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Transformation principles of an existing building in a building automation

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Contents

1 Abreviations

IT	Information Technology
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information and Communication Technology
BIM	Building Information Modelling
BAS	Building Automation System
BMS	Building Management System
FM	Facility Management
ICS	Intelligent Control System
WSN	Wireless Sensor Network
BIS	Building Information System
DB	Data Base
QR Code	Quick Response Code
AR	Augmented Reality
BEMS	Building Energy Management Systems
API	Application Programming Interface
TCP/IP	Trasmission Control Protocol/Internet Protocol

2 Introduction

The goal of this deliverable is to describe a methodology to transform an existing (also historical) building into a building automation, and to consider the cost-benefit ratio based on the SEEMPubS experience at the Polito's campus according with the specification of WP1, WP2, WP3, WP4 and WP6.

Even though the building automation industry has established its first standard called European Integration Bus EIB/KNX over more than 40 years ago, this standard, and many others established in the meantime, have never led to veritable integration of systems in the building automation industry.

Working in existing and historical buildings like the campus of Polito we found systems that are used as "control islands" (e.g. for heating and for lighting). This practically meant that we found many control panels at different places in the building, many parallel (cable) networks, and thick cable packages, which are not connected. We further had to face *vendor lock-in* and the resulting high prices because the number of standards was so high that each vendor had such specific ways of integrating the modules. For this reason, sometime it is difficult and slow to use sensors or modules from different vendors. But this is a daily condition when we work with existing buildings when have to co-exist existing systems with new ones. This is especially true in historical buildings for the reason described in the next section of this document.

We know that the only way to solve the problem just described is the use of new technologies from different vendors - properly defined on the basis of characteristics and costs - as integration of the existing ones, and middleware like LinkSmart to guarantee interoperable data exchange in real time. Moreover, it is essential to define the correct ontologies and a BMS able to manage all the data optimally.

Finally, it is necessary to consider that there are challenges associated with the use of wireless technology in buildings. First, wireless devices require a power supply to operate. They either have batteries or harvest energy from, for example, sunlight or temperature gradients. Second, the communication range depends on a number of factors including the radio frequency, the space layout and the construction materials used in the building. Other electronic and wireless devices can also interfere with the wireless signals and may cause data exchange problems between the automation devices.

It is known that historically, building system cabling infrastructures were often designed, installed and maintained independently from IT network systems. This is the case of the buildings selected as demonstrator in SEEMPubS.

Traditional dedicated building systems, such as lighting, HVAC, monitoring and energy management must now coexist with ICT including different types of data exchanged using interoperability standards. This change needs:

- robust and diverse applications (existing and new) integrated by middleware;
- real-time data and services delivery;
- greater performance requirements;
- reducing energy costs as essential goal;
- availability and flexibility of the system;
- improvement of the awareness of end users.

An innovative, unified management system like the one proposed in SEEMPubS must leverage a physically mapped logical network to provide the monitoring and reporting capabilities that are crucial to efficient infrastructure diagnosis and troubleshooting. The ability to view both the physical and logical topology of an infrastructure extends real-time intelligence through both layers. A device and building ontology (D4.4 - *SEEMPubS Device Ontology*), a Building Management System based on the use of middleware (D4.5 - *Pilot Devices*), interoperability (D5.2 - *3D Parametric Model*) for the data exchange, and Building Information Modelling (BIM) (D5.2) for the data visualization, are the way to obtain this goal. At present both are investigated and developed as result of R&D in SEEMPubS and will be demonstrated at the end of WP5 (month 36 of the project).

The document is structured in three sections.
The first section describes the methodology used to transform the buildings of Polito's campus into smart buildings thanks to a new Building Automation Systems (BAS) designed specifically starting from a survey of the existing one.
Section two synthetizes the essential decisions that characterized the activities of the SEEMPubS project during the two past years and summarizes the costs that have been incurred to implement the BAS in the selected rooms used as prototype (both test and references).
The last section analyses the main results obtained and introduces the activities that will be used in the future, according with the SEEMPubS project.

3 Methodology to transform existing buildings into buildings automation

The aim of this first section of the deliverable is to define the methodology based on the use of a middleware for an efficient BAS, and BIM for an interoperable Building Management System (BMS), which would allow for more agility in the alignment to innovative aims developed in the SEEMPubS project easily to be replicated in other existing (also historical) buildings in Europe. As the details of each solution adopted in SEEMPubS are described in other deliverables already submitted, in this document we suggest the principle that can be adopted in other buildings using similar tools. The focus of the document in fact is the methodology and not the description of the tools[1].

The starting point of this methodology can be linked to a Peter Drucker's unequivocal admonition that has influenced generations of managers: "*If you can't measure it, you can't manage it*"[2].
In effect, "*you can't manage what you don't measure*" and "*what gets measured gets managed*" are often quoted statements that demonstrate the importance of measurement that provides quantitative information that can be used in effective decision making to improve operation.
The solutions adopted in SEEMPubS are based on the state-of-the-art overview and on the lessons learned from the earlier studies. Of course, the roots of building automation for energy saving must consider control of HVAC, lighting and electrical systems. As measurement of each parameter must be automatically and correctly processed, this can be achieved working contemporary on three principles:

- *The goal*: Transformation of the services, IT, and physical environment in a way that enhances the experience, provides new services with the possibility to save energy, optimizes data utilization, and introduces new ways of working and living.
- *The strategy*: Integration of information and communication building systems into a common IP network (web-based), reducing operating expenses while optimizing building management operations and performance.
- *The foundation*: Creation of a BIM-based "building information network" for a flexible and scalable network for the facility's information utility.

In this way it is possible to consider that BAS are primarily used to maintain comfortable indoor conditions whilst minimizing the used energy. But, the importance of building automation systems has increased during recent years and current systems are now able to integrate various building systems, such as lighting and HVAC with each other and to communicate with other information systems, for instance, the Facility Management (FM).
The ability to collect, process and transmit data from several building systems is the main goal of the SEEMPubS project as shown in figure below, where in horizontal integration, data is exchanged on the same hierarchical level (for example, between HVAC or lighting

[1] Who is interested in the tools can use the dedicated deliverables that are indicated step by step.
[2] https://docs.google.com/viewer?a=v&q=cache:ckVdsPeJadkJ:www.hks.harvard.edu/thebehnreport/November2005.pdf+&hl=it&gl=it&pid=bl&srcid=ADGEEShUADf3SaEyiOo1JAVy6WGt_M-rwLI3MMiHBfkCE_VpM3rBSurzbL8jPSoj3m5z7HckjYeWICXsHuD_uvae7hBDgioGWGBb3tgBv_twxoHr--FJ79EPvCCSRAupsLSSpkNIn6zd&sig=AHIEtbRGauHFfmJRI4AhDT_h5-VaHiZoew

systems) while the vertical integration aims at data exchange between the field level and the FM applications thanks the Intelligent Control System (ICS) defined in D2.1.1 and D2.1.2 based on detailed Control and Conservation Strategies described in D2.3.1 and D2.3.2.

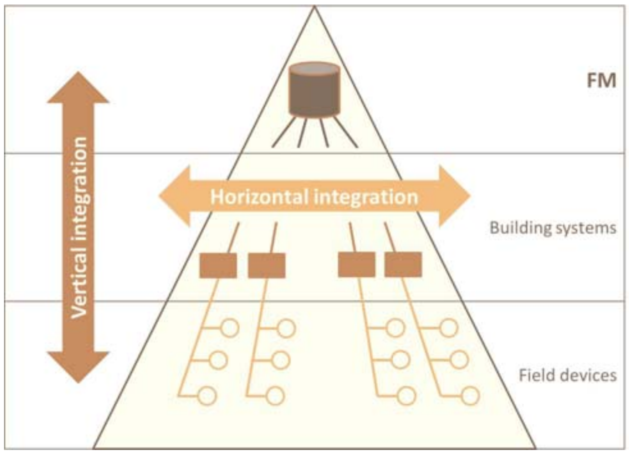


Fig. 01 – Horizontal and vertical integration in the SEEMPubS project.

Keeping in mind these considerations, the methodology used in the SEEMPubS project to transform existing buildings into smart buildings can be illustrated by dividing it into eight points as briefly described in the paragraphs below:

1. Find the relevant problems which have research potential
2. Innovate, i.e., construct a solution idea
3. Examine the scope of applicability of the solution
4. Obtain a general and comprehensive understanding of the energy saving by ICT
5. Know the state of the art
6. Demonstrate that the solution works
7. Define the cost/benefit ratio of the solution proposed
8. Verify the impact of the research on end-users.

3.1 Find the relevant problems which have research potential

For the SEEMPubS project, the key words in this first point are essentially two: *middleware* and *interoperability*.

3.1.1 Middleware

SEEMPubS aims at interconnecting various kinds of systems and technology to allow smart energy management in existing buildings. The LinkSmart[3] middleware (D4.5) with its ability to interconnect heterogeneous devices, services and whole subsystems is used to tackle these problems of interoperability (D2.1.1). In SEEMPubS, the LinkSmart Middleware is used to integrate existing building management systems and sensor networks with new technologies to be developed within the scope of the project. In SEEMPubS, the integration concerns: BMS (Siemens Desigo), Energy Meters (smart plug) and Wireless Sensor Networks (WSNs).

[3] http://www.LinkSmartmiddleware.eu

With the SEEMPubS system, we need to be able to process sensors data on a semantic level, which allows recognizing and deriving context and situations with potential to save energy. Semantic abstraction is achieved by the SEEMPubS Ontology (D4.4) and the SEEMPubS Context Framework (D3.3).

3.1.2 Interoperability

Interoperability is one of the major goals of SEEMPubS to achieve seamless data exchange at the software level among diverse applications, each of which may have its own internal data structure. Furthermore, interoperability is essential for the use of the BIM as a process that organizes and updates multidimensional representations which are associated with heterogeneous data to support communication, collaboration, simulation and optimization (D5.2).

For the SEEMPubS project we assumed that a database must be the core of the Building Information System (BIS). In this way the data that should be used for the building management are defined paying particular attention at their subsequent exchange between different applications and their visualization modality. The goal is to realize an innovative and efficient BIM-based management system.

3.2 Innovate, i.e., construct a solution idea

The main innovation in the SEEMPubS project is essentially related to a *new communication infrastructure*, a *web based software*, a *new BMS* and the development of *new technologies*.

3.2.1 New communication infrastructure

A new communication infrastructure has been designed (D2.1.2). The figure below shows the SEEMPubS Device Proxies, which send information to a global database, which stores sensor measurements (note that the proxies may manage data in local databases as well). The State DB can be accessed via a Web Service interface to which the proxies report their measurements. Pre-processing of sensor data may be done individually in the proxies.

The State DB handles all communication with the SEEMPubS Device Proxies distributed over the network. This database acts itself as a proxy between the Web Service interface and the applications. It transfers current data/measurements to the application. The purpose of the State DB is to prevent the applications from slowing down due to possible issues with the communication with the sensors and also to avoid having large amounts of measurements on application specific databases.

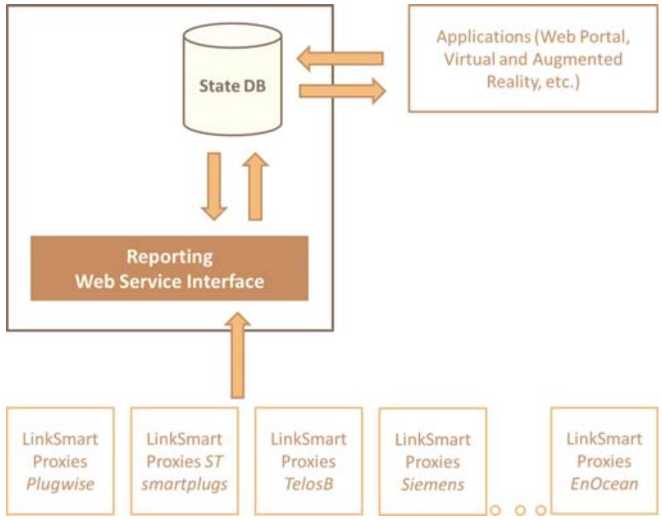


Fig. 02 – The SEEMPubS State DB Architecture.

3.2.2 Web-based access software

A web-based software has been designed (D2.4.1), making use of modern concepts of web services, to fulfil three fundamental features:

- to store the information, coming from the WSN in a customized database;
- to interface the WSN to the web, exporting the data stored in the database;
- to manage and configure the WSN nodes, both locally and remotely.

To do this, the software used runs on a PC-Gateway.

3.2.3 New Building Management System

A new BMS has been designed considering the integration of (D2.1.2):

- integrated modelling solutions based on BIM;
- interoperability between software;
- QR Code, Virtual and Augmented Reality (AR) for maintenance and operation as well as for data communication to end users;
- smart metering for energy consumption awareness;
- integration technologies by middleware;
- intelligent wireless and wired sensors networks for energy performance monitoring and controlling;
- energy performance audit solutions;
- website for collecting and disseminating energy-efficiency data;
- user awareness and decision support;
- standards-based solutions for building life-cycle management.

3.2.4 New technologies

The development of new technologies in SEEMPubS is guaranteed by the ST Microelectronics Smart Plug[4] (D4.2) and the Ultra-wide-band (UWB) wireless sensor networks (D2.4.2) developed by KULeuven.

3.3 Examine the scope of applicability of the solution

The selection of a correct *demonstrator* in this point is essential because of the applicability of the results in other cases. Equally important is the *compatibility between different wireless sensor nodes*.

3.3.1 Demonstrator

In SEEMPubS the demonstrator is located in the buildings of the campus of Politecnico, a centre of teaching and research strongly committed to collaboration with industries that covers an area of more than 315.000 sm. This campus is characterized by three different types of buildings (D1.1):

- *Historical building*. The Valentino Castle, a building that derives from various design phases which began in the mid-1500s.
- *Modern building*. The Main Campus, a site that was inaugurated in November 1958, characterized by an aesthetics based on the rigour of its lines.
- *Contemporary building*. The Cittadella Politecnica, a former industrial area, designed in 1994 regaining the most interesting industrial buildings, demolishing other less appealing and constructing new buildings.

For each building we have selected test rooms based on a selection of different characteristics and features:

- representativeness with respect to the Campus and other public buildings;
- energy saving potentials;
- problems and difficulties for modelling;
- existing services and easiness of intervention;
- existing monitoring;
- costs for setting up the experiment;
- presence of a reference room.

A preliminary diagram that link all this data has been defined at the beginning of the project (D1.1) as shown in the figure below and it must be verified based on the results of the project.

[4] The ST smart-plug is not a commercial product and it is released for demonstration scope only, so it has been delivered with some limitations.

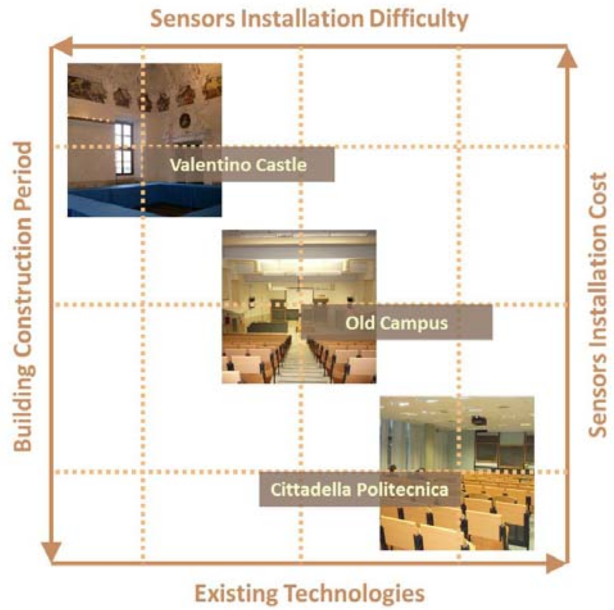


Fig. 03 – Test and Reference rooms selection scheme.

3.3.2 Compatibility between different wireless sensor nodes

One of the advantages of the SEEMPubS project is the compatibility between different wireless sensor nodes that work in different standards. Different subsets communicate in various communication platforms which need separate software to control them, but by applying the LinkSmart platform, the user can manage all subsets and subsystems part of the whole system connected through gateways as interface regardless of their link standards. For different subsets, an interface connects them to the middleware. Of course, this method could be applied everywhere.

The SEEMPubS platform is shown in the figure below. The LinkSmart proxy layer is shown as the connection between the different devices and technologies and LinkSmart and should be customized for each communication link. Once a LinkSmart proxy for a certain technology is available it can be re-used, extended, and integrated into other LinkSmart networks with very low effort. More detailed information on how to develop such proxies can be found in D2.2.2 – *Updated Implementation of the Intelligent Control System*.

3.4 Obtain a general and comprehensive understanding of the energy saving by ICT

The key elements in this point are: the *Building Automation System* (BAS), the *Building Energy Management Systems* (BEMS) and the *Building Management System* (BMS); the Ontology, the *Context Energy Framework* and the *Building Information Modelling*, closely related to each other.

3.4.1 Building Automation System, Building Energy Management System and Building Management System

As data managed by BAS and BEMS often flow separately - BAS data are related to system operation and can include alarm functionality for preprogrammed, important criteria while BEMS data generally focuses on the major energy consuming devices in the premises -, the SEEMPubS platform has been designed and implemented in order to allow the suppression of the barriers that usually exist between proprietary systems.
Moreover, it is known that oftentimes large buildings like Politecnico's campus are equipped with BMS that are controlled centrally to define light and heating schedules etc. However, such systems often lack fine control over single rooms or don’t allow end-users to influence pre-defined schedules and don’t realize the full energy saving potential. In order to increase the energy efficiency of such buildings, it is necessary to extend existing solutions with new technology like sensor/actuator networks, smart energy meters etc.
When trying to integrate different technologies into one common system, a major issue is the heterogeneity of devices and corresponding interoperability issues. Different systems use different kinds of programming models, communication protocols, vendor-specific APIs, etc.
An approach to overcome these issues of heterogeneity is to abstract those diverse standards in a higher layer, which offers a uniform interface. This is where a middleware like LinkSmart normally comes into play as introduced before.

SEEMPubS implements a 3-layered software architecture and on each layer we deal with different kinds of information and different kinds of privacy and security issues (D2.2.2 and D4.7).

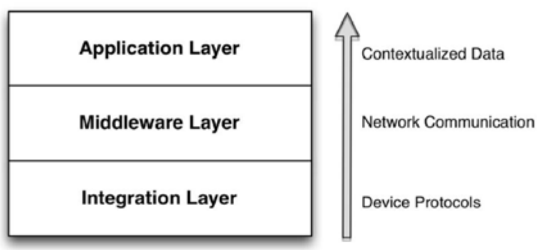


Fig. 04 – SEEMPubS levels of information.

The *Integration Layer* deals with specific device communication protocols that are implemented by any kind of vendor (e.g. ZigBee stack, EnOcean EEP).
On the *Middleware Layer* LinkSmart is used as an enabling technology for integration of heterogeneous technologies and, which is more important when talking about security, for communicating among the different components. In fact in SEEMPubS we have communication from and to Proxies that actually are connected to the sensors and actuators.
On the *Application Layer* we deal with already contextualized data, which could be misused to create user profiles, e.g. people entering offices, numbers of people entering rooms and so on.

3.4.2 Ontology

Thanks to the LinkSmart Device Ontology (D4.4 and D4.6.2) it is possible to describe device related information, which can be used in both design and run time. The SEEMPubS Ontology provides a taxonomy for the energy efficient building domain, describing a model that is used to

support the development of energy efficiency applications. This model describes the (semi-) static environment of the SEEMPubS world, independently from the type of implementation or platform used in development of such applications. It models devices, sensors, actuators, rooms, and observable properties such as temperature, humidity and so on. To map from the domain to the implementation it also models proxies, services, and events. All applications built on the SEEMPubS platform will use this common model.
The basic ontology is composed of several partial models representing specific device information:

- *Core Ontology*: contains a taxonomy of various device types and the basic device description, manufacturer and model information.
- *Device Capabilities*: represent the hardware properties and software descriptions.
- *Device Services*: describes the models of device services in the terms of operation names, inputs and outputs. The device services are connected to the Quality of Service ontology used to annotate the services and their parameters to several quality factors.

3.4.3 Context Energy Framework

In SEEMPubS, the Context Energy Framework's main goal is to interpret the data provided by sensors and devices into information that can be used by the SEEMPubS system to control devices within a room in the most energy efficient way possible.
Once the data is acquired through the proxies it can be used for several goals:

- Detect uncomfortable levels of ambient factors (e.g. temperature, light, CO_2, humidity, noise)
- Detect energy leakage (e.g. old devices consuming too much energy, unnecessary turned on devices)
- Inform users about the current state of the room and its devices (e.g. temperature, humidity, electrical and other energy consumption, lighting, heater or cooler status, number of people).

In order to achieve these goals the system needs three essential components: a *Reasoning component*, a *Model component* and a *Rule engine*. The Reasoning component executes a series of actions needed to reach a desired state or goal. For instance, a possible goal to reach is turning off lights when the last person leaves the room; this goal implies some action such as detect if there are no persons in the room, find all lights within the room, turn off the lights. In order to do this the Reasoning component uses the Model component that is an ontology model describing the entire environment available for the SEEMPubS system such as the building, rooms, users, devices, sensors etc. and also the relationships between them.
The relationship among objects and entities described by ontology enables the system to find the specific room and the specific devices that the Reasoning components needs to interact with. However, as in any well-functioning system there has to be rules. Within SEEMPubS, this task is accomplished by the Rule engine: the Rule engine manages a set of rules, both general (e.g. never turn off alarm system) and more specific (e.g. turn off corridor lights after 6 p.m.), that are usually identified by the building manager.

3.4.4 Building Information Modelling

In SEEMPubS BIM is used (D5.2) as method for a continual data cross-check and updating in order to assure that the integrated model (architecture, structure, HVAC and lighting systems) is as much accurate as possible for any use (energy performance, thermal comfort, lighting and management).

A special approach must be taken to model an historical building like the Valentino Castle characterized by monumental elements like frescoes, spiral columns, painted architecture or stuccoes that make the architectural part essential (not always easy to be modeled).

3.5 Know the state of the art

The elements to be considered in this point are: the *energy performance diagnoses* and the *ontology*.

3.5.1 Energy performance diagnoses

Energy performance of buildings is investigated by energy performance diagnoses evaluating its energy consumption and its impact in term of greenhouse gas emission (D1.2).

In SEEMPubS, energy performance diagnoses are used to describe buildings (area, orientations, walls, windows, construction materials …), as well as its heating/cooling system, its hot water production system and its ventilation system. They indicate, according to the cases, either the quantity of energy effectively consumed (based on the building's bills), or the estimated energy consumption for a usual use of the building.

3.6 Demonstrate that the solution works

This is the main part of the methodology and it is exactly the goal of the WP5 as demonstrator of the whole project. Each part developed in the other WPs is linked, tested and eventually corrected in case of not acceptable results. In fact, testing, monitoring and simulation are used, in the SEEMPubS project, to demonstrate the efficacy of ICT based environmental control and monitoring systems, to reduce buildings energy consumption.

Several topics linked each others must be considered in this part as described below.

3.6.1 Control and monitoring strategies

In SEEMPubS control and monitoring strategies have been defined (D2.2.1 and D2.3.1) for:

- ***Lighting optimization*** mainly based on the following strategies:
  - A central scheduling policy which is enforced for the whole building by the facility manager. This strategy is also called *Time switching*. This strategy entails to turn automatically on and off luminaires at scheduled times to avoid energy waste for lighting out of working hours.
  - *Presence detection* is the control strategy that entails to turn luminaires on and off respectively when the presence or absence of people is detected in a space.
  - *Daylight exploitation* automatically adjusts the intensity of electric lighting based on the intensity of the daylight that enters the room. The users requires to set the level of intensity that they desire, and the lighting controller will sense the amount of the daylight entering in the room, and adjust its intensity based on this value.
  - *Shading regulation* complements is also intended to exploit the daylight regulating the shading automatically when it detects daylight being blocked by the shading when glare condition or overheating are not present in the room.
- ***Heating/Cooling improvements***. The control strategy proposed in SEEMPubS is based on a communication between all sub-systems (heating/cooling, lighting, other electricity used).

- ***Appliance optimization***. To optimize the power consumption of appliances, it is quite difficult to define a policy that can be applied for each case and device, since each device behaves differently e.g.: coffee machine could be on without any presence of the users if it is making coffee. But when it would be on 24/7 per week because the user forgot to turn it off before he leaves on vacation, it should be automatically recognized by the policy and shut off. Therefore we propose that users are able to provide their own device policy and profiles to control individual devices, when they should be on and off. These profiles and policy could then be exchanged among users so that gradually, new users do not have to define device policies from scratch and could download these existing policies and apply them for their devices.

3.6.2 Energy conservation strategies

As consequence of the previous point, energy conservation strategies are under evaluation (D2.3.2) through software simulations for:

- ***Lighting***. The total annual energy used for lighting depends on different aspects, mainly related to: indoor daylight availability; building usage, in terms of target illuminance and occupancy profile; user behavior, in terms of interaction with the lighting plant and the shading devices; lighting plant characteristics, such as the installed electric power density and the adopted lighting control system.

  To take into account, as a whole, the aspects cited above, the software *Daysim* was adopted for the lighting simulations. Daysim is a Radiance based code that uses a dynamic Climate-Based Daylight Modelling (CBDM) approach, to estimate the indoor annual daylight availability, and it provides, beyond the traditional Daylight Factor (DF), a series of climate-based daylighting metrics, as the Daylight Autonomy DA, the Useful Daylight Illuminance UDI, the Annual Light Exposure, etc. Furthermore, from the annual daylighting data, Daysim calculates the electric lighting energy consumption as a function of the building usage, the users behavior and the lighting plants characteristics.
- ***HVAC***. The thermal simulations, carried out with the software *TRNSYS* are based on the rooms and plants features (collected during the first phase of analysis) and on some assumptions. In particular a hypothesis was made to calculate the hot water temperature which circulates in the heating network. It was supposed that this temperature depended on the exterior temperature by a linear law during winter period. An optimization of the heating or cooling restart delay in the morning has been tested using simulation and implemented in the system: it is based on the difference between the set point temperature and the internal one at each time step and considering the hour of the occupants arrival. The fan coil speed position has also been defined according to similar rules. During the general schedule of occupancy, presence detection that inform the system of the vacancy activate a lower set point (3 degrees lower) in the room.
- ***Other electrical loads***. The control and monitoring strategies designed for the SEEMPubS project include the continuous monitoring of different electrical appliances such as PCs, printers, etc. through wireless plugs able to measure the absorbed power and to switch the devices on and off.

  A further implementation of the energy conservation strategies could provide for control rules to be implemented in the LinkSmart system to avoid energy wastes due to electric appliances left on when unused.

3.6.3 Selection of control architecture

In general, **wired control architecture** (D2.1.2 and D5.1) were mainly adopted in the modern parts of the Politecnico Campus (both Main Campus and Cittadella Politecnica) where more structural interventions are facilitated by the buildings and systems features and by the presence of pre-existing building management systems (Siemens-Desigo). Even so, some wireless devices were also used, for instance to monitor the electric energy consumptions of lights or other equipments (PC, printers, etc.) or to collect more detailed data of indoor air temperature distribution by distributing a greater number of sensors within the space.

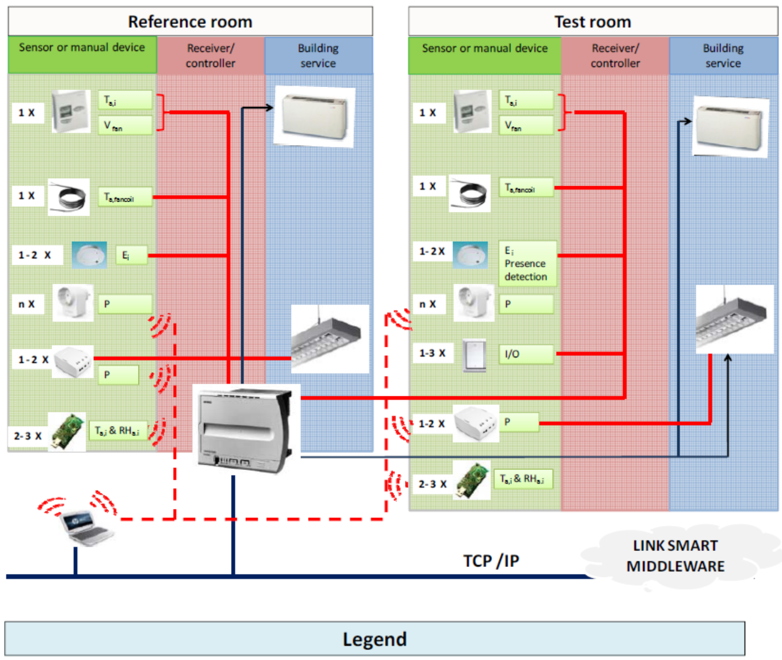


Fig. 05 – Example of wired & wireless architecture designed for the Main Campus.

Protocol-wise the wired solution is based on BACNet/OPC, while the wireless solution uses EnOcean technology. The selected products are from Siemens, Thermokon and Eltako.
In general the wired architecture, consisted of different devices (sensors, modular controllers and switches) will communicate with the LinkSmart thanks to specific modular controllers connected to the Living Lab by means of the TCP/IP network.

Wireless control architectures (D2.1.2 and D5.1) are mainly used in the Valentino Castle due to the architectural constraints (paintings, stuccos and historical structures) that didn't allow destructive interventions on the buildings components.

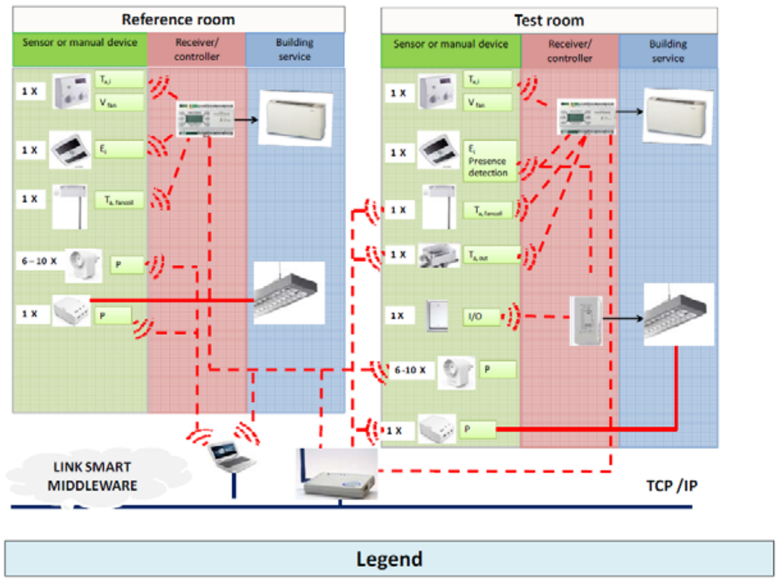


Fig. 06 – Wireless architecture designed for the DITER Offices in the Valentino Castle.

The wireless architecture, consisted of occupancy sensors, light switches, temperature sensors and thermostats, thanks to access points for EnOcean, is connected to the LinkSmart by means of the TCP/IP network.

In both, wired and wireless networks, a two-way communication between LinkSmart and all wireless networks is installed.

In addition to these architectures above described, some other networks have been added:

- with the TelosB networks, it is possible to integrate the monitoring of the indoor air temperature and relative humidity in addition to the monitored data through the installed devices (thermostats),
- with the Plugwise networks it is possible to monitor energy consumption of the lighting systems and the other loads (PCs, monitors, printers, faxes, table lamps, etc.).

From this control and monitoring architecture several data will be processed based on the scheme presented in the Figure below (D5.1). Data will be collected (Field level 1), sent to the main system (Field level 2) and elaborated (System level) to provide different users with the required information to monitor and manage the energy consumption and operation of the building systems and appliances in comparison with the ensured comfort conditions (Service level).

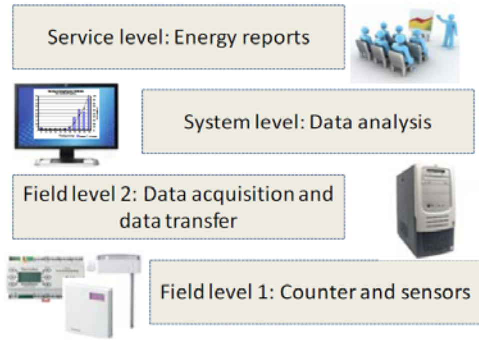


Fig. 07 – Four levels for ongoing/continuous control and monitoring system.

The devices and sensors that have to be used within the SEEMPubS project were identified in detail in D2.1.2 *Updated Specification of the Intelligent Control System* and also described in D4.5 *Pilot devices* (see Tab. 01).

3.6.4 Device integration

As introduced in paragraph 3.2.1, for device integration, in SEEMPubS two classes of proxies have been used to process data from both sensors and actuators into a semantic level. The first class is the *Room Proxies*, which represent a whole room in a building. This representation of a room (or other physical location) performs data fusion, querying and distributed processing for a location and may have several sensors and actuators attached. The sensor readings are reported as events using the LinkSmart Event Manager and the Room Proxy subscribes to events from the sensors in the room.

Observations from sensors are represented as *observation properties* of the Room Proxy, and situations - or contexts - that occur as a result of context reasoning are represented as *situation properties*. The context reasoning, using the ontology and rule evaluation, is performed by the Context Manager. Both the Context Manager and the Room Proxies queries the Ontology Manager for information on which observational properties or context attributes (e.g. “Air Temperature”, “Relative Humidity”) a proxy measures or influences and what data type is used for measurements (e.g. “decimal number”, “text string”) and unit (e.g. “Watt”, “lux”). The Room Proxy supports historical data and querying for properties providing specific information about the conditions in room such as temperature level, humidity level, CO_2 level etc. but cannot be used to change the conditions in the room. This can be done by the second class of proxies, *Device proxies*. These proxies represent a single device and provide information such as current energy consumption, measured by a smart plug for a specific device or a group of devices.

Both Room Specific Sensor Manager and Device Specific Sensor Manager act as data acquisition components in case of update requests.

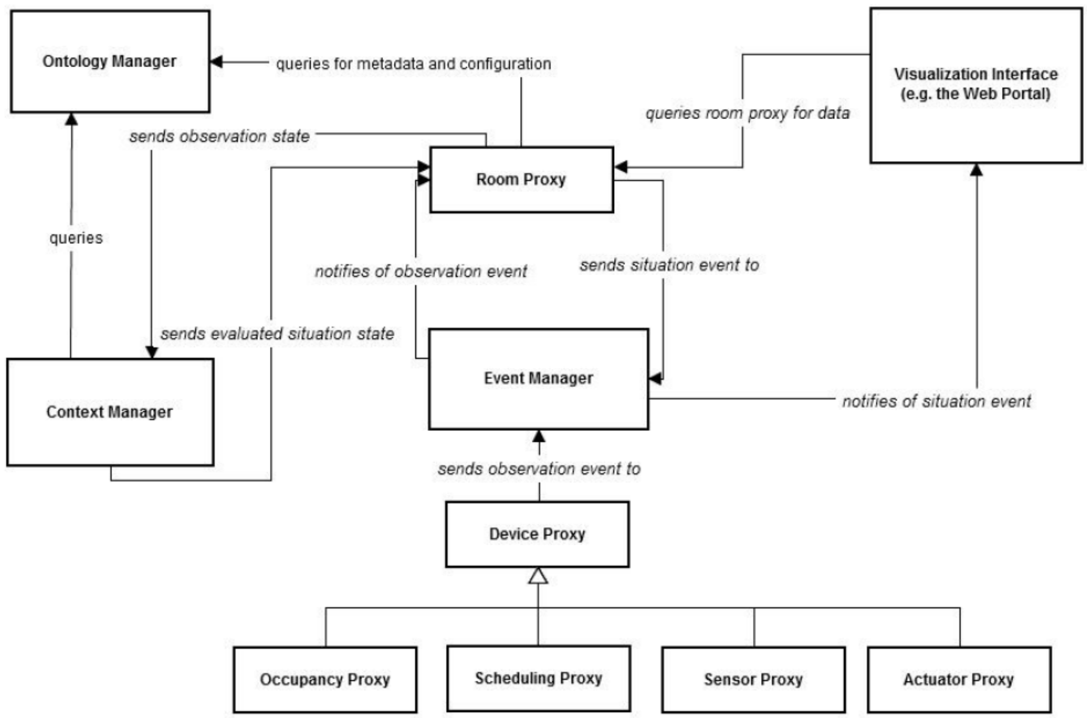


Fig. 08 – Interaction between components in the SEEMPubS system.

For the **WSN integration**, in SEEMPubS, a web-based protocol handles the communication between the middleware and the motes. Using this protocol, the middleware is able to query the sensor network concerning node identities (i.e., the communication addresses of the nodes, e.g., IPv6 addresses), node configuration and capabilities, and perform actuation as well as retrieving sensor values. Motes with limited capabilities may not be able to implement such a protocol themselves (e.g., handle incoming HTTP based calls), in which case a proxy can be used in-between the middleware and the motes. In such a solution, the middleware will communicate with the proxy using the web-based protocol, while the proxy will communicate with the motes using some simpler protocol.

A WSN Discovery Manager and a Mote Device Proxy handle the middleware support and handling of the mote protocol HTTP calls. Depending on the hardware capabilities of the sensor motes (e.g., processor and memory), the support for the HTTP based mote protocol is either implemented directly on the motes themselves, or via a proxy that sits in-between the middleware and the motes. The first solution means that the motes are able to receive and make HTTP calls directly via software running in the motes, while the latter will use a proxy that intercepts the HTTP traffic to the motes and “converts” these into some simpler type of messages, which the node can handle (and vice versa in the other direction).

Such a proxy will typically run on the gateway to which the coordinator sensor node is connected (e.g., via a USB cable).

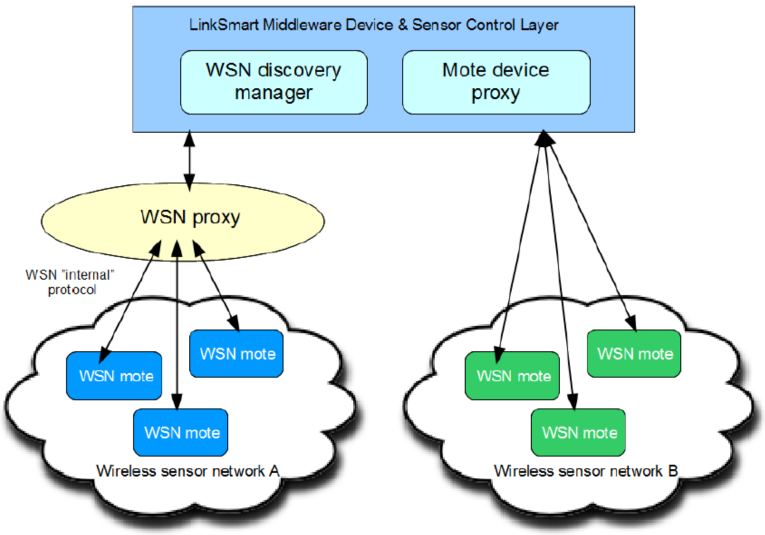


Fig. 09 – Wireless Sensor Networks Integration.

In the case that the sensor network has nodes with limited capabilities and WSN Proxy is present (Wireless sensor network A in Figure above), the WSN Discovery manager interacts with the WSN proxy and registers new devices in the LinkSmart Middleware, either by querying the WSN Proxy for connected sensor nodes or by registering a new device when a previously unknown node reports a reading to the WSN Proxy.
A Mote Device Proxy is created for each discovered sensor node. Sensor node readings are reported to the WSN proxy, who is acting as a front-end to the middleware. The proxy stores the latest measurements and provides these to the middleware. Only when needed, will the WSN devices awake and send the new information to the proxy. This minimizes communication over the WSN, allows the LinkSmart Device Proxy to respond quickly and saves a lot of energy in device's batteries, extending their active life.

Finally, an efficient solution to **integrate BMS**[5] into the SEEMPubS application is to have LinkSmart that communicates with an OPC[6] server, which can be a protocol bridge to get in front of different protocols of different BMSs.
The basic approach of communication between a middleware, such as LinkSmart and different protocols is to realize a special proxy for each protocol. Nevertheless, some communication technologies allow making protocols conversion, to simplify interface between heterogeneous systems, and OPC is one of these technologies.

To demonstrate that solutions work in each part considered above, a SEEMPubS prototype is used as frame of reference for the specification of large-scale pilots as well as to validate the SEEMPubS software architecture (see figure below).

[5] At Polito Main Campus and Cittadella Politecnica a DESIGO BMS already existed.
[6] OPC is an industry standard created with the collaboration of a number of leading worldwide automation hardware and software suppliers, working in cooperation with Microsoft, under the OPC Foundation organisation (http://www.opcfoundation.org/).

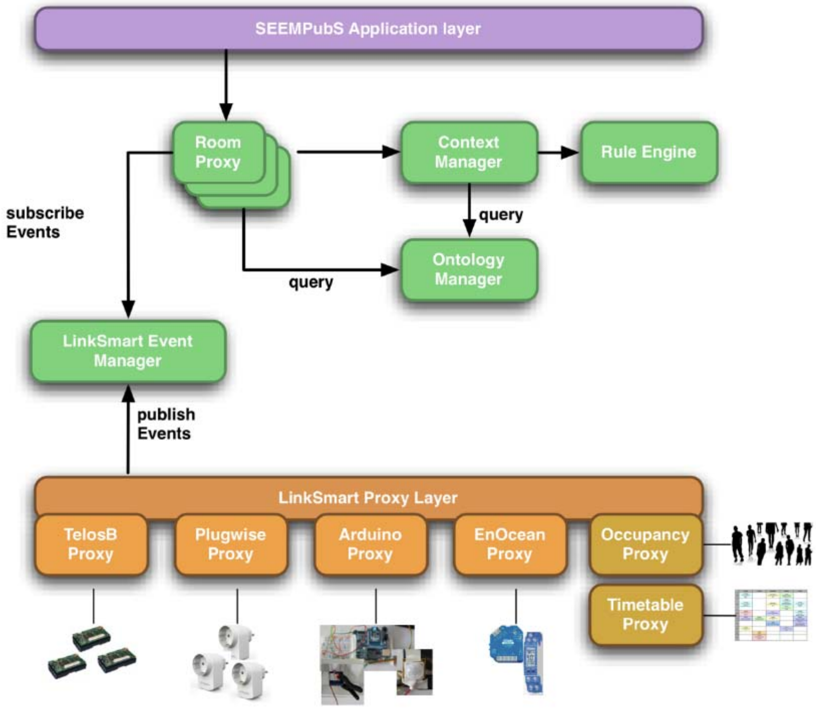


Fig. 10 – SEEMPubS software architecture.

3.6.5 The use of interoperability

In SEEMPubS, interoperability is used for both data communication: between devices and BMS thanks the LinkSmart middleware; and between software for energy simulations.

As shown in figure below, interoperability between the architectural model realized with Revit and energetic software (Daysim and Radiance for lighting analysis; Trnsys for thermal analysis) has been tested as detailed in D5.2 – *3D parametric model* and summarized in figure below.

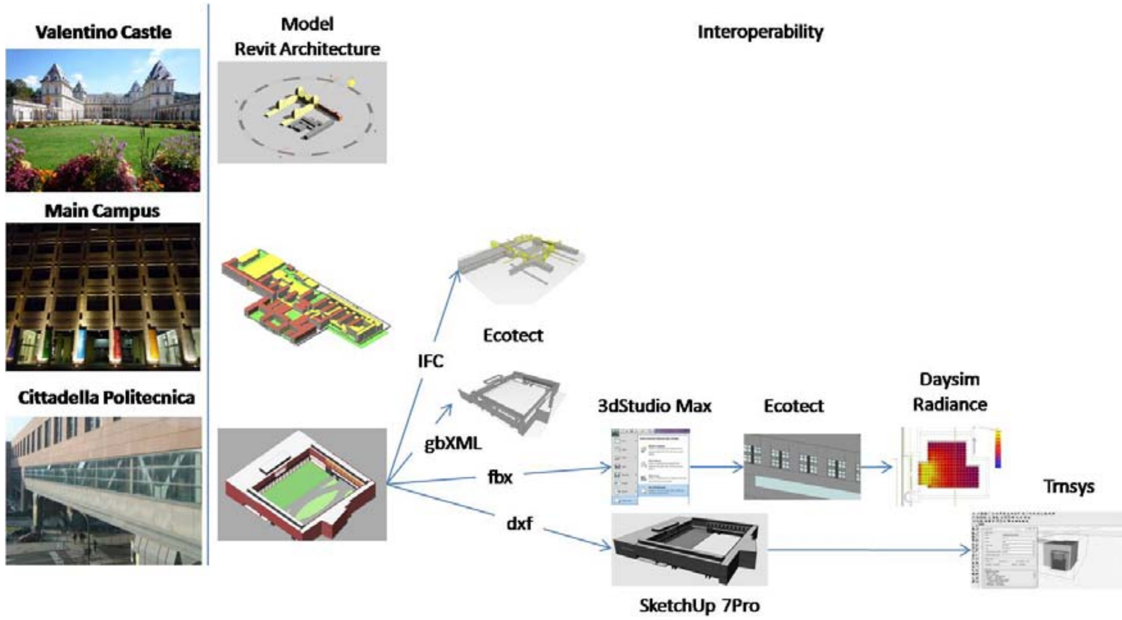


Fig. 11 – Conceptual map of data exchange between interoperable software.

3.6.6 Test plan

Last but not least, as a new platform has been defined and new applications are under development, a test plan regarding unit, integration and system testing has been detailed taking into account the iterative and incremental approach used in SEEMPubS (D4.1). This means that SEEMPubS should use automatic testing whenever possible. In addition "adequate" testing needs to be seen in the context of what is currently needed of the platform.

3.7 Define the cost/benefit ratio of the solution proposed

New HW and SW architectures have been designed (D2.1.1). The purpose of the SEEMPubS project is to present a modular and flexible architecture that can be integrated with the existing BMS system and adds new functionalities and a more accurate control and monitoring capabilities that a room's lighting and heating/cooling needs. Starting from the general architecture it's possible to create a sub set of this architecture to well fit a specific room's constrains (especially in historic buildings like the Valentino Castel).

Sensors are used to achieve the implementation of the projects control strategies for lightning, heating and cooling and also to adjust the LinkSmart middleware to fit the projects objectives.

The following table provides an overview of the different technologies that have been applied in the SEEMPubS project. For each technology a LinkSmart Proxy has been developed, which allows the seamless integration of each technology into the interoperable SEEMPubS system.

Type	*Manufacturer*	*Model*	*Comment*
Energy/Power	ST Microelectronics	ST Smartplug	Wall mounted electrical outlet Energy-Meter including switch.
	Plugwise	Circle Stealth	Circle is an energy-measuring plug that is put between a socket and the appliance plug. Stealth is for “inline” installation when a Circle is not suitable.
Temperature	Texas Instruments	CC2530	A mote equipped with a temperature sensor.
	Moog Crossbow	TelosB	A mote equipped with a temperature sensor.
	Thermokon	SR04 PST	Indoor temp.
	Thermokon	SR65	Outdoor temp.
	Thermokon	SR65 AKF	Fan coil temp.
Switch	Eltako	FSR61/8-24 UC FT4F-rw/an	Wall mounted switch with optionally separated control buttons (by radio).
	ST Microelectronics	ST Smartplug	Wall mounted electrical outlet Energy-Meter including switch.
	Plugwise	Circle Stealth	Circle and Stealth include switching capabilities.
Humidity	Moog Crossbow	TelosB	A mote equipped with a humidity sensor.
Light/Illuminance	Thermokon	SR-MDS Solar	Ceiling multi sensor designed for motion detection (passive IR) and ambient brightness.
	Moog Crossbow	TelosB	A mote equipped with a lighting sensor.
	Texas Instruments	CC2530	A mote equipped with a lighting sensor.
Motion Presence	Thermokon	SR-MDS Solar	Ceiling multi sensor designed for motion detection (passive IR) and ambient brightness.
Fan coil control	Thermokon	SRC-DO8	A control device for fan coil status.

Tab. 01 – The heterogeneous SEEMPubS Hardware Infrastructure.

The criteria used in SEEMPubS to evaluate the cost/benefit ratio is the Return On Investment (ROI) because of its versatility and simplicity. As known, the return on investment formula is:

$$\text{ROI} = \frac{(\text{Gain from Investment} - \text{Cost of Investment})}{\text{Cost of Investment}}$$

At the end of the project it will be possible to calculate the ROI because the cost of investment is known (see paragraph 3.3 on this deliverable) and the gain from investment could be calculated comparing results between test and reference rooms deriving from energy saving.

3.8 Verify the impact of the research on end-users

The goal of the SEEMPubS project is not only to optimize automated energy management strategies but also to address the people that are affected by such automated environments.
The ***Volere Scheme*** is used in this field (D3.1, paragraph 2.1) to ensure that all important aspects of requirements are carefully addressed and that the methods applied have proven their value in practical work.

Since the beginning (D3.1, paragraph 2.2) the main types of stakeholders have been identified in the studied processes inside the SEEMPubS project. They have been divided into:

- *Sedentary stakeholders*. Users within this category are employees characterized by spending most of their working hours, typically in the same room on a desk:
  - Administration employees, researchers and Ph.D. students
  - Managers and professors
  - Building (energy) managers
- *Nomad stakeholders*. Users within this category are employees or students characterized by spending most of their working/studying hours on different rooms, moving from time to time to a different one, and in general do not spend the whole day in Politecnico's premises:
  - Students
  - Cleaning/services staff
- *Occasional stakeholders*. Users within this category are typically visitors, which stay short periods inside Politecnico's premises.
  - Official visitors
  - Casual visitors

Within the SEEMPubS platform, thanks the ***Context Energy Framework*** (D3.1, 3.2, 3.3 and 4.6.1) it is possible:

- to provide meaningful information to end users via different media (web portal, mobile application, public ambient visualizations, etc.);
- to allow end users and applications to influence rules for actions depending on contexts (in addition to very simple rules working only on low-level sensor data).

A *community portal* and an *Android application* for smart phone and tablet are under development to guarantee an innovative communication of the data as detailed below.

3.8.1 Community Portal

The Community Portal (D3.1, 3.2, 3.3, 4.6.1 and 4.6.2) combines all kind of interfaces that provide possibilities for the users to interact with the SEEMPubS system. More specifically, the following requirements regarding the interaction with the system could be identified: what information to present; what to control; system behaviour; means of presentation.
Creating awareness is one of the means to achieve energy efficient buildings. The SEEMPubS project intends to use community portals and other ways of visualization depending on the users and also the building type. There are different kinds of users with different levels of influence on the system e.g. employees, visitors, energy manager. These can be divided into three categories:

1. *High-influence users*: these users have access and knowledge to operate and control the system, e.g. building manager, system manager, energy manager. They can be found in any kind of building.

2. *Medium- or low-influence users*: these users are often and regularly found in public spaces such as office buildings (employees) or campuses (students) and have access and control rights on some of the subsystems within the building.
3. *No-influence users*: these users are often visitors or customers which have none or very little access to the system.

The Community Portal is accessible through different user interfaces and conveys information through different output channels: Web Portal and Mobile Apps (smart phone and tablet).
The implemented web portal has three different access levels: student, employee and energy manager.
The first, *student level*, is open for anyone and does not require the user to log in to the web portal. At this level the user is allowed to see information such as air temperature, relative humidity, light levels, room capacity etc. Eventually the user will be able to see information about the class going on in the room e.g. Object programming with Professor Luca Singoalla. The users can use their smartphones to express their discomfort with the climate within the room using QR Code located into the room.
The second level, *employee level*, requires the user to log in to the web portal in order to see information about the user's own office. This information includes current and historical energy consumption, air temperature, relative humidity, light levels etc. These users can compare their own energy consumption daily, weekly and monthly, and will eventually be able to compare their own consumption with other offices in an anonymous way.
The third level, *energy manager*, is also required to log in to the web portal where he gets access to see information about every room in the campus. This user can also see the feedback provided by the students on eventual climate discomfort and try to resolve the issue.

Fig. 12 – The SEEMPubS Web Portal interface.

Mobile units such as smartphones and tablets are also natural usage platforms for interaction and visualization of data. For instance, temporary visitors can use their smartphones to provide feedback on the climate in classroom, or a building manager can receive alerts while on the move.
As an extension to the web portal, a mobile application has been developed which allows the users within a classroom to express their opinion/vote on e.g. the room temperature or air quality. The result of the voting can then be accessed by the energy manager or building manager.

All of the implementations of the community portal reside on top of the SEEMPubS Middleware and especially on the Context Framework. Context information is used to present to the user meaningful visualizations instead of e.g. raw sensor data. The community portal contains the three following main components:

- The *SEEMPubS Context Framework Proxy* (SCFP) handles all communication with the SEEMPubS Context Framework nodes distributed over the network and it provides a stable interface for the web portal to protect it from the occasionally connected nature of the SEEMPubS Context Framework nodes.
- The *Web Service Interface* enables the communication to and from the SCFP as well as the SEEMPubS Context Framework. This makes it possible to implement the SCFP and the Context Framework nodes using different software platforms.
- The *end-user applications* include all application and presentation logic with interfaces for web users, smartphone applications, and ambient visualizations. Depending on the application they have their own database adapted to the applications requirements on data cashing, user preferences etc.

3.8.2 Android application

In order to increase the building awareness and to enhance any possible maintenance works, an Android application has been developed in order to provide real time building information related to a specific room exploiting both **Augmented and Virtual reality** (D5.2).

The rooms have been modeled in 3D providing a detailed description considering not only the structural information (e.g. room's dimension, HVAC system, lighting system, etc.) but also the deployed motes. It is worth noting that this information comes from commercial heterogeneous networks devices via SEEMPubS proxies and from third party software (e.g. ARCHIBUS) as well. Therefore a specific proxy has been developed to interface the proprietary software into the SEEMPubS Framework.

The purpose of this solution is to overcome the limits related to the 2D visualization, presenting a 3D environment populated with real time building data as shown in figure below.

Fig. 13 – Visualization of architectural and system using a BIM model visualized into a tablet.

Further applications are under testing integrating QR Code and Virtual and Augmented Reality and will be available at the end of the project.

4 Equipments and data for energy saving at the campus of Politecnico

Starting from the data integration in the SEEMPubS project as shown in the figure below, the aim of this second section of the deliverable are to provide an overview of the data that are under processing in the project, and to detail type, quantity and cost of the equipment that have been selected for each building.
Based on these data, preliminary considerations on cost/benefit ratio are possible at this stage of the project, as shown in the graphs at the end of chapter.

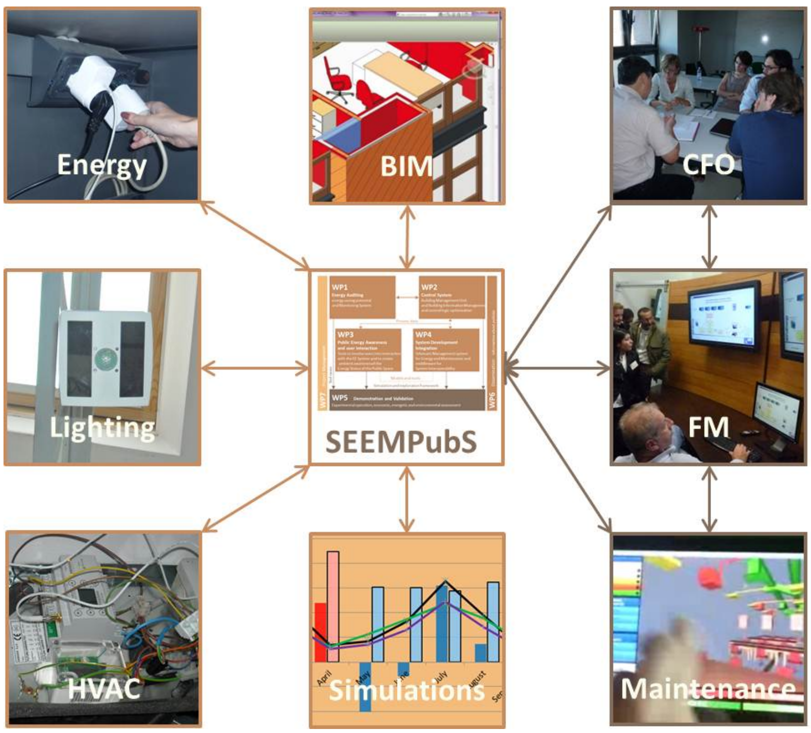


Fig. 14 – The data integration in the SEEMPubS project.

4.1 Data: type and processing

As described in D5.1, the data recorded from the hardware devices and processed through the SEEMPubS platform are divided taking separately into account the data related:

- to indoor comfort conditions;
- to energy consumptions concerning separately the thermal energy and the electric energy; and
- to the use of spaces and building services.

In each case the following elements have been considered:

- type of sensor used to collect environmental data,

- sensor’s number and position,
- measured quantity,
- timing of data communication,
- corresponding communication protocol,
- basic data processing,
- basic data representation.

All quantities (air temperature, illuminance, energy consumptions, etc.) and information (occupancy, light status, HVAC status, etc.) have to be monitored and outlined together with basic hypothesis of data processing, and the systems performance must be correlated to boundary conditions (environmental condition, control strategies, systems operations, users’ behaviour, etc.) in order to provide synthetic and meaningful performance metrics to facilitate the decision-making process towards more effective interventions for energy saving and comfort optimization.

4.2 Equipments: type and quantity

As preliminary described in several deliverables of WP1 and WP2, all rooms selected in the campus of Polito (D1.1 - *Building selection: criteria, methodologies, and description of the selected buildings*) are unified in their aim to save energy by making smart use of ICT in the BAS (D2.1.1, D2.1.2, D2.4.1 and D2.4.2). One of the main characteristics of the SEEMPubS project (how data has to be gathered and presented to users and how often frequent it is updated) is that it is necessary to integrate a wide variety of pre-existing systems in the real buildings which obviously couldn’t be replaced for this project (D2.1.1 - *Initial Specification of the intelligent control system* – paragraph 2), and that have been integrated with new ones as described in D2.1.2 (*Updated Specification of the Intelligent Control System* – paragraph 3) The final specification on sensors optimization (typology choice, solutions and number of sensors) will be detailed into D1.4 (*Specification on sensors optimization: typology choice, solutions and number of sensors*) at the end of the project, but at present (at the beginning of the WP5 - *Demonstrator*) we are able to describe the solutions adopted that will be tested (and eventually updated) during the last year of the project. We are sure that only minimal integration could be necessary depending on the comparison between expected and real results.

As described in D5.1 and anticipated before:

- Wireless control architectures are mainly used in the Valentino Castle due to the architectural constraints.
- Wired control architecture were mainly adopted in the modern parts of the Politecnico’s Campus where more structural interventions are facilitated by the buildings and systems features and by the presence of pre-existing building management systems. Even so, some wireless devices were also used, for instance to monitor the electric energy consumptions of lights or other equipments (PC, printers, etc.) or to collect more detailed data of indoor air temperature distribution by distributing a greater number of sensors within the space.

Before to continue, it is essential to underline that tables below synthetize equipments and commissioning (without VAT) of the SEEMPubS project divided for each Test/Reference room selected and must be considered in addition to existent equipments that are not evaluable, and the sensors provided by the partners that can’t be evaluable because under development and not commercialized already.

4.2.1 Valentino Castle

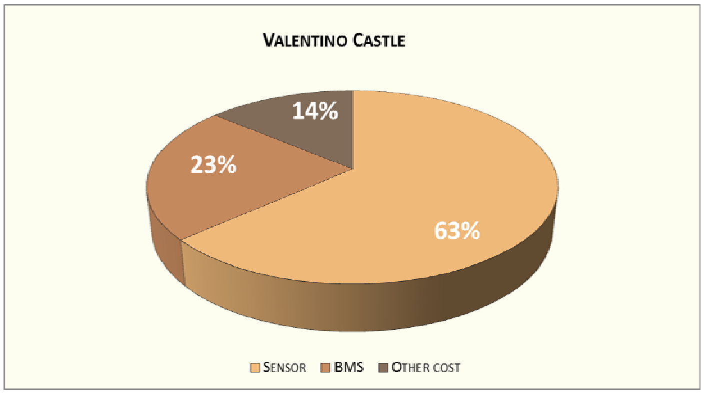
Valentino Castle: Student offices			
Rooms ID: TO_CAS01/XP02/G002 , TO_CAS01/XP02/G005			
Abbreviation	Description	Quantity	Unit Price
SRC-D08 Type2	The SRC-DO8 Fan Coil is a radio controlled fan coil controller. It can be used for 2-pipe and 4-pipe systems and can control up to 3 fan stages. For efficient energy saving a time switch is integrated. Moreover, it is possible to make use of the function “energy stop” by seamlessly connecting wireless window contacts SRW01 and wireless window handles SRG01, i.e. if the window is opened the controller switches off the heating and cooling function. Furthermore, the SRC-DO8 Fan Coil has 3 to 5 outputs with a simple switching function which can for example be used as a signaling contact or for control of lighting, blinds or shutters. Parameterization of the individual functions is made via an easy to handle configuration menu.	2	€ 578,00
SR04 PST	Battery-and wireless room sensor for temperature and ventilation control in connection with the receiving interfaces SRC-x and higher-graded control systems. Radio telegrams according to EnOcean standard. Depending on the device with integrated temperature sensor, rotary knob for set point adjustment, rotary knob for fan speed adjustment, presence key. With integrated solar energy storage for maintenace-free operation.	2	€ 218,00
SR65 AKF	Battery -and wireless air-duct sensor for temperature control in connection with the receiving interfaces SRC-x and higher-graded control systems. Detection of measuring values via the higher-graded control system. Transmission to receiver by means of radio telegrams according to EnOcean standard. With integrated temperature sensor and solar energy storage for maintenance-free operation.	2	€ 135,99
SR-MDS Solar	The battery- and wireless ceiling multi sensor is designed for movement detection in room or office spaces. In addition, the sensor detects the ambient brightness in rooms. Radio telegrams according to EnOcean standard. With integrated solar energy torage for maintenace-free operation.	1	€ 241,49
FT4F-rw/an	Wireless flat pushbuttons, 80x80mm external dimensions, internal frame dimensions 63x63mm, 15mm high. Generates the power for wireless telegrams itself when the button is pressed, therefore there is no connecting wire and no standby loss.	1	€ 48,80
BSC-BAP-TX	LAN - Access Point for control of “embedded intelligenge” products and other EnOcean compatible devices. Integration of up to 128 actuators and an optional number of transmitters that are compatible with EnOcean wireless technology per BAP.	2	€ 789,00
PLUGWISE	Home Basic type F. Set 1 Circle+, 8 Circles, 1 Stick, 1 Source Home Software	1	€ 310,88
LS14250	Battery	4	€ 10,00
NETBOOK	ASUS netbook atom dual core N570 1GB W7 320GB starter	2	€ 211,57
	TOTAL COST		€ 4.506,29

Valentino Castle: DITER offices			
Rooms ID: TO_CAS04/XP03/L005, TO_CAS04/XP03/L006			
Abbreviation	Description	Quantity	Unit Price
SRC-D08 Type2	The SRC-DO8 Fan Coil is a radio controlled fan coil controller. It can be used for 2-pipe and 4-pipe systems and can control up to 3 fan stages. For efficient energy saving a time switch is integrated. Moreover, it is possible to make use of the function “energy stop” by seamlessly connecting wireless window contacts SRW01 and wireless window handles SRG01, i.e. if the window is opened the controller switches off the heating and cooling function. Furthermore, the SRC-DO8 Fan Coil has 3 to 5 outputs with a simple switching function which can for example be used as a signaling contact or for control of lighting, blinds or shutters. Parameterization of the individual functions is made via an easy to handle configuration menu.	2	€ 578,00
SR04 PST	Battery-and wireless room sensor for temperature and ventilation control in connection with the receiving interfaces SRC-x and higher-graded control systems. Radio telegrams according to EnOcean standard. Depending on the device with integrated temperature sensor, rotary knob for set point adjustment, rotary knob for fan speed adjustment, presence key. With integrated solar energy storage for maintenace-free operation.	2	€ 218,00
SR65 AKF	Battery -and wireless air-duct sensor for temperature control in connection with the receiving interfaces SRC-x and higher-graded control systems. Detection of measuring values via the higher-graded control system. Transmission to receiver by means of radio telegrams according to EnOcean standard. With integrated temperature sensor and solar energy storage for maintenance-free operation.	2	€ 135,99
SR-MDS Solar	The battery- and wireless ceiling multi sensor is designed for movement detection in room or office spaces. In addition, the sensor detects the ambient brightness in rooms. Radio telegrams according to EnOcean standard. With integrated solar energy torage for maintenace-free operation.	2	€ 241,49
SR65	The module SR65 DI has one digital input for dry contacts by which the switch status can be evaluated. The status of the contact (opened/closed) is transmitted by radio signal to a receiver (SRCx), which provides this information to a controller for data logging.	1	€ 128,17
FT4F-rw/an	Wireless flat pushbuttons, 80x80mm external dimensions, internal frame dimensions 63x63mm, 15mm high. Generates the power for wireless telegrams itself when the button is pressed, therefore there is no connecting wire and no standby loss.	1	€ 48,80
FKR12/1-10V	RS485 bus dimming actuator Constant light controller FKR12/1-10V for electronic ballast units 1-10V	2	€ 121,00
BSC-BAP-TX	LAN - Access Point for control of “embedded intelligenge” products and other EnOcean compatible devices. Integration of up to 128 actuators and an optional number of transmitters that are compatible with EnOcean wireless technology per BAP.	1	€ 789,00
LS14250	Battery	5	€ 10,00
NETBOOK	ASUS netbook atom dual core N570 1GB W7 320GB starter	1	€ 211,57
	TOTAL COST		€ 3.816,50

COMMISSIONING SERVICES		
Abbreviation	Description	Unit Price
Commissioning	System start-up and operation test	€ 3.000,00

MANPOWER COST		
Place	Description	Cost
DITER	Plant predisposition and equipment installation	€ 930,00
STUDENT o.	Plant predisposition and equipment installation	€ 880,00
	TOTAL COST	€ 1.810,00

Valentino Castle	
Description	Cost
Sensor	€ 8.322,79
BMS	€ 3.000,00
Other cost	€ 1.810,00



4.2.2 Main Campus and Cittadella Politecnica

Main Campus: ADMINISTRATIVE offices			
Rooms ID: TO_CEN03/XP02/I007, TO_CEN03/XP02/I005			
Abbreviation	Description	Quantity	Unit Price
BPZ:PXC64-U	Freely programmable modular automation stations for HVAC and building services. Native BACnet automation station with communication via BACnet over Ethernet / IP, LonTalk, or PTP. BTL label (BACnet communications passed the BTL test). High performance and reliable operation. Comprehensive management and system functions (alarm management, time scheduling, trends, remote management, access protection etc.). An Integrated Web server supports generic or graphic Web operation as well as transmission of alarms by e-mail or SMS. P-bus for connection of external TX-I/O or PTM I/O modules with any data point mix. Integration platform for subsystems and 3rd party systems. For stand-alone applications or for use within a device or system network. Supports the following methods of operation: – QAX... room units – Local or network-compatible operator units – PX-WEB (operation via Web browser, touch panel or PDA)	1	
BPZ:PXA30-N	Extension modules for BACnet on Ethernet/IP operation for integration into modular PXC...-U automation stations	1	
BPZ:TXB1.PBUS	Interface between the automation station PXC64-U/PXC128-U and the bus of the TX-I/O modules - Integrated DC 24 V, 1.2 A to supply power to TX-I/O modules and field devices - USB port for tool connection	1	
BPZ:TXA1.K12	One set of address keys, numbers 1-12 with 1 reset key.	1	
BPZ:TXM1.8U	8 Inputs/outputs signaled with green LED, with local operation as per ISO 16484 with LCD signal display (same functionality as TXM1.8U-ML, but with current input/output). 8 universal I/O points, individually configurable as: DI: Message signal, message impulse (with storage function) or counter impulse (25 Hertz) AI: Temperature sensor, DC 0..10V, or 4..20mA AO: DC 0..10V, 4..20mA (for 4 I/O points)	3	
BPZ:TXM1.6R	6 outputs signaled with green LED, without local operation. 6 DO (relay switch), individually configurable as: Continuous or impulse contact Single-stage or multi-stage Three-point positioning output with internal stroke model Hardware bolting device is by means of external wiring the two-way contacts.	3	
BPZ:QAX30.1	Room unit with sensor and PPS2 interface	1	
BPZ:QAX33.1	Room unit with sensor, setpoint and operating mode selector, fan speed selection, and PPS2 interface	1	
BPZ:QAP22	Cable temperature sensor PVC 2 m, LG-Ni1000	2	
BPZ:ARG22.2	Aluminium bar attachment for QAP	2	
PARTIAL COST			€ 6.577,00
Thermokon MSD	The ceiling multi-sensor model MDS is designed for occupancy detection in room or office spaces. In addition, the sensor detects the ambient brightness in rooms. The measured quantity can be used for a fixed light control by means of downstreamed dimming resistances. Optionally, the device is also available with an additional sensor for temperature detection.	3	€ 143,78
NETBOOK	ASUS netbook atom dual core N570 1GB W7 320GB starter	1	€ 211,57
	TOTAL COST		€ 7.219,91

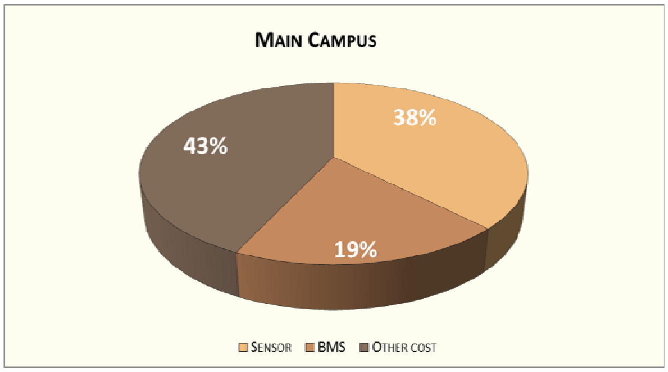
Cittadella Politecnica: DAUIN Labs			
Rooms ID: TO_CIT11/XP02/100, TO_CIT11/XP02/101			
Abbreviation	Description	Quantity	Unit Price
BPZ:TXB1.PBUS	Interface between the automation station PXC64-U/PXC128-U and the bus of the TX-I/O modules - Integrated DC 24 V, 1.2 A to supply power to TX-I/O modules and field devices - USB port for tool connection	1	
BPZ:TXM1.8U	8 Inputs/outputs signaled with green LED, with local operation as per ISO 16484 with LCD signal display (same functionality as TXM1.8U-ML, but with current input/output). 8 universal I/O points, individually configurable as: DI: Message signal, message impulse (with storage function) or counter impulse (25 Hertz) AI: Temperature sensor, DC 0..10V, or 4..20mA AO: DC 0..10V, 4..20mA (for 4 I/O points)	5	
BPZ:TXS1.EF10	Transfer of DC 24 V for the supply of TX-I/O modules and field devices Fresh provision of AC / DC 12 24 V for field device supply Transfer of the bus signal	1	
BPZ:TXM1.6R	6 outputs signaled with green LED, without local operation. 6 DO (relay switch), individually configurable as: Continuous or impulse contact Single-stage or multi-stage Three-point positioning output with internal stroke model Hardware bolting device is by means of external wiring the two-way contacts.	3	
BPZ:QAX30.1	Room unit with sensor and PPS2 interface	1	
BPZ:QAX33.1	Room unit with sensor, setpoint and operating mode selector, fan speed selection, and PPS2 interface	1	
BPZ:QAP22	Cable temperature sensor PVC 2 m, LG-Ni1000	2	
BPZ:ARG22.2	Aluminium bar attachment for QAP	2	
PARTIAL COST			€ 4.718,00
Thermokon MSD	The ceiling multi-sensor model MDS is designed for occupancy detection in room or office spaces. In addition, the sensor detects the ambient brightness in rooms. The measured quantity can be used for a fixed light control by means of downstreamed dimming resistances. Optionally, the device is also available with an additional sensor for temperature detection.	4	€ 143,78
NETBOOK	ASUS netbook atom dual core N570 1GB W7 320GB starter	1	€ 211,57
	TOTAL COST		€ 5.504,69

Cittadella Politecnica: DAUIN offices			
Rooms ID: TO_CIT11/XP04/157, TO_CIT11/XP04/158			
Abbreviation	Description	Quantity	Unit Price
BPZ:TXM1.8U	8 Inputs/outputs signaled with green LED, with local operation as per ISO 16484 with LCD signal display (same functionality as TXM1.8U-ML, but with current input/output). 8 universal I/O points, individually configurable as: DI: Message signal, message impulse (with storage function) or counter impulse (25 Hertz) AI: Temperature sensor, DC 0..10V, or 4..20mA AO: DC 0..10V, 4..20mA (for 4 I/O points)	5	
BPZ:TXA1.K24	One set of address keys, numbers 1-24 with 2 reset keys.	1	
BPZ:TXS1.12EF10	Power supply for max. 130...160 points	1	
BPZ:TXM1.6R	6 outputs signaled with green LED, without local operation. 6 DO (relay switch), individually configurable as: Continuous or impulse contact Single-stage or multi-stage Three-point positioning output with internal stroke model Hardware bolting device is by means of external wiring the two-way contacts.	3	
BPZ:QAX30.1	Room unit with sensor and PPS2 interface	1	
BPZ:QAX33.1	Room unit with sensor, setpoint and operating mode selector, fan speed selection, and PPS2 interface	1	
BPZ:QAP22	Cable temperature sensor PVC 2 m, LG-Ni1000	2	
BPZ:ARG22.2	Aluminium bar attachment for QAP	2	
PARTIAL COST			€ 4.534,00
Thermokon MSD	The ceiling multi-sensor model MDS is designed for occupancy detection in room or office spaces. In addition, the sensor detects the ambient brightness in rooms. The measured quantity can be used for a fixed light control by means of downstreamed dimming resistances. Optionally, the device is also available with an additional sensor for temperature detection.	2	€ 143,78
NETBOOK	ASUS netbook atom dual core N570 1GB W7 320GB starter	1	€ 211,57
	TOTAL COST		€ 5.033,13

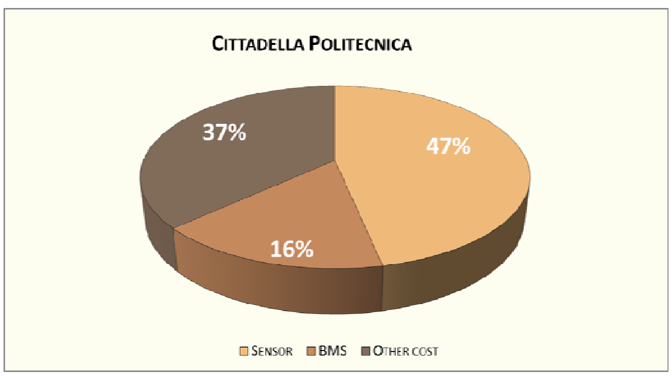
SIEMENS GATEWAY INTERFACE RS232/MODBUS - HYDRA			
Abbreviation	Description	Quantity	Unit Price
BPZ:PXC00-U	Automation station for the Integration via PXA30-K11 or PXA30-RS, without a P-Bus interface and therefore without a connection for DESIGO I/O modules.	1	
BPZ:PXA30-RS2	Integration of third-party equipment and systems into the DESIGO building automation and control system at the automation level - Plugs into the PXC00-U modular system controller	1	
BPZ:PXA30-N	Extension modules for BACnet on Ethernet/IP operation for integration into modular PXC...-U automation stations	1	
BPZ:LICENSE	Desigo license	1	
BPZ:Commissioning	Performance: commissioning	1	
	TOTAL COST		€ 11.157,00

MANPOWER COST		
Place	Description	Cost
DAUIN	Plant predisposition and equipment installation	€ 6.660,00
DAUIN	Testing and commissioning	€ 580,00
ADMINISTRATIVE o.	Plant predisposition and equipment installation	€ 5.780,00
ADMINISTRATIVE o.	Testing and commissioning	€ 1.420,00
DAUIN+ADM.	Connections and variants	€ 1.440,00
DAUIN+ADM.	Variants test	€ 680,00
	TOTAL COST	€ 16.560,00

	Main Campus	
	Description	Cost
	Sensor	€ 7.219,91
	BMS	€ 3.719,00
	Other cost	€ 8.260,00



	Cittadella Politecnica	
	Description	Cost
	Sensor	€ 10.537,82
	BMS	€ 3.719,00
	Other cost	€ 8.300,00



4.3 Equipments: costs/benefit ratio

Provided that the cost detailed in the tables and graphs above and summarized in the diagram below are specific for the SEEMPubS Test and Reference rooms and must be taken by way of example because it could be different in other case studies.

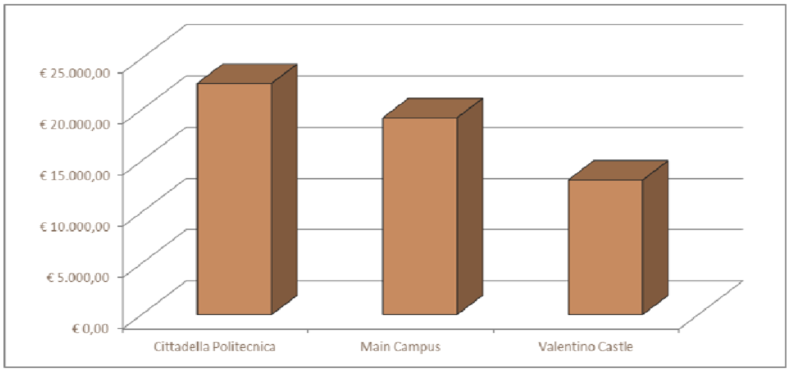


Fig. 15 – SEEMPubS total Cost for Equipments and Installation.

Preliminary, general considerations are possible about the use of **wireless technologies** in automation because offer several benefits:

- reduce the need for cabling;
- temporary building automation installations are easier to implement;
- allow placing sensors where cabling is not appropriate for aesthetic, conservatory or safety reasons;
- enable better indoor conditions and energy savings through improved sensor location;
- are easily reconfigurable and extendible.

In particular, thanks the reduction of need for cabling, the savings can be significant as shown in the graph below. This partly forces us to re-examine the graph proposed at the beginning of the project (see Fig. 03), where we assumed that at the Valentino Castle (historic building) we would have higher costs for sensors installation. Of course these data concerning the Test and Reference rooms selected at the beginning of the SEEMPubS project as described in D1.1. In the future it will be possible to connect other rooms, on the same device, reducing the cost per m².

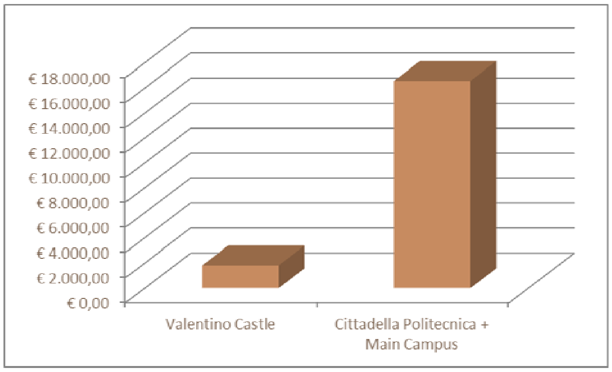


Fig. 16 – SEEMPubS total Cost for Installation.

5 The real use of the SEEMPubS project at the campus of Politecnico

The aim of this last section of the deliverable is to demonstrate as the BAS developed in SEEMPubS can be used to optimize building operation at the campus of Politecnico by managing and controlling various devices in the building. The main functions of the BAS are linked with:

- Automatic switching on and off
- Optimization of plant operation and services
- Monitoring of plant status and environmental conditions
- Provision of energy management information
- Management of electrical load
- Remote monitoring and control.

5.1 The Energy Management Strategies

Building operation and maintenance aims at maintaining the property's value and providing a comfortable indoor environment for building users, based on the elements synthetized in figure below.

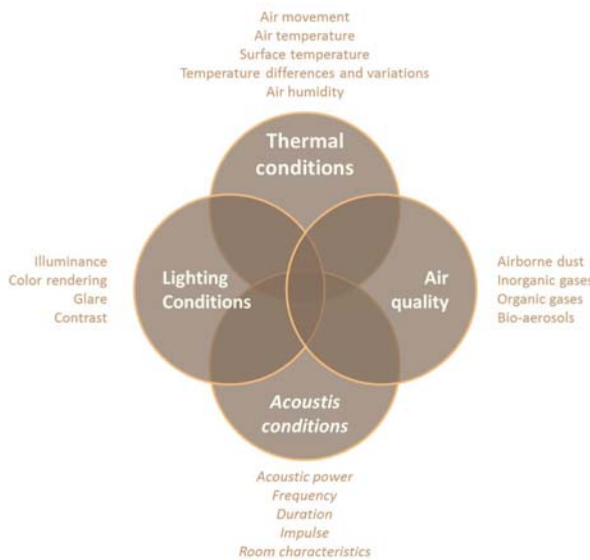


Fig. 17 – Indoor environmental quality factors.

There have been a number of developments in building operation and maintenance during the last years. One of the most significant changes is the increasing importance of environmental issues. As known, buildings are a large source of carbon emissions and therefore have a central role in preventing the global climate change. Several countries have tightened building codes and introduced incentives to reduce carbon emissions in buildings and SEEMPubS fits perfectly in this context. This has also changed how buildings are maintained. Another clear change has occurred in the relationships between the actors of building operation and maintenance. In the past it was common that building owners, users and service providers belonged to the same organisation, where as nowadays there is a tendency of separation where the actors are a part of different legal entities. The drivers for this change have been outsourcing and real estate's "sale-and lease-back" model. This change has highlighted the importance of contracts, service descriptions, service level agreements, performance measurements and so on.

On this context, the characteristics of the solution that accumulate prior knowledge in the SEEMPubS project linked with the Polito's FM project are:

- Set up of an integrated system that use correctly the interoperability to exchange data between applications in order to optimize the whole process;
- Presentation of the performance information in a format that can be used by the whole building operation and maintenance organisation in both building performance monitoring and control;
- Presentation of the information in a format that can be used by the end users to improve their awareness in the energy consumption.

The approach used in the SEEMPubS project that could be used for the Energy Management Strategy at Polito is shown in the figure below and can be split in two essential parts: **Long-term energy management** concentrates on energy saving investments whereas **short-term activities** focus on energy consumption monitoring and optimization of building operation. Energy performance measurement is an essential part of short-term energy management and is a useful method when determining energy consumption levels, comparing energy usage with design intent or when making comparisons with other buildings, or assessing opportunities for improvements or evaluating the success of energy efficiency actions.

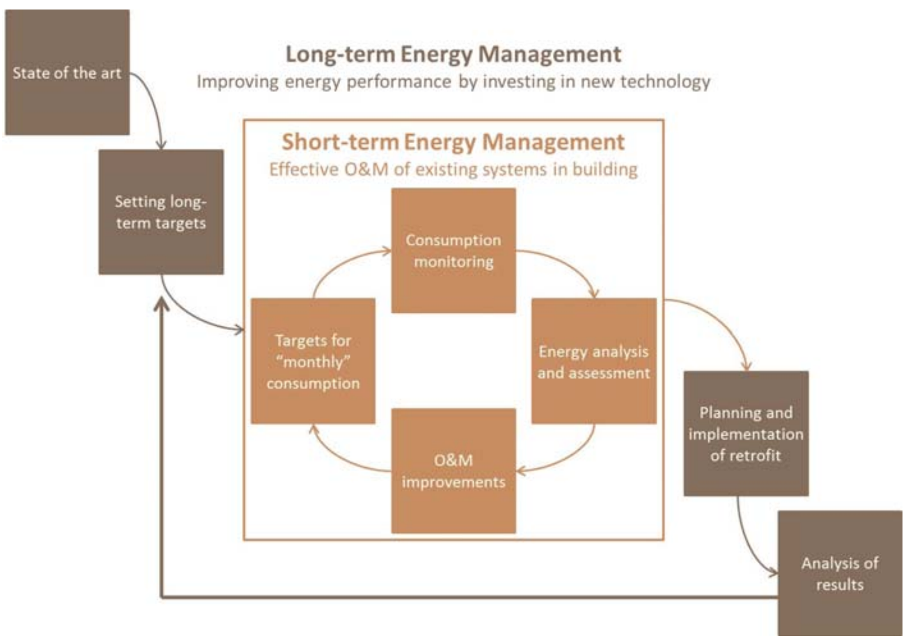


Fig. 18 – The Energy management strategies approach used in the SEEMPubS project.

5.2 The Living Lab

Starting from the paragraph before, using a dedicated Living Lab (available thanks the WiFi4Energy[7] project) at the end of the SEEMPubS project the system at Polito could be capable of:

- Visualizing building performance from energy, indoor conditions (lighting, humidity and CO2) and HVAC system perspectives;
- Displaying the performance metrics in a manner that is easy and intuitive to understand also for non-technical users (using virtual and augmented reality in addition to traditional graphs and tables);
- Providing high-level performance reports which enable the overall building performance to be assessed at a glance;
- Providing information that can be utilized by the whole building operation and maintenance organisation in both building performance monitoring and performance control.

In order to finish the process it is necessary to complete each step of the SEEMPubS project as described in the figure below.

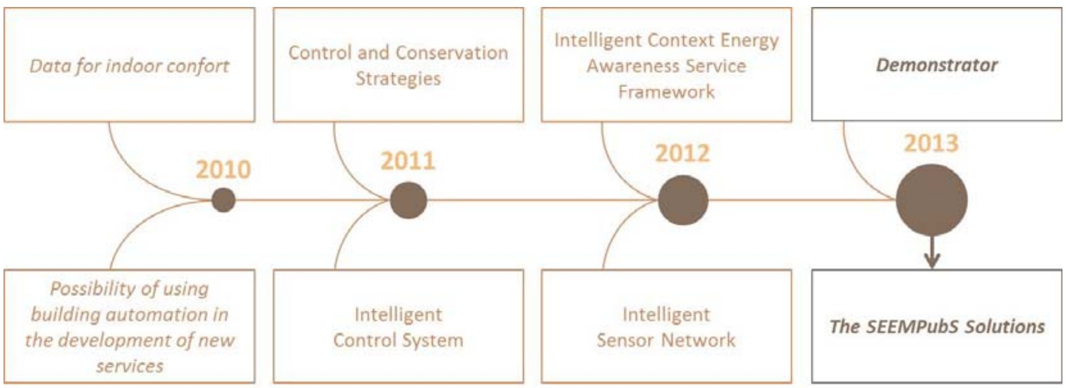


Fig. 19 – The main steps of the SEEMPubS project that have to be completed for its daily use of the Living Lab also after the end of the project.

[7] http://www.wifi4energy.polito.it/

6 Conclusion

Several lessons have been learnt from the SEEMPubS activities summarized in this document:

- Today's building automation systems have limited capabilities to manage and visualize large amounts of data. **Interoperability** is the key word to solve this problem and a middleware like LinkSmart is essential as basis for the BMS.
- The evolution of BMS is following the development of information technology and industrial automation and in the future, building processes and systems will become more complex as we reach for higher levels of energy efficiency. The **BIM** methodology should help linking different type of information in the same data base.
- The **wireless technologies** should be used to reduce cost of installation not only into historical buildings.
- **Virtual and augmented reality** and **QR Code** should be used together to optimize the data communication in addition to the Web Portal to improve the users' awareness on energy saving.