decentralized architecture.

3.1.2 Decentralized architecture

In a control system with decentralized architecture, "intelligence" is distributed among different controllers, interconnected by a bus that will support the exchange information among them and the actuators and interfaces connected to the controllers (see Figure 6) [4].

Main advantages include:

- It is more flexible and scalable than a centralized architecture.
- Greater fault tolerance than the centralized architecture.

Disadvantages:

- More difficulty in the configuration of the communications system. Each device usually needs an address within the network.
- Longer length of wiring which increases the set-up cost and limits its use in large installations.
- Malfunction of an element does not prevent the correct operation of the other elements of the installation.

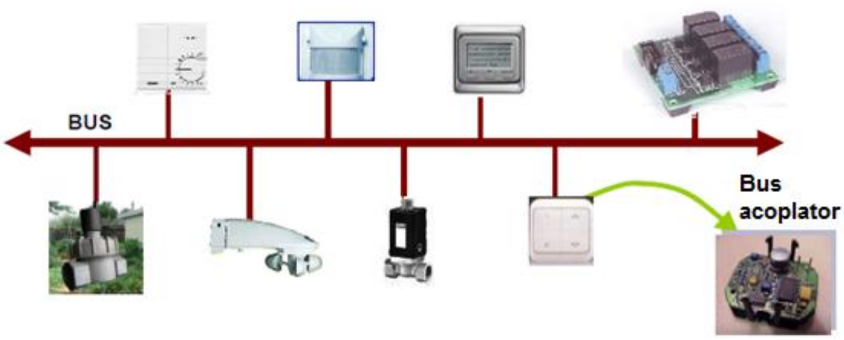


Figure 7 Distributed architecture.

3.1.3 Distributed architecture.

There is not a centralized controller in this type of architecture but all the intelligence systems are distributed by all the modules (e.g. sensors or actuators) as it is presented in Figure 7.

Each element has a capacity to process the information received and to act by itself. Main advantages of distributed systems are:

- High flexibility and easiness for reconfigurations.
- Scalability: They tend to be adaptable to any size installation and upgrades are simple.
- Possibility of plug and play technologies that simplify the assembly.
- Saving of wiring, thereby reducing costs, especially in installations and projects at large scale.

Disadvantages:

- Expensive components, due to the increase in complexity for meeting the necessity of including routing techniques and protocols used.
- Need for compatibility between equipment and components.
- Offer of limited products based on the protocol used.

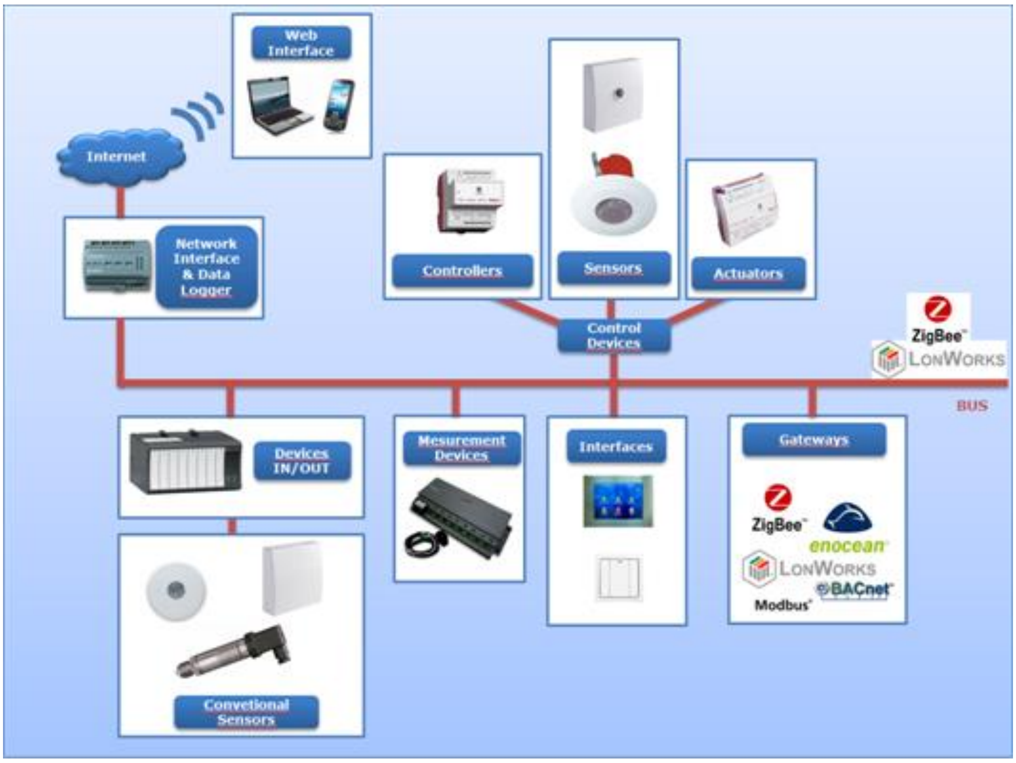


Figure 8 Architecture hybrid/mixed

3.1.4 Architecture hybrid/mixed

In a control system with hybrid architecture, different types of architectures, such as centralized, decentralized and distributed, are combined. In a system of this type, it can be found a central controller, various decentralized controllers and interfaces, sensors and actuators which are also controllers (see Figure 8).

A high reliability must be associated to all elements of the management system, and should prevent that the failure of one of its parts could produce the collapse of the entire system. An architecture that is adapted to these conditions is shown in Figure 8. Systems that have this hierarchical architecture are highly flexible and provide a high level of fidelity.

LEVEL 1. Consisting of the field elements located at the facilities (sensors and actuators), which will collect the measures and digital inputs to be sent to the second level. This level will act directly on the facility according to the orders received from higher level.

LEVEL 2. This level consists of distributed control processors open programming to which will be assigned regulatory functions, control and monitoring of the production of heating and cooling, air conditioning and power control.

They may work independently from the rest of the controllers that are connected to the same bus as well as from the central control system, while they receive and send information to the control center via the system bus.

LEVEL 3. This level is formed by the Building Control Center. Composed of a Management Central Computer, it will have the mission of coordinating and monitoring the building installations acting through the elements of the lower levels. This level will have a user interface to facilitate the control of the building installations.

From General Control Center, it will be possible to act on the various facilities so that, orders can be given, automatically or manually, for either activation or deactivation and change the operating parameters of the facility (temperature set points of the different dependencies, lighting schedules, etc.). Some features of the system are:

- Monitoring the status of all facilities, by displaying synoptic diagrams of each facility monitored.
- The reception of any alarm produced.
- Equipment starts and stops automatically.
- Graphical and numerical recorders to track the historical evolution of the installation signals.
- Event Logging of alarms of the different installations and user commands.
- Access Control System, through a system of user configurable passwords.

3.2 Transmission Way

There are several types of technologies which enable the transmission of information among different devices of the system of monitoring and control. Currently there are two technologies, differentiated by the necessity (or not) of a physical medium for sending and receiving the signal.

3.2.1 Wired System.

It uses a physical medium to transmit signal (wire) among devices. There are different kinds of transmission depending on wire.

- Wiring itself: An own wiring transmission is the most conventional way for controlling and monitoring systems. The most common types are: shielded pair, twisted-pair (1 to 4 pairs), coaxial or fiber optic. This own wiring (bus) is often used to power to the devices connected to it.

Main technologies are:

1. IEEE1394: IEEE 1394 (known as FireWire by Apple Inc. and as i.Link by Sony) is a standard platform for high speed serial data transmission. Its speed makes the interface be used for the interconnection of digital devices, video cameras, hard drives, printers, digital video, scanners, etc. to computers.
2. USB: Universal Serial Bus was created in 1996 by seven companies: IBM, Intel, Northern Telecom, Compaq, Microsoft, Digital Equipment Corporation and NEC. The standard includes the transmission of electric power to the connected device. Some devices require very low power, so several devices can be connected without requiring extra power supplies. The USB cable supports four speeds of data transfer.
3. Ethernet (LAN): Networks of local area and devices under the IEEE 802.3 standard that defines the CSMACD Protocol. Ethernet is currently called wired networks that use the frame format described below, although it has CSMACD as medium access method.

- Shared wiring: Several solutions use shared wiring and/or existing networks for the transmission of the information, for example, the mains (Power Line Communication – PLC), the telephone network or data network.

They consist of:

1. Home Plug. Its objective is to use the power of electronic appliances line to establish a line of communication among them and thus cover the market where WIFI cannot reach by: distances, thick walls among rooms, interference, etc. It has a low cost of implementation and it does not require additional wiring; however, it has a limited supply of products.

2. HomePNA: This is a local area network which works without new cables. This network allows to join PCs, printers and other resources such as: HUBS, routers, xDSL, etc., achieving speeds of data transmission up to 320 Mbps with guaranteed quality of service (QoS).

3.2.2 Wireless System

It does not need a physical medium to transmit signal among devices. Many control systems use solutions of wireless transmission among different devices, either primarily radio frequency or infrared technologies. They are classified into three categories organized by range:

- WPAN (Wireless Personal Area Network): It covers small areas (10 m), has a low-power transmission (Tx 10 mW) and low power consumption. The main technologies are:

1. IEEE 802.15.1 (Bluetooth): Global standard of wireless communication that enables the transmission of voice and data among different devices through a secure radio link.

2. IEEE 802.15.3: WiMedia Alliance (UWB): It differs substantially narrow frequency band radio (RF) and technologies "spread spectrum" (SS), such as Bluetooth and 802.11. UWB uses a very high bandwidth of the spectrum of RF bandwidth.

3. IEEE 802.15.4 (ZigBee): Set of protocols of communication of high level for use with digital radios for low consumption, based on the IEEE 802.15.4 standard for wireless personal area networks (wireless personal area network WPAN).

4. Infrared Data Association (IrDA): Technology based on rays of light moving in the infrared spectrum. They support a wide range of electrical, computer and devices communications, allowing two-way communication between two endpoints at speeds ranging from 9,600 bps to 4 Mbps.

- WLAN (Wireless Local Area network): It covers relatively large areas (100 m), has a high power transmission (Tx 100 mW) and high power consumption. The main technologies are:

1. IEEE 802.11 (Wifi) x: This is a set of standards for wireless networks based on the IEEE 802.11 specifications. Created to be used in wireless local networks, nowadays its use is also frequent for Internet access.

2. HiperLAN2: Global standard for LAN bandwidths that operate with a data range of 54 Mbps in the 5 GHz band frequency. It is a standard solution for a short range of communication that allows a high data transfer and a quality of traffic service between stations based WLAN and user terminals.

- WMAN (Wireless Metropolitan Area Network): It covers huge areas (100 Km), being the main technologies following:

1. IEEE 802.16 Worldwide Interoperability for Microwave Access (Wimax): It is the latest wireless technology developed by the industry that allows to access to broadband for fixed and mobile everywhere, and can co-exist with WiFi and 3G. It is based on the interface of air IEEE 802.16 wireless broadband access using an architecture point-multipoint (PMP) or in mesh.

2. GSM Global System for Mobile communications Group Special Mobile: It is a worldwide standard, with great coverage, not proprietary and continues under development for digital mobile phones. GSM differs from its predecessors mainly in voice channels, being the signals in this case digital.

3.3 Communication Protocols

There are different types of technologies that enable to communicate the various devices that make up the system of monitoring and control. A key element within these systems is the communication protocol. A protocol is the rule set standard for representation, signaling, authentication and error detection, which allows sending information through a channel of communication between the different elements connected.

There are two main types:

- *Owners or closed*: They are specific protocols in particular and which are only used by one manufacturer. They may be variants of standard protocols. Because they are closed, only the manufacturer can make improvements and those devices that can "speak" the same language. This protects the rights of the manufacturers, but limits the appearance of continuous developments in systems. Therefore while systems with standard protocol are developing, they are gaining market share to proprietary protocol systems. Another problem is the useful life of the system, as a proprietary system depends strongly on the life of the company. If the company disappears, system disappears and installations are left without any support or spare parts.

- <u>*Standards or open*</u>: They are protocols defined among several companies in order to unify criteria. There are no patents on the protocol so that any manufacturer can develop applications and products that carry implicitly communication protocol. Standard protocols for monitoring applications more extended at present are LonWorks and KNX (see Figure 9).

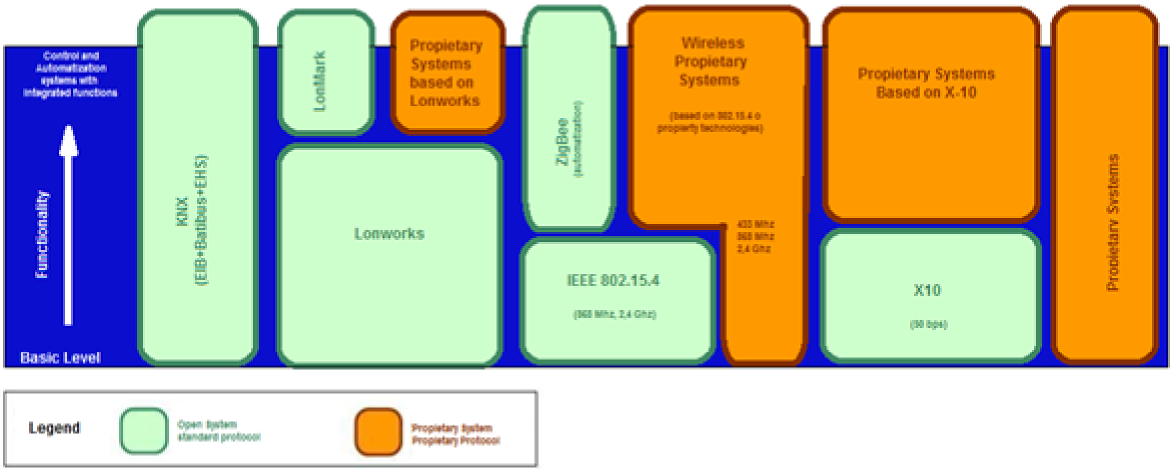


Figure 9 Classification of technologies, protocols and authorization systems [4]

3.3.1 KNX Technology

KNX allows transferring data from control of all building management components. KNX eliminates the problems that have isolated devices, ensuring that all components communicate through a common language.

This standard is based on others with more than 20 years of experience in the market, they are: EIB, EHS and BatiBUS. The devices are connected through twisted pair, radio frequency, strength or IP Ethernet communicating information. Devices connected to the bus, both sensors and actuators, are used for the control of building management equipment in all possible applications: lighting, shutters, security systems, energy management, heating, ventilation systems and air conditioning, monitoring and signaling, systems interfaces to services and control of buildings, remote control, measurement, audio video systems, control of property, etc. (see Figure 10).

All these functions can be controlled, monitored and signaled using a uniform system without need for additional control centers [5].

Figure 10 KNX features.

The main advantages of the KNX technology are:

- KNX is independent of any technology both hardware and software. The KNX technology has become worldwide the first open standard royalty-free and independent of the hardware platform for home and building control systems. It is completely free of additional payments in the form of royalties to members of payment.
- Interoperable. It ensures that products from different manufacturers used in diverse applications will operate and communicate with each other. This allows a high flexibility in the extension and modification of installations.
- Quality of the product. The Konnex Association requires a high level of quality control during all stages of life product. For this reason, all members of Konnex developing KNX products under the KNX trademark have to comply with ISO 9001 before they can apply for certification of KNX products. In addition to ISO 9001, products must comply with the requirements of the European standard for electronic systems in homes and buildings, i.e. EN 50090-2-2. In case of doubt, the Konnex Association is authorized to test products for certification again either may require a declaration of conformity of the hardware manufacturers.
- Functionality independent of the manufacturers. The KNX standard contains various application profiles for several common applications in homes and buildings. Under the supervision of the technical specifications, working groups make proposals to standardize different functions (inputs, outputs, parameters and data) in the specific domain of application. To ensure a high cross-discipline and multi-vendor interoperability, the Task Force Interworking revaluates these proposals for taking the decision to incorporate a standard KNX application profile.
- Common Software manufacturer independent engineering tool. The Konnex Association puts at disposal of all software manufactured by an independent engineering tool to plan the logical connections and configure KNX certified products.

In summary (see Table 1) KNX also offers: KNX is an optimized system in electrical installations for applications in homes and intelligent buildings controlling:

Energy management	Lighting	Blinds and awnings	Heating, ventilation and air conditioning	Security	Display	Automatic and remote access
Monitoring of energy peaks **Current detection** **Monitoring networks** **Control of loads** **Measurement** **Account of the energy pulses** **Registry data** **Display**	On, shutdown and regulation Automatic lighting Control constant Lux Timed control Scenes DALI gateway	Centralized control and groups Position programming Note the Sun located Automatic programming Improvement of climate Protection from wind and rain Security mode SMI gateway	Individual room control Central control and automatic Modes of operation time-out Programs for safety The flow Control valve Underfloor heating Fan coil units Electric heating	Intrusion control Smoke detection Technical failures Access control Preventive technologies Simulation of presence Fault monitoring Supervision of the Bus	Drivers Touch panels and display panels IR remote control PC display Web servers WAP PDA	Logical relationships Timed functions System monitoring Access to Internet Remote control Remote programming Messages

Table 1: KNX capabilities.

KNX also offers.

High-tech	Fast start-up	Flexibility	Lower risk	User-friendly tools	Ways of communicat ion:
Independence of products and manufacturers in the installation, as well as KNX is standard to comply with rules European (CENELEC in	Quick Assembly thanks to the convenient organization of wiring.	Independence of products and manufacturers in the installation, as well as KNX is standard to comply with rules European (CENELEC in 50090 and CEN EN 13321-1), and international (ISOIEC 14543-3).	Quick Assembly thanks to the convenient organization of wiring.	Independence of products and manufacturers in the installation, as well as KNX is standard to comply with rules European (CENELEC in 50090 and CEN EN 13321-1), and international (ISOIEC 14543-3).	Quick Assembly thanks to the convenient organization of wiring.

50090 and CEN EN 13321-1), and international (ISOIEC 14543-3).					

Table 2: Other properties of KNX

Twisted pair (twisted pair TP): Two wire buses, dedicated exclusively to the transmission of data from the control system and automation. This is ideal for new buildings.

Power line, data is transmitted through wires force existing in the building, typically lines of 230 V. This is ideal for the rehabilitation of existing buildings or buildings where it is not allowed to install new cables from bus.

Wireless radio frequency (RF): signals are transmitted by radio frequency, therefore it is not required any physical bus. They are ideal for buildings of high architectural value (e.g. with glazed facades) or hard to reach items.

IP Protocol: KNX telegrams can be encapsulated in IP telegrams to be transported by local networks or Internet. They are ideal to bind large facilities among themselves, even if there are large distances, or for remoting maintenance of facilities (see Figure 11).

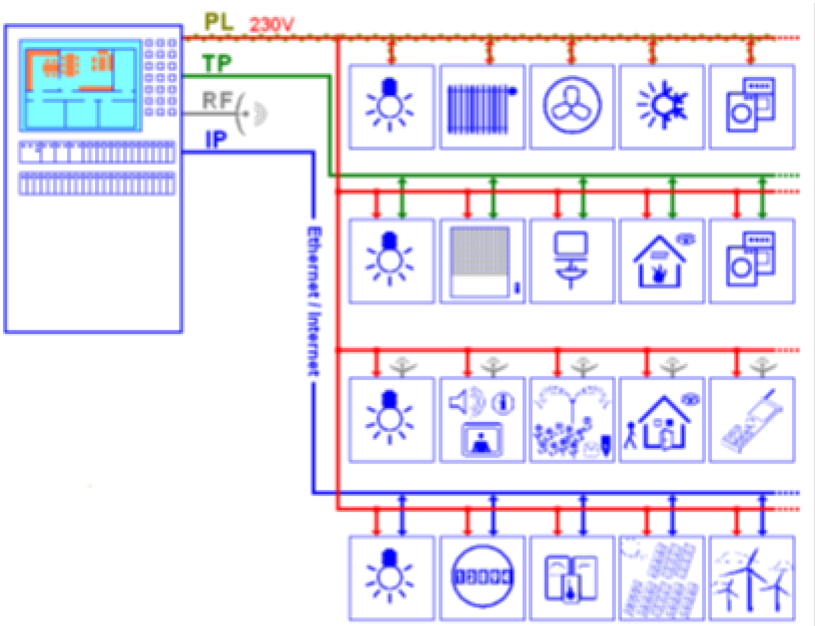


Figure 11: Ways of communication of KNX.

3.3.2 LonWorks Technology (LonMark)

The Echelon Corporation introduced the LonWorks technology in 1992. Since then, a large number of companies have used this technology to implement distributed control networks and automation. The success achieved in the United States and some countries in Europe is based on reliability, but it has only managed on the segment of tertiary buildings (offices, administration, etc), because it is expensive for applications at residential sector.

It was initially intended to deal with the range of applications of X-10, however, its simplicity makes that the application scope of this system ranges currently from industries, buildings, homes and cars and even other small devices.

LonWorks offers a solution with decentralized architecture, end-to-end, which allows to distribute the intelligence between sensors and actuators installed and covering from the physical level to the level of implementation of the majority of control networks projects.

Its architecture is an open system. A manufacturer who wants to use this technology can do it without relying on proprietary systems.

LonWorks can operate on RS485 opto-isolated, attached to a coaxial cable or of pairs twisted together with a transformer, on common carriers, fiber optic and even radio.

LON (Local Operating Network) technology makes possible a new generation of low cost items that communicate with each other. With this technology it is possible to create networks of smart devices that communicate process and control multiple applications in automation of enterprises, buildings, vehicles, etc.

LonMark is a technology opened by any LonMark devices from where any manufacturer can interact with other devices with the same label. In this case, the LonMark products are built on proprietary technology of LonWorks based. Two concepts are defined:

- LonMark, logo: the LonMark logo is a symbol, accredited by the LonMark Interoperability Association, which certifies that a device can be used on any interoperable LonWorks network.
- *LonMark*, object: A LonMark object is a LonWorks implemented following a functional profile. I.e., the device in question shall submit essential programming conditions so that it can be considered a LonMark object.

Description of the LON network: A network is a system of data transmission that allows sharing resources and information. One of its objectives is to make all programs, data and equipment available to any computer on the network that requests it, regardless of the physical location of the resource and the user.

A LON network consists of smart devices, also called nodes, connected by one or more ways and communicating between them using the same protocol.

The nodes are programmed to send messages to other nodes to detect changes in any of their inputs and to act as a response to messages that you receive, in their outputs. A LON network node can be interpreted as objects that respond to different inputs and produce certain outputs. The full operation of the network arises from the various interconnections between each of the nodes. While the function developed by one of the nodes can be very simple, the interaction between all can give rise to deploy complex applications.

The four basic elements of LonWorks ® are:

- Protocol LonTalk ®: LonTalk ® Protocol consists of a series of services that provide reliable and secure communications between the nodes of the network. The LonTalk ® Protocol features are as follows:
- Reliability: The protocol supports acknowledge receipt end-to-end with automatic retries.

- Variety of media: twisted pair, mains, radio frequency, coaxial cable and fiber optic.
- Response time: It uses a proprietary algorithm for the prediction of collisions that manages to avoid the loss of benefits that occurs by having a shared access medium.
- Interoperability: The LonMark brand in a device with the LonTalk ® protocol in a LON ® product ensures the connectivity of the products developed by different manufacturers.
- Neuron Chip: It is the heart of the LonWorks ® technology. LonWorks ® nodes contain a Neuron Chip for processing all messages from the LonTalk ® Protocol. Each Neuron Chip has a unique 48-bit (ID) identification number assigned during manufacture (recorded in EEPROM memory) and which allows addressing any node within a LonWorks® network. This ID is used as network address only during the installation and configuration of the node.

Neuron Chip has a communication model that is independent of the physical medium on which works; i.e. information can be transmitted over twisted pair cables, current carrier, RF, etc.

Communication between the nodes of a network is realized by the variables of network that are defined in each node. The network variables can be shared by other nodes, although only the network variables that are of the same type can be connected.

Transceiver	Physical environment	Speed	Network	Transceiver	Physical environment	Speed
FTT-10[a]	Twisted pair	78 Kbps	Bus, Star, 2.700m (bus)	500m (free)	64	FTT-10 LPT10

Table 3: Transceiver FT 10-Features.

- LonWorks ® transceivers: These devices serve as the interface between the Neuron Chip and the physical environment. LonWorks ® user can choose between several transceivers for communication with LonWorks ® technology. This flexibility allows to optimize the design of the network.
- Software installation of network and applications: LonMaker is a software package that provides the necessary tools for the design, installation and maintenance of control LonWorks networks.
- The network structure: The LON network structure adopts a distributed architecture (see Figure 12) that is one in which the control element is located next to the item to control. It has the following advantages:

Figure 12 Example of a LonWorks network on twisted pair [6]

Sensors and actuators are equipped with its own intelligence and exchange information directly about with others. A "central controller" is not necessary since the reporting process is conducted locally; Minimal wiring and maximum flexibility of expansion (see Figure 12).

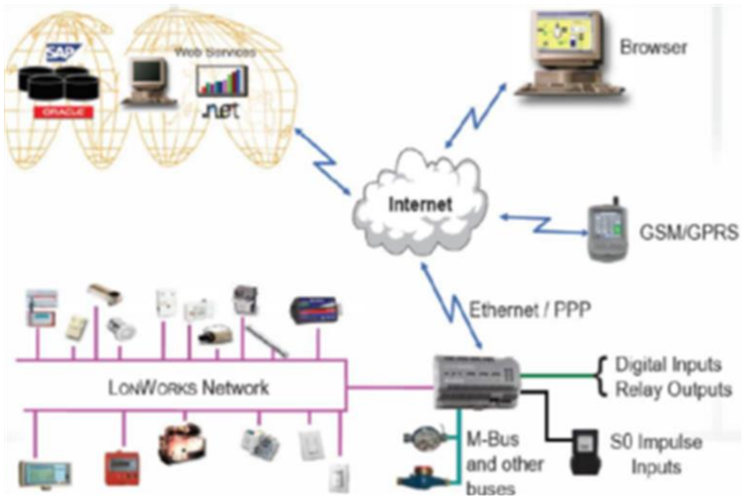


Figure 13 Example of integration on LonWorks with other protocols/systems.

3.3.3 BACnet (Building Automation and Control Network)

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." [2] 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 [3].

The main goal of BACnet is to provide interoperability between devices that work together from different vendors or generations through the digital exchange 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

In building automation, the distributed system can be depicted using a three layer 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 management functions belong to Management level. “BACnet can be used at all levels of building automation, but it is particularly suited for management functions. As a result, it 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.” [2].

The protocol defines how and which messages can be transported from one device or system to another. The different types of messages are the following:

- Binary input or output values
- Analog input or output values
- Software binary and analog input and output values
- Schedule information
- Alarm and event information
- Files
- Control logic

In 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). In the network layer (third layer), the relay of messages between similar or different networks is taken care off so devices communicate regardless the lower layer technology used in these networks. “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.” [1]

Above the network layer (in OSI model) is the transport layer. In this layer, BACnet uses User Datagram Protocol (UDP), which belongs to the Internet Protocol family. UDP is a very simple protocol that is used for transporting datagrams without acknowledgement or guaranteed delivery. For this reason, the BACnet application layer is responsible for controlling retransmission of a packet. Finally, the application layer is responsible for the object types, services and procedures involved in any communication of a BACnet implementation (these concepts are explained in the following paragraphs).

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 writeable (W) properties which can be optional or mandatory for each object type. Developers are free to define additional non-standard object types or properties if required.

For communication between devices, BACnet defines services that can be used to access objects. Those services are divided into five groups:

- Object Access Services
- Alarm and Event Services
- Remote Device Management Services
- File Access Services
- Virtual Terminal Services

From the operator point of view, BACnet Operator Workstation (B-OWS) is now the user interface for the system. While it is primarily used for the operation of a system, the B-OWS may also be used for configuration activities that are beyond the scope of BACnet standard. The B-OWS is not intended for the direct digital control of systems but it does enable some functions in the five IAs defined above. A B-OWS GUI, configuration and programming tools and additional tools for integrating disparate networks vary depending on the manufacturer. Unfortunately, there is no standardized development environment available (as there is in other protocols). As a result, the practical use of BACnet is strongly influenced by proprietary tools and, to a certain extent, limits the operation of components from different manufacturers." [1]. BACnet describes devices such as:

- Building Controller (B-BC), which is a programmable automation device capable of carrying out a variety of building automation and control tasks.
- Advanced Application Controller (B-AAC), which is a control device with limited resources compared to a B-BC, intended for specific applications that do not require much programming.
- Application Specific Controller (B-ASC), which is a controller programmed by the manufacturer and therefore the user can only change the parameters.
- Smart Actuators and Smart Sensors, which are simple devices that can communicate using BACnet and then only send values as electrical signals upon request.
- Routers, which are responsible for interconnecting networks that have the same or different network technology.
- Gateways to Other Systems allowing BACnet networks to connect with other networks such as KNX and LONWORKS.

"Devices must conform precisely to the requirements of the BACnet standard. To show that a device conforms to the protocol, the manufacturer must supply a Protocol Implementation Conformance Statement (PICS) that identifies all the sections of BACnet that are implemented in the device.” [1] The BACnet Testing Laboratory (BTL) is an independent institution to support compliance testing and interoperability testing for BACnet products. “Once a product has passed all the tests it is awarded the BTL mark.” [1]

In order to integrate BACnet devices with the ICT world Gateway, there are products available which translate among BACnet- BACnet/IP and BACnet- BACnet/WS. Both allow common IT systems and applications to access BACnet protocol data.

3.3.4 X10 Devices:

The encoding format X-10 is a standard using transmission of current carriers (Power Line Carrier PLC). It was introduced in 1978 for the Control system of the home to Sears and Radio Shack Plug´n Power systems. Since then, X-10 has developed and manufactured versions O.E.M (Original Equipment Manufacturer) of its system of Control of the home for many companies including Leviton Manufacturing Co., Stanley Healtth Zenith Co., Honeywell, Norweb and Busch Jaeger. In fact there are currently more than eight million installations. All these systems use the X-10 encoding format and are compatible.
The X-10 system is mainly characterized by:

- Be a decentralized system configurable but not programmable.
- (Connect and operate) simple installation and easy to use by the user.
- Applicable to single-phase and three-phase installations.
- Great maturity on the market with almost absolute compatibility with products of the same range, ignoring manufacturer and age.
- Flexible and expandable.
- For small to medium-sized.

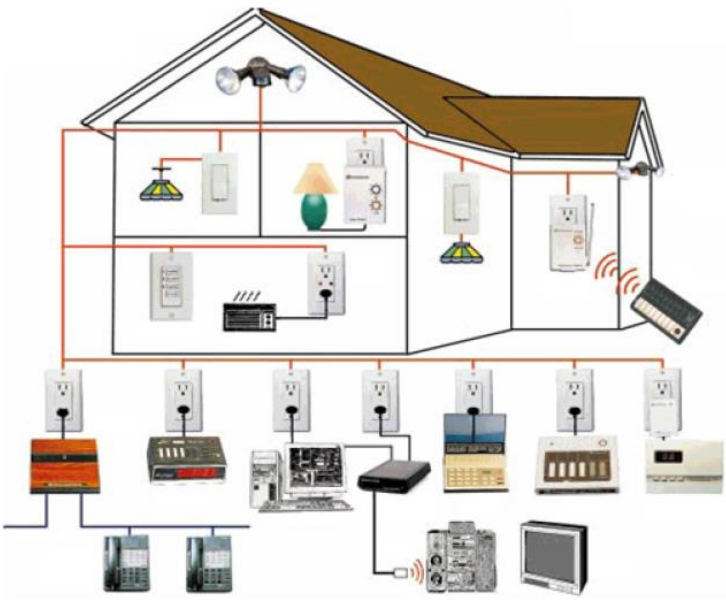


Figure 14:X10 Installation

Figure 14 shows an example of installation X10. Installation network is the basis of all current-carrying system (X10). The basic and fundamental element of current-carrying technique is the double use of the existing electrical installation, as a driver of energy and information. With the X10 components, the network, as well as power supply, is also responsible for the transmission of signals of control for various electrical appliances. These current-carrying signals can be sent to any point of the installation and at the same time relevant information may be requested from that point.

The system allows to remote control of various electrical receptors, from one or several points and can work both in single-phase alternating current and three-phase networks.

Working principle of the X-10 Protocol: transmissions are synchronized with the step zero of the mains voltage, with the dual purpose of, on the one hand, synchronized transmitters and receivers and on the other hand, seize the moment in which the interference caused by electrical equipment is minimal. Encoding consists of generating 120 kHz of 1ms duration pulses on step zero (1 logical: no pulse, 0 logical: presence of pulse).

A full message on X-10 consists of the beginning (1110) code, followed by the letter's home address and a control code.

Home address is encoded with four bits, allowing the identification of 16 different codes, appointed by letters A to P. In the devices, it is selected via a rotary switch.

Control code (4-bit) may be a unit address or a code of commands, depending on whether the message is a command or an address.

Address codes are selected through a second rotary switch (numbers 1 to 16).

The control codes include a series of commands defined in the Protocol: turn on, turn off, increase and reduce intensity, etc.

The principle of encoding X10 allows the activation and response defined up to 256 receivers, checkpoints of appliances or consumer groups. This makes possible the mounting of large networks.

Due to the characteristics of the physical medium used, information is transmitted twice so get to reduce the chance of error in transmission. In addition, each pair of blocks of information should be preceded by six steps by zero (three cycles of network), waiting the necessary time for a receiver to process the received data from address. Each one of the eleven cycles Network airs a block of data, and a standard transmission X - 10 normal needs 47 cycles of the network signal. At a frequency of 50 Hz this means a time equal to 0.94 seconds to transmit a complete order.

In addition to the low transmission speed, the Protocol does not provide rigorous mechanisms for confirmation or error detection, so that the transmission is not reliable, and therefore it does not guarantee the correct execution of the control orders. There are three types of X-10 devices: those who can only transmit orders, which only receive them and those which can send them and receive them. The nodes are equipped with two small rotary switches, one with 16 letters (a-p) and the other with 16 numbers (1-16), allowing to assign an address of 256 characters. In one installation, it could exist multiple receivers set to the same address. When a transmitter sends a frame with that direction, all will have a pre-allocated function. Any receiving device can host orders from different transmitters.

There is also a range of accessories and components that help to solve problems in the facilities, among which we can highlight the following:

Coupler Repeater - 10 X. It ensures the quality of the signal X 10 when the distance between controller and receiver module is too long and the signal suffers from attenuation.

Phase coupling filter. This module X 10 sends signals to prevent 10 X over current carrier out of the housing and cause disturbance in another facility. It suppresses interference coming from abroad, like the parasitic, orders X 10 to other neighboring installation. In addition it engages the three phases, in the case of a three-phase installation.

Programmer tester. It is capable of transmitting and receiving each of the commands, in addition to the extended commands X 10. It is a basic tool for installers of devices X 10 which allows knowing levels of noise, signal levels, and others.

Figure 15 shows an example of installation X 10. Filters and couplers are placed in the header of the low voltage network and signal amplifiers. All devices will be connected to a network of 230Vac. Sensors, such as buttons, or binary inputs for detectors will be responsible to send orders, and actuators (wall modules, plug or built-in) will active load on the basis of the received commands. They could be also drivers more complex (such as a computer) for functions to implement more complex services.

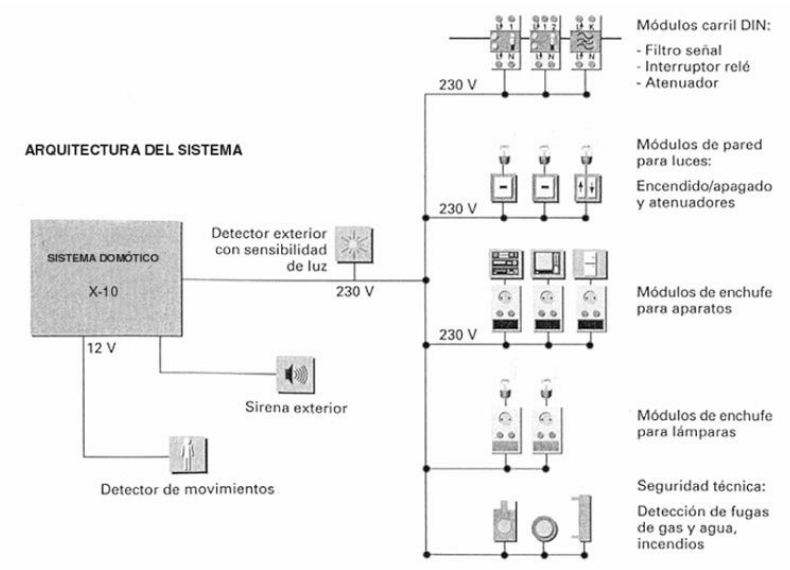


Figure 15: Components in X10 system

3.3.5 CEBus

In the United States, the EIA (Electronic Industries Association) recognized the need to develop a standard about the systems of automated households and a Committee was organized in 1983. The final document, after several revisions, was available in 1992 EIA 92 and covers both the electrical characteristics and procedures of the system of communication modules.

The CEBus standard architecture follows the OSI (Open Systems Interconnection) reference model, dealing each of the levels of certain functions of the communication network. CEBus uses only four of the seven OSI levels: physical, link, network and application. The interface between the different levels of the CEBus node is defined as a set of primitives of service, providing every service to the immediately superior. CEBus consists of three areas:

- Physical environment and topology.
- Protocol of communication (how to access the middle and build messages).
- Programming language (a set of actions that can be performed in the system).

Protocol and language are common to all elements CEBus, but there are 6 different physical media:

- Mains (PL).
- Twisted pair (TP).
- Infrared (IR).
- Radio frequency (RF).
- Coaxial (CX).
- Optic Fiber (FO).

The selection of the environment is carried out according to parameters such as energy saving, comfort, ease of installation of CEBus products, safety, cost and simplicity of the system. Many media co-exists in an installation. Each one would constitute a local subnet (Local Medium Network), which are connected by routers. CEBus encompasses several channels of communication: one control and various data. Devices are exchanged in the control channel messages and commands to control the home automation installation. Data channels are used for the transmission of voice, music, TV, video etc, and are assigned by requesting through the control channel. In general, the distribution of the different signals is follows:

- Video signals: using two coaxial cables, one for the internal signals and one for external.
- Voice and data signals: four twisted pairs known as TP0 to TP3 (TP0 reserves for 18Vdc feeding).
- Rest of signs: through the network of BT, connecting computers to standard plugs. Using a technique of modulation with expanded spectrum of Intellon Corp.
- The speed of data transmission achieved is 10 Kbps, and can be used both in homes already built as new constructions.

CEBus is a very ambitious standard emerged as a result of the cooperate between the European Union and Japan, However here not many systems are installed, which is mainly due to the tight commercial supply of devices and its high price.

3.3.6 ZigBee Alliance

The ZigBee Alliance is an association of companies working together to enable reliable, cost-effective, low-power, wireless networked, monitoring and control products based on an open global standard.

The goal of the ZigBee Alliance is to provide the consumer with ultimate flexibility, mobility, and ease of use by building wireless intelligence and capabilities into everyday devices. ZigBee technology will be embedded in a wide range of products and applications across consumer, commercial, industrial and government markets worldwide. For the first time, companies will have a standards-based wireless platform optimized for the unique needs of remoting monitoring and control applications, including simplicity, reliability, low-cost and low-power. The ZigBee Alliance defines its focus as follows:

- Defining the network, security and application of software layers
- Providing interoperability and conformance testing specifications
- Promoting the ZigBee brand globally to build market awareness
- Managing the evolution of the technology

The ZigBee Alliance is growing and consists of hundreds of promoters, participants and adopters. ICT solution providers must pass through a certification process before being Best able to display the ZigBee label. The website also serves as an information portal and collaborative platform for industry related news, events and resources.

3.3.7 Modbus.

Modbus is also an open serial communication protocol which was published by Modicon in 1979 for use with its programmable logic controllers for industrial applications. It has become a standard communications protocol in industry, and it is nowadays the most commonly available means of connecting industrial electronic devices. The simplicity of Modbus TCP/IP enables any field device, such as an I/O module, to communicate on Ethernet without the need for a powerful microprocessor or lots of internal memory. Due to the high speed of Ethernet, the performance of Modbus TCP/IP is excellent. Since Modbus is implemented on top of the TCP/IP layer, users can also benefit from IP routing enabling devices located anywhere in the world to communicate without worrying about the distance between them.

3.4 Selection criteria of LonWorks technology

After the above analysis, LonWorks has been chosen as the protocol to implement the communications within iNSPiRe project, since it brings together many of the main features of the alternatives proposed. Mainly:

- LonWorks is an open and standardized protocol, with moderate costs, able to secure a certain future stability (in terms of development of equipment, etc.) and is backed by a standard. It is independent of the transmission medium.
- LonWorks control networks are valid for installations of great importance in terms of number of devices and geographic installation volume as the control of the generation and/or the comfort in one factory. It is also valid for small facilities (e.g.. Monitoring HVAC system in a house).
- Currently it boasts a wide range of products in the market both industrial sector and dwelling and there is a large number of manufacturers and devices that work with this Protocol, what facilitates the establishment of control networks.
- It complies with the international standards, both American and European: ANSI CEA-

709.1 and EN 14908 (CEN). LonWorks is easily scalable, extensible, due to the possibility of installation on a network of free topology.

- Linked with the previous feature, the LonWorks control networks can be as networks of control architecture distributed, centralized, or even mixed, according to the needs of each installation.
- The two previous features converge in ease of installation, both hardware level and logical Assembly.
- There are a lot of modules or devices that are plug-and-play, just to include them in the network. This is because most devices come preconfigured to perform some tasks in particular.
- These devices are programmable or configurable, so it is possible to change its functionality without more than load a different configuration file.
- The type of connection, either twisted pair (FT-10) or the own main power supply (power-line) greatly simplifies the physical devices connection, since it is through a two-wire bus in both cases.
- LonWorks provides a number of tools for configuration, monitoring, diagnosis and control of the developed network.

Through gateways, Protocol is interoperable with most other protocols described above. Therefore:

- It allows designers of each project to use the best device for each system or subsystem without being forced to utilize whole line products from the same manufacturer.
- Interoperable products increase the supply on the market allowing to complete different manufacturers in a segment that otherwise it would be completely prohibited. In this way, manufacturers are striving to have the best solution and this translates into higher quality and freedom of choice for the end user.
- Interoperability reduces the project costs since there is not an exclusive dependence from a single manufacturer.

Interoperable systems allow the maintenance of buildings and monitoring industrial plants by using standard tools, no matter which company has made each subsystem.

4 System Monitoring Devices

The monitoring system to be installed and commissioned is aimed to analyze the behavior of the building in terms of energy as well as the comfort and behavior of the users of building. In this respect, a thorough study of the building conditions and systems is needed, in order to set the parameters to be monitored.

4.1 Measured data and parameters.

A measurement point can be described as a combination of a sensor/meter and its location. To define the measurements points in a building it has to know what are the data required by the wanted functionalities and how to get this data.

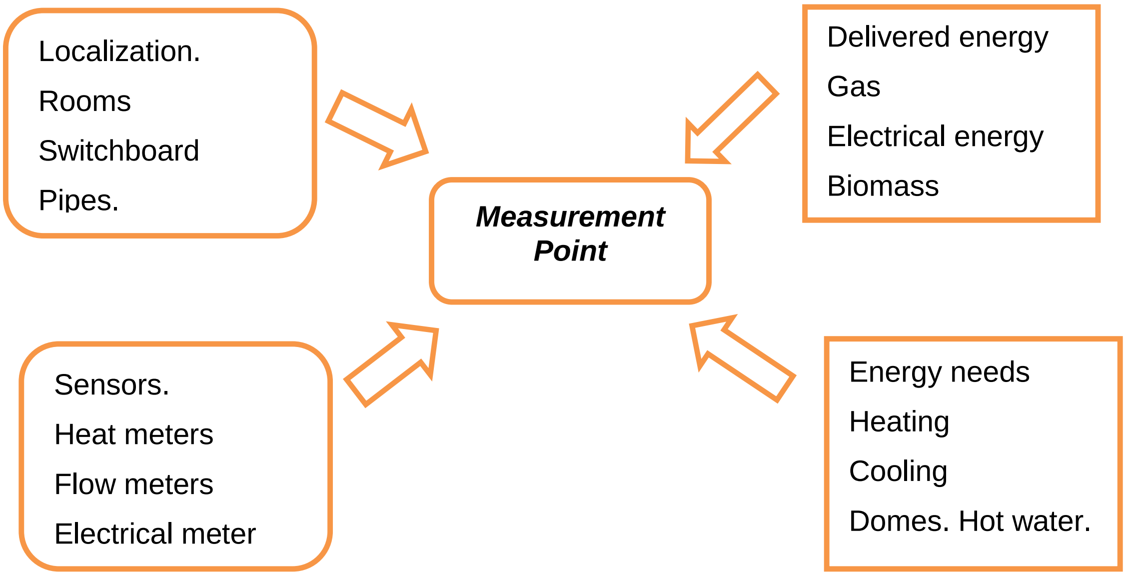


Figure 16. Measurment Point.

Each indicator needs two types of data:

- Static data such as building geometry (air volume, area , façade), datasheet of equipments, etc.
- Dynamic data such as energy consumption, temperatures, flows. Recording frequency has to be defined for these data, and it usually depends on project goals (yearly, monthly, daily or time series). Also it exists a dependence in indirect data derived from measurements are considered dynamic.

After the identification of these data and considering buildings and facilities, location of the meters is determined, taken into account their needs of measure in the schematic diagram and other criteria such as:

- Applicability of the measurement;
- Needs of local visualization, maintenance etc;

- Optimization of sensor position.

Once data are stated, as shown in Figure 16, measurement points in the building can be identified by selecting the method of measurement and the meter location.

Indicator	Energy	Data	Recording Frequency
Annual primary energy consumption	Electricity	Electrical consumption	Monthly
Annual delivered heating energy	Heating	Fluid temperature Flow	Monthly
Annual total gas consumption	Gas total load	Gas consumption	Monthly
Flat thermal consumption	Heat	Thermal energy (heat meter) Outdoor temperature	15 min
Flat electrical consumption	Cooling Lighting Appliances	Electrical meters	15 min
Comfort		Humidity Air temperature Luminosity Convective transfer coeffiecient	15 min

Table 4: Data monitoring.

4.1.1 Monitoring Scheme

Roughly speaking, a monitoring system is composed of sensors, gateways and data acquisition system. These components are included in a network, which can have different architectures (see 3.1 Installation Architecture).

Monitoring system architecture specifies the connection between different components of the installation: sensors, actuators and controllers (see Figure 17).

The use of diverse wired and types of networks makes possible the existence of different parameters as the complexity of cabling, speed of transmission, vulnerability, network management, rate of malfunctions, etc. Main architectures are centralized, decentralized, distributed and hybrid/mixed:

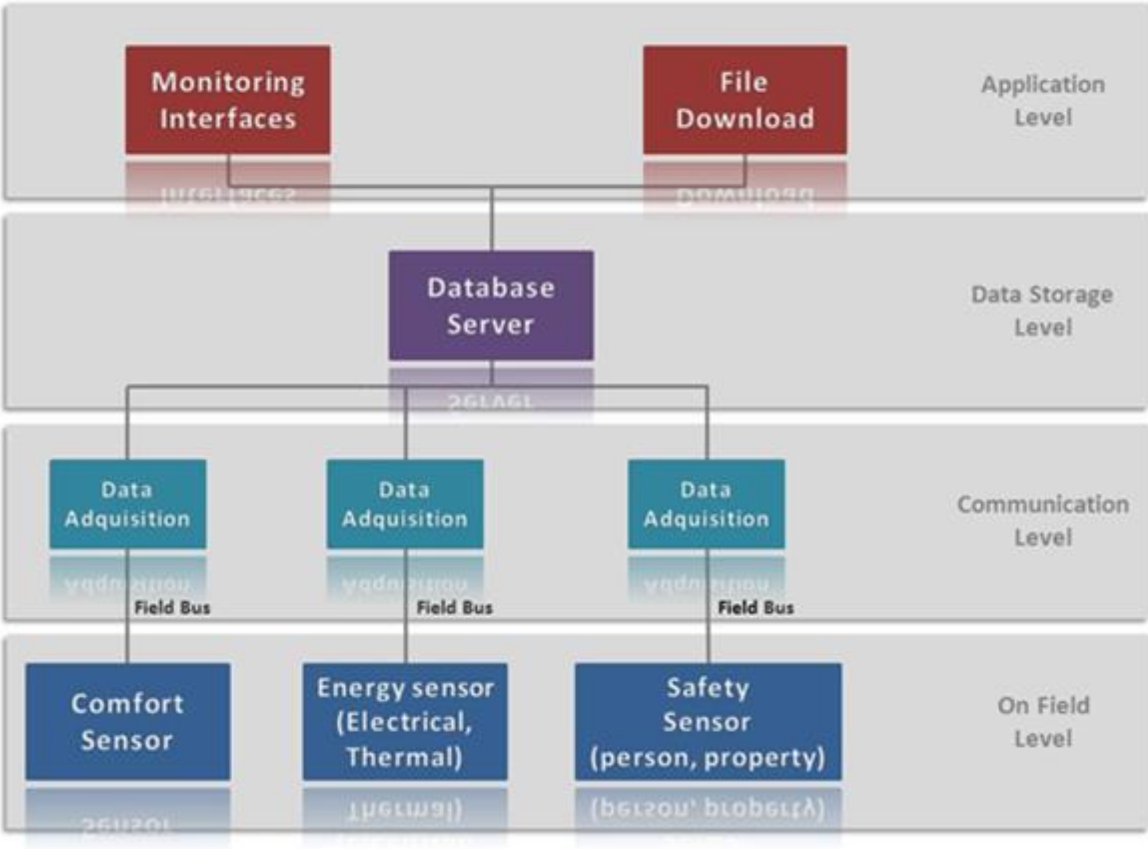


Figure 17 Monitoring scheme.

4.2 Metering energy method.

Ideally, all energy consumption should be directly metered, but this is not always practical or cost effective. With this in mind, the Building Regulations ask for at least 90% of each incoming energy to be accounted through the use of metering. The regulations also provide various estimation methods to be used where direct metering is impractical. This allows flexibility to mix and match in order to:

- Overcome practical installation problems.
- Optimise capital and installation costs.
- Integrate metering into the services as they are designed.
- Ensure that operators have a practical method of establishing an audit of energy use.

Using a combination of the five methods it is possible to develop a metering strategy that meets the Building Regulations, while ensuring that the level of metering is appropriate, practical and cost effective for the building or design.

- Direct metering: It provides directly the consumption through electric power, gas, oil, heat or steam meters. It is suggested for loads of major consumptions, total building consumptions, or when the measure is used for submetering per area.

- Hours meter: It can measure the operating hours of a piece of equipment that works at a constant known load (e.g. fans without VSD, lighting, etc.). This provides a relatively cheap and simple way of reasonable estimate of consumption (= kW·hours run load factor). If load factor is constant, it can be known with a power measurement through a portable meter. But, if there is a load control, it becomes difficult to estimate the load factor and this method is unfeasible.
- Indirect metering: It can be used to estimate energy consumption (e.g. measure cold feed water consumption and temperature difference to estimate hot water consumption). This is a relatively cheap and simple way to reach a reasonable estimate of consumption.

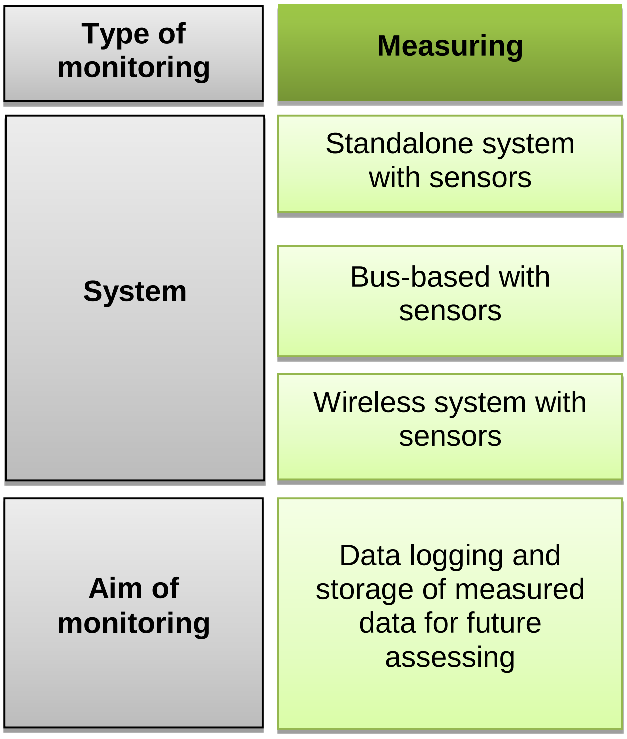


Figure 18: Kind of monitoring

- By difference: Two direct meters can be used to determine a third measurement by difference. This method should be used if the two measurements are acquired through direct metering. Moreover this should not be used if an estimated value is subtracted, because the cumulative accuracy will be very poor. Subtracting a small consumption from a large consumption should also be avoided, because the accuracy margin on the large meter may exceed the consumption on the smaller meter.
- By data analysis: Starting from one measurement, it allows the breakdown of different energy uses or area consumptions by knowing how the buildings operate.
- Estimation: Calculations can be used to estimate consumptions of small power.
- Many types of instruments and sensors are worldwide available for the monitoring of energy consumption, temperature, relative humidity, air current etc. The data logging

evolves from manual to fully automated. The available instruments and sensors are decisively characterized by the choice of the monitoring concept. It should be noted that a considerable proportion of the costs are caused by the data loggers and not by the cost of the sensor.

4.3 Sensors

The goal of a sensor is the conversion of quantities of a specific nature to another, usually electric. These magnitudes can be physical, chemical, biological, etc.

In a building, they shall be responsible for providing the information necessary for its subsequent management. Typical sensors are temperature, humidity, presence, lighting, CO_2, leak water and gas, etc. The most important characteristics that define a sensor performance are:

- Amplitude: Difference between the limits of measurement.
- Calibration: Known pattern of the measured variable that applies while observing the output signal.
- Error: Difference between measured value and current value.
- Accuracy: Correlation between measured value and current value.
- Scaling factor: Relationship between the output and the measured variable.
- Reliability: Probability of no error.
- Hysteresis.
- Precision: Dispersion of output values.
- Noise: Unwanted disturbance that modifies the value.
- Sensitivity: Relationship between the output and the change in the measured variable.
- Operating temperature: Running/Working temperature of the sensor.
- Error area: Band of permissible deviations from the output.

It is possible to perform several classifications of sensors according to their characteristics, for example attending to their power:

- Actives: They must be electrically powered at the appropriate levels (voltage, current, etc.). They are the type of sensors most common.
- Passives: They do not need any electrical power.

Examples of active sensors are temperature, as PT-100, PT500, PT1000 probes. They are sensors whose resistance varies with temperature, by modifying both the current that runs through them, which has to be supplied by the corresponding generator.

According to the type of signal involved, sensors can be classified as:

- Continuous: They provide continuous signals.

- Discrete: When the signals provided are isolated. A discrete sensor has a finite number of possible outputs that correspond to a finite number of possible values of the variable to be measured: presence or not presence, open or close circuit, lighting or not, etc. They tend to be simpler, cheaper and more reliable.

The output of a continuous sensor is a magnitude whose values vary continuously depending on the measured variable. Some examples include the lighting, temperature, pressure, humidity and wind.

Signals from a sensor should be upgraded and/or adapted to the driver or system that receives them. Signal conditioners are used to perform this conversion. There are several standards of signal conditioning, some voltage (0-5V, 0-10V) and other current (0-20mA, 4-20mA).

In the following sub-chapters, it will describe a series of sensors that may be installed in each one of the demo sites, according to the required needs. Features of these sensors as well as their prices are shown.

4.3.1 Energy Management Sensors

The study to be done on the use and consumption of the heating / cooling systems will show their behavior and the difference which exists between holidays and weekdays.

The inlet cold water temperature will have a great impact, due to the influence in the thermal increase suffered by the thermal equipment to obtain the temperature of hot water consumption or the temperature required for heating.

The measurements of environmental variables (temperature, relative humidity) and energy consumption (hot water, heating, cooling, electricity) will be recorded and analysed, in a real situation of occupation and in real time, which will give information about use conditions and behavior of the building.

Specific parameters will be defined after a detailed study of the thermal systems and the possibilities of including some sensors and meters in the main installation.

Heat meter

Heat meters are devices that are installed into the respective supply return line from a radiator, a radiant floor, domestic hot water, etc., in order to determine the amount of heat consumed; which is calculated by the counter. For this, the temperature difference between flow and return line and the flow rate is measured.

The measuring device is able to calculate the current heating power i.e. the energy delivered per unit time from the amount of water per unit time (the measurement interval), the temperature difference and the known heat capacity water. This measure variable is integrated over time by the heat meter, so that the previously consumed heat energy is known at any point in time. The heat energy is measured in Megawatt hour (MWh) or kilowatt-hour (kWh).

For the use in the monitoring context, the heat-measuring device(s) should be equipped with electrical interfaces so that the measuring values can be recorded and gathering in real time.

The choice of the electrical interface used in this context depends on the possibility of being implemented in an existing or prospective monitoring concept.

Currently, heat meter with following types of electrical interfaces are offered:

- Potential-free contact or S0-interface according to EN 62053-3 for the transfer of impulses.
- Analog interfaces 0…5 Volt or 4…20 mA to pass analog measuring values. These interfaces are used to transfer real time values. As values for this, the current performance and the current flow of water are suitable.
- M-Bus (EN 13757-2 (physical and link layer) / EN 13757-3 (application layer). The M-bus interface is a serial computer interface. All values generated and acquired in the meter are sent through this interface.
- Open Metering Interfaces The open metering system (OMS) stands for a manufacturer and interdisciplinary communication architecture for smart meters on the basis of M-bus in the context of smart metering (intelligent counter). It is the only system definition, which integrates all media (electricity, gas, heat and water including sub metering) into a system worldwide.

Heat meters are available commercially and must be fitted by technically competent companies. The cost of a heat meter for an exclusive installation is between 100 € and 300 €, depending on the configuration. The estimate of cost for the professional installation depends on the country-specific costs.

If no communication interfaces are available for monitoring, heat-measuring devices should be used. These achieve the most important consumption data in non-volatile memory, providing at least monthly data on the display.

Figure 19a shows an example of an available commercially heat meter for connection to a communication line. In addition, the so-called non-invasive heat meter can be used (Figure 19b) in installations where heat meters are not allowance due to constructional and or other conditions. Unfortunately the cost of such counter is quite high (5000 € - 7000 €), but the unit is portable and can be easily used for a different measurement task.

a. Commercially available heat meters with M-Bus module or pulse output

b. Non- invasive heat cool meter using also for hot water metering.

Figure 19. Heat meters.

Another alternative to the invasive heat meter is the measurement of pressure and temperature in the supply and return line of the heating system. The knowledge of these variables allows then the determination of the energy demand.

An estimation heat can be also calculated using a relatively simple method, which consists of the capture of supply and return temperatures of the radiator(s) and the entire system. This can be done by proper attachment of temperature sensors to the particular lines. Thus, the energy consumption can then be evaluated taking into account the characteristics of the heating system.

The heat meter allocation in the building depends on the existing heating circuits and their accessibility. As part of the energy monitoring, it would be desirable that the heat consumption is detected in very small units, i.e. in individual rooms. Due to different conditions, there should be installed at least one heat-meter of the total heat production, even for each heat unit. In this context, in Figure 20 a basic scheme for the installation of heat meters is shown.

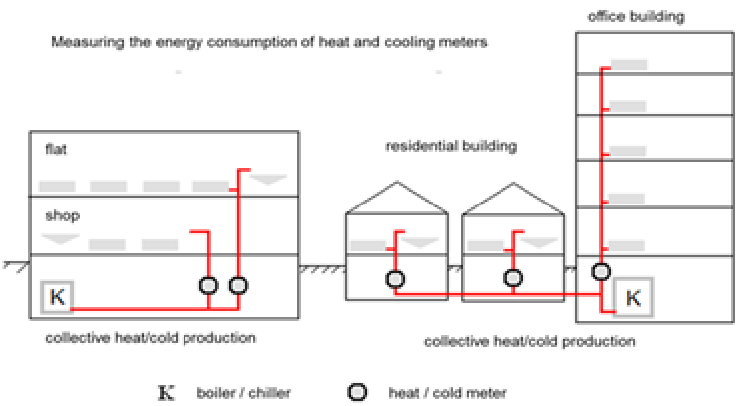


Figure 20 Examples for installing heat meters.

Electric meter

The electric meter is a measuring instrument integrating over a time course to record the amount of delivered or consumed electricity. The associated physical unit is the kilowatt hour (kWh). Figure 21 left shows a conventional universal power meter with mechanical consumption gauge. It is possible to provide this type of electric meter with a reading device. These devices record the status of the mechanical consumption display using an optical institution. Using text recognition (OCR), the captured image will be transformed into electronic information. This information can then, as in the electronic energy meters using various data interfaces, be transmitted. Therefore, an automatic reading of the meter is possible.

The relative error of counter measurement accuracy is 2% in the household sector. Meters for class 1, 0.5 and 0.2 are also used at high electrical work. .

If a new electric meter I is installed, it is necessary to be sure that it is an electronic energy meter according to IEC 62053-21 to -23 (Figure 21 right).

Figure 21 Electric energy meters.

Figure 22 shows electric energy meters that can be used for individual consumers, and their main characteristics.

a. Electronic electricity meters used for individual units.

- Adjustable current transformer ratio
- Accuracy class 1
- Output pulse for active energy (reference and distribution)
- Analog out: 0-20 mA for active power
- Application: Both Buildings and rooms

b. Electronic power

- Consumption measuring 1Wh . 9999 kWh
- Resolution: 0,1 W
- Max. recording time: 2376 h
- Accuracy class 1: ± (1% + 1 W)
- Indicationg range: 0.001 – 15,000 kWh
- Range of capicity: 1.5 – 3,000 W

Figure 22. Electricity energy meter for individual consumers.

Universal Power meters are usually installed by the energy provider at the country-specific cost rate. Electronic electric meters for employing in individual user units or individual supply lines must be installed by professional companies. An electric meter costs depending on the equipment between 200 € and 600 € (excluding installation costs). Electricity meter for the analyzed power of individual consumers costs around 45 € and can be installed easily.

Also in the distribution of electric meters, it is desirable to record the energy demand in preferably small units. Electricity meter in the building can be arranged in a similar way as the heat meter shown in Figure 20.

Domestic hot water meter

Water meters are measuring instruments for determining the total or individual consumption in buildings or apartments. It can be distinguished between two types of meters:

- Meters which show only the amount in any period of time and
- Meters that collects the amount per unit of time (such as volume flow / hour).

Old hot water meters are usually manually readable and they can be considered by a new installation. For this purpose, a meter with output pulse should be installed in order for hot water consumption to be recorded in appropriate measurement intervals.

Hot-water meters must be installed by professional companies. The costs are exclusive for the country- and depending on the configuration, the specific rate for the installation, run between 30 € and 65 € per meter. The installation of water meters is subject to dependent boundary conditions as it occurs with the heat distribution meters. Also, it is desirable to be able to analyze the hot water demand of most small units. If there is no such possibility, there should be least one meter for the total hot water demand and a meter for each unit available. Hot water meter in the building can be arranged in the same manner like Figure 23 illustrated for the installation of heat meters. Also non-invasive measurement system can be used.

- Temperature range: 0…90 °C
- Working range: 0,1…99999 m³/h
- Pulsverhältnis: 1 Impuls / 10 l
- Accuracy: ± 1%

Figure 23 Pulse water meter.

4.3.2 Room sensors

Temperature and % relative humidity

The recording of temperature and relative humidity in a building has an extremely importance in several aspects.

On one hand these values are used for the evaluation of user comfort (room climate) and the energy demand, on the other hand for the monitoring and evaluation of the historical surfaces and critical construction details adjusting near field climates and surface temperatures. HVAC systems are another area of application of these sensors.

For the temperature measurement, resistance sensors with different accuracy are usually used. These sensors are based on the principle that the electrical resistance of a conductor or semiconductor depends on the temperature. Higher accuracies are achieved with so-called PT 100 sensors, but they cause considerable costs. Figure 24 shows such a sensor. This sensor reads the relative humidity and temperature, being their costs around150 €.

Relative humidity

- Working range: 0…100 % rF
- Analog out: 0…1 V
- Accuracy at 20° C: ± 3 % rF (10…90 % rF) ± 5 % rF (< 10 % rF u. > 90 % rF)
- Sensor: HC101

Temperature

- Working range: -40…60 °C
- Accuracy at 20° C: ± 3 %
- Sensor: PT 100 (DIN EN 60751)

Figure 24. Coupled temperature (PT100) and moisture sensors

However, NTC or PTC temperature sensors are less expensive, which are already commercially available by 2 € and their accuracy is enough for many monitoring tasks (see Figure 25). The temperature values collected using the resistance of the sensors is measured in degrees Celsius (°C).

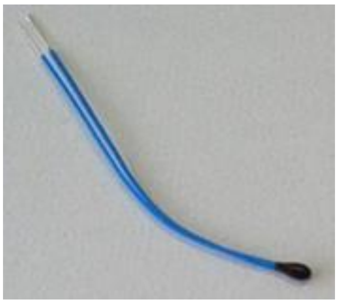


Figure 25 Temperature sensor as thermistor (NTC).(Range -55 to 70ºC± 0,2 ºC)

The measurement of the relative humidity is typically capacity, i.e. the sensor consists of a capacitor with a dielectric hygroscopic polymer. A relative humidity increase makes also enhance the capacitance of the capacitor. The measuring signal is independent of the ambient pressure and directly proportional to the relative humidity. The humidity sensor is largely maintenance-free and can be used also below freezing, however, his long term stability is limited and the sensor signal can be disturbed by condensation or rain. Figure 26 shows a corresponding sensor. These sensors are commercially available by about 25 € provided a sufficient accuracy for the foreseen measurement tasks.

Figure 26. Capacitive humidity sensor.

Light Sensor

An increase of building energy efficiency can be also achieved by optimizing the day-light illumination. There is an assumption which the building lighting accounts approximately 10% of total electricity consumption. To evaluate the incident daylight in a room, sensors can measure the light intensity. The illuminance lux (lm/m²) is the photometric equivalent of irradiance.

For the selection of a suitable sensor for the measurement task, commercial sensors with various measuring ranges are available. Table 5 gives some examples of the illumination intensity at different locations.

Location	Illumination [lx]
Surgical field illumination	20000…120000
Sunny summer day	60000…100000
Cloudy summer day	20000
Cloudy winter day	3000
Well-lit workplace	500…750
Pedestrian zone	5…100
Full moon night	0,25
New moon night	0,01

Table 5 - Illumination intensities.

Figure 27 shows a suitable monitoring sensor for detecting the illumination intensity. The cost of a sensor of this type is 200 € and its main characteristics are:

- spectral range: 360 – 720mm
- Accuracy: ± 3 %
- Analog output: 0…10 V
- Possible working range: 0…5, 0…10, 0…20, 0…80, 0…100 Klux alternatively 0…1000, 0…2000 lux

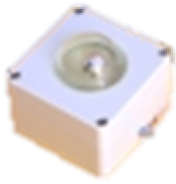


Figure 27. Sensor for light conditions.

CO_2 level

Indoor air quality refers all non-thermal aspects of the ambient air, which will affect the comfort and health of users. The concentration of CO_2 in an indoor environment is used as a general indicator of the total quantity of organic emissions and odors given off by humans. Because of the human respiration, the CO_2 content of the indoor air reflects the intensity of the use of a room directly. The CO_2 concentration is measured in ppm (parts per million).

In Table 6 is shown the classification of the indoor air quality, under DIN EN 13779, it is seen that room air is not delimited by an absolute value. In fact, the indoor air quality is defined as the concentration difference between room air and outside air and as consequence, the installation of an additional sensor for measuring outside CO_2 concentration is required.

Category	Description	Difference at outdoor air in ppm
IDA 1	High indoor air quality	350
IDA 2	Medium indoor air quality	500
IDA 3	Modest indoor air quality	800
IDA 4	Low indoor air quality	1200

Table 6:Classification of the indoor air quality (DIN EN 13779)

A sensor for determining the CO_2 (see Figure 28) concentration in the air cost up 200 € - 300 €. Finally, room climate, i.e. room temperature and the relative humidity can be often measured at the same time. Its main characteristic are:

- Measurement principle: Non-Dispersive Infrared Technology (NDIR)
- Working range: 0…2000 / 5000 ppm
- Analog Output: 0 - 5 V / 0 - 10 V / 4 – 20 mA
- Accuracy at 25 °C, 1013 hPa 0-2000 ppm < ± (50 ppm + 2 % of measuring value)

0 - 5000 ppm< ± (50 ppm + 3 % of measuring value)

- Response time p63: < 195 sec

Figure 28 CO_2 Sensor for rooms.

DEW POINT SENSOR

The dew point temperature is referred to as the temperature at which the condensate is formed on a surface. The greater is the effect; the lower is the temperature of the surfaces and higher relative humidity.

As part of energy rehabilitation of buildings, the application of an internal insulation is often the choice. At low ambient temperatures, this installation causes a reduction of temperature between the exterior wall and interior insulation. As a result, the temperature behind the insulation may drop under the dew point of the ambient air. Water vapor diffusion or convection of air from the living room leads to an increase in humidity in this area. For this reason, the monitoring of critical structural details such thermal bridges recommends using dew point sensors. An energetic retrofitting is often combined with the installation of HVAC ventilation systems whose control patterns are often not adapted to the building materials. The operation of these systems can lead the temperatures falling below the dew-point at historic surfaces what implies the formation of condensate. As a consequence a dew point sensor is useful here too.

Figure 29 shows a commercial dew point, with a higher precision, which can be reached with conventional capacitive measurement methods. Sensors of this construction and with this method of measurement are in a cost range from 300 € to 400 €. Main characteristics are:

- Range: -60 – 60º Td
- Analog out: 0 – 10V/ 4 – 20mA
- Accuracy: ± 2°C Td (Dew point)
- Automatic calibration

Figure 29. Dew point sensor.

HEAT FLUX SENSOR

Heat flux or thermal flux is the rate of heat energy transfer through a given surface and is measured in W/m². There are two points to note when measuring heat flows in buildings. On one hand, the thermal properties of a wall do not generally change and on other hand, it is not always possible to insert the heat flux sensor in the wall, so that it has to be mounted on top of the wall. When it occurs, it has to take care that the added thermal resistance is not too large. Also the spectral properties should match the spectral properties of wall as closely as possible. If the sensor is exposed to solar radiation, this is especially important and painting the sensor in the same color as the wall must be considered. Also the use of self-calibrating heat flux sensors in walls should be taken into account.

Heat conduction processes are irregular in walls which makes measure the heat flow for a sufficient period. Furthermore, the flex sensor surface and the wall surface must be close due to long recording time and small sampling rate compared to the thermal time constants of the wall Figure 30 shows a typical heat flux sensor. Depending on the version, the cost of such a sensor can be between 350 € and 800 €.

Figure 30 Typical heat flux sensor

Figure 31 displays a transparent heat flux sensor for the determination of the U-value and the thermal quality of windows, glazing, walls, roofs and building facades.

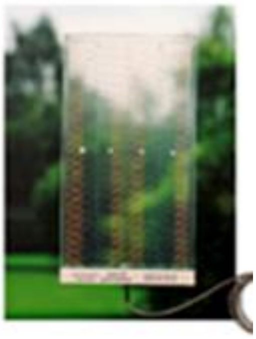


Figure 31. Transparent head flux sensor.

Solar irradiation

The total solar irradiation that hits a horizontal surface is called global radiation and it consists of the direct radiation and the diffuse radiation. The diffuse radiation emerges from reflection by clouds and dust or water particles. The unit is W/m^2 for instant radiation power or kWh/m^2 for radiation energy in a time period.

Solar irradiation is a factor that influences the energy consumption of building as well as the ambient temperature, but a standardized normalization method does not exist.

But for the calculation of climate corrected outputs by solar energy systems (solar thermal collectors or photovoltaics) and for their comparison the monthly or annual solar radiation is the appropriate measure.

If comparing systems to each other the output is normalized to one of the systems, when assessing a lot of systems a reference value is chosen according to the approach on heating degree-days.

The equipment to measure the present value of both global and diffuse radiation is called pyranometers and the unit is watts per square meter (W/m²). Figure 32 shows pyranometers, which is equipped with electrical interfaces for the connection to a data communication line. Pyranometers are also available as standalone devices for connection to corresponding data logger varying its cost between 300 € and 600 €.

a. Global radiation *b. Diffuse radiation*

Figure 32. Pyranometers.

A separate measurement of global radiation in the context of monitoring may be omitted if there is a weather station close to the building able to measure data with the necessary accuracy.

WIND SENSORS

The wind speed is measured typically with a small rotating wind meter known as an anemometer. The wind speed is measured in m/s. Together with a wind direction sensor and a recording device; anemometers are permanently installed as a part of a weather station. A wind direction sensor is a meter to determine the wind direction and it is based on a mobile measuring element that aligns to the dynamic pressure of the wind. The wind direction is based on the compass rose and has a range 1-360º.

A wind sensor with analog output incurs in an amount of costs 125 € to 250 €. The cost of sensor necessary for determining the wind direction are between 170 € and 250 €. See Figure 33.

- Working range: 0 – 35m/s
- Accuracy: : ± 3 %
- Analog out: 0…10 V / 4…20 mA
- Application: Weather station

Figure 33 anemometer

4.3.3 Other devices

Gateways

A gateway is a connecting element between different networks of a house or building (control automation, telephony, television and information technology) to a public data network, such as Internet, by making, where applicable, adaptation and translation between different protocols.

In our network it is possible that we need to use gateways to communicate different variables between them, for example to communicate gas measurement signal with an electric measurement.

Gateway: Lonworks – ModBus IP – BacNet IP

The TAC Xenta 913 is a cost-effective way to integrate a large variety of products into a LonWorks network. The TAC Xenta 913 supports the most commonly-used open protocols, like Modbus, BACnet and LonWorks. It also supports some manufacturer-specific protocols, like I/NET and Clipsal C-bus. The TAC Xenta 913 acts as a gateway and transfers data point values from one network to another (see Figure 34).

- Working range: -20…50 ° Td
- A: RS232 2400 – 57600 bps, RJ45, 8-p
- A: RS485 2400 – 57600 bps, async. terminal block
- B: RS232 RJ10, 4-p
- C: RS485 sync. (SDLC) terminal block
- LonWorks TP/FT-10, terminal block
- Ethernet. TCP/IP, 10Base-T, RJ45

Figure 34 Lonworks – ModBus-BacNet gateway.

The Xenta 913 can be configured to act as the sole master on a Modbus and/or J-Bus serial network to allow monitoring and control of one or more slave devices via an I/NET or LON control system. Both the RTU and ASCII protocol formats are supported (see Figure 35).

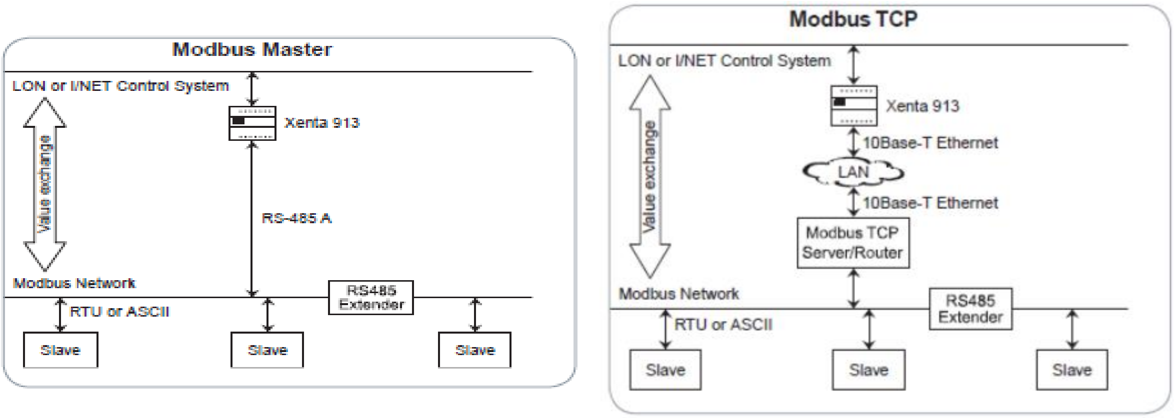


Figure 35 Xenta configuration

The Xenta 913 can be configured to connect one or more target BACnet IP devices to allow monitor and control values via and I/NET or LON control system.

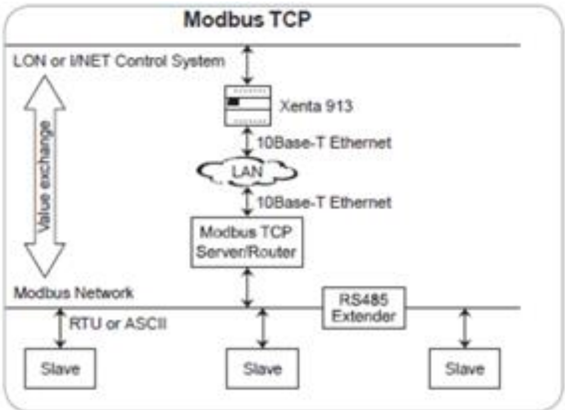


Figure 36 Xenta one or more target.

Gateway: IP - LonWorks – Mbus - Serial Port

The i.LON SmartServer provides universal connectivity for devices attached to it, making their data available to corporate IP networks and internet, and providing local device monitoring and control via built-in scheduling, alarming, and data logger applications. Appliances, meters, load controls, lights, security systems, pumps, valves virtually any electrical device can be connected, remotely configured, monitored, and controlled from across the room, or across the globe (see Figure 37). Main characteristics are:

Figure 37 LonWorks-Modbus.BacNet gateway

- Memory: 64MB flash memory,64MB RAM
- Operating Input Voltage 100 – 240VAC, 50/60 Hz
- Power Consumption: <15 Watts
- Controls: Service button, Reset button
- Indicators: Power On/Wink
- Ethernet link, Ethernet activity, LONWORKS Service, BIU, PKD, Tx, Rx
- (2) Digital Inputs, (2) Relay Outputs, (2) Metering Inputs
- Remote Network Interface connections
- Ethernet Port: 10/100BaseT, auto-selecting.
- Ethernet Connector: RJ-45, 8 conductor

Network and device interfaces

- IP via built-in 10/100BaseT Ethernet interface, optional internal 56K V.90 analog modem, or external GSM/GPRS or 3G modem.
- TP/FT-10 free topology twisted pair or PL-20 C-band power line ISO/IEC 14908-1 (LONWORKS) with built-in LONWORKS transceiver.
- Modbus RTU with built-in RS-485 transceiver.
- Modbus TCP (Modbus TCP/IP) with built-in Ethernet interface, optional internal analog modem, or external GSM/GPRS modem.
- M-Bus with built-in RS-485 transceiver and optional M-Bus translator. Custom drivers using built-in Ethernet, RS-232, and RS-485 interfaces

4.4 Data acquisition/ Data logger.

Data acquisition is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer. Data acquisition systems (abbreviated with the acronym DAS or DAQ) typically convert analog waveforms into digital values for processing. The components of data acquisition systems include:

- Sensors that convert physical parameters to electrical signals.
- Signal conditioning circuitry to convert sensor signals into a form that can be transformed to digital values.
- Analog-to-digital converters, which convert conditioned sensor signals to digital values.

They are equipped with a microprocessor and an internal memory for data storage. Some data loggers interface with a personal computer and utilize software to activate the data logger and view and analyze the collected data, while others have a local interface device (keypad, LCD) and can be used as a stand-alone device (see Figure 38).

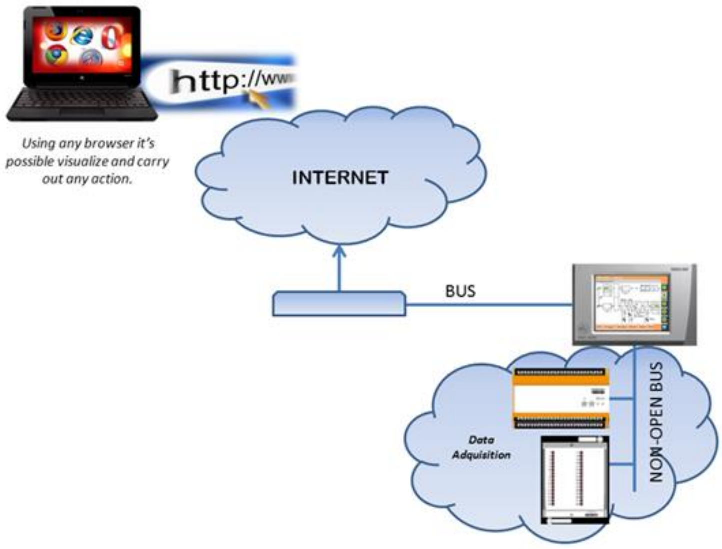


Figure 38 General architecture data acquisition system

Data loggers vary between those that have a general purpose and a wide range of measurement applications to those which are very specific and measure only one type of environment or application. General purpose types are usually programmable; however, many remain as static machines with only a limited number or no changeable parameters. Electronic data loggers have replaced chart recorder in many applications.

One of the primary benefits of using data loggers is the ability to automatically collect data on a 24-hour basis. Upon activation, data loggers are typically deployed and left unattended to measure and record information for the duration of the monitoring period. This allows for a comprehensive, accurate picture of the environmental, thermal etc. conditions being monitored, such as air temperature and relative humidity etc. Figure 39 shows general structure of our monitoring system, which will be the same in each case study. We will have 3 options to access data:

- Option1: Remote access to database.
- Option2: CSV files through email.
- Option3: CSV files through ftp server.

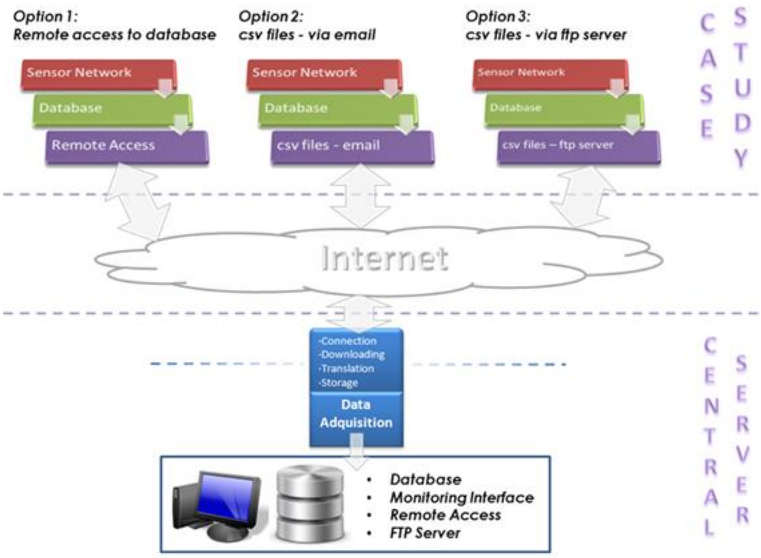


Figure 39 Global monitoring system architecture.

4.5 Interfaces

The user interface is a tool with which the user can communicate with a control or monitoring system, an individual device or a set of devices, data, etc. Interface includes all points of contact between the user and the system, and ways with that the user has to interact. An interface must be easy to understand and easy to use. User interfaces can be divided into three large groups:

- Hardware level, the devices used to enter, process and deliver the data normally is embedded in the device itself and they can be keyboard, mouse, display, barcode scanners, etc.
- Software interfaces, designed to deliver information about the processes and control tools, through what the user usually observes on the screen.
- Software-Hardware interfaces, establishing two-way communication between the system and the user. These interfaces allow the user to fully interact with the system. User can view all information and user can make changes in the system state.

Current interfaces usually offer many possibilities to the user in terms of data visualization and control refers. Most of these interfaces are SCADA systems. In these systems the information is divided into sections aimed at control of devices, and sections intended for visualization of data, events, records of historical, etc.

An example of this system type is that based on the TAC Vista (Schneider) software. These interfaces provide capabilities for control and monitoring (SCADA systems) and are easily configurable. Interaction with the control system is full. The following figure shows the control of an Air Conditioner Machine using this software (see Figure 40).

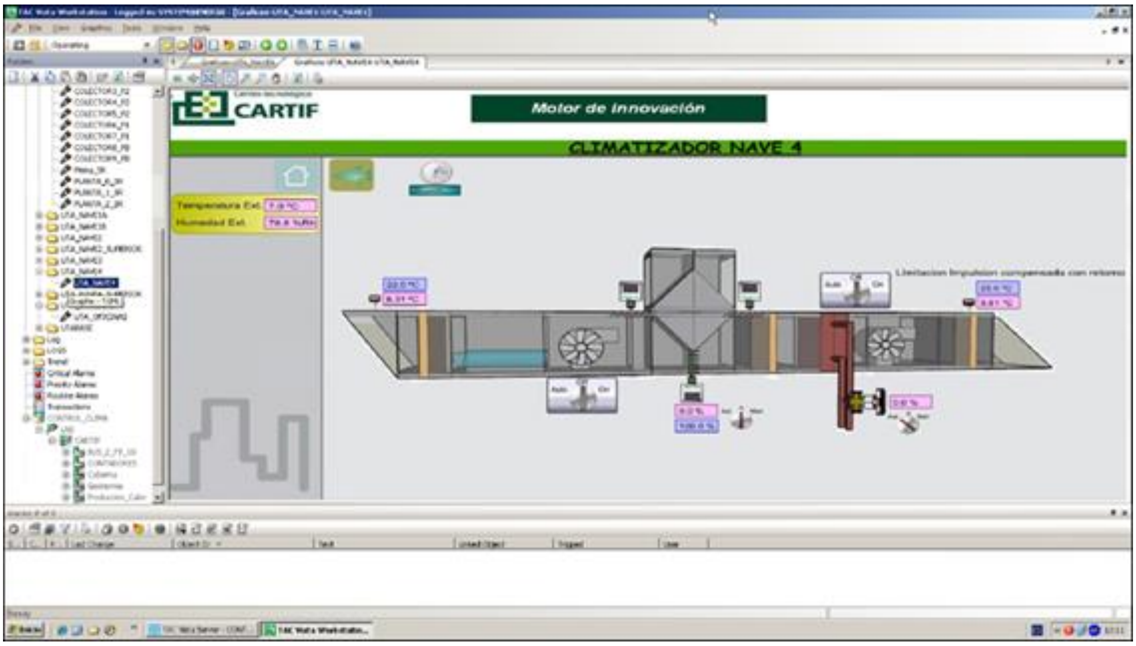


Figure 40 TAC vista SCADA (example CARTIF)

5 FarECHO® monitoring system in the case studies.

The FarECHO system installed within the three demo cases in the framework of iNSPiRe project offers a service of remote monitoring, energy management, communication, alarming and data-logging. The system is composed by the following elements:

1. Devices such as sensors able to monitor the energy flows and comfort conditions;
2. Data logger together with gateway that allows to communicate with all the installed sensors;
3. Software dedicated to the management of energy flows in buildings;
4. A centralized server where the data are stored.

For the three demo sites an open system with LonWorks communication protocols has been selected. This decision takes into account the need to have a decentralized architecture, end-to-end, which allows to distribute the intelligence between sensors installed. Moreover a large number of companies use this technology to implement distributed control networks and automation, and a variety of devices are available on the market.

A standard set of monitoring devices for the three demo sites has been selected in order to speed up the design and the installation phase. Indoor comfort, outdoor boundary conditions and thermal/electrical consumptions have to be assessed in order to produce a monthly report for functional areas, to schedule an action plan and optimize with a fine-tuning the control systems of the thermal/electric existing plants.

5.1 Monitoring architecture

5.1.1 Indoor comfort

A sensor from Eltako electronics has been selected for the acquisition of the indoor comfort into the dwellings/offices. FCO2TF63 series is a wireless indoor sensor which measures CO_2, relative humidity and temperature. A wireless technology has been selected in order to reduce as much as possible the interference for the occupants due to the installation. For this reason a wireless base station is needed in order to get signals from the comfort sensor and transfer it to a gateway via LON protocol. A Wireless Transceiver produced by Thermokon has been selected for this purpose (see Figure 41).

In the residential demo case, one receiver per dwelling has been installed in order to acquire data from a set of indoor comfort sensors. In the office building, one receiver was sufficient.

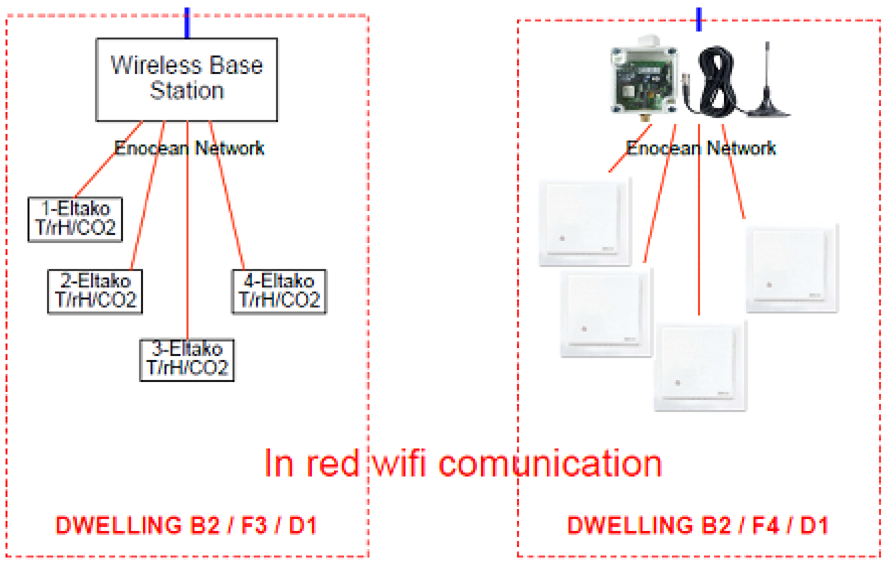


Figure 41 - Indoor comfort sensor together with the wireless base station installed within each dwelling.

5.1.2 Thermal and electricity loads

The thermal consumptions is due to heating loads and domestic hot water preparation purposes. The monitoring of thermal energy flows requires a heat meter installed along the pipelines.

A Multical 602 produced by Kamstrup is an all-purpose energy calculator for heat together with a pulsed flow sensors and with 2 wired temperature sensors. This meter saves energy data on a yearly, monthly, daily and hourly basis, which provides the operations manager with a complete performance analysis. The meter can be fitted with LON communication.

The Countis series electricity meter by Socomec is the modular active energy meter selected for the three demo cases. The pulse output is gathered by a LON pulse memory module that redirects the information into the LON-network (see Figure 42).

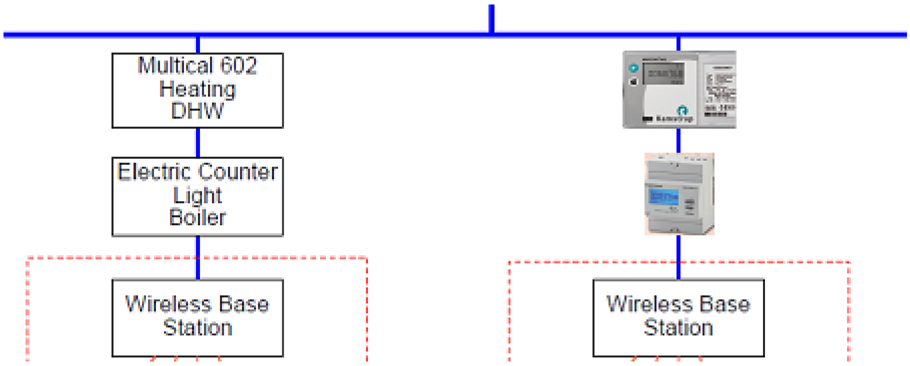


Figure 42 - electric and thermal metering in each dwelling.

5.1.3 Weather conditions

Outdoor temperature, relative humidity and direct and diffuse solar radiation are assessed through a Warema weather station. A Warema sensor is used to record temperature and humidity, while two Deltaohm pyranometers are used to gather diffuse and total solar radiation. The weather station is connected to a Warema Lonse III (LON sensor unit), enabling the integration into the LON-network.

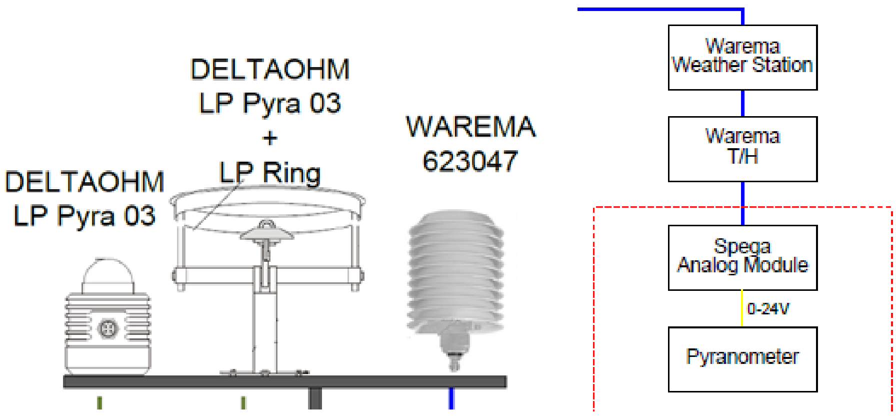


Figure 43 - Weather station and connections with the monitoring system.

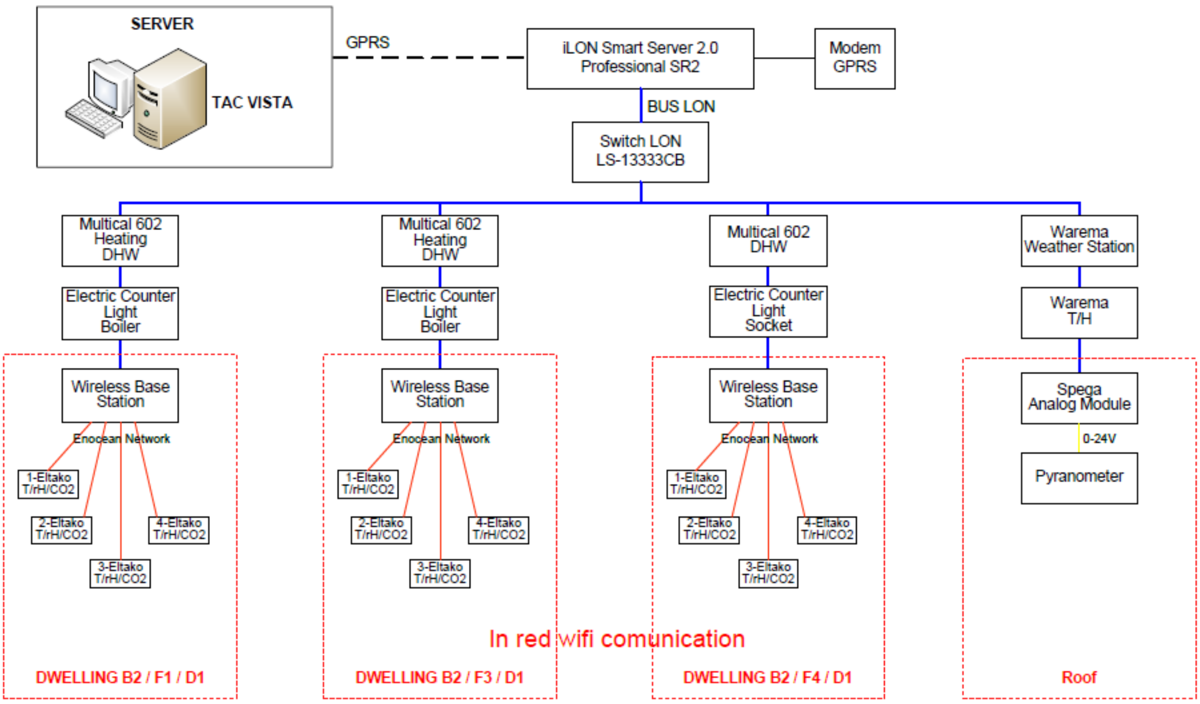


Figure 44 - General architecture of the monitoring systems.

5.1.4 Monitoring architecture

As displayed in Figure 44, the LON network consists generally of several branches, one branch per each functional area (i.e. dwelling or office), plus one for the weather station. For this reason an L-Switch XP by Loytec has to be installed due to the system decentralization. For the management of all the data within the LonWorks network an iLON Smart Server manufactured by Echelon has been mounted. Finally a 3G modem sends all the data to a monitoring server at FarSystems premises.

5.1.5 FarECHO® monitoring software

FARSystems produced an energy management tool, which is key to the FarECHO system. The software gives a cloud service that can be via a web address and a login access. Starting from the data collected, an energy analysis with an hourly, daily and monthly base can be exploited. In Figure 45, an example of electricity monthly data is reported.

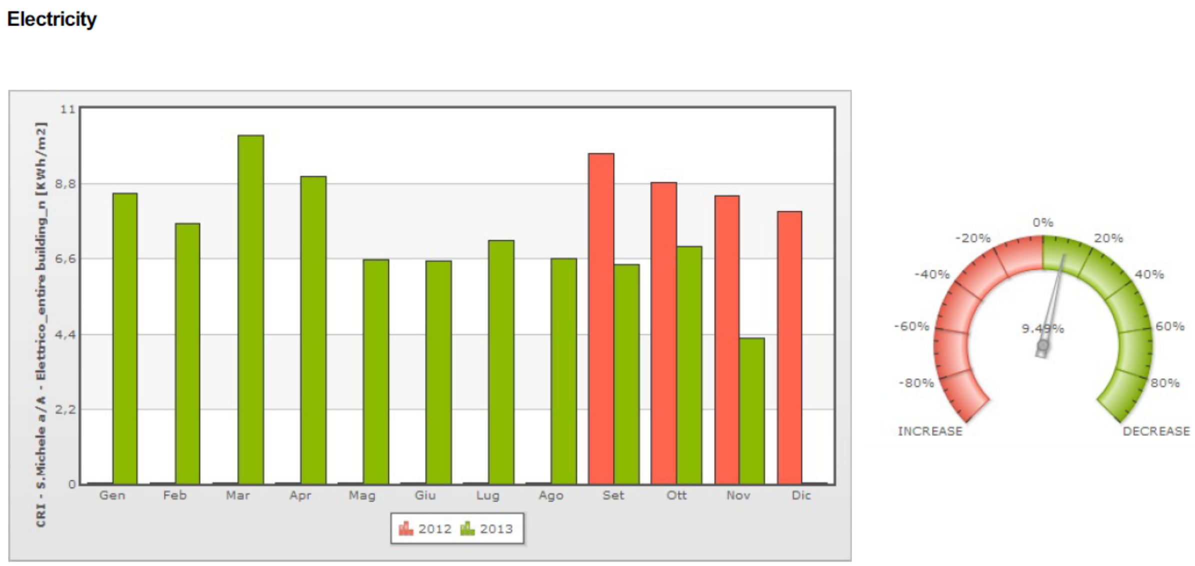


Figure 45 - Electricity monthly profile with a comparison to the previous year.

Apart for the energy and comfort data analysis, the software allows setting and monitoring alarms associated with the alert thresholds. Each alarm is configured according to a class, allowing to manage in a simplified way the behavior of the system, managing notice to the relevant professionals (e.g. maintenance, energy manager and administrator).

An automated reporting tool organizes information for the users suggesting possible energy saving strategies.

Figure 46 – Example of an automated report generated by the software

5.2 Monitoring guidelines and overview

The partitioning of the energy fluxes within the building allows an accurate distinction of the energy carriers, the systems and the different loads inside the building. The delivered energy carriers include in general fossil, district and electrical energies (gas, oil, biomass, district heat, district cooling, and electricity) as well as environmental energy (soil, ground water, extract air, waste heat and solar radiation). The consumed energy inside the building represents the loads occurring in the zones including the circuits, i.e. heating, domestic hot water, cooling, lighting and other electrical uses. The systems in between provide the energy need and - if necessary - include a transformation process. The media to be measured define the type of the required sensors, i.e. calorimetric counters (heat/cold meter) or electrical meter.

A flow diagram and the documentation of the building is the starting point to illustrate the sensor location, connections and communication. The flow diagram shows which streams and parameters are monitored and where the sensors are located, Figure 47. The building documentation further specifies the exact location and interconnections of the sensors. Additionally, the monitoring system overview should specify the logic behind the installation of each sensor (which parameters is being monitored and why? What is the expected outcome from the analysis?). The commissioning phase provides an opportunity to further evaluate the monitoring strategy and help to identify if corrective measures are needed (e.g. additional sensor, change of sensor position).

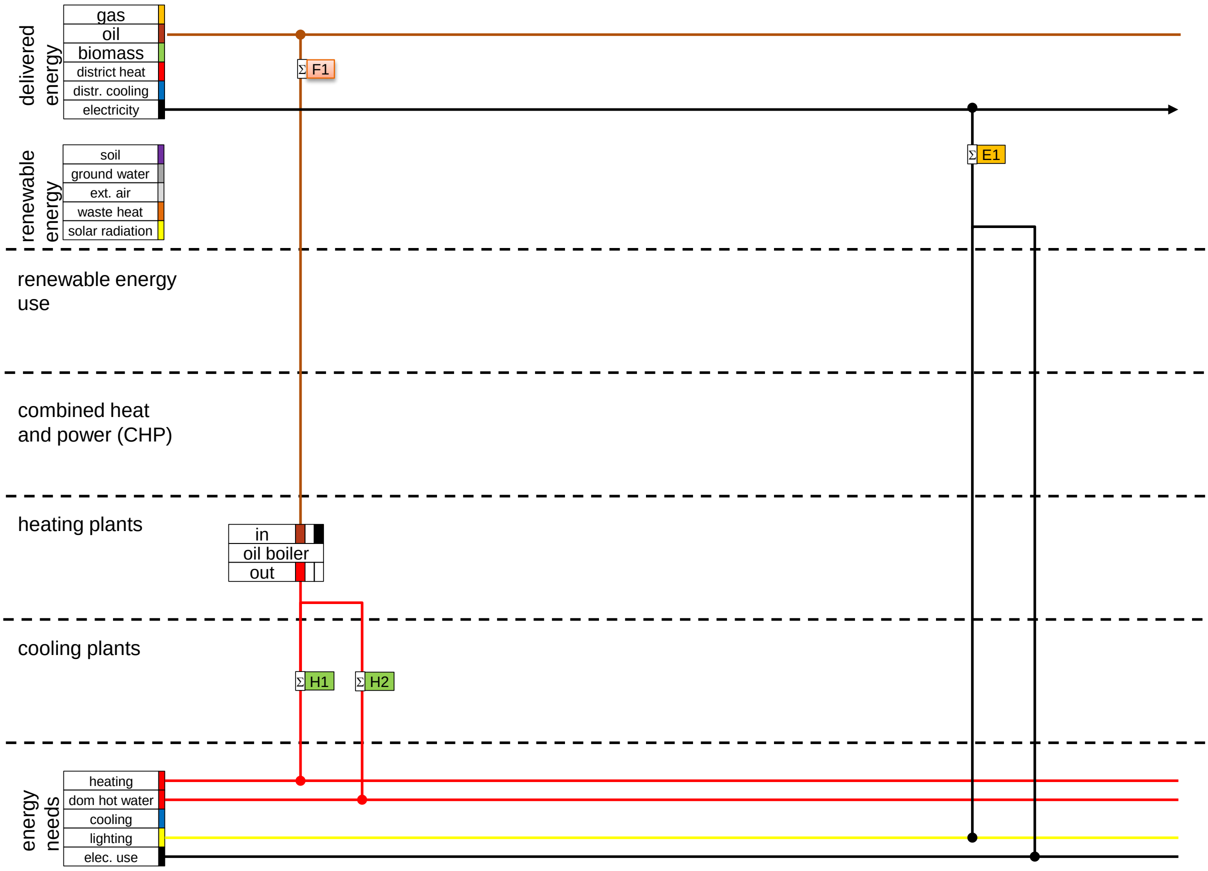


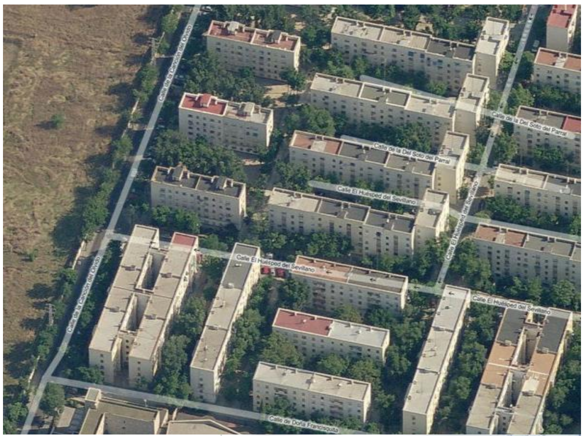
Figure 47. Schematic of a general flows and parameters monitored.

6 Monitoring system installed at the three demo sites

In the following section short cards of the installed monitoring systems at the 3 demo sites are shown.

6.1 Madrid (Spain)

- Name of the Demo Site: Madrid demo Building.
- Address: Cancion del Olvido 45-47
- City: Madrid
- Location (Coordinates): 40.35, -3.69
- Altitude (m): 650
- Annual Degree days: 1824 (heating18ºC base), 1088 (cooling 18ºC)
- Year of Construction: 1960
- Buliding type: Residential
- Number of Occupant: 60
- Thermal Gross area (m^2): 1307,22
- Thermal Gross Volume (m3): 3542,82
- Energetic Class (kWh/m2-year): F (158 kWh/m^2)



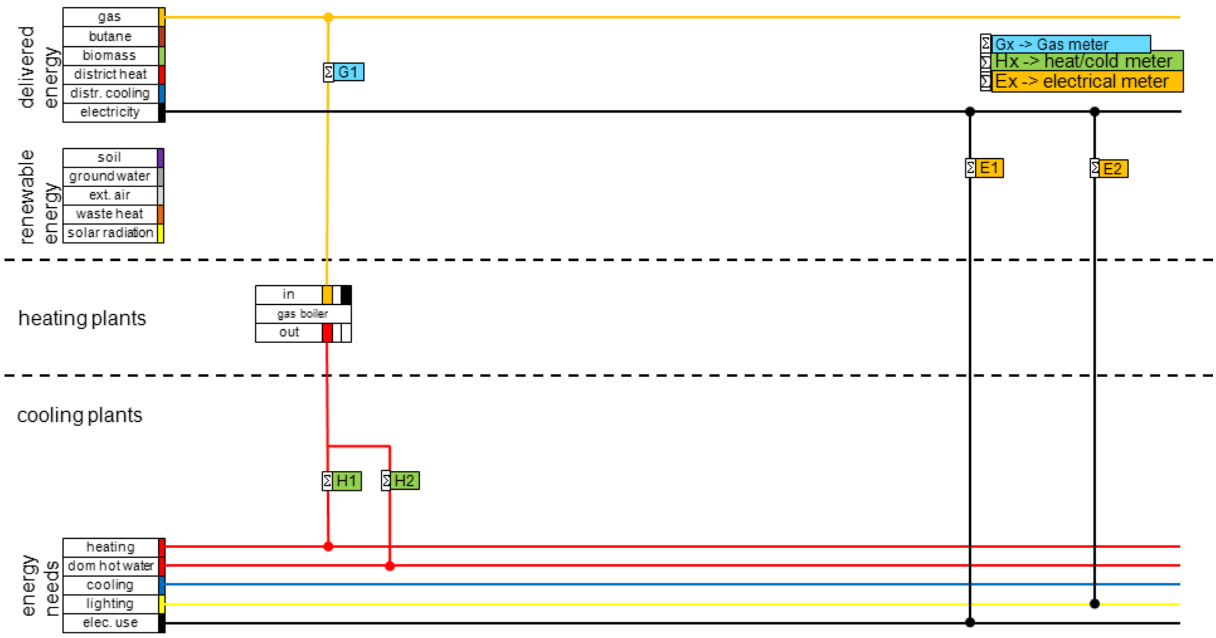
Although building is split in 2 blocks and each blocks has ten dwellings within iNSPiRe project, only three dwellings will be selected for the monitoring task (B2/F1/D1, B2F3/D1, B2/F4/D1). The selection of the monitoring equipment is done taking into account different uses and heating systems of the dwellings.

6.1.1 Dwelling B2/F1/D1 (block 2, floor 1, dwelling 2)

This apartment is setup with a gas boiler connected to the heating system and domestic hot water. Separate lines are present for lighting and plugs (see Figure 48). The following equipment was installed:

- 2 heat meters (Figure 49).
- 2 electric meters.
- 4 comfort sensors for each flat

Gas consumption is not assessed via the monitoring system, however gas consumption will be requested monthly to the owners. Specific schematics of the monitoring hardware installation are reported in Annex I.



B: block / F: floor / D: door
B2 / F1 / D1

Figure 48 - Monitoring and energy flow scheme to Madrid. B2/F1/D1

Figure 49. Heat meters and wireless receiver B2/F1/D1

6.1.2 Dwelling B2/F3/D1

This apartment is setup with a gas boiler for the domestic hot water preparation and a butane boiler connected to the heating system. Separate lines are present for lighting and plugs (see Figure 50). The following equipment was installed:

- 2 heat meters (Figure 49).
- 2 electric meters.
- 4 comfort sensors for each flat

Gas consumption is not assessed via the monitoring system, however gas and butane consumption will be requested monthly to the owners.

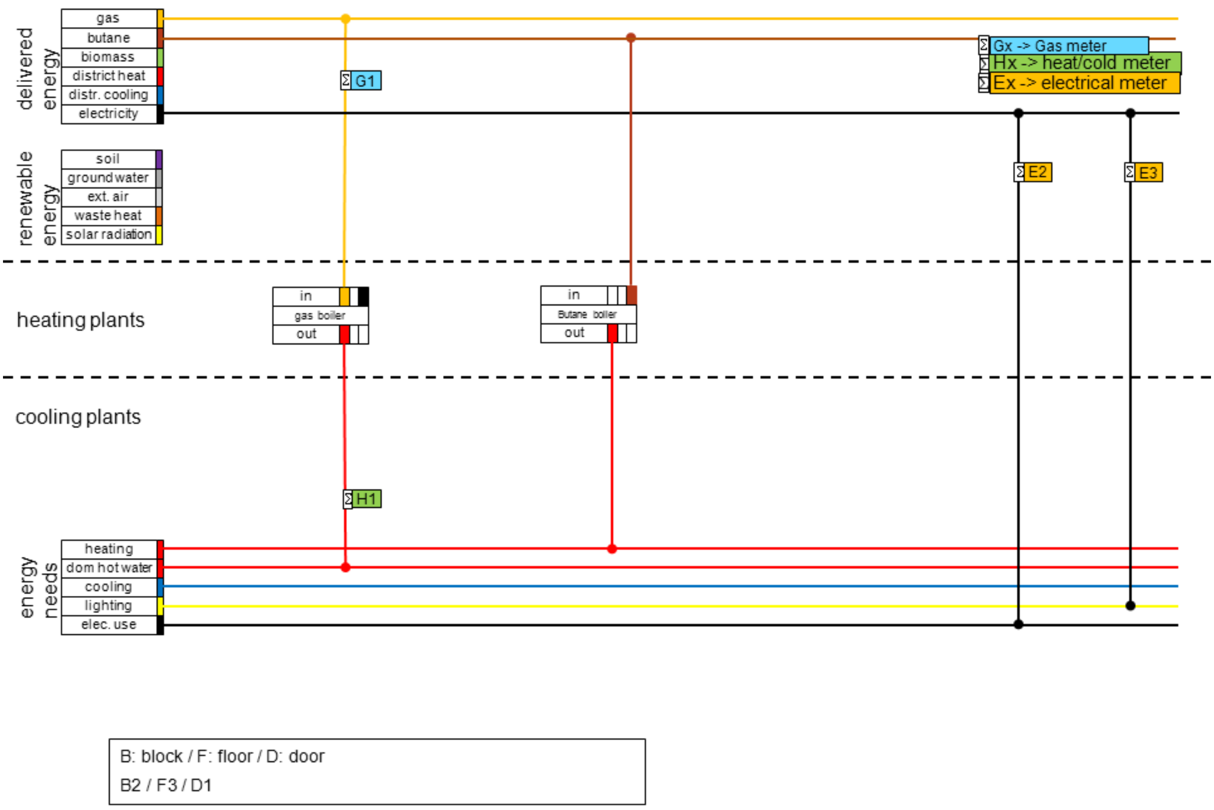


Figure 50: Monitoring and energy flow scheme to Madrid. B2/F3/D1

6.1.3 Dweling B2/F4/D1

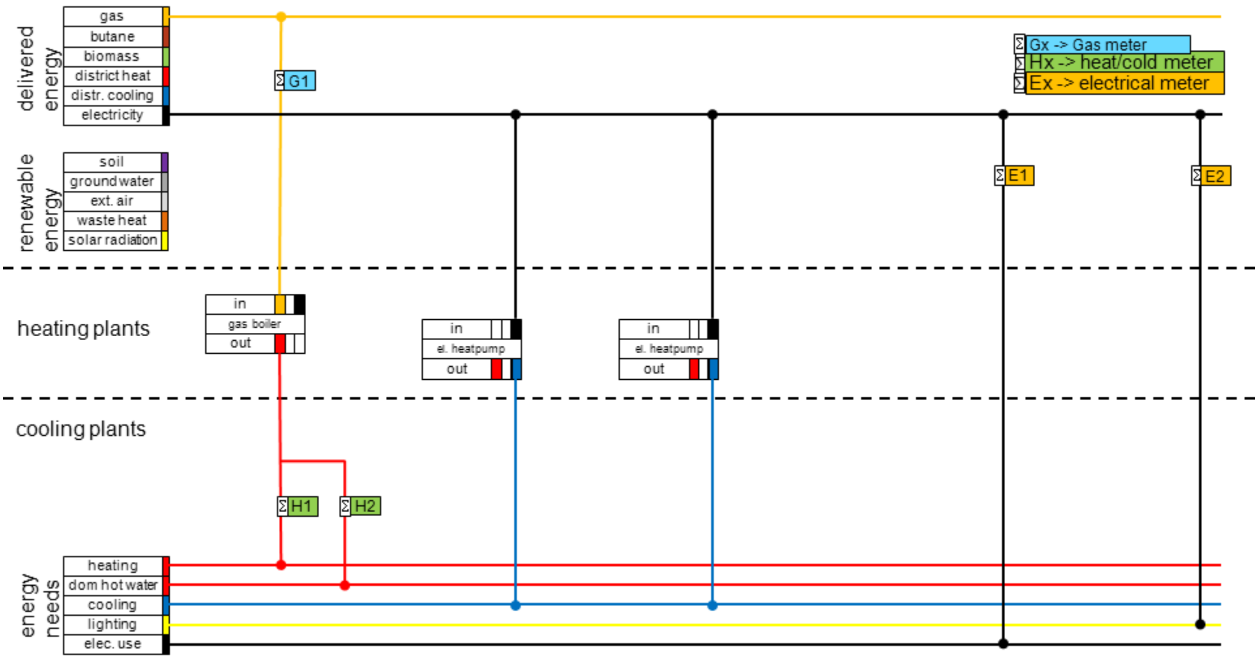
This apartment is setup with a gas boiler connected to the heating system and domestic hot water. A couple of electric heat pumps are installed for air conditioning in the living room and main room. 2 main electric lines can be distinguished lighting and plugs (see Figure 53Figure 48), the electricity consumption of the split units will be extrapolated by the analysis of the electricity consumption data. The following equipment was installed:

- 2 heat meters (Figure 49).
- 2 electric meters.
- 4 comfort sensors for each flat

Gas consumption is not assessed via the monitoring system, however gas consumption will be requested monthly to the owners. A weather station was installed on the roof of the building (see Figure 52).

Figure 51 – Comfort sensors installed in B2/F4/D1

Figure 52 – Weather station installed



B: block / F: floor / D: door
B2 / F4 / D1

Figure 53: Monitoring and energy flow scheme to Madrid. B2/F4/D1

6.2 Ludwigsburg (Germany)

- Name of the Demo Site: Multi Family house Ludwigsburg
- Address: Karl-Dieter-Str. 24
- City: Ludwigsburg
- Location (Coordinates): 48.886, 9,165
- Altitude (m): 293
- Annual Degree days: 3247 (heating 18ºC base)
- Year of Construction: 1971
- Buliding type: Multi-Family House
- Number of Occupant: 12
- Thermal Gross area (m^2): 478.8
- Thermal Gross Volume (m3): 1040,9
- Energetic Class (kWh/m2-year): (188 kWh/m^2)

Zone	Useful Area (m2)	Uses
Basement-Apartment	47,4	Living
Basement – Laundry	13,8	Wash machines
Basement-other rooms	46,1	Store and technical rooms
Basement-Stair case	11,2	Circulation
Ground floor-Stair case	11,2	Circulation
1st floor – Apartment	105,9	Living
1st Floor – Stair Case	11,2	Circulation
2nd Floor – Apartment	77.2	Living
2nd Floor – Stair Case	11,2	Circulation

Table 7. Building distribution Ludwigsburg.

The building has four flats but monitoring is performed on 3 flats only (i.e. cellar, ground and attic). Figure 47 shows displays the energy flow scheme for the building. A centralized oil boiler produces heating and domestic hot water for each dwelling. An electricity line leaves the cellar to each dwelling; the lighting and uses lines are mixed within the apartments therefore only the whole electricity consumption of every apartment is monitored.

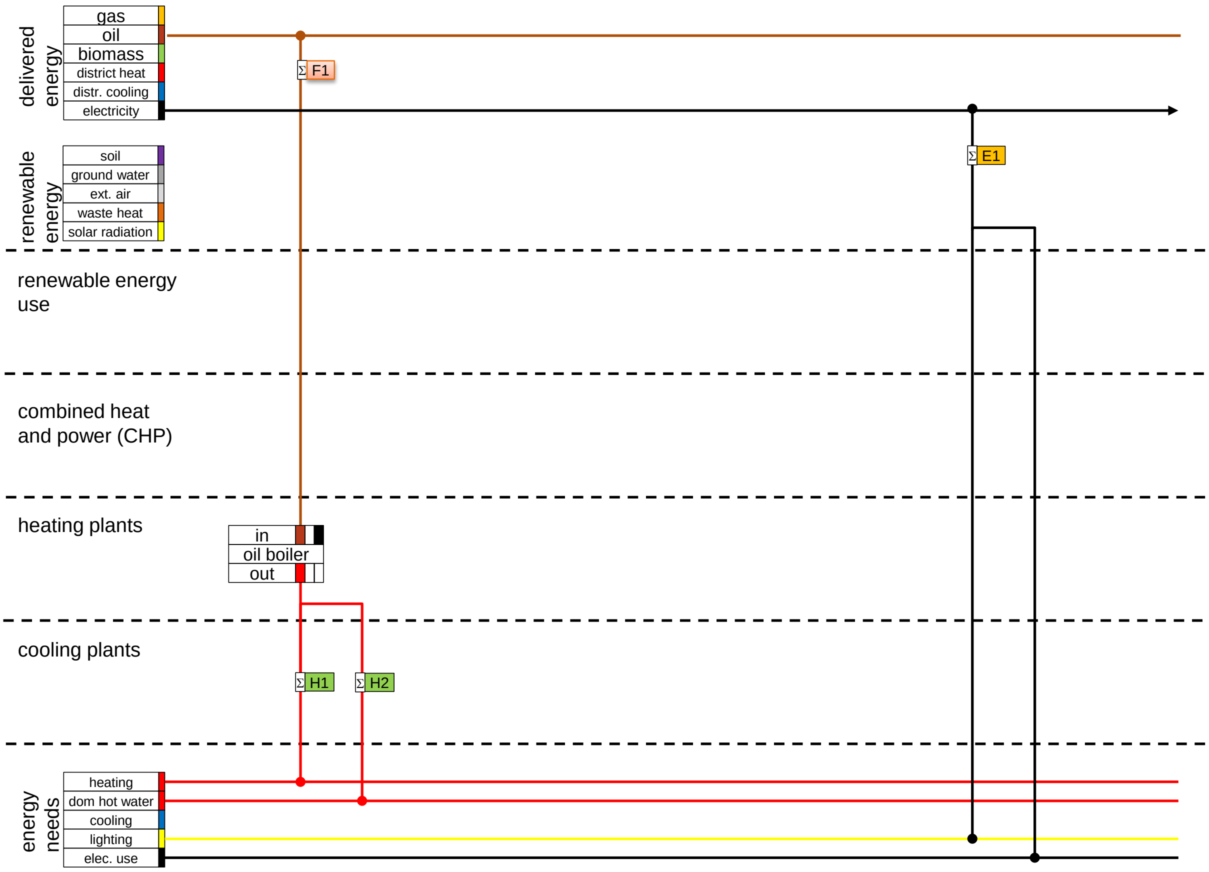


Figure 54 Monitoring and energy flow scheme

Figure 55 – Heat meter on the DHW pipeline (left) and on the heating pipeline (right)

Required equipment to account the energy performance of the building are:

- 2 calorimeters (Figure 55).
- 3 electric meters.
- 1 weather station.
- 4 or 5 comfort sensors for each flat (Figure 56)

Figure 56 – Comfort sensor (left) and receiving station (right) in the cellar floor

6.3 Verona (Italy)

- Name of the Demo site: Office area of the factory Officine Tosoni Lino S.p.A
- Address: Viale Postumia, 71, 37069 Provincia de Verona, Italia
- City. Villafranca di Verona
- Location: 45.37, 10.86
- Altitude (m): 54
- Annual Degree days
- Year of Construction
- Building type: Offices
- Number of occupant:
- Thermal gross area (m^2). 200
- Thermal Gross Volume (m^3)
- Energetic class (kWh/m^2year)

Figure 59 shows the energy flows and sensor systems for Verona case study: a gas boiler provides heating and DHW. Four electric lines are setup driving lighting, plugs, split units and a centralized chiller installed on the roof. 1 heat meter and 4 electric meters were installed (see Figure 57).

Figure 57 – Electric meters installed

Gas consumption is not assessed via the monitoring system, however gas consumption will be assessed monthly. This demo site has got 6 comfort sensors installed. One of these sensors will be installed in the adjacent industrial site, whereas the rest will be set up in office area. All sensors are wired and not wireless as other demo sites. In this case, 5 occupancy sensors and 5 brightness sensor are also setup, due to the need of monitoring if the strict lighting requirements are met. These sensors are also wired to the LonWorks bus. The weather station is located on the roof of the office.

Figure 58 - Comfort sensor (left), brightness sensor (center) and receiving station (right)

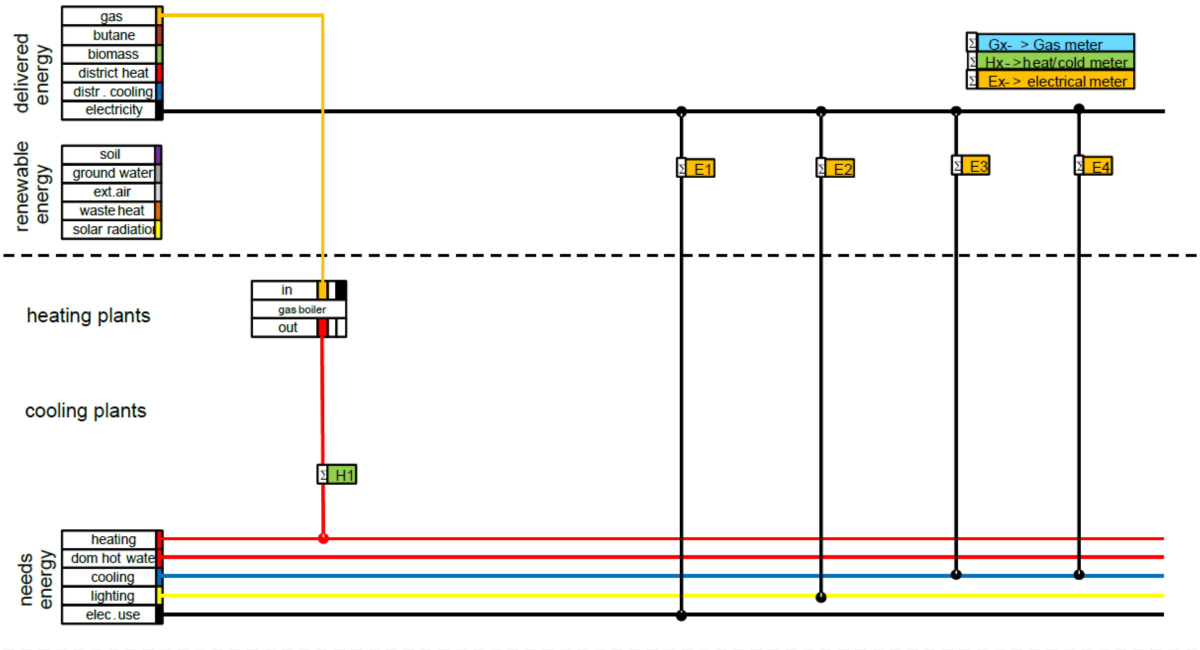


Figure 59 - Monitoring and energy flow scheme in Verona

7 Annex I

7.1 Madrid (Spain)

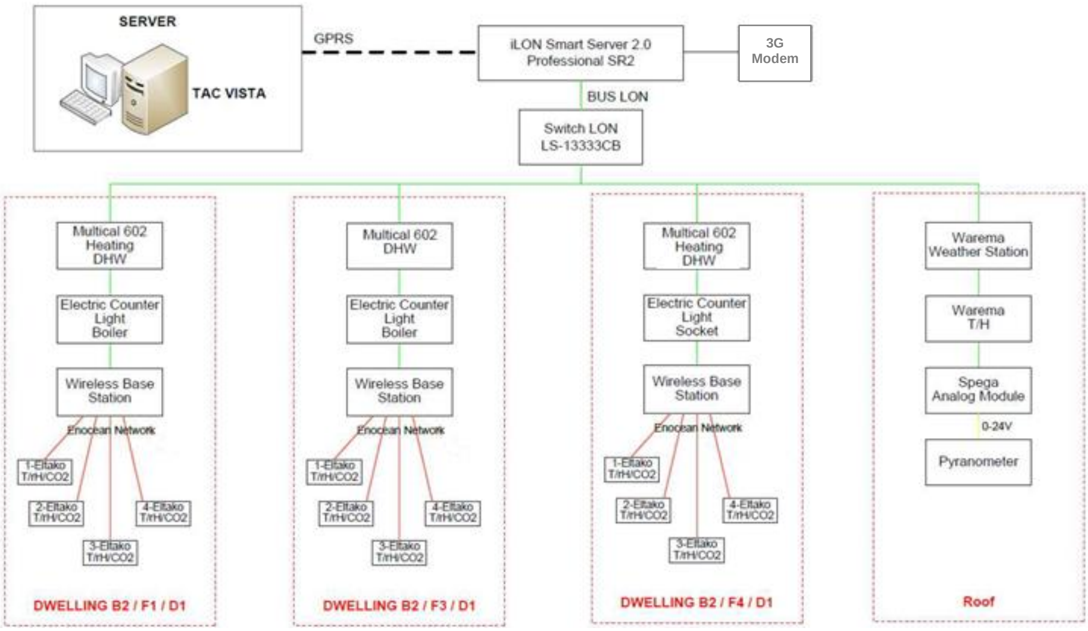


Figure 60: Dwelling selected & distribution of LonWorks cable for monitoring

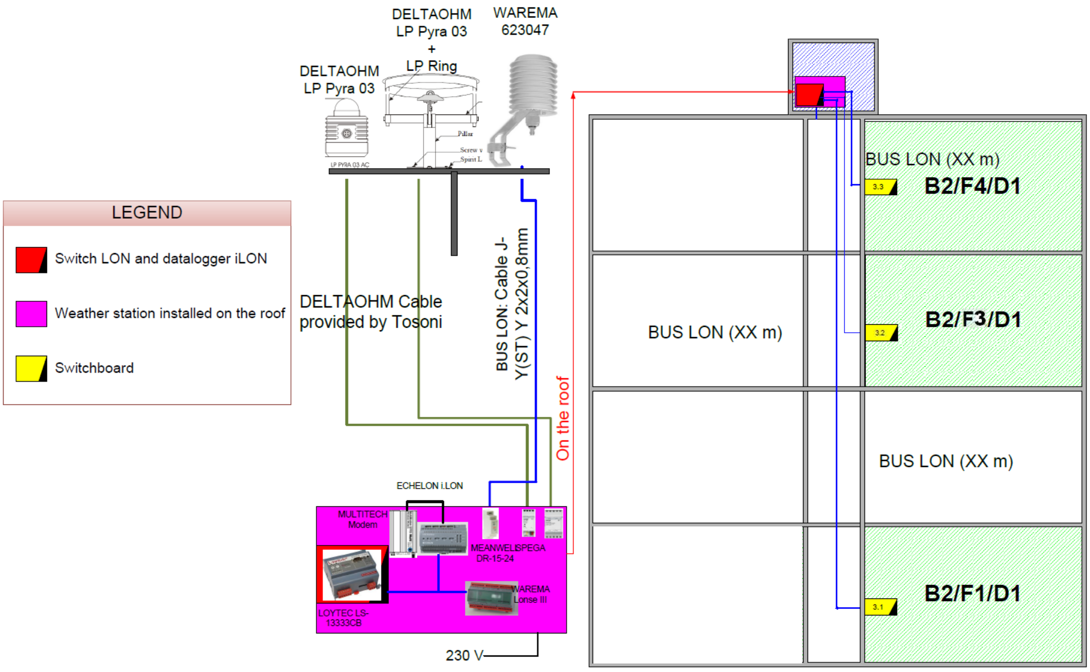


Figure 61: LonWorks distribution on building

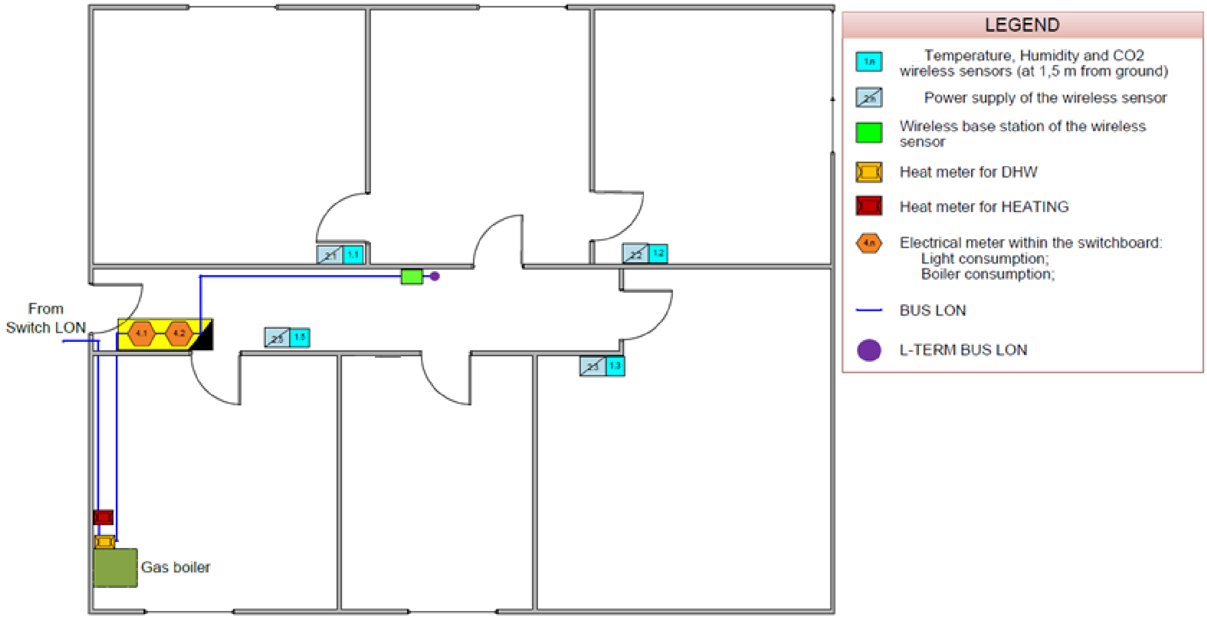


Figure 62: Installation Plan in B2/F1/D1

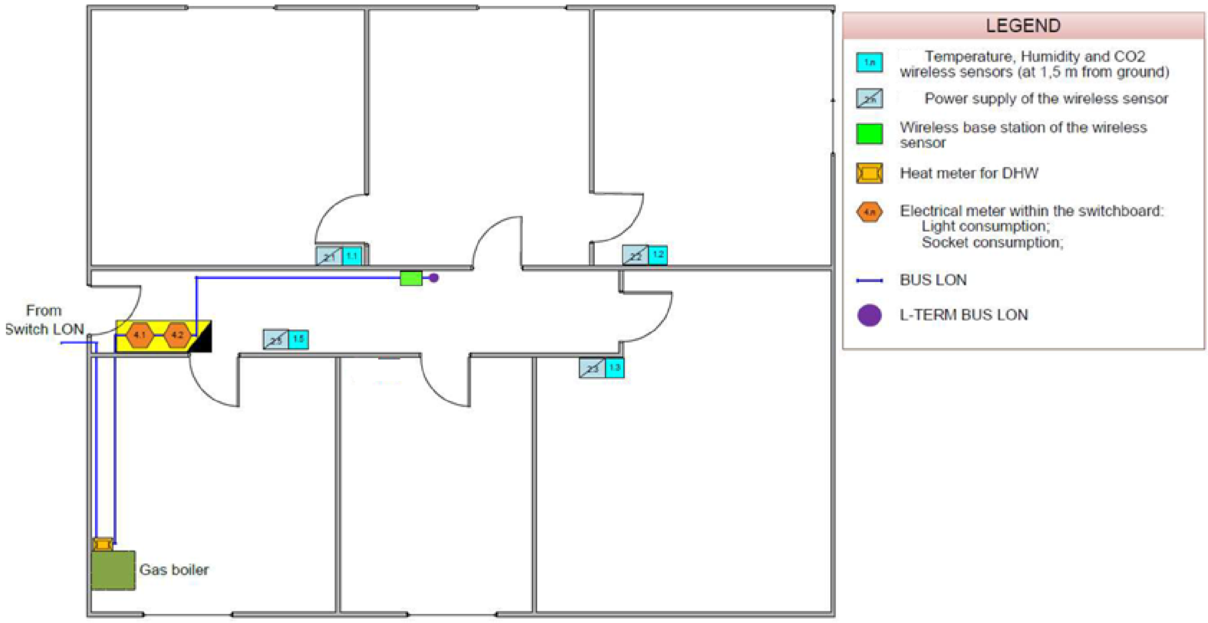


Figure 63: Installation Plan in B2/F3/D1

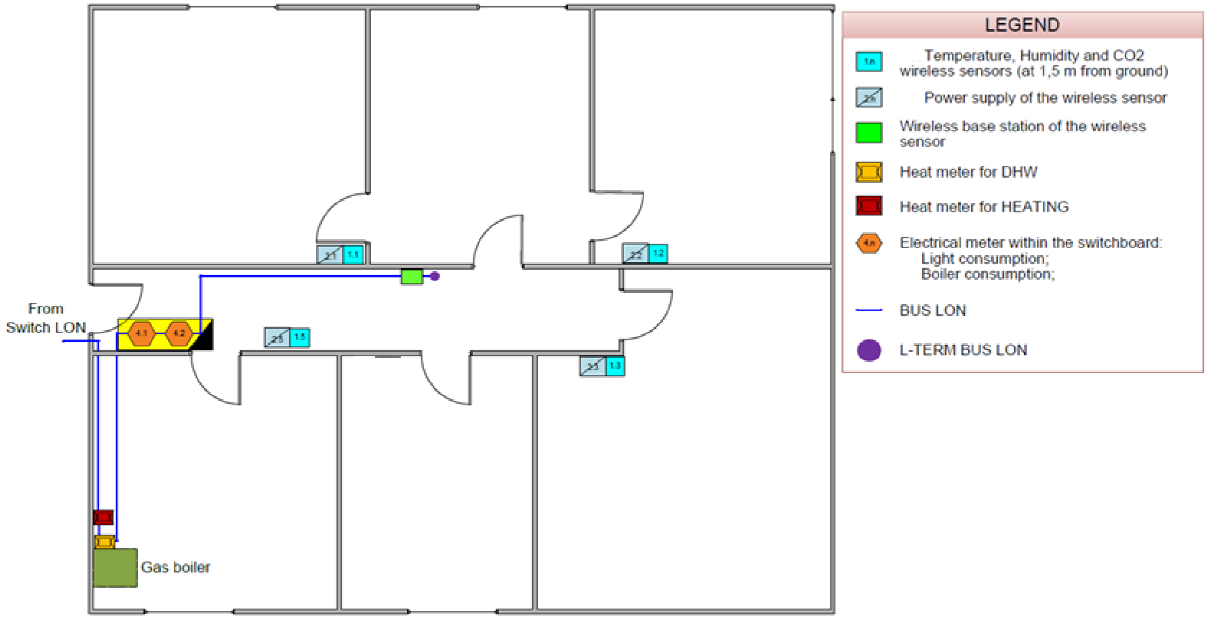


Figure 64: Installation Plan in B2/F4/D1

7.2 Ludwigsburg (Germany)

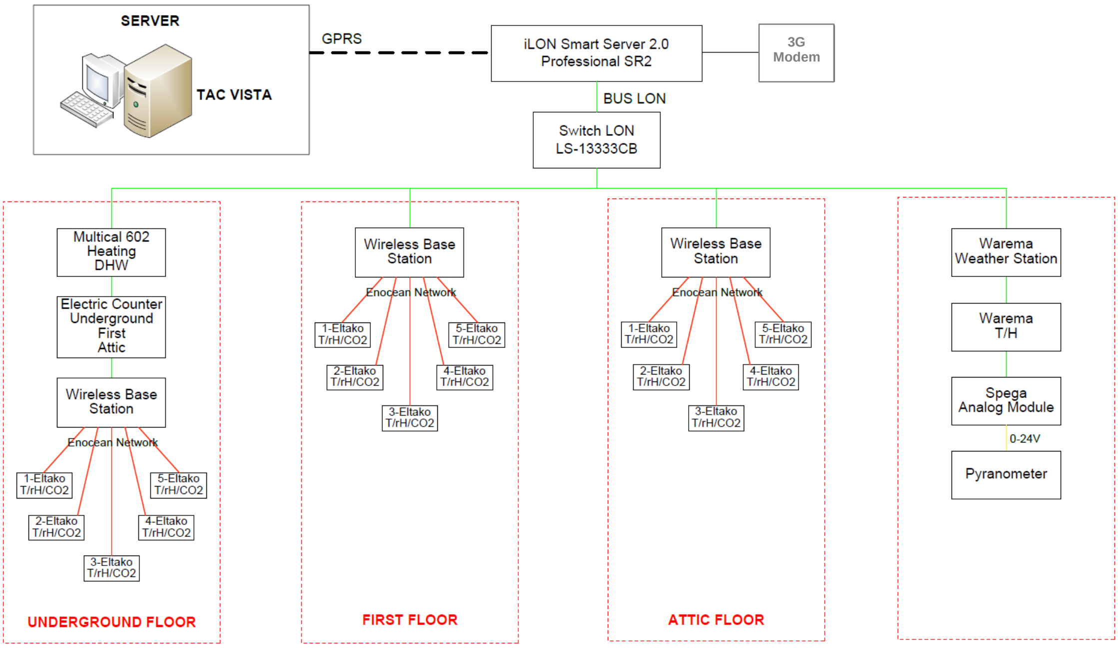


Figure 65: Dwelling selected & distribution of LonWorks cable for monitoring

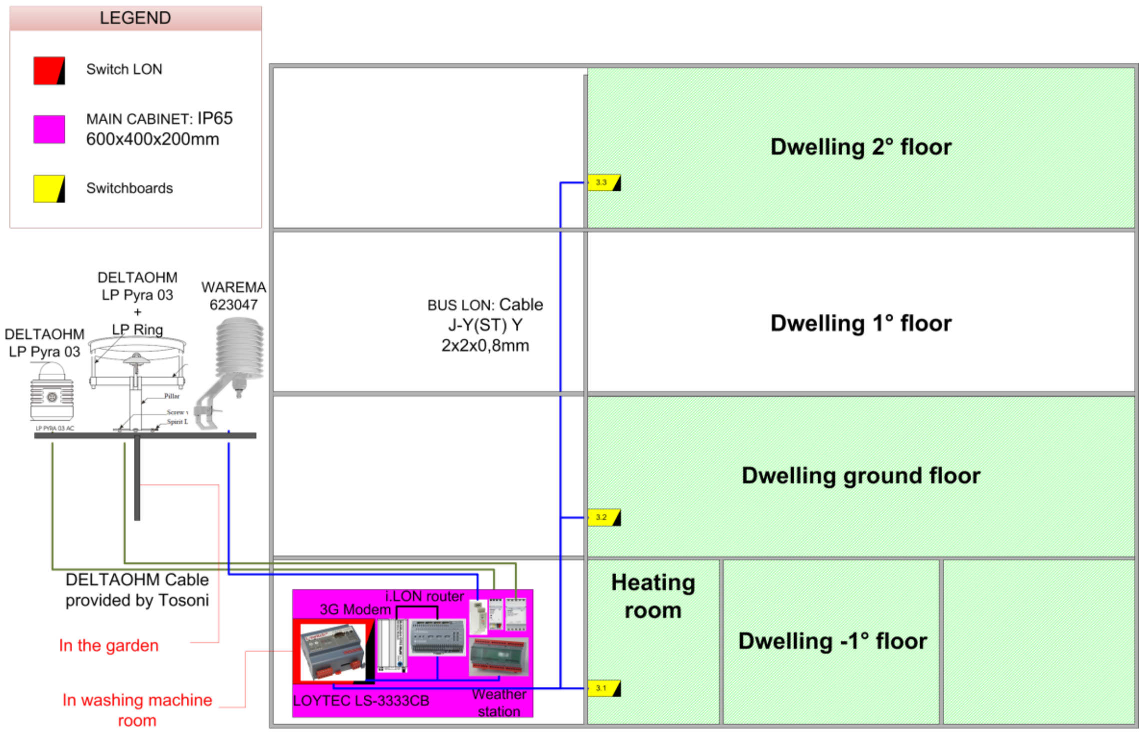


Figure 66 - Lonworks distribution on dwelling

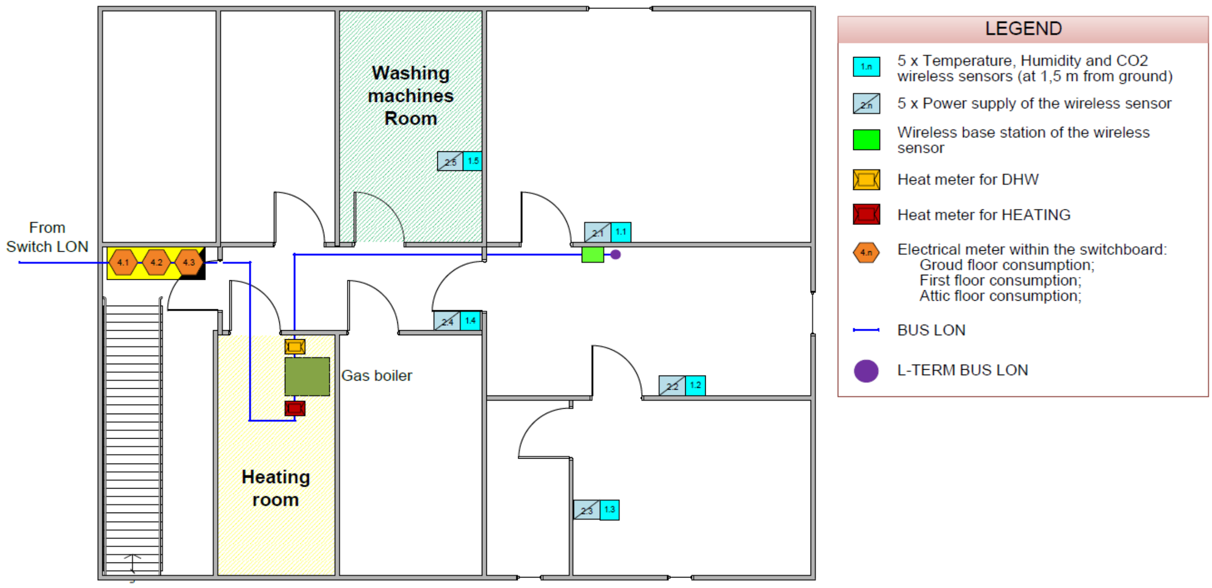


Figure 67 - Installation plan in cellar floor

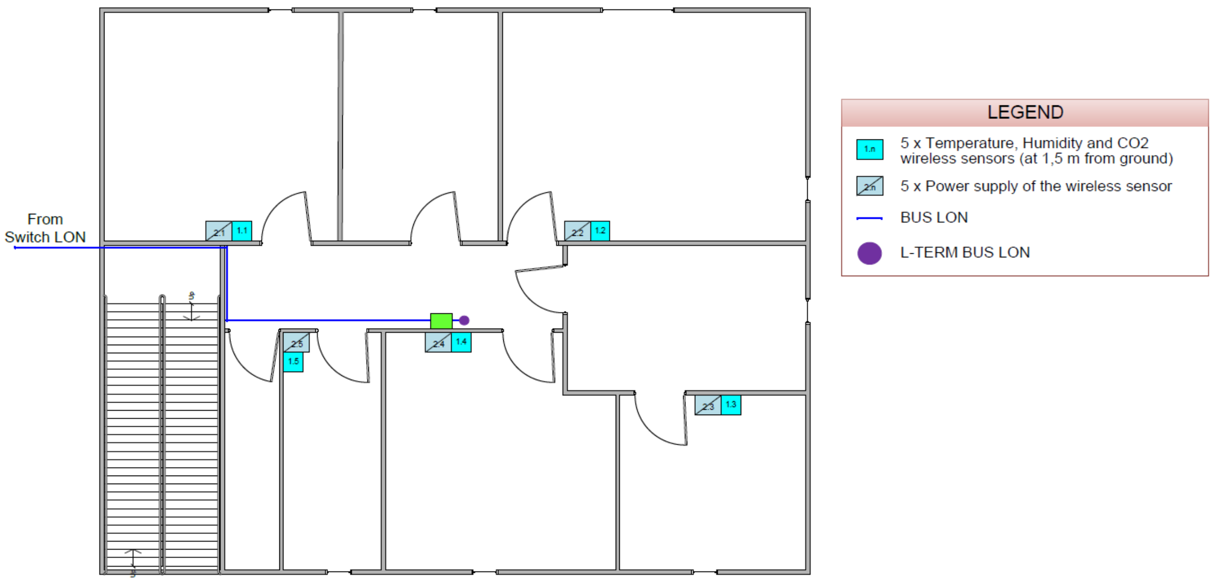


Figure 68 – Installation plan in first floor

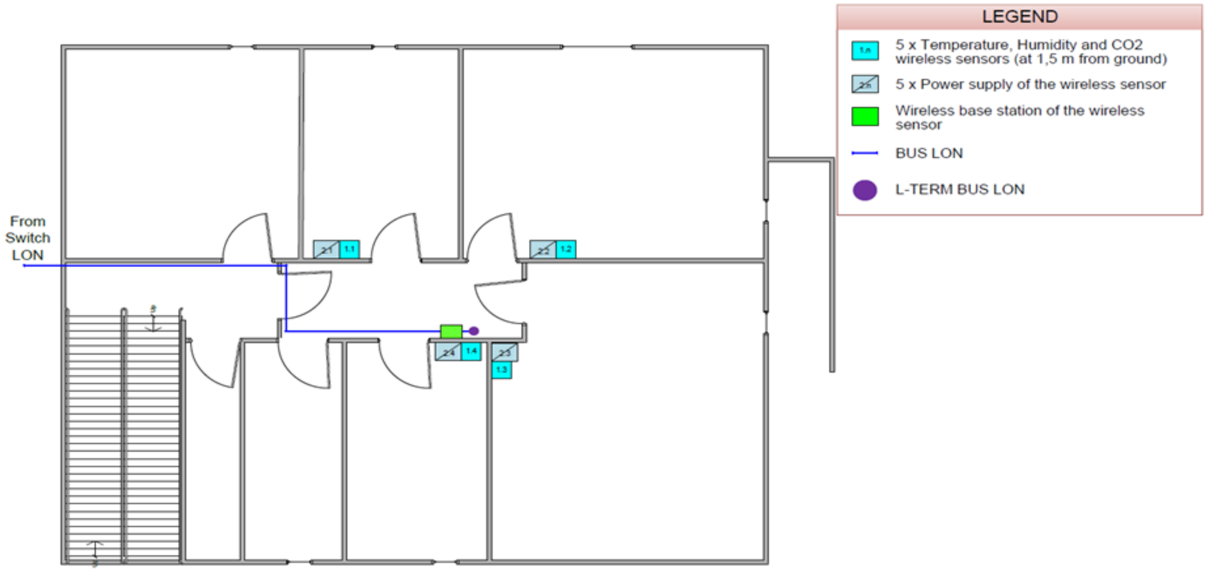


Figure 69 - Installation plan in attic floor

7.3 Verona (Italy)

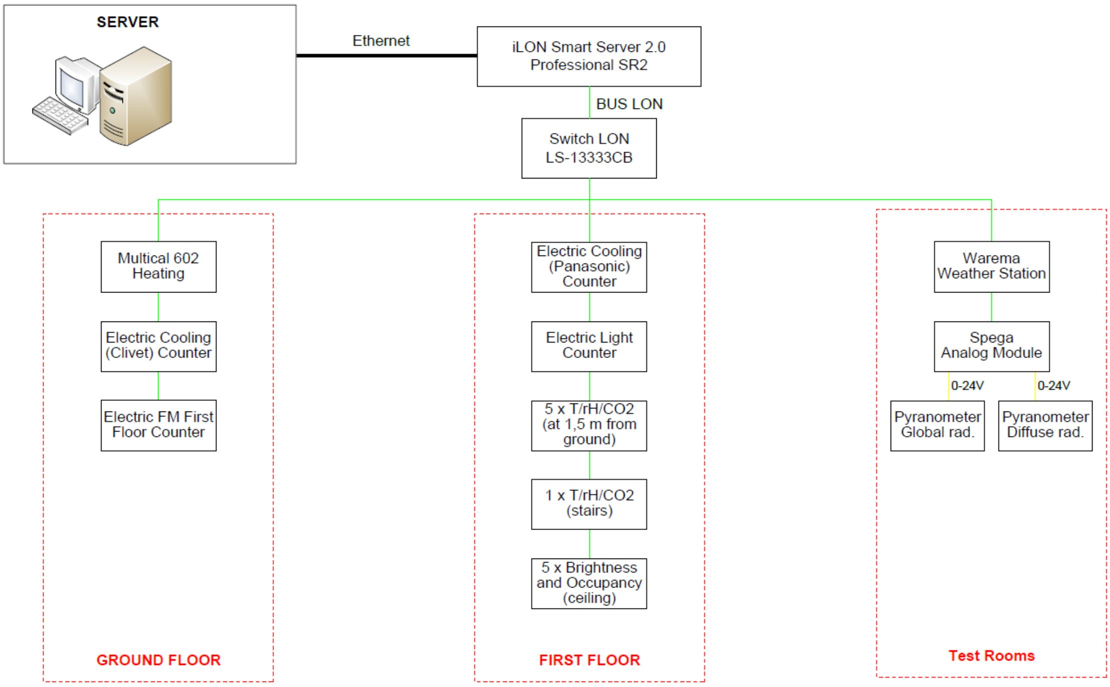


Figure 70: Dwelling selected & distribution of LonWorks cable for monitoring

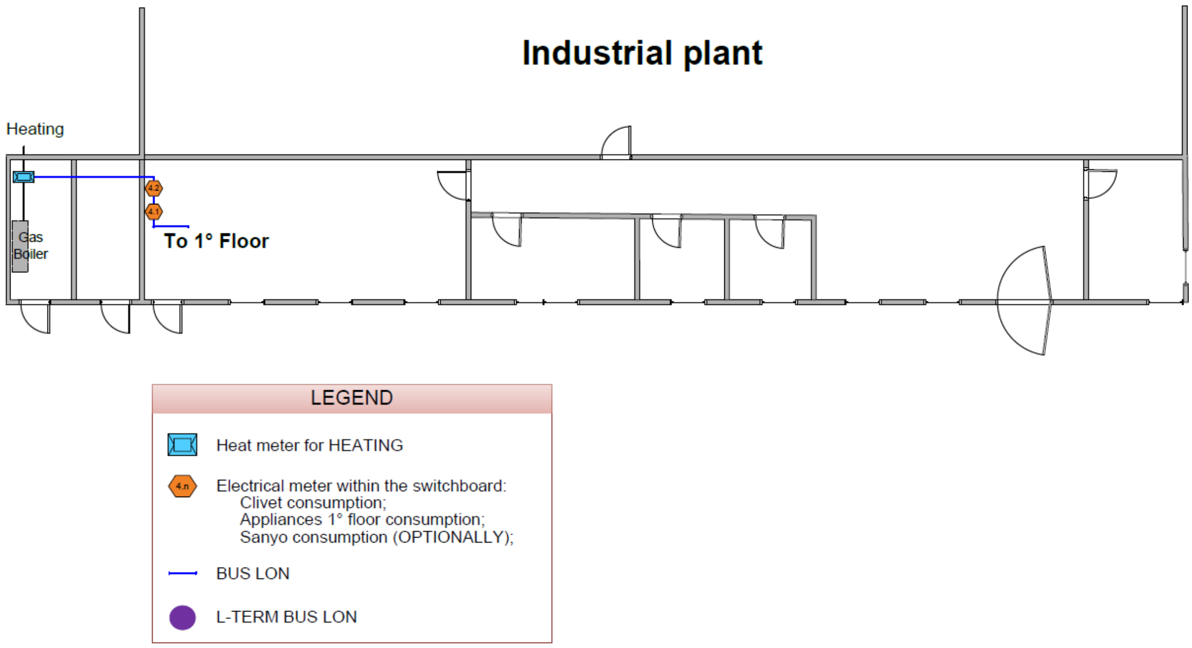


Figure 72: Installation Plan in FIRST FLOOR

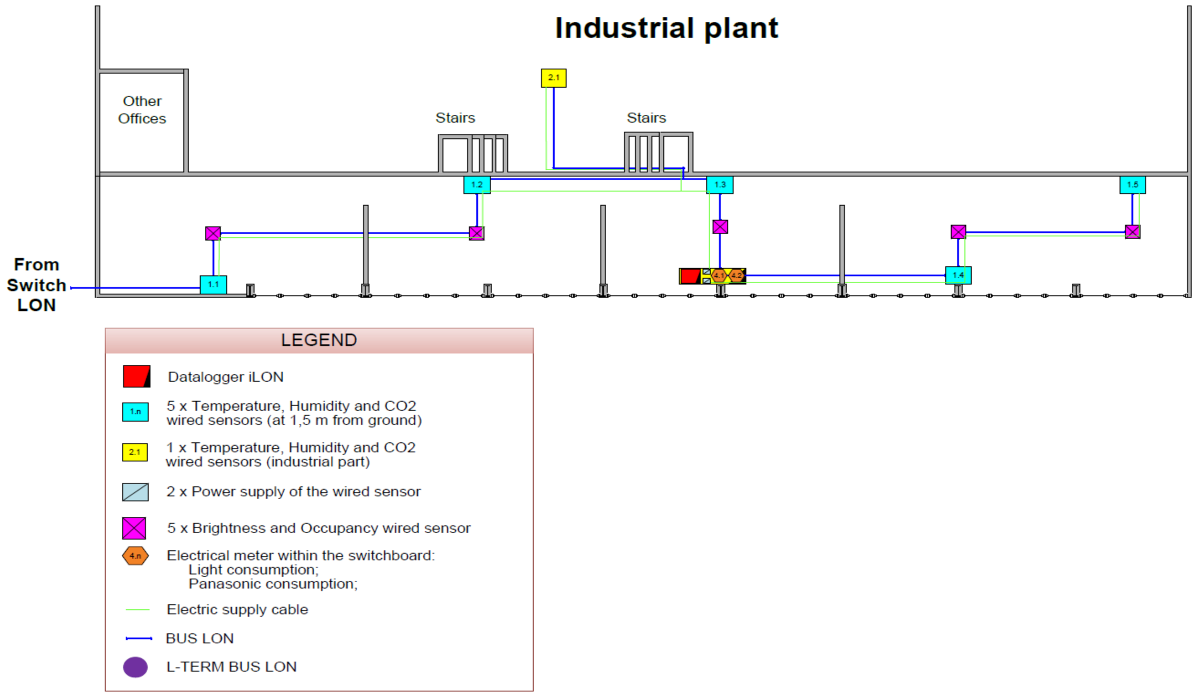


Figure 73 Installation Plan in FIRST FLOOR

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