EcoShopping - Energy efficient & Cost competitive retrofitting solutions for Shopping buildings

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Deliverable 5.1

System requirements, specifications and architecture

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Lead contractor............................. AIT

Authors:

Sergio Leal .... AIT

Andre Oliveira .... ISA

Sven Fischer................................ FHG

Emil Loncar.................................. NOVA

Jon Martinez .... SOL

Jose Manuel Garcia...................... ANC

Emil Lezak .... IZNAB

Dissemination level		
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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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<tr><td>Description of the related task and the deliverable in the DoW</td><td colspan="8">(1) System requirements identification and description which will facilitate the use-cases defined in Task2.2.Therefore the requirements, both functional and non-functional will be formalized and prioritized for theimplementation within the timeframe and scope of the EcoShopping project based on the user needs, state ofthe art and market. AIT will lead this subtask working together with SOL, ANC and IZNAB.
(2) System specification identification and description in which existing components that can be readily includedinto the EcoShopping framework will be identified. Interfaces, functional requirements such as expected inputsand outputs, type and amount of sensors necessary, requirements towards the sensor network, etc, as wellas the non-functional requirements (for example, max expected computation time, data security and privacy)stemming from the intended usage of the service will also be defined and described. NOVA, FHG and ISA willprovide rich information and dedicate in this task.
(3) System architecture that will enable effective deployment of the project services. For example, this task willdefine how data will be acquired, stored and accessed as well as how communication between different unitswill take place, the structure and connectivity between units etc. AIT, with the global understanding of the systemrequirement, will lead this subtask with the support of other partners.The output of this task should be a design that can also serve other commercial buildings; the system shouldhave a better portability and compatibility.</td></tr>
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1. PUBLISHABLE EXECUTIVE SUMMARY

This deliverable defines the very basis of the EcoShopping Intelligent Automation Unit(IAU) including the system requirements, the system specification and the system architecture.
The requirement specification includes a listing of standards which should be considered when developing the IAU. Furthermore, concepts of the data model, communication and hardware systemsrelevant for EcoShopping are described.
In addition, this document describes several modules of the IAU which have to be considered when developing the EcoShopping project.

The target group are the system developers. This document supports their implementation and development work by defining the system requirements, specification and architecture.

2. INTRODUCTION

2.1 Purpose and target group

This document aims to define the system requirements, specification and architecture ofthe Intelligent Automation Unit (IAU) Platform together with a low cost novel monitoring system which is a combination of a distributed fixed sensor network and an autonomous mobile Robot. The integration of the mobile robot, which collects environment data and offers service to visitors, not only brings an improved user oriented monitoring, but also enhances the building security with the integrated acoustic event detection system. Together with the collected data from the sensor network, an instant representation of the building status is provided to the IAU, which then evaluatesmultiple scenarios, selecting the best strategy that fulfils the predefined energy saving goals with the minimum cost/impact. A Thermal Dynamics Modeling, calibrated with monitoring data, will be used in the optimization process performed by the IAU. The system performs an optimization calculation and executes the corresponding control, the result is that, the system will exploit the renewable energy and the inertia of the building which serves as a large thermal storage as much as possible, reduce the cost by load shifting, switch on the heating or cooling system and lighting more accurately in terms of time and temperature within an acceptable range (e.g. before the commercial building opens, the HVAC starts up to adjust the comfort, when the tariff is lower, the system may also start heating or cooling). The partial load behavior of the HVAC existing equipment will be investigated in detail and integrated into the IAU. The dependence of the HVAC equipment on variables such as outdoor temperature will be monitored and taken as additional data.

The target group are the system developers. Thisdocument supports their implementation and development work by defining the system requirements, specification and architecture.

2.2 Contributions of partners

Project partner AIT brings extensive knowledge in building model and simulation alongside with system requirements, specification and architecture definition. AIT had the leading role in the development of this document, contribution for the entire document.
Project partner ISA provide a well-founded knowledge and experience in energy efficiency, and multi-utility remote metering , which comprises sensors, meters, and anumber of flagship devices capable of remotely sensing parameters such as water, gas, and electricity consumption,air quality, people’s presence, among other features. ISA was one of the main contributors for this document, describing everything related to the fixed sensor networks.
Project partnerFhG provide extensive knowledge in the field of acoustic sound pick technologies, e.g. concerning noise reduction and acoustic source localization and general signal enhancement and human increase SoA by development and publication of new algorithms that are adapted to the specific problems in EcoShopping and EeB in general.FhG was one of the main contributors for this document, describing everything related to the acoustic sensor networks and mobile robot.
Project partner NOVAMINA is specialized in design and implementation of components. Optimized, energy-efficient and networked sensing systems were realized in several projects including audio and building automation applications. Therefore, there is a solid S&T base of knowledge and experience in data computing and control.NOVAMINA was one of the main contributors for this document, describing everything related to the control system.

Project partner Solinteloverall experience involves advanced simulation processes, monitoring stages fromenergy cycles and building retrofitting analysis. As such within this document Solintel contributed mainly with the definition of the non-functional requirements.

Project partner ANCODARQ is specialized in construction and retrofitting.As such within this document ANCODARQ contributed mainly with the definition of the user characteristics.

Project partner IZNAB as a consultancy specialist, namely in innovative materialdevelopment, energy efficiency and life-cycle analysis apart from life- cycle cost models supported this document mainly regarding the system constraints, assumptions and dependencies.

2.3 Baseline

The state of the art regarding the commercial systemstechnologies,are BACnet[1], LonWorks[2], and KNX[3]. Particularly, for building control, current operation of HVAC and commercial lighting systems are based onschedules, either occupancy or time dependent [6][7][8]. Theforecast and control accuracy is expected to be enhanced byimplementing an advanced control model such as Stochastic Model Predictive Control(SMPC) compare the widely use Rule-Based Control (RBC) andDeterministic MPC (DMPC).

Related other (EU) projects:

In the “Sounds for Energy Control of Buildings” (S4ECoB) project the primary goal is the establishment of more energy-efficient buildings through the optimization of existing BMS.

The “Experimenting Acoustics in Real environment using Innovative Test-beds” (EAR-IT) project aims to develop acoustic mass flows maps which provide awareness of the flows of masses.

The ”Calculating Optimizations and Forecasts For Energy Efficiency/Simulationsgestützte Entwicklung eines numerischen Systems zur Energie-Optimierung” COFFEE/SENSE-O project uses the ISO 50001 process to support optimisation measures in buildings. The project aims to build on the existing approach with a comparative thermal simulation and subsequent vulnerability analysis.

The members of S4ECoB, EAR-IT, EcoShopping and COFFEE/SENSE-O projects were invited to join to the discussion among others Intelligent Automation Unit requirements, specification and architecture. In the discussion the participants decided to keep in touch and to consider information exchange at least related to informationmodelling.

2.4 Relations to other activities

The work described here is mainly limited to WP5 (Intelligent Automation Unit). Although intermediate inputs from tasks Task2.3 have been utilised, namely regarding the user needs, services and scenarios (D2.4).

This intermediate result of T2.2 is the main starting point when developing the final version of the EcoShopping IAU(T2.2). The development of IAU tools in tasks T5.2, T5.3, T5.4, T5.5, T5.6 and T5.7 will be carried out in close collaboration with this task (System requirements, specifications and architecture).

3. TECHNOLOGY & STANDARDS BASELINE REVIEW

EcoShopping aims to not only increase the energy efficiency of a building, but also to optimize the investments necessary to achieve this major goal by incorporating innovative approaches and new technology that adds additional value (e.g. a multipurpose mobile robot platform).

Advancing beyond current state of the art, Signal Processing Units (SPU), including the acoustic data and environmental data processors will be developed, **together with the more accurate building model, user behavior, weather and consumption profile will be taken asinputs to the IAU, to have a further calculation.**

Nowadays, all buildings are built with a certain amount of automation for HVAC, shading, and lighting and theyhave established Building Automation Management (BAM) systems. Depending on the target use of the building, also other applications for indoor comfort might rely on an automation infrastructure (hygiene, accesscontrol, media facades and outdoor lighting, multimedia, evacuation, etc.). Unfortunately, most of the BAMs do not at all or poorly take into consideration the micro climate of the building in real time. They just switch devices,heating elements, lights etc. on or off at the predefined time.

Regarding the commercial systems, there are still proprietary systems in use, but open and standardized solutions dominate the market.The three internationally standardized technologies are BACnet[1], LonWorks[2], and KNX[3] each focused on certain markets. The application of these technologies for energy management is still straight forward; only recent developments show more sophisticated approaches like weather-predictive controls or Wide area loadmanagement. The mentioned technologies have generic interfaces for energy management. One exception isBACnet with its BACnet load management object [4]. This load management object can be embedded into anyenergy consuming device to represent its abilities for load shedding. Other protocols have no or entirely differentapproaches (e.g. Zigbee Smart Energy Profile[5]) to this topic.

Information security, scalability, interoperability, intelligence are still challenges for building automation.Another challenge for certain application is the ratio between sensor costs and sensor information quality.Especially occupancy and people count is important for lighting, HVAC and emergency applications. Individualsensors, may they be light beams, floor sensors, passive infrared sensors or even cameras with sophisticatedpattern-recognition algorithms have a limited reliability when it comes to occupancy and person count. A widelyused strategy in such cases is sensor fusion where multiple and diverse sensor information is combined toincrease information quality. One advantage of sensor fusion is the fact that a number of cheap sensors canoften outperform an expensive one.

Particularly, for building control, current operation of HVAC and commercial lighting systems are based onschedules, either occupancy or time dependent [6][7][8]. While time dependent control of lighting (e.g. car-parkareas) and heating/cooling/ventilation uses pre-set time intervals, occupancy dependent operation of thesesystems requires pre-set occupancy information or sensors to determine real-time presence and number ofoccupants in a particular building zone and/or surrounding areas (so-called demand controlled ventilation,DCV45). In both cases, current operation of HVAC and lighting systems is less than optimal.

In the case of pre-set time and occupancy schedules, the systems do not save energy when actual occupancy isless than scheduled, i.e. no lighting intensities and airflow rates are reduced when people are not present in thebuilding/surrounding zone. In case the sensor detects occupancy, the critical information is the number ofoccupants within a building zone, as the required standard supply flow rates depend upon the number ofoccupants. At the same time supply flow rates are directly related to the energy consumption of the buildingHVAC system in two ways:

- They impact the fan energy consumption;
- They impact the heating or cooling energy consumption for air conditioning.

Current state-of-the-art cost-effective ways to provide real-time occupancy information, based on CO2 sensorreadings, have energy-saving potentials, but actual energy-saving estimates are not available. Furthermore,CO2 sensors have insufficient accuracy and a number of potential installation/maintenance pitfalls preventingthem from providing maximum HVAC energy efficiency. For example, the time necessary for the CO2levels to rise and sensors to detect this change, initiating increase in air supply rates, may be too long, such thatby the time the air is actually delivered to the occupant zone, the occupants have already left the area. This isparticularly true for the building zones with highly fluctuating occupant density, such as shopping centers, car parks,public transportation buildings, airports, etc. In fact, studies have shown that direct occupant-counting resultsshow much lower uncertainties in determining the exact number of occupants than presently used sensors.Additionally, no single sensing technology is available to provide required accuracy in determining exactnumber of occupants.

Progressing beyond the current SoAin building energy management system design, EcoShopping willimplement optimized building energy management (BEM) strategies developed using calibrated building simulation models, based uponthe multiple building sensor readings. The advantage of such simulation assisted solution is evidence-basedoptimal system performance, while using the building energy simulation model is expected to save time, effortsand financial resources, compared to the actual field trials within the building.

Furthermore, the results of the BEM optimization will reveal how various simulation input parameters such asweather conditions, time of day and occupancy, influence the simulated energy efficiency of the appliedtechnologies, and will provide a basis for further analyses on its prospective applicability.

Intelligence will be enhanced by improving the integratedmodels and control strategies. In the development of the IAU, aspart of the Building Automation Management (BAM), user patterns, price changes, consumption andweather forecasts will be bring to real, while the models used will beimproved, a “low cost thermal storage system” – the large buildingitself, will be considered as an important parameter allowing thesystem have a higher flexibility to exploit the renewable energy andload shifting. On the other hand, as a more intelligent system, theforecast and control accuracy is expected be enhanced byimplementing an advance control model such as Stochastic MPC(SMPC) compare the widely use Rule-Based Control (RBC) andDeterministic MPC (DMPC).

4. System Requirements

4.1 Functional Requirements

Taking the advantage of enabling ICT tocreate visionary future monitoring and controlling systems, local energy efficiency will beimproved by including the possibility to match the energy balance of the neighborhood both locally and with the grid and energy markets (Figure 1).

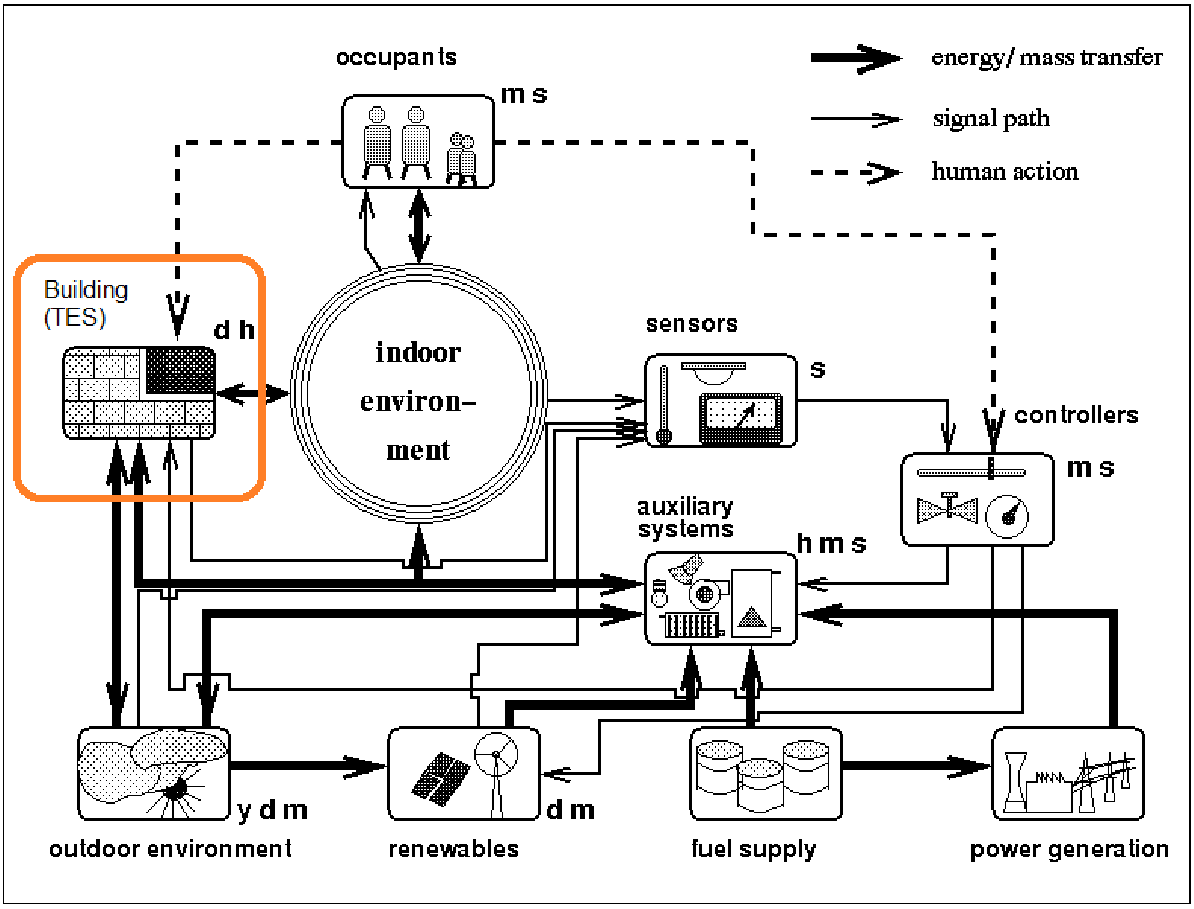

Figure 1. Building as an integration of energy.

A dynamic model describing the building as a big thermal storage is built. For bigbuildings, as the space and mass it contains increases the inertia of the building increase.In order to take advantage of this "thermal battery", a **Reduced Building model which can present the dynamic thermal storage**(Figure 2), should be developed in order to have an accurate control and most importantly, to exploit the maximum potential of free energy, such as night cooling and solar air conditioning. Knowing the behavior of the building's thermal tank, the IAU could calculate the perfect time to start HVAC on the morning before open the building in order offer comfortable environment later, or calculate the time to start the ventilation system at night to make use of the outer air to cool down the space, at the meantime, with in the set-point of the comfort, together by controlling the renewable energy base HVAC system, which offers the basic supply, the IAU can have a more flexible react toward the demand, consequently, the total energy consumption could be greatly reduced.

In order to reduce the sensing cost, improve the sensing data quality and building **a Mobile Robot will be introduced to the building**. This robot, not only serves as mobile sensing platform, but also reacts as a building watcher, providing information to visitors and watching over the building. The integration of the robot is less invasive compared to fixed sensor installations, more importantly, allows the system to be a **real User Oriented**. A mobile robot gathers sensor data more locally, i.e. closer to the users of a building and therefore offers **more reliabledata** (the convenience of people is the most important thing besides energy efficiency). Hence, a feedback loop can be established. Furthermore, for areas with higher occupancy, parameters collected by fixed sensor may have a lower quality; this fact can be taken into account more precisely by using locally gathered data instead of sparsely distributed fixed sensors. On the other hand, the mobile Robot is a key-technology for **other applications** such as **security and safety**, the integration of the cameras and acoustic sensor working together with the acoustic event detection (AED) enables the building to have an all-around control and enhanced protection. For the project, as a novel idea and at least an eyes catching equipment, the mobile robot can present information about the project to the public directly from the test-bed, which makes it **valuable for dissemination and communication** of the project goals. From the point of view of economics, the integration of the Robot will be **very cost effective** although not all other benefits that it brings to the building have been included, the return of investment will be less than 2 years considering the robot can at least substitute one night watcher employee **A semi-automatic learning system could retain its auditory capacities from an Internet-based repository, allowing the enhancement of applications in other domains and information services in the future**.

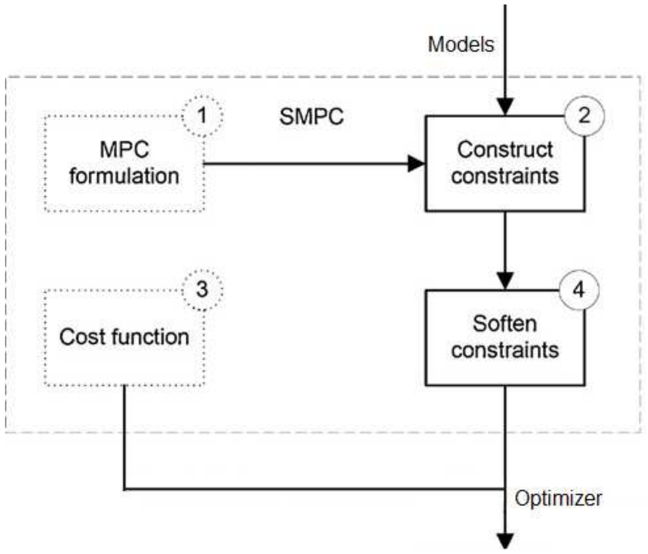

*Figure 2.*Reduced model used for optimization purposes

Acoustic and environmental sensing and processing in large spaces and open environments can provide near real-time information about the estimated occupancy level, air condition, temperature, humidity, illuminance.Particularly, the integration of acoustic sensor, allows detecting sounds as a pre-processing step for succeeding AED. This AED expresses the meaningfulness of the sound or noise and includes the semantic tags of meaning and the stamps of position and time, such as “nobody is here now” or“someone is crying and needs help” is helpful for monitoring building security and occupancy level which also is an important parameter not only for lighting control, but also for air conditioning due to the human heating emission will also raise the cooling demand in summer or reduce the heating demand in winter.

4.2 Non-Funtional requirements

In EcoShopping a great effort will be given tothe “Continuous Assessment”, the optimizationbenefits for buildings energy efficiency will be calculated based on comparison of:

1. The integration of easy-to-install energy consumption monitoring technology enables the identification ofthe gap between theoretical and experimental performance, thus improve the optimizationprocedure. The improved and original (calibrated) simulation runs, and the improved and original energymonitoring datasets covering variety of operating conditions. Such calibration would mean that thesimulated results sufficiently correspond to real measured electricity consumption under varying weatherconditions for the demo building locations. Additionally, a second baseline comparison will be donebetween the improved building simulation and monitoring dataset to a representative energyperformance for similar facilities.
2. Comparing annual and monthly bills before and after the installation of IAU, consumptions (kWh) andcost (€), during the first year and the third year with full deployed system in each pilot buildingand control space.

These comparisons will be used to derive relevant evaluation factors and decision criteria:

- The ecological performance factors will include percentage of energy saved compared to thebaseline, and percentage of CO_2emissions saved, based on a typical mix of energy sources at thegeneration facilities;
- The financial performance factors will include savings in energy costs, but also expenses in sensorcosts, installation and maintenance costs, financial market conditions, building added value due toinstallation of the proposed technology and impacts on productivity and extra information services.

The various use cases defined in D2.4 will be investigated and ranked in an early stage of theproject with the goal to identify the most promising application for the demo site.Concerning security integration, sounds can provide a clear added value

- Infrared Technology: Even if infrared solutions are of lower costs, acoustic sensing can provide a betterintegration with security system, since sound processing can be used not only for energy efficiency butalso for automatic danger situation detection.
- Image processing: Image processing can provide similar capabilities to sound processing for automaticdetection of danger situations. But with higher costs (economic and ecologic) due to a bigger and agreater installation for a visualfor real-time video streaming instead of sound streaming.

To achieve a sustainable building operation it is indispensable to have the building's energy consumption and the operation data. To reach an efficient energy management the key tool is a precise monitoring data. The collected information lays the groundwork for future measures to reduce operating costs and lower energy consumption. For these two purposes, it is required an efficient monitoring that combines advanced technology with continuous analysis to ensure the maximum integrity of the collected data.

Non-functional requirements represent the quality goals and constraints of the monitoring system. Different non-functional requirements will be explained in order to design a quality IAU, which can react precisely to the needs of the building. For this purpose a reliable and accurate monitoring system (fixed sensor network and mobile robot) has to be designed. Below, there are described four different non-functional requirements concerned to the monitoring network such as Accuracy, Precision, Resolution, Sensitivity, Range, Offset, Linearity, Hysteresis and Response time, which will allow to have a quality monitoring data.

Accuracy

The accuracy of the sensor is the maximum difference that will exist between the actual value (which must be measured by a primary or good secondary standard) and the indicated value at the output of the sensor. Again, the accuracy can be expressed either as a percentage of full scale or in absolute terms.

Precision

The concept of precision refers to the degree of reproducibility of a measurement. In other words, if exactly the same value were measured a number of times, an ideal sensor would output exactly the same value every time.

Resolution

This specification is the smallest detectable incremental change of input parameter that can be detected in the output signal. Resolution can be expressed either as a proportion of the reading (or the full-scale reading) or in absolute terms.

Sensitivity

The sensitivity of the sensor is defined as the slope of the output characteristic curve or, more generally, the minimum input of physical parameter that will create a detectable output change. In some sensors, the sensitivity is defined as the input parameter change required to produce a standardized output change. In others, it is defined as an output voltage change for a given change in input parameter.

Range

The range of the sensor is the maximum and minimum values of applied parameter that can be measured.

Offset

The offset error of a transducer is defined as the output that will exist when it should be zero or, alternatively, the difference between the actual output value and the specified output value under some particular set of conditions.

Linearity

The linearity of the transducer is an expression of the extent to which the actual measured curve of a sensor departs from the ideal curve. Linearity is often specified in terms of percentage of nonlinearity.

Hysteresis

A transducer should be capable of following the changes of the input parameter regardless of which direction the change is made; hysteresis is the measure of this property.

Response time

Sensors do not change output state immediately when an input parameter change occurs. Rather, it will change to the new state over a period of time, called the response time. The response time can be defined as the time required for a sensor output to change from its previous state to a final settled value within a tolerance band of the correct new value.

This collected monitoring data will allow identification and validation via the simulation models the most promising application for IKVA shopping center in the four different seasons during the year, which will depend on the occupation level and weather. The comparison between both theoretical and experimental performance will help to find, identify and correct the explained gap to reach as much as possible the theoretical (ideal) performance after the retrofitting process.

On the other hand, there are several specifications that are related to user interface and will allow the building operator to have the control of the settings and localize the inefficient performance values. The service platform will have requirements with regard to:

Hardware Platform

It will be able to host web server that will serve as user interface for the building operator and building owner.

Visualisation Module

A friendly visualised and/or animated environment displaying results should be provided. For example, node mobility, data packet and energy level should be displayed at different timeline. This could promote better understanding and interpretation of the result.

4.3 User characteristics

Two users are foreseen for the IAU. One is the human user the other is a software client.The human user has an administrator role. It has a good knowledge of the system, and is responsible for the deployment and initial configuration of the IAU.The software client is responsible for requesting system jobs to the IAU or any of its modules. As response the software client receives the requested results.

The Human User

The role of the human user is basically managing the IAU of the building. In large buildings such as shopping centers, where heterogeneity and hybridization spaces, uses, people who use it and times of affluence make the facility management tasksvery complicated. The administrator has to rely on technology to monitor building occupancy and obtain values, such as temperature, humidity and so on, to adjust the installations and provide more consistent with how the building is used. A shopping center is not always occupied in the same way, has a schedule where the influx of people is greater at certain times and others in the least.

The shopping center manager will want to save energy at all times and adjust the parameters to make it as efficient as possible, without losing benefits to building users. Comfort and security are the foundation to any user of the shopping center that uses it.

In the other direction, is the shopping center owner who wants to spend the least money possible every month. This urges the Administrator to lower direct costs in energy expenditure, maintenance and common security.

It is in the initial phase of the project where it can be addressed these issues in the operation of the shopping center to be flexible and change technologies as needed. Anticipate the flow of customers to use the building, at what times will have more affluence and at what times less, so use more or less energy.

This energy may be ”stored” in the capillary tube technology that works at low temperature, being the most effcient and cost effective (the energy losses are reduced) way to reach and mantain ideal room temperature, and due to the distribution of low temperature water it is ideal to be linked with solar thermal air-water heat pump.

This system will be used to provide thermal mass (”inertia”) to the building against temperature fluctuations to lower the energy consumption. The role of the administrator is to take as much advantage as possible of the renewable energies, being aware of the implementation of this added thermal mass and taking into consideration the shopping center schedule.

The simulation of a network of occupancy sensors would help us in the flow of people, gauging which are more static and where more dynamic and adjusting the HVAC facilities to the profile of the users of the shopping center. These systems installations have to be smart and pick the functioning and behavior of customers in the building.

<u>The Client Software</u>

The data generated from the simulations have to be processed and analyzed by one or several specialized software in energy efficiency and building maintenance management. In order to have a much more precise prediction and control, models of the building and weather forecast data will be needed within the building management system

The Ecoshopping Building Simulation module will be reduced to a model based on a simplified geometry of the building and it will generate a series of data through the parameters of the default program and using the montored data to modify it in order to increase the accuracy and accommodate for changes in the building behaviour.

The outputs generated by the Ecoshopping Building Simulation module will inform the client software with the analysis of the data collected from the systems and it will allow evaluating the environmental data and the achieved energy efficiency. The systemms control with regard to their requirements and the indoor comfort will be displayed in the web portal and smart digital applications. These interfaces will receive the data from the platform and with the energy consumption visualization and behaviour transformation, several parameters will be analysed, such as identification of consumption patterns and real time information on energy consumption.

Two types of user accounts will be assigned for the web service interface:

On one hand, a super user will have all the control settings opened. This account will be used by the building operator in order to maintain in proper working conditions the implemented systems and the indoor air quality of IKVA shopping center.

On the other hand, a username with its password will be created to allow building owner to follow the building behaviour tracking the collected monitoring data with its analysis.

4.4 Performance Requirements

For the fixed sensor network and control system, data (e.g. electric energy, heat energy, air temperature and humidity, illuminance, and others) should be registered at the typical sampling rate of one sample of the available variables per 15 minutes.

Audio processing needs to be performed in real-time, since new data is recorded constantly. This leads to an update interval for the estimated occupancy level of about 4 seconds. This should be faster than it is actually required by the overall system. So it will be possible to calculate and use average occupancy levels at 1 minute, 5 minutes, 15 minutes or any other interval, required by the IAU.

The Building simulation tool performance depends on two factors:

- the input data accuracy, and
- the simulation execution time.

To perform on EcoShopping context means to execute a rapid simulation, even though few data concerning the building are available. In this case, also the 15 minute intervale should be ensured.

4.4.1 Reliability

The full system should be reliable able to perform autonomously with no need for human intervention. As some of the devices are battery based, it is foreseen that those devices should need maintnance for battery changing with a periodicity of no less than 6 months. Simulations outcomes can only be as accurate as the input data itself.

4.4.2 Availability

Simulations must be available on demand.Occupancy level data as well as other information (sensor data, energy consumption, etc.) should be available by means of a centralized data base. So, to a limited degree, it can be accessed by shop customers, using the mobile robot for an information terminal. For example the robot may display the current rate of energy savings due to the EcoShopping optimizations or the current weather forecast and related adjustments to the heating system. Wi-Fi must be available throughout the building otherwise the robot could be (temporarily) unable to receive instructions or provide sensor data.

4.4.3 Security

For development of web server HTTPS communication protocol will be used providing SSL/TLS security capabilities. Customers (children) must be prevented from fooling around with the mobile robot platform, e.g. blocking in an inaccessible areas, tampering with any controls or vulnerable components, pushing it down the stairs, or climbing on-top of it to take a ride. The fixed sensors might also be tempered with. Some of these risks can be avoided by choosing an appropriate operating area.

4.4.4 Maintainability

The fixed acoustic sensors are still under development. Once applied and properly configured they are expected to require little to no maintenance. However, sensors should not be blocked by other equipment, misplaced boxesor shop fit display equipment – especially if the store is reorganised or refreshed.

The mobile robot platform has a limited operating time of up to 16 hours. Its batteries must be recharged regularly which takes about 6 hours. The building site should be clear of any dead ends or badly accessible areas. Otherwise the mobile robot could become stuck because of customers hanging out or misplaced goods blocking its way. In such cases manual assistance could be required to clear the passage.

4.4.5 Portability

The defined architecture and fixed sensors are not site specific and can be easily ported to other places, requiring only a design and installation phase according to the new place.

The acoustic sensor array will be a fixed installation; however the same technology can be applied to other places, too. The sensors on the robot platform will be mobile.

4.5 Data Requirements

This section describes the data requirements for IAU.Sensors play a vital role in any building management system, monitoring safety, efficiency of systems and providing information on status of the building. They are critical components in automation control as they provide the data necessary for the effective and efficient operation of the whole system. This data is processed then stored in the central database that will be also used to store all other information for efficient operation. Other components of IAU will use data from the EcoShopping Database so reliable operation of it is desirable.

4.5.1 Input data

Input data are the data that supports the IAU operation, which includes building data (such as building area, building height, building type/building year); thermal characteristics (such as isolation/wall type, fenestration (%), location (weather/solar path/orientation), infiltration, internal gains, ventilation); electrical characteristics (such as electrical consumption and energy source). Furthermore other input data has to be taken into account such as Renewable Energy Sources (RES) production, thermal consumption and thermal production.

4.5.2 Output data

Output data are the results of the dynamic simulation of the thermal and energy performance of buildings over time. This includes energy demand for heating, cooling, humidification/dehumidification and electric.Including the following simulated values:

- current consumption [kWh]
- energy consumption [kWh]
- heating energy consumption [kWh]
- cooling energy consumption [kWh]
- temperature [°C]
- humidification/Dehumidification energy consumption[kWh]

Other values may be calculated from these simulated values, for example:

- current consumption per office space [kWh/m2, a]
- heating energy consumption per office space [kWh/m2, a]
- current consumption per employee [kWh/x, a]
- energy consumption per gross floor space [kWh, a]/[m2]
- current consumption per gross floor space [kWh, a]/[m2]
- heat consumption for heating and warm water per gross floor space [kWh, a]/[m2]
- heating energy consumption per office space [kWh/m2, a]
- heat energy consumption per area [kWh, a] heated/[m2]
- energy consumption per employee [kWh, a]/[x]
- current consumption per employee [kWh, a]/[x]
- heat consumption per employee [kWh, a]/[x]

Output data from IAU are control signals for the HVAC actuators.

4.5.3 Data quantitiy

A model is created based on some basic information concerning the building. This information may be static, or dynamic. Static data is the one concerned with the building (building data). The dynamic data is concerned with the building systems (monitoring data).The simulation input data quantity is typically in the order of some kilobytes. Only building data is used to generate the model. The simulation output data in the other hand is much bigger. Typically, a simulation of the electrical energy consume is performed for a period of 1 year, using a time interval of 15 minutes. If a building with 5 zones is simulated, the amount of samples would be 175200. This means, up to 5 Mb of data is generated and has to be stored on the EcoShopping Database.

Regarding the fixed sensor network and control system, data (e.g. electric energy, heat energy, air temperature and humidity, illuminance, and others) should be registered at the typical sampling rate of one sample of the available variables per 15 minutes, which means that high quantities of data are expected to be collect, stored and transmitted. Due to the high data quantities, data packaging might be necessary, especially for the output data.

4.6 Interfaces Requirements

This section describes the requirements regarding the system's interfaces. The Ecoshopping system will be presenting the following interfaces:

- User interfaces – Used for presenting the system status and sensor data to the end users (the system front-office) and to enable the possibility to configure the system and its simulation parameters (the system back-office);
- Software interfaces – The software interfaces represent the machine to machine interfaces needed to inter-connect the different software modules of the platform.
- Hardware interfaces – The hardware interfaces are machine to machine interfaces used to transfer data and commands among the system's hardware components such as sensors or actuators.

4.6.1 User interfaces

This section describes the system's front-office and back-office.

The front-office user interface aims to present system information to the facility stakeholders such as sensor values (real time or historical), indicators or reports. The back-office user interface enables the possibility to interact with the system parameters such as simulation or building parameters.

Front-office

The Ecoshopping system will present front-office user interfaces to enable users to interact with it. Several distinct categories of users/stakeholders with different functional requirements are foreseen to potentially use the system's user interfaces. The different stakeholders considered are:

- Facility owner – This represents the facility owner. This type of user has interest on knowing how the facility behaves in terms of running costs over time and to access if any change on the building has the expected return of investment;
- Facility Manager/Administrator – This user is the local responsible for managing the facility. This user has interest on knowing everything happening on the facility and is responsible for implementing and accessing the effect that any change produces over time. This user is also responsible for identifying non-optimal performance or

abnormal behaviours on the facility and coordinates the technical team or actuate on the system to solve them;

- Technician – This user is responsible for the maintenance of the good status of the entire building. Real time data from the measured variables are a good asset to help this user with his work;
- Member of the public – This user has no interest on the building itself but to access the good quality of the environment during his visit and the ecological footprint of the building.

The functionalities presented by the system's user interface can also be categorized. The following list describes the functional categories presented by the user interface:

- Current status – This function enables the users to have a idea of both the system and facility status in terms of functionality and behaviour;
- Real time monitoring – This function gives the possibility to provide real time data from the sensors (i.e. energy consumptions or measured air parameters) to the users in a simple format, such as a synoptic view of the facility;
- Actuate on the system – Users may control the system using this functionality. Depending of the facility and installed system capabilities, this control may be in terms of parameters, such as set-points, or in terms of manual control of equipment such as pumps or boilers.
- Historical data – This function enables the users to analyse and compare facility data and performance at a medium and long term
- Calculation of indicators – Taking in account the data from the facility several indicators can be obtained by calculation such as comfort or performance indexes
- Reporting – The user interface is capable of presenting reports to the users containing key information to access the facility performance.

Table 1depicts the different user interface's stakeholders and their typical usage of the presented functional requirements.

Table 1. User interfaces stakeholders and their functional requirements.

User	**User interface functionalities**					
	Current Status	Real time monitoring	Actuate on the system	Historical data	Calculation of indicators	Reporting
Facility Owner				•	•	
Facility Manager	•	•	•	•	•	•
Technician	•	•				

Public	•

The presented user interface functionalities may be split in two distinct categories (

Table 12). The first category considers functionalities very close to the field, with the need of no or little data processing and storage, with low response latency time between the user interface functionality and the field. Due to the requirements of the category, the ideal location for the provisioning of these functionalities is at the pilot facility, delivered directly by the sensor gateway. The second category considers functionalities that require high capabilities in terms of data processing and storage needed to provide long term historical data, processed indicators and reports; as these functionalities need high computational capabilities and don't have low latency requirements to the facility, the best location for the provisioning of the functionalities is at the cloud level. According to the two different categories, two distinct user interfaces are envisioned to the system: a local user interface, running on the facility's gateway and a remote user interface, running at the cloud level.

Table 2.User interfaces and their functionalities.

User interface functionality	Local User Interface	Remote User Interface
Current Status	•	
Real Time monitoring	•	
Actuate on the system	•	
Historical data		•
Calculation of indicators		•
Reporting		•

The next figures (Figure 3. and Figure 4.) depict examples of the system's user interfaces. The local user interface example presents a synoptic view of the facility with the current process values acquired in real time from the facility sensors. The remote user interface example presents the facility electricity consumption historic from a full day.

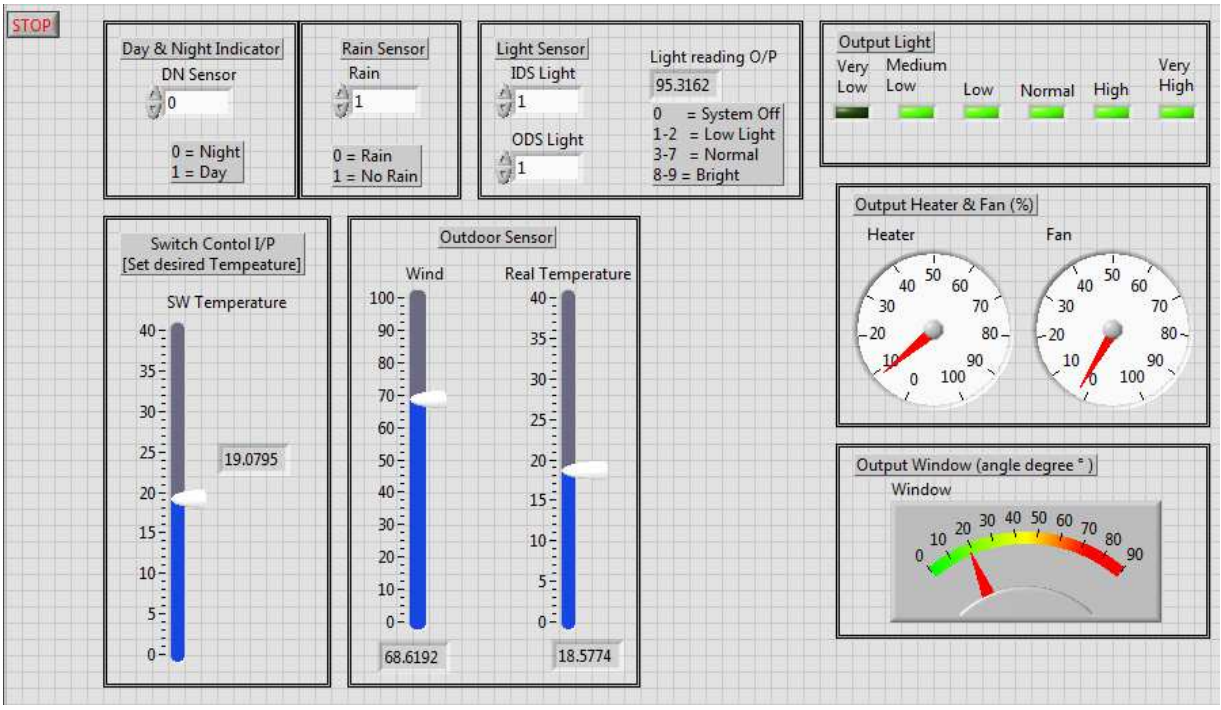

Figure 3. Example of local user interface view (synoptic view).

User interfaces will be based on web technologies, requiring only a web browser and an internet connection to access them. The user interfaces should be protected by access credentials composed by username and password pairs for each one of the users. It is recommended that the user interfaces are also protected by HTTPS protocol. Despite of being possible to access the web based user interfaces from anywhere, it is recommended that the access to the local user interface be restricted from inside the facility.

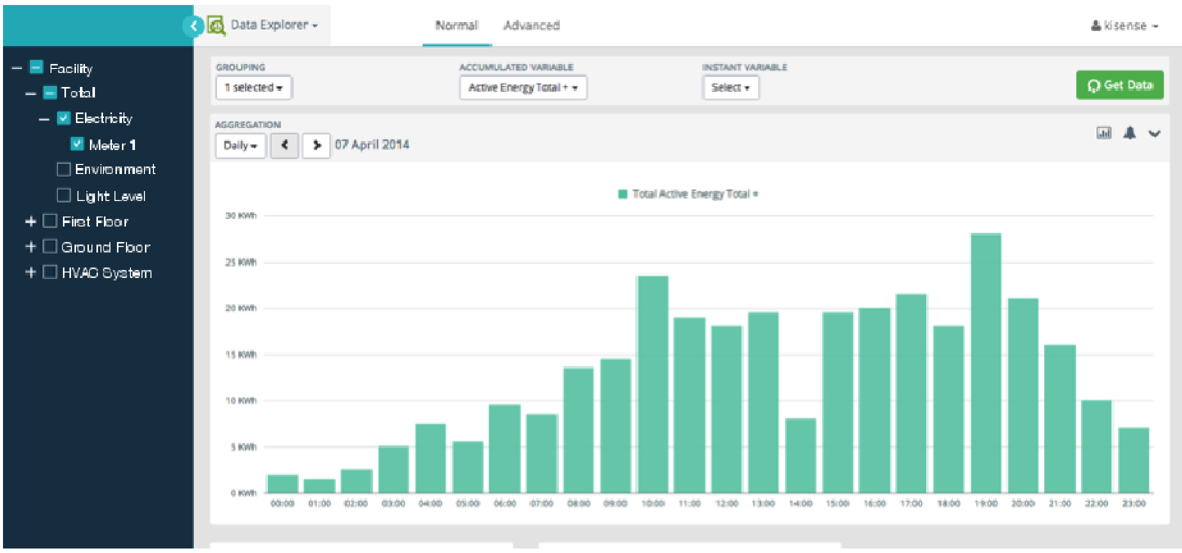

Figure 4. Example of remote user interface view.

Back-office

The Ecoshopping system will present back-office user interfaces to enable users to interact with it.Two users and consequently two user interfaces are foreseen for the building simulation module. One is the human user the other is a software client.The human user will interface though an administrator application interface which allows performing installation, configuration and setup of the building simulation module. An example is shown in Figure 5.The software client will interface thought a machine-to-machine interface which allows the exchange of data (building, simulation and configuration data) between both the building simulation module and the software client.

Figure 5. Model generation user interface example.

The mobile robot platform will be used as a public information terminal, providing information on the EcoShopping project, the current energy consumption/savings (which might be a privacy issue), advertisements or a weather forecast.

4.6.2 Software interfaces

In order to enable the possibility to transfer data between the distinct software components of the system, a set of software interfaces has been specified in this document. The following list in *Table* 3. describes the foreseen software interfaces.

Table 3. List of software interfaces.

Component providing interface	Interface type	Purpose
Sensor gateway	Web Service	This interface enables the possibility of providing data collected from the sensors to the other software components such as the Data Server installed at the cloud level.
Data Server	Web Service	This interface enables the possibility of providing raw data collected from the facility, data processed by the Data Server (aggregated data, indicators, etc) and simulated data provided by the simulation unit commited to the Data Server. The interface also enable sthe possibility to store simulated data provided by the simulation unit.

Mobile Robot	Web Service	The Robot may use the specified Web Service interface to access information from the Sensor Gateway/Data Server, e.g. for showing a diagram on its display unit. However it will act as a client and won't run a Web Service of its own. There will be an "private" WiFi TCP/IP connection between the Audio Processing Unit and the Robot (as part of the acoustic sensor network). Acoustic sensor data from the robot will be channeled through the Audio Processing Unit. (See 5.2.3.1.7 "Connection to Storage")

4.6.2.1 Sensor Gateway software interface

Sensor gateway offers a web services processing interface and this interface supports JSON. JSON (JavaScript Object Notation) is an open standard format that uses human-readable text to transmit data objects consisting of attribute–value pairs. It is used primarily to transmit data between a server and web application, as an alternative to XML.JSON is a text format that is completely language independent but uses conventions that are familiar to programmers of the C-family of languages. JSON is built on two structures:

- A collection of name/value pairs. In various languages, this is realized as an object, record, structure, dictionary, hash table, keyed list, or associative array.
- An ordered list of values. In most languages, this is realized as an array, vector, list, or sequence.

These are universal data structures. Virtually all modern programming languages support them in one form or another. It makes sense that a data format that is interchangeable with programming languages also be based on these structures.In JSON, they take on these forms:

- An object is an unordered set of name/value pairs
- An array is an ordered collection of values
- A value can be a string or a number or true or false or null or an object or an array
- A string is a sequence of zero or more Unicode characters
- A number is very much like a Java number, except that the octal and hexadecimal formats are not used.

4.6.3 Hardware interfaces

The fixed sensors network makes use of several distinct hardware interfaces for transferring information between components, namely the acquired data samples.

- Modbus – An open, simple and robust serial communication protocol, developed in 1979 by Modicon (currently part of Schneider Electric). In this project two variants of the Modbus protocol are used: the Modbus RTU, used on the top of a RS485 connection; the Modbus IP, used on the top of an IP connection, over Ethernet.

- M-Bus – A relatively new protocol defined in Europe, also known as Meter-Bus, broadly used for remote reading of meters, such as heat meters. This communication protocol has several positive aspects such as capability of powering the remote meters by the bus master.

- RF ISM 868MHz – This is a protocol used some of the ISA radio devices that uses the ISM 868MHz radio band.

- 2.4GHz IEEE 802.15.4 –This is a communication protocol for low bitrate wireless networks, serving as base to well-known communication protocols such as Zigbee.

4.7 Other Requirements

Simulation results are stored on the EcoShopping Database, as metadata, along with the building data. This enables future comparisons between buildings with similar characteristics.

In the case that simulation workload demands increase, parallel simulation servers may be necessary. This means that a distribution function is necessary for the simulation resource planning. Data packaging might be necessary due to the high data quantities resulting from the simulation.

4.8 Constraints, Assumptions and Dependencies

The design of the software shall conform to IEEE, EN, and ISO standards for software development practices. Also the ISO 50001[9] shall be followed on terms of energy management.

The implementation of the integrated energy management and optimization approach attempted in this project depends on technological factors that are not always within the range of the project partners. A possible risk is the unavailability of the EcoShopping Database. On this case, no simulation is possible.

Another risk is the lack of sufficient monitoring data for creating a reliable energy profile, e.g. because the building automation system does not cover vitally important systems like HVAC. The countermeasure is an extension of the installation to monitor the most important energy relevant data like overall consumption of the HVAC system.

TheCompactRIO (cRIO) hardware platform complies with European Union EMC & Safety Compliance Declaration (CE), European Union Product Safety (Demko),European Union Hazardous Locations (Ex).

Intelligent control system has the risk of being unstable for the whole range of input parameters (because of nonlinearities in the system). Poorly designed feedback can cause the system to be unstable. Unstable system has no control over his outputs. Even if the system is stable there is a possibility that it is not stable enough to ensure stable operation.

If there is unavailability of the EcoShopping databese and no bulding and/or weather model is possible to generate information then intelligent optimization proces is very limited.

As a result of the Directive of Energy Performance of Building (EPBD) a number of EN standards have been developed to harmonize the energy calculation methods concerning buildings. In this context, a new European standard EN 15232 ‘‘Energy Performance of Buildings – Impact of Building Automation, Control and building Management’’ [10] was compiled to support the EPBD. The standard describes methods for evaluating the influence of building automation and technical building management on the energy consumption of buildings. Four efficiency classes A to D have been introduced to this purpose. Furthermore, the ISO 50001 ‘‘Energy Management Standard’’ [11] enables organizations to establish the systems and processes necessary to improve energy performance. Building automations are a fundamental part of the energy management systems. However, the traditional automation system may have limited level of intelligence, based on their purely ‘‘mechanical logic’’. In the traditional automation systems, each sensor and actuator needs its own wiring, which makes the initial installation cost high. Expansion is also a problem, and even ongoing maintenance costs are high.

Data exchange takes place both between and within the different levels. To this end, numerous systems and communication protocols have been developed at international level, mainly Dupline, European Installation Bus (EIB), BatiBus, European Home Systems Protocol (EHS), X-10 international standard for communication among electronic devices, Consumer Electronics Bus (CEBus), Home bus System (HBS) as well as C-Bus communications protocol for home and Building automation, DALI for the lighting control, among others. The higher level in the pyramid needs to handle multiple systems within the different levels using lower number of components and higher amount of data. In particular: Component level: Sensors, switches, relays, as well as valves, motors and other units comprise the lower level of the industrial automation pyramid.

- Device level: Counters and timers store, display and control the sequence of an event or process.
- Process level: Programmable logic controllers (PLCs) are a process control system based on a set of digital and analog I/O received from the assigned sensors and actuators on the components level. Larger more complex systems can be controlled by a Supervisory Control and Data Acquisition (SCADA) system or Personal Computer (PC) logging all events and alarms, archiving all measured readings and graphically displaying the status of the operational systems.
- Plant level: The last level of industrial automation pyramid focuses on high-level planning and control application in the plant operation that is be used for design, analysis, optimization, process planning, production scheduling, materials handling, inventory control, maintenance, and marketing. Computer-aided design (CAD), computer-aided engineering (CAE) and computer-aided manufacturing (CAM) systems are the most common examples.

Energy end-users have the capacity to monitor the energy consumption and control the operation of buildings' appliances without their active involvement in the different parts of buildings' installation. In particular, the proposed tool could include:

- Simulation: This tool provides organized and statistically analyzed data sets on the energy use in the buildings and their energy efficiency and economic performance. Hence, the end-users identify the energy consuming sectors of the building through real time monitor and comparisons of energy consumption profiles from different time periods.
- Optimization: At the same time, this management tool has the ability of running alternative optimization scenarios for achieving ‘‘intelligent’’ management of the building electric loads towards efficient energy and environmental management.

There are following steps of the Automation Units, which dependencies strongly characterize the all the Monitoring System:

Step 1– Energy users' profile: The user provides general information about the building and the consumed quantities of each energy form. Moreover, a portable electrical energy analyzer is used for determining building user's behavioral profile. The energy consuming sectors of the building and also the untapped energy efficiency potentials, depending on the energy use profile of the building and the users' requirement, can be identified.

Step 2– Identification of energy-efficient automation functions: The system incorporates energy-efficient automation functions for heating, cooling, ventilation and/or lighting based on the:

- Recent guidance and decisions of the National Law.

- The information gathered in EcoShopping Deliverable 2.1
- Energy efficiency requirements of EN 15232.
- ISO 50001 Energy Management Standard.

The proposed tool provides effective automation and control of heating/cooling, ventilation/air conditioning and lighting that leads to increase operational and energy efficiencies according to the energy efficiency requirements of EN 15232. Complex and integrated energy saving functions and routines can be configured on the actual use of a building depending on the real user needs to avoid unnecessary energy use and CO2 emissions. These functions include individual room control with communication between controllers, temperature control of distribution network water temperature regarding heating/cooling control, air flow, temperature and air humidity control concerning ventilation and air conditioning, as well as automatic or manual daylight control and occupancy detection for lighting. Moreover, the tool can be appropriately customized so as to provide information for operation, maintenance and management of buildings especially for energy management (trending and alarming capabilities and detection of unnecessary energy use). In addition, the proposed tool provides the opportunity, especially to the users of tertiary sector building, to increase energy efficiency, reduce costs and improve energy performance into the framework of ISO 50001 Energy Management Standard.

Step 3– Parameters' selection: based on the energy-efficient automation functions, a number of sensors that measure and record temperature, relative humidity, air quality, movement and luminance in the building areas are selected for the examined application of the case study building. In addition, controllers, such as switches, diaphragms, valves and actuators are correspondingly used.

Step 4– Energy consumption simulation: The proposed automated system can monitor the energy consumption using the network of sensors and metering equipment (energy analyzer). The data from building automation systems transfer through Master Generator to PC. These data are collected, stored and organized, enhancing the interactivity of building automation systems. The software processes data, providing averages, pick-load, statistics and graphs regarding electrical consumption and economic impact. Therefore, the user will be able to identify the weak points of his building and also the energy efficiency potential through real time monitoring and comparative analysis of energy consumption profiles from different time periods. This is a powerful tool for sensitizing users on their energy consumption, so as to mobilize them for its decrease.

Step 5 – Energy consumption optimization: Apart from analyzing the building's energy profile, the proposed tool integrates control scenarios using optimization techniques which minimizes energy consumption and rationalizes the energy use in the highest degree. In this context, a deterministic optimization method is applied, based on control algorithms to achieve peak load reduction while still maintaining the building as a healthy, productive and comfortable environment for the building occupants. More specifically, the lighting level, temperature, relative humidity and air quality are the main parameters that are manipulated to achieve the required indoor conditions. The data on energy use profiles, including among others electricity bill data and peak demand, are used for the formulation of control algorithms. The proposed tool at this level minimizes the energy consumption of the building and assists energy users to save substantial amounts of money.

5. SYSTEM SPECIFICATION

5.1 System overview

In this section a brief system overview of the Intelligent Automation Unit (IAU) with a Monitoring System will be described.
As a part of the IAU the Monitoring System will consist of distributed fixed sensor network and an autonomous mobile robot. A combination of distributed fixed sensor network and mobile robot, will be a energy efficient and adaptable system which monitors the occupancy level, temperature, humidity, noise in buildings and surrounding areas and transfers the data in near real-time to the IAU. An integrated autonomous mobile robot carrying different kind of sensors will be walking around the building and serve also as a mobile sensing platform. Because of that the quality of data collected with the mobile robot and with the distributed fixed sensor network will be more precise and accurate. On the other hand, this robot, as an extension of the IAU, offers more functions to the visitors and building security. Distributed fixed sensor network will provide acoustic and environmental sensing so it will provide near real-time information about the estimated occupancy level, air condition, temperature, humidity, etc. This is not only very helpful for monitoring building security and occupancy level but is also important for lighting controland air conditioning.

The goal of the IAU is to evaluate all the variables and give a strategy that fulfills the thermostat settings with the minimum impact/cost. An integrated building simulation model, calibrated with monitoring data together with user behavior, weather prediction and consumption profile will be used in the optimization process performed by the IAU. Optimization interacts directly (or user approval) with building management system to intelligently analyze, predict, and automatically optimize energy consumption in the shopping center. The result is reduced energy consumption and lower HVAC energy costs while maintaining occupant comfort. Automation control is also part of the IAU. Building automation can be regarded as a special case of process automation, with the process being the building indoor environment. The process consists of numerous sub-processes, both discrete and continuous. The most complex processes by far are present in the HVAC domain. Since HVAC processes involve large (thermal) capacities, changes in system parameters occur only gradually. Since the process behavior is slow, requirements on controller response times are relaxed compared to industrial control applications.Figure 6. depicts simplified IAU block diagram.

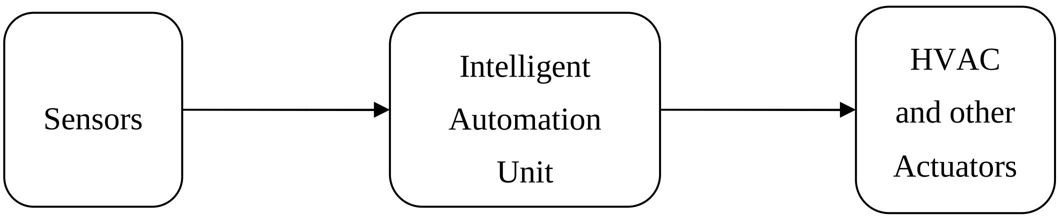

Figure 6. Simplified IAU block diagram.

5.2 Software specification

5.2.1.1 Data Server software interface specification

This section describes the Data Server application programming interface (API). This API is provided by the Data Server for the other application or components to use. The API tries to conform to the RESTful principles of the HTTP protocol thus providing a machine friendly, robust and predictable interface to the system functionalities. Except otherwise noted, all data is to be transmitted using the JSON data format.

Before proceeding to the specification of the above mentioned API, there are four main concepts that are central to the Data Server platform and that should be clearly understood. These four concepts are:

- Local: A physical location that has the remote metering hardware installed. Locations usually correspond to a house or a building where the metering hardware is installed.
- Unit: The hardware that is located at the customer's location and that receives the data readings from devices. A unit usually communicates with the server using a TCP/IP connection.
- Device: Another piece of hardware that is located at the site being monitored. Devices can read several parameters (current, power, etc.) and send the data that has been read to its governing unit. There can be more than one device associated to unit. A device can be, for instance, a socket plug that is used to monitor the consumption of a specific appliance, or it can be a clamp that is used to monitor the current on a specific wire. A device usually communicates with its unit using some form of wired or wireless connection.
- Tag: A measurement end point that stores the data readings of a specific device. If a device measures current and power then it has two tags associated, one for current and another for power. A device may have one or more tags; in other words, it may measure one or more parameters.

All operations, except otherwise noted, must be invoked using HTTPS protocol and provide an HTTP Authorization header like "Authorization: ISA <session token>" where session token is received as a response when a session is created. See Sessions' methods documentation for more details about authentication.

To ease reading and add meaning, this document follows these simple writing conventions.

Variables are represented as <type: description of the value>. The possible data types are string, number, date, time and Boolean.

Resources can be represented in the following formats:

- Single resource – Resource
- List of resources - [Resource]
- Paged list of resources - [Resource]+

In result to each request performed to the API, a specific response code (Table 4) is returned in the reply to the requester. The following table lists the possible response codes and their meaning:

Table 4.Response status codes and their description .

Response Status Code	Description
200 OK	Successful request. Response body contains the resource representation requested
201 Created	Resource was successfully created.
204 No Content	Resource was successfully updated and its representation didn't change compared to what was sent by the client. Or, resource was successfully deleted.
304 Not Modified	Your cached resource is still up-to-date.
400 Bad Request	The request contains invalid data, check error details.
401 Unauthorized	Insufficient credentials to access resource.
404 Not Found	Resource not found.
405 Method Not Allowed	The verb used in the request is incorrect.
500 Internal Server Error	General server side error. Please try again later.

General conventions

Operations that return lists of resources can return these as a list (represented as [Resource]) or as a paged list (represented as [Resource]+). In either case, the results can be filtered and ordered by fields defined on an operation basis.

Non-paged lists are returned as [] (arrays) of resources whereas paged lists are returned as {} (objects) with the following properties:

{

"PAGE": <NUMBER: CURRENT PAGE NUMBER (ZERO BASED)>,

"PAGE_SIZE": <NUMBER: NUMBER OF MAXIMUM RECORDS PER PAGE>,

"TOTAL": <NUMBER: TOTAL NUMBER OF RECORDS>,

"LIST": [RESOURCE]

}

Methods which return paged lists, accept the following URL parameters to customize the list returned:

?page=<page>&page_size=<page size>

All these parameters are optional. Defaults and allowed values are:

- page - default is 0;
- page_size - default is 50, allowed values are between 1 and 200;

Search operations allowing user-defined ordering specify valid order properties as:

Order: <PropertyName1>, <PropertyName2>

For example, an operation documented as:

Order: Id, Type

Allows the caller to specify none, one or both properties as ordering. If none, the bold property is used as the default (ascending) order. If a '-' (minus) is prepended to a property, the ordering is descending. Order is specified as the 'order' query parameter with a list of values. All of the following are valid order parameters:

?order=[Id]

?order=[-Id]

?order=[Type]

?order=[Type,-Id]

Search operations allowing user-defined filters, specify valid filter properties as:

Filter: <PropertyName1>, <PropertyName2>

Filters are defined using a custom language which allows use logical and relational expression to build the desired filter. A simplified language grammar is:

Table 5.Property description .

<table>
<tr><th colspan="3">Logical Expression</th></tr>
<tr><td>Relational Expression</td><td>|
&</td><td>Relational Expression</td></tr>
</table>

Relational Expression		
Property	= < <= > >= !=	"string" number @timestamp
Property	=% %= %	"string"
Property	in	["string",…,"string"] [number,…,number]

<table>
<tr><th>Symbol</th><th>Operation</th></tr>
<tr><td>&</td><td>Logical AND</td></tr>
<tr><td>|</td><td>Logical OR</td></tr>
<tr><td>=</td><td>Equals to</td></tr>
<tr><td><</td><td>Less than</td></tr>
<tr><td><=</td><td>Less or equal than</td></tr>
<tr><td>></td><td>Greater than</td></tr>
<tr><td>>=</td><td>Greater or equal than</td></tr>
<tr><td>!=</td><td>Different from</td></tr>
<tr><td>=%</td><td>Starts with</td></tr>
<tr><td>%=</td><td>Ends with</td></tr>
<tr><td>%</td><td>Contains</td></tr>
<tr><td>In</td><td>Exists in list of values</td></tr>
</table>

The expected and returned format for the date data type, except where noticed, is the number of milliseconds between January 1, 1970, 00:00:00 UTC, and the desired date. For instance, 2012 January's first would be sent as 1325376000000.

The time data type is used for specifying a time stamp in a generic day. For this data type, the expected format, except where explicitly stated, is the number of milliseconds since the beginning of one day using the UTC standard. This means that the time stamp 20:00:00 of one day would be sent as 72000000. This also means that this data type only accepts values between 0 and 86400000, including these two values.For numbers, the decimal separator used is '.' (dot).

API Entities

E1 - Consumption

This entity represents a consumption report.

```
{ "UnitId": <number: unit id>,
 "Granularity": <string: type of granularity (instant, daily, hourly, monthly or yearly)>,
 "TagId": <number: tag id>,
 "Date": <date: begin date (using the unit time zone) of the time interval to which this consumption data corresponds>,
 "Read": <number: value of the consumption in the default measurement unit of the respective tag type>,
```

```
 "ReadCurrency": <number: value of Read converted to default currency of the supplier>,
 "ReadCarbon": <number: value of Read converted to carbon dioxide values>,
 "Trees": <number: number of trees necessary to compensate the emission of ReadCarbon>,
 "Cars": <number: number of cars which emit ReadCarbon to the atmosphere>,
 "CurrencySymbol": <string: symbol that represents the currency which is used in the value contained
in the field ReadCurrency>
}
```

E2- Device

This entity represents a device.

```
{
"Id": <number: id>,
"Name": <string: name>,
"DeviceTypeId": <number: device type id>,
"TariffId": <number: tariff id>,
"Tariff": <Tariff: tariff>,
"ModuleType": <[ ModuleType]: list of module types that are associated to the device>,
"FixedCostId": <number: id of the fixed cost associated to a tariff>,
"UnitId": <number: unit id>,
"LocalId": <number: local id>,
"Interval": <number: interval between data acquisitions>,
"IsCommunicating": <boolean: flag indicating if it is communicating>,
"Index": <number: index of the device in the unit>,
"Address": <string: Device ID that comes with the Device>,
"Deleted": <boolean: flag indicating if the device is deleted or not>,
"State": <Number: string: the device initial state. By default it is deactivated >,
}
```

E3 - Session

This entity represents a session in the API.

```
{
"Token": <string: session token>,
"Timeout": <number: session timeout in seconds>
}
```

E4 - Tag

This entity represents a tag.

```
{ "Id": <number: id>,
 "UnitId": <number: unit id>,
 "Name": <string: name>,
 "Index":<number: The address of the tag in device>,
 "LocationId": <number: location id>,
 "TagTypeId": <number: tag type id>,
 "Created": <date: date when it was created>,
```

```
 "Active": <boolean: flag indicating if the tag is active>,
 "Deleted": <boolean: flag indicating if the tag is deleted>,
 "Communicate": <boolean: flag indicating if the tag is communicating>,
 "Manual": <boolean: flag indicating if the tag is manual>,
 "Visible": <boolean: flag indicating if the tag is visible>,
 "Validate": <boolean: flag indicating if the tag should be validated>,
 "InternalAddress": <number: internal address>,
 "VirtualField": <string: data value over which the virtual tag is calculated (value of the tag
reading or difference between two values)>,
 "DeviceId": <number: id of the device>
}
```

E5 - Unit

This entity represents an unit

```
{
"Id": <number: id>,
"Name": <string: name>,
"State": <number: unit state id>,
"MacAddress": <string: mac address>,
"LocalId": <number: local id>,
"ModuleType": <[ ModuleType]: list of module types that are associated to the unit>,
"B64AccessKey": <string: access key for direct communication with unit. Note: currently this field has
the same value for all units, but this will be changed in the future>,
"TimeZoneId": <string: time zone id for this unit>,
"HashedSerial": <string: public unit identifier>,
"Interval": <number: communication interval>,
"LastComm": <date: date of last communication>,
"DomainId": <number: id of the domain this unit belongs to>,
"TypeId": <number: unit's type id>,
"IsActive": <boolean: flag indicating whether this unit is valid or not>,
"IsComm": <boolean: flag indicating whether this unit is communicating>,
"Local": <Local: local associated to the unit>,
"Deleted": <boolean: flag indicating if the unit is deleted or not>,
"Dev
"Devices": <[Device]: list of devices that are associated to the unit>,
MonthlyObjective": <number: decimal value that corresponds to the value, in the currency associated to
the user account, of the monthly objective for the unit>,
"LastConfigDate": <date: date of the last configuration change>
}
```

E6 - TagDatas

This entity represents a tag data for the data insertion methods

```
{
"TagId": <number: id>,
"Values": <[Values]: name>,
}
```

E7 - Values

This entity represents the data values for the data insertion methods

```
{
"Value": <number: the value of the sample>,
"Data": <number: epoch timestamp in ms of the sample>,
}
```

API Operations

This section describes the most important API operations for usage by the other EcoShopping modules.

Op1 - CreateSession

This method Logs a user in the API.

Request	*POST /sessions* *User* *Required fields:* *Login* *Password*
Responses	*201 Created* *Session* *Possible error codes:* *400 Bad Request* *null_or_empty.user.password* *invalid_length.user.password* *null_or_empty.user.login* *invalid_length.user.login* *invalid.social_provider* *null_or_empty.facebook.access_token* *null_or_empty.facebook.email* *null_or_empty.user.email* *401 Unauthorized* *no_permissions_to_access*

Op2 - FindUnits

This method returns one list with the details of one set of units, optionally filtered and ordered by lists of its ids and local ids, and optionally showing the information of the local of each unit returned.

Request	*GET /units* *Include: Local,Device,FixedCost,Tariff,Interval* *Where: Id, LocalId, HashedSerial, IsComm* *Order:* ***Id****, LocalId, HashedSerial, IsComm* *Required fields:* *None*

	Optional fields: *Include* *Where* *Order*
Responses	*200 OK* *[Unit]+* *Possible error codes:* *400 Bad Request* *invalid.include_parameter* *invalid.where_parameter* *invalid.order_parameter* *404 Not Found* *not_found.unit* *not_found.local (not implemented yet)*

Op3 - FindTags

This method returns one list with the details of a set of tags, optionally filtered and ordered by lists of its ids, unit ids, tag type ids and device ids.

Request	*GET /tags* *Where: Id, UnitId, TagTypeId, DeviceId* *Order: **Id**, UnitId, TagTypeId, DeviceId* *Required fields:* *None* *Optional fields:* *Where* *Order*
Responses	*200 OK* *[Tag]+* *Possible error codes:* *400 Bad Request* *invalid.where_parameter* *invalid.order_parameter* *401 Unauthorized* *no_permissions_to_access.tag* *no_permissions_to_access.unit* *no_permissions_to_access.device* *404 Not Found*

	not_found.unit *not_found.tag_type* *not_found.device* *not_found.tag*

Op4 - GetConsumptions

This method returns a set of consumptions filtered by granularity, begin date, end date and a list of tag identifiers. It is important to note that some of the tag types are instantaneous (for instance, temperature and humidity). In those cases the request to this method should include the optional field InstantsType, which will determine how the value of Read (one of the fields of the objects Consumption that are returned in this method) will be calculated. If the optional field InstantsType is passed with a null value, the method will treat the request as it was passed the value Avg in that field, for each tag that is noncumulative. If the tag is cumulative, the value passed in the field InstantsType is ignored.

Request	*GET /consumptions/<string: the type of aggregation in which we want to obtain the consumptions >?from=<string: begin date (in the unit time zone) of the time interval to which the calculation will be performed>&to=<string: end date (in the unit time zone) of the time interval to which the calculation will be performed>&tags=<string: list of comma separated tag identifiers, delimited by characters [and]>&instantsType=<string: the instants type>* *Granularity: Instant, Hourly, Daily, Monthly, Yearly* *InstantsType: Avg, Max, Min, Stdev* *Avg – Average* *Max – Maximum* *Min – Minimum* *Stdev – Standard deviation* *Required fields:* *Granularity* *From* *To* *Tags* *Optional fields:* *InstantsType*
Responses	*200 OK* *[Consumption]* *Possible error codes:* *400 Bad Request* *null_or_empty.granularity* *null_or_empty.from_date* *null_or_empty.to_date* *null_or_empty.tags* *invalid.consumption_granularity – invalid_value.granularity* *invalid.generic.dates – invalid_value.from_date ; invalid_value.to_date ; invalid_date_relation.from_date_vs_to_date*

	invalid.instant_type – invalid_value.instant_type *401 Unauthorized* *no_permissions_to_access.tag (not implemented yet)* *404 Not Found* *not_found.tag (not implemented yet)*

Op5 - Data Insert

This method enables the possibility to insert data into the server on a specific tag. This method can be used for submitting simulation result data or occupancy data obtained by the Ecoshopping systems.

<table>
<tr><td>Request</td><td><pre>
POST http://data_server_ip/api/1.1/data HTTP/1.1
Accept-Encoding: gzip,deflate
Content-Type: application/json
User-Agent: Jakarta Commons-HttpClient/3.1
Host: 213.228.179.13:5555
Content-Length: 48
Body:
{
    "TagDatas": [
        {
            "TagID": 2606,
            "Values": [
                {
                    "Value": 11.42,
                    "Data": 1399635600000
                },
                {
                    "Value": 11.11,
                    "Data": 1399635900000
                }
            ]
        }
    ]
}
</pre></td></tr>
<tr><td>Response</td><td><pre>
204 No Content
 Cache-Control: no-cache, no-store, must-revalidate
 Pragma: no-cache
 Expires: 0
 Server: Microsoft-IIS/8.0
 Access-Control-Allow-Origin: *
 X-AspNet-Version: 4.0.30319
 X-Powered-By: ASP.NET
 Date: Fri, 09 May 2014 13:55:16 GMT
</pre></td></tr>
</table>

API Usage Scenario

In order to use the API, first an authentication has to be performed using the CreateSession method. This method needs a valid username and password and, if the authentication is valid, returns a token that can be used to identify the user in the following requests. An example of one possible pair request/response to this method is shown below.

Request	*POST http://data_server_ip/api/1.1/sessions HTTP/1.1* *Accept-Encoding: gzip,deflate* *Content-Type: application/json* *User-Agent: Jakarta Commons-HttpClient/3.1* *Host: 213.228.179.13:5555* *Content-Length: 48* ***Body:*** *{* *"Login":"my_username",* *"Password":"my_password"* *}*
Response	*HTTP/1.1 201 Created* *Server: ASP.NET Development Server/10.0.0.0* *Date: Fri, 29 Jul 2011 14:17:15 GMT* *X-AspNet-Version: 4.0.30319* *Content-Length: 117* *Cache-Control: private* *Content-Type: application/json; charset=utf-8* *Connection: Close* *{* *"Timeout": 900,* *"Token": "qv6/8VpPAK9+Hon6RQVSIMZCRMZMKAZ+L9y3/0qXkJ7N+PyAsda0mdAv6YZV6zyC4+ReDWwGqQiuGMnANqqHsw==",* *}*

The authentication token is valid for the “timeout” value, which is in this case 900 seconds. After the timeout has expired, a new token must be generated using the same method.

After the authentication has been performed, a method to discover the user’s units may be called: the FindUnits Method. An example request and response follows.

Request	*GET http://data_server_ip/api/1.1/units?Where=Id%3D94%7CId%3D2&Order=-LocalId%2CId&Include=Local HTTP/1.1* *Accept-Encoding: gzip,deflate* *Accept: application/json* *Authorization: ISA qv6/8VpPAK9+Hon6RQVSIMZCRMZMKAZ+L9y3/0qXkJ7N+PyAsda0mdAv6YZV6zyC4+ReDWwGqQiuGMnANqqHsw==* *User-Agent: Jakarta Commons-HttpClient/3.1* *Host: 213.228.179.13:5555* ***Body:***
Response	*HTTP/1.1 200 OK* *Server: ASP.NET Development Server/10.0.0.0* *Date: Fri, 29 Jul 2011 15:18:09 GMT* *X-AspNet-Version: 4.0.30319*

	Content-Length: 508
	Cache-Control: private
	Content-Type: application/json; charset=utf-8
	Connection: Close
	{
	"List": [
	{
	"B64AccessKey": "000111222333444555",
	"Id": 94,
	"Local": {
	"CountryCode": "PT",
	"Id": 85,
	"IsStorage": false,
	"Name": "B0605-Trofa",
	"UserId": 1,
	"ZipCodeId": 190856
	},
	"LocalId": 85,
	"MacAddress": "00-04-A3-22-81-D8",
	"Name": "B0605-Trofa",
	"State": 1
	},
	{
	"B64AccessKey": "000111222333444555",
	"Id": 2,
	"Local": {
	"CountryCode": "PT",
	"Id": 4,
	"IsStorage": false,
	"Name": "iMeter ESI Testes",
	"UserId": 1,
	"ZipCodeId": 71756
	},
	"LocalId": 4,
	"MacAddress": "00-04-A3-22-88-C7",
	"Name": "iMeterTeste ESI",
	"State": 1
	}
	],
	"Page": 0,
	"PageSize": 50,
	"Total":2
	}

This response shows the list of units in the database that match the request criteria and their respective information. The list is composed by 2 elements, the ones whose id is 94 or 2, using the fields “LocalId” (in decreasing order) and “Id” (in crescent order) for ordering. The page size used to show the results list is 50 and only the first page (page 0) of that list is shown (which is the only one, in this particular case). The information of the each unit's local is also displayed.

The tags belonging to a unit can also be retrieved. For this task, the FindTags request should be issued. The following table illustrates an example of the retrieval of the tags from a Unit.

Request	*GET http://data_server_ip/api/1.1/tags? where=TagTypeId+in+%5B4%2C5%5D+%26+UnitId+%3D+2 HTTP/1.1* *Accept-Encoding: gzip,deflate* *Authorization: ISA qv6/8VpPAK9+Hon6RQVSIMZCRMZMKAZ+l9y3/0qXkJ7N+PyAsda0mdAv6YZV6zyC4+ReDWwGqQiuGMnANqqHsw==* *User-Agent: Jakarta Commons-HttpClient/3.1* *Host: 213.228.179.13:5555* ***Body:***
Response	*HTTP/1.1 200 OK* *Server: ASP.NET Development Server/10.0.0.0* *Date: Fri, 29 Jul 2011 15:18:09 GMT* *X-AspNet-Version: 4.0.30319* *Content-Length: 508* *Cache-Control: private* *Content-Type: application/json; charset=utf-8* *Connection: Close* *{* *"List": [* *{* *"Active": true,* *"Communicate": false,* *"Created": 1311870060000,* *"Deleted": false,* *"DeviceId": 895,* *"DomainId": 2,* *"Id": 2684,* *"InternalAddress": 0,* *"LocationId": 151,* *"Manual": false,* *"Name": "Energia Activa",* *"RemoteId": null,* *"TagTypeId": 4,* *"UnitId": 2,* *"Validate": false,* *"VirtualField": null,* *"Visible": true* *},* *{* *"Active": true,* *"Communicate": false,* *"Created": 1311870060000,* *"Deleted": false,*

	"DeviceId": 896, "DomainId": 2, "Id": 2687, "InternalAddress": 0, "LocationId": 151, "Manual": false, "Name": "Energia Activa", "RemoteId": null, "TagTypeId": 4, "UnitId": 2, "Validate": false, "VirtualField": null, "Visible": true }], "Page": 0, "PageSize": 50, "Total": 2 }

This response shows the list of tags in the database that match the request criteria and their respective information. The list is composed by 2 elements, the ones whose tag type id is 4 or 5 and unit id is 2, using the default ordering (by the field "Id", in crescent order). The page size used to show the results list is 50 and only the first page (page 0) of that list is shown (which is the only one, in this particular case).

The values from each tag may be also retrieved from the API. For this task the GetConsumptions method should be used. The following table illustrates a GetConsumptions request.

Request	***Full path:*** *http://data_server_ip/api/1.1/consumptions/daily?to=1406105200000&from=1304982000000&tags=%5B2684%5D* ***HTTP method:*** *GET* ***Authorization HTTP header:*** *"ISA qv6/8VpPAK9+Hon6RQVSIMZCRMZMKAZ+l9y3/0qXkJ7N+PyAsda0mdAv6YZV6zyC4+ReDWwGqQiuGMnANqqHsw=="* ***Media type:*** *Application/json* ***Body:***
Response	***Media type:*** *Application/json* ***Body:*** [{ "Cars": 329.622, "Date": 1311897600000, "Granularity": "daily", "Read": 109.874, "ReadCarbon": 38.4559, "ReadCurrency": 13.3052, "TagId": 2684, "Trees": 219.748,

	"UnitId": 150 }]

5.3 Hardware specification

This section describes the different used hardware interfaces in the different sub-systems of the platform.

5.3.1 Fixed sensors network

The fixed sensors network makes use of several distinct hardware interfacesfor transferring information between components, namely the acquired data samples (Table 6).These are described in section 4.6.3.

Table 6. Communication protocol and components

Communication protocol	Components
Modbus RTU	Electrical Meters Light sensors M-Bus to Modbus RTU gateway/converter
Modbus IP	RF ISM 868MHz to Modbus IP gateway
M-Bus	Heat Meters
RF ISM 868MHz	Air temperature and humidity sensor Air CO2 sensor
24.GHZ IEEE 802.15.4	Sensor Gateway Remote Nodes

5.3.2 Fixed acoustic sensor network

It is the purpose of the fixed acoustic sensor network to gather occupancy data by means of acoustic sensors in large public area. Therefore, a sensor network can be used as fixed and unobtrusive installation. Placing the microphones at reasonable positions a large environment can be monitored. In addition, it is possible to permanently monitor environments of particularly relevance, such as stairway corridors or cash decks.

5.3.2.1 **Functional Components specification**

Using multiple microphone-arrays to, e.g., enhance localization accuracy requires a clock skew well below the sampling interval. This low clock skew is usually achieved by physically distributing a clock signal to every module. This requires separate cables which is not suitable for usage e.g. in large buildings.

PTP Standard IEEE1588 [12] states that – if specialized hardware is used directly above the physical layer – clock skews around 10ns can be achieved.

This specialized hardware can be implemented in FPGA achieving lowest possible delay from message reception to response transmission. Although several microprocessor models for FPGA exist, the system described in this contribution is solely based on finite-state-machines to provide the best possible deterministic behavior of the system.

5.3.2.2 **Network Design/Structure**

The acoustic sensor network consists of one PTP-master and several more slaves. The network traffic itself is isolated from the other network traffic by using a dedicated Ethernet switch. However, this switch is reserved for the acoustic network traffic; no dedicated PTP switch is needed, lowering the hardware costs. The audio data streams are sent to the audio-processing-unit using the user datagram protocol (UDP). The audio-processing-unit is not involved in the PTP synchronization and can thus be connected through an existing gigabit Ethernet with any additional data traffic, assumed enough free data bandwidth is available. Nevertheless, the audio stream alignment of all received data packages is managed on the external audio-processing-unit. Please note, that the used network protocol is theoretically feasible to integrate other sensors as well and not only acoustic sensors.

5.3.2.3 **Microphone Hardware**

Small electret microphone capsules (e.g. Panasonic WM61a) or recently new available MEMS microphones[1] are used. Working with up to 10V phantom power, the analog microphone signal is transferred to the microphone slaves using symmetrical wiring. The analog to digital signal conversion is performed on the data capturing board as part of the microphone-array slave.

5.3.2.4 **Microphone Position**

The microphones are connected to the microphone-array slave by symmetric wiring. The analog signal transmission requires a distance not longer than two meters between the microphones and the microphone-array slave. The cable length between a single microphone-array slave and the Gigabit switch should not exceed a length of 70 meter.

The distance between the dedicated Gigabit-switch and the audio-processing-unit highly depends on the used Ethernet network. If a standard Cat5-Ethernet wiring between the switch and processing-unit is used, than again the distance should not exceed 70 meter.

5.3.2.5 **Field-programmable gate array (FPGA) – based Microphone-Slave**

The overall design mainly consists of five parts:

- Data Capturing (Additional PCB-Design with ADC and preamp)
- Audio Interface (I²S)
- Data Buffer (2 Mbit internal SRAM)
- PTP Clock Management
- Protocol Stack

[1]http://www.digikey.com/us/en/techzone/sensors/resources/articles/mems-microphone-apps.html

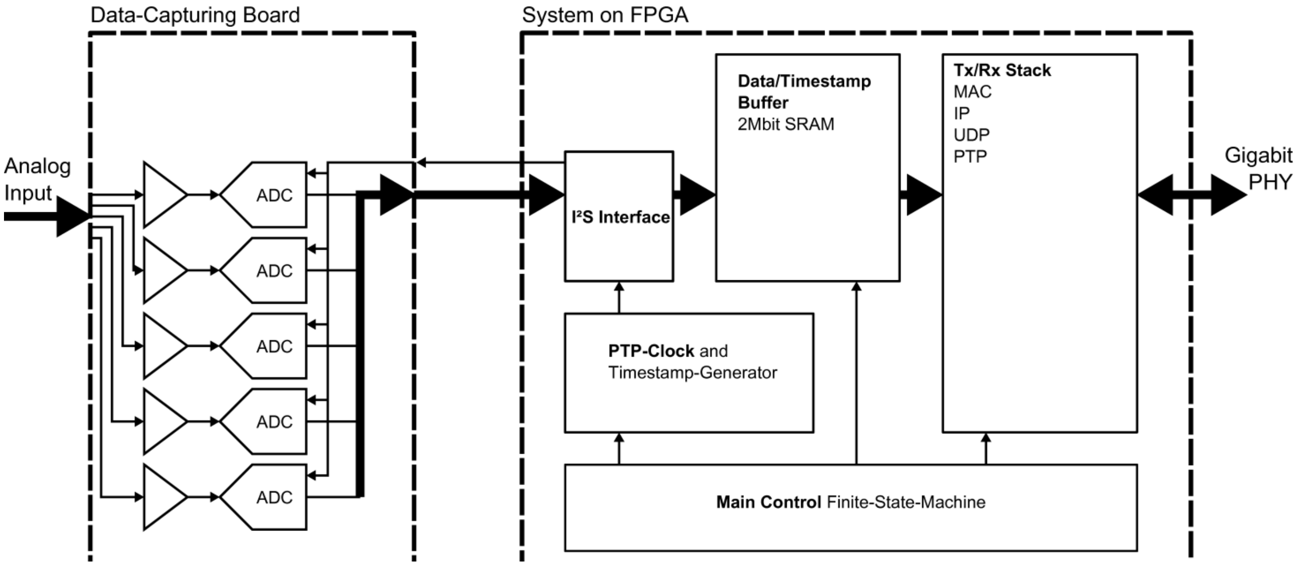

Figure 7. Structure of the Modules consisting of FPGA-Board and Data-Capturing Board.

Figure 7. depicts the system architecture of a single microphone-array slave. The analog microphone signals are first fed into the data-capturing board (left input in Figure 7.). After the analog digital signal conversion (ADC), the signal is forwarded to the FPGS board using the I²S interface. Within the FPGA board the time-synchronization, with the other microphone-array slaves, and the UDP data-package generation, is performed. The generated UDP signal-data packages are sent via standard Ethernet connection.

It is very important that the modules are capturing the reception and transmission times exactly. Instead of travelling through a large software protocol stack, the message can be captured directly, when using dedicated hardware.

PTP uses three messages to determine the message delay and the clock skew between master and slave. Figure 8. shows synchronization process for PTP protocol.

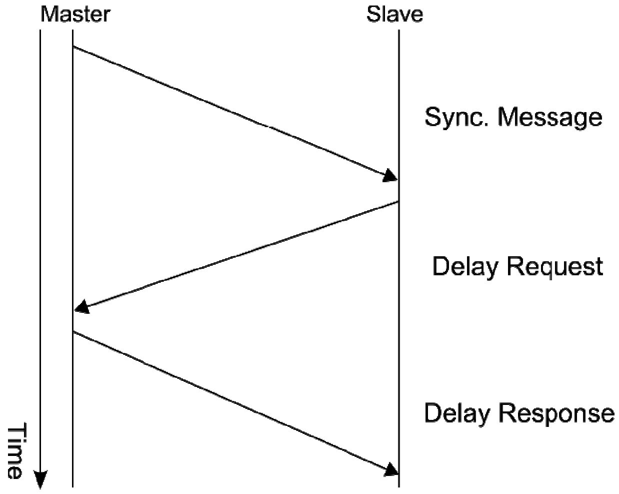

Figure 8. PTP-Synchronization Process using 3 Messages to determine clock deviation of slave.

The Figure 9. depicts a prototype of a microphone array FPGA slave without the data-capturing board. The data-capturing board will be attached on top of the FPGA circuit using the pin headers.

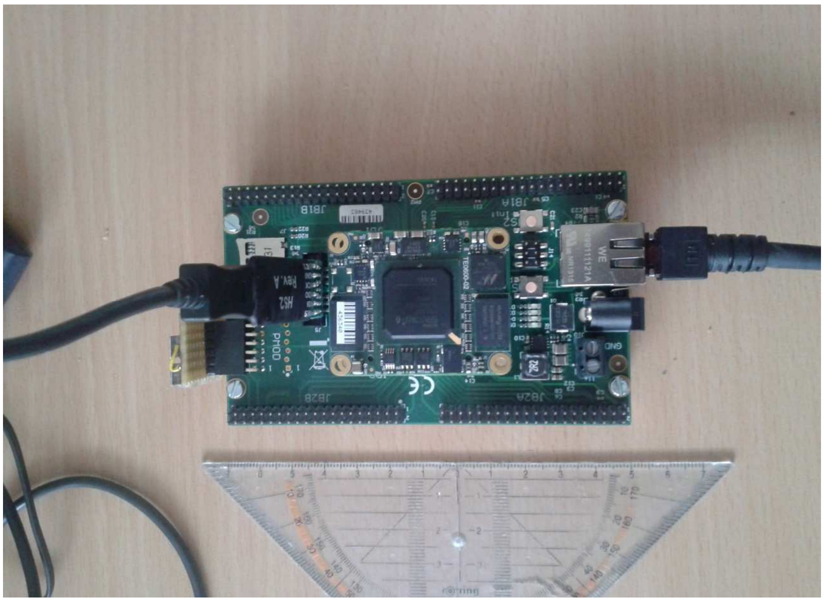

Figure 9. Prototype of a microphone array slave.

5.3.2.6 Connection to Mobile Robot Platform

The acoustic sensors mounted on the mobile robot platform will also be made of a single microphone slave (with up to 10 microphones) similar to the fixed sensor array hardware and data protocol. The (audio/meta)-data from the mobile robot platform and from the fixed sensor network is fused in the audio-processing-unit.

The audio data processing can either be performed autonomously on the mobile robot platform itself or the raw audio data is send to the audio-processing-unit using a wireless Ethernet connection. However, it is not possible to synchronize the raw audio data from the mobile robot platform and from the fixed sensor platform.

5.3.2.7 Audio Processing Unit

The audio-processing-unit gathers all raw audio data from the fixed acoustic sensor network, as well as metadata from the mobile robot platform. Subsequently, the data fusion and final metadata generation is performed on the audio-processing-unit. The metadata is sent to the data storage if required.

The acoustic sensor network is still under development, hence the exact requirements and specifications for the audio-processing-unit PC are only some general pointers. It will be a reasonably powerfull PC, since real-time processing of multi-channel audio data can be quite demanding. It will also have the ability to communicate with the mobile robot platform via WiFi. The location of the audio-processing-unit must be within reach of the acoustic sensor network, i.e. less than 70 meters distance. Depending on the existing IT-structure and the final location, an appropriate design (desktop, tower, rack) can be choosen.

5.3.2.8 Connection to Database/Storage

The fixed acoustic sensor network has access to the database storage using the audio-processing-unit. The individual microphone array slaves do not need to have access to the database-storage, since they only provide measurement data. It may be necessary to have access to the microphone nodes for maintenance issues.

The audio processing unit will send the estimated occupancy level data to the database storage.

5.3.2.9 Expected Performance

The minimum skew as well as the latency of the streaming system will be strongly dependent on the used network topology. The latency increases with every network element used between streaming system and host. For an optimal performance the system should be isolated from other network traffic by a separate Ethernet-Switch.

The major goal of this contribution is to reach a clock skew of below 500ns. The second goal is to reach a maximum latency of less than 10µs from the modules to a host directly connected to the isolating switch.

5.3.2.10 Number of Components

Ten microphones can be attached to a single slave. Currently, up to seven slaves can be used within a single acoustic sensor network. In total, this makes up to 70 microphones. Furthermore, the network interface protocol could be modified to handle up to 20 slaves in a single network. Each fixed acoustic sensor network requires a dedicated Gigabit switch.

5.3.2.11 Expected Energy consumption

One major objective of the EcoShopping project is the reduction of the energy consumption of the equipped building. Therefore, the overall EcoShopping system itself should have a low energy consumption.

Following, we list the expected energy consumption of each single system component:

- 5-20W for each microphone slave
- 12W for Gigabit switch
- 90W for the Processing unit

5.3.2.12 Costs

The anticipated costs depend on the specific setup on each demo site. The expected costs for each system component of the fixed sensor network are as follows:

- 350-400€ FPGA
- 3-4€, per microphone
- 80€, switch
- 1000-3000€, Processing unit
- Unknown costs for cabling

5.3.2.13 Features and Advantages of the Fixed Sensor Network

With the fixed audio sensor network a highly synchronous audio data network is available to the EcoShopping project. Due to the used standard Ethernet TCP/IP network connection a simple and easy to install hardware setup is available. No additional audio capturing card (short: soundcard) for the processing unit is necessary. Without the need of a soundcard, a spatial separation between the processing unit and fixed acoustic sensor network is possible. Each component of the network only consumes low amount of energy. The proposed fixed sensor network is highly adjustable to the specific conditions at each installation/demo site. Additionally, the integration of other sensors is possible. The used design will consume less than 20% of total FPGA-fabric on the used chip. This allows the integration of fast preprocessing-routines (e.g. IIR-Filter, FFT, etc.) on the slaves itself. In the long term, the system could also be able to stream from the host to the module, to enable isosynchronous audio output from spatially distributed modules Finally it is possible to use Power-over-Ethernet (PoE) to create small capturing modules that are easy to install.

5.3.2.14 **Risks and Disadvantages of the Fixed Sensor Network**

No direct connection between the mobile robot platform and the fixed acoustic sensor network and its microphones is possible. No synchronization between the raw audio data of the mobile robot platform and the fixed sensor network is possible. The cable length between the dedicated Gigabit switch and a single microphone array slave should not exceed more than 70 meter. Each slave needs to be configured with the correct number of slaves active in a network. Therefore, a manual jumper setting on each slave is needed. Thus, when adding or removing a slave form the network all remaining slave need to be reconfigured additionally. If the Ethernet network of the building is not suitable to connect to a Gigabit switch a complete dedicated acoustic sensor network up to the data processing unit would be necessary.

5.3.3 Mobile robot platform

The fixed sensor network is supplemented by a mobile robot system, based on the MetraLabs SCITOS G5 platform (http://metralabs.com). The basic G5 robot module already includes an industrial PC with Wi-Fi (IEEE 802.11a/b/g), and it conforms to the European CE-guidelines for the public indoor sector and is approved by the German Technical Inspection Agency (TÜV). According to the requirements at hand, it will be extended with optional components and equipped with custom-build modules. This includes a laser scanner for navigation, cameras for surveillance, a touchscreen display unit and acoustic sensors. (c.f. Figure 10.) The additional human-machine interface module comprises a movable robotic head with eyes that are able to wink, and a 15” touch-screen display at a resolution of 1024-by-768 pixels.

The mobile robot unit runs on differential high torque gear-motors, enabling driving speeds up to 1,4 m/s, or rotations up to 200 °/s. Equipped with acoustic sensors and pre-processing capabilities, the robot acts as a mobile sensor module within the fixed sensor network, thus adding a dynamic component. Such a mobile module can improve the sensor network reliability by putting sensors right where they’re needed, eventhough its limitations. The robot may compensate for weak-points within the fixed network, thus the fixed sensor network can be implemented with fewer sensors, while the robot substitutes missing sensors on demand.Just like the fixed sensors, the robot features microphones that are used to record acoustic data. Similar to the network’s processing unit, the robot will process the acquired data and estimate the occupancy level at the robot’s current location. Via Wi-Fi, the occupancy level data will be transmitted for interpretation.

Using acoustic event detection algorithms, the robot unit may perform safety and security duties. Acoustic events (e.g. someone yelling for “help”) can be detected and a notification is send to an operator. The (remote) operator may use the robot unit’s cameras to assess the situation. During business hours, the robot’s touch-display unit may provide information on the EcoShopping project, current energy consumption.

The robot is powered by 24V lithium batteries with 60Ah, which enables it for up to 16 hours of autonomous operation. The robot may automatically drive to a special recharging station. A full recharge takes about 6 hours.

The SCITOS G5 mobile robot platform features a build-in Linux-based industrial PC system, running the 12.04 Long-Term-Support (LTS) version of Ubuntu (Precise Pangolin). This operating system supports a broad range of hardware and is officially supported until April 2017. Sensor modules (e.g. microphones, temperature or humidity) will be added to the custom-build robot system, as they are provided to the robot’s manufacturer. The preferred interfaces for adding new sensors are USB or Ethernet-connections on the Linux-PC.

However in case the sensor hardware proves to be compatible with the robot's internal CAN bus systems, it may also be integrated that way.

Figure 10. The MetraLabs SCITOS G5 mobile robot platform base module (left), with aditional human-machine interface module (middle) and casing closed (right).

5.3.3.1 **Specification of the Microphone Positions on the Robot**

Suitable locations for the acoustic sensor on the mobile robot platform are still to be evaluated. At this point it is planned to place eight microphones on top of the robot's head. However, in this case, cable connections could become a problematic since the cables would have to go through the rotating robot head. An alternative position is just below the spherical head around the robot's neck. Cable connection would be simplified, but the sound field will be partially affected by the head and the robot's display unit. The most optimal microphone locations are still under investigation. In any case, it is planned to have two additional microphones placed inside the robots casing to record the inherent noise of its internal systems. These recordings will be used to identify and attenuate the effects of sounds of robot during audio processing.

The robot will be equipped with a similar acoustic sensor module, as it is used by the fixed sensor network. The sensor module will be powered by the robot's battery and provide the audio data to the robot's internal PC via its Ethernet network adapter.

5.3.4 Control system

For control system National Instruments Compact Reconfigurable Input/Output (cRIO) hardware will be used. The NIcRIO-9014 embedded real-time controller features an industrial 400MHz Freescale MPC5200 real-time processor for deterministic, reliable real-time applications. The cRIO-9014 contains 128MB of DRAM and 2GB of non volatile storage. The Compact RIO embedded controller is designed for extreme ruggedness, reliability, and low power consumption with dual 9 - 35 VDC supply and a -40 to 70 °C operating range temperature. With the 10/100 Mbits/s Ethernet port, you can conduct programmatic communication over the network and built-in Web (HTTP) and file (FTP) servers. For additional storage capability, the cRIO-9014 has a full-speed USB host port to which you can connect external USB-based storage media (flash drives and hard drives) for embedded logging applications requiring additional storage. Also, cRIO-901x controllers include an embedded fault-tolerant file system that provides increased reliability for data logging. Picture of the cRIO-9014 embedded controller is shown in Figure 11. .

Figure 11. cRIO-9014embedded controller.

The cRIO-9014 runs the NI LabVIEW Real-Time Module on the VxWorks real-time operating system (RTOS) for extreme reliability and determinism.Working principle of cRIO-9014 is given in Figure 12.

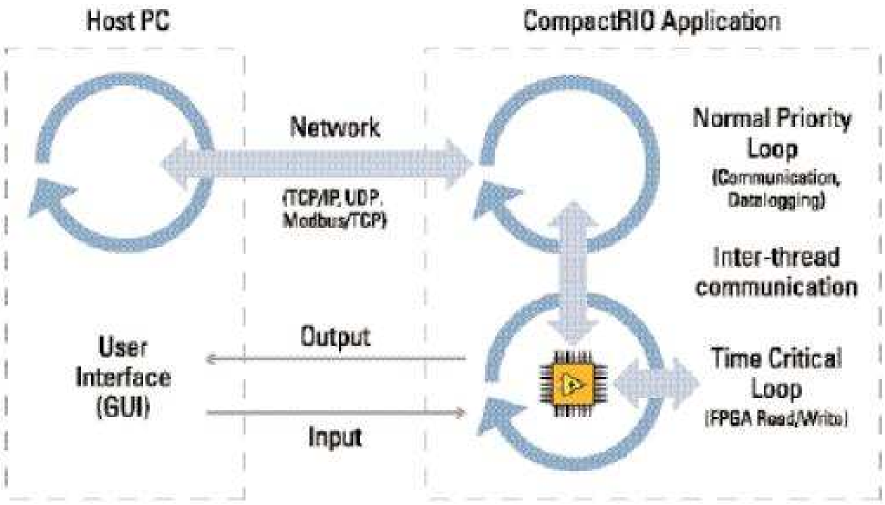

Figure 12. CompactRIO software architecture.

These NI Compact RIO real-time controllers connect to any four or eight slot Compact RIO reconfigurable chassis, see Figure 13. . The user-defined field-programmable gate array (FPGA) circuitry in the chassis controls each I/O module and passes data to the controllers through a local PCI bus using built-in communication functions.

Figure 13. Four and eight slot Compact RIO reconfigurable chassis.

5.3.4.1 **Embedded Software**

You can synchronize embedded code execution to an FPGA-generated interrupt request (IRQ) or an internal real-time clock source. The NI LabVIEW Real-Time ETS OS provides reliability and simplifies the development of complete embedded application. That includes time-critical control and acquisition loops in addition to lower-priority loops for post-processing, data logging, and Ethernet/serial communication. Built-in elemental I/O functions such as the FPGA Read/Write function provide a communication interface to the highly optimized reconfigurable FPGA circuitry. Data values are read from the FPGA in integer format and then converted to scaled engineering units in the controller.

5.3.4.2 **Built in server**

In addition to programmatic communication via TCP/IP, UDP, Modbus/TCP, IrDA, and serial protocols, the cRIO controllers include built-in servers for Virtual Instrument Software Architecture (VISA), HTTP, and FTP. The VISA server provides remote download and communication access to the reconfigurable I/O (RIO) FPGA over Ethernet. The HTTP server provides a Web browser user interface to HTML pages, files, and the user interface of embedded LabVIEW applications through a Web browser plug-in. The FTP server provides access to logged data or configuration files.

5.3.4.3 **Other components**

No hardware interfaces are foreseen for the building model module. Hardware interfaces from Automation Control to HVAC actuators will be defined in WP4, T4.1 so it is not possibleyet to provide information on hardware interfaces regarding IAU.

6. SYSTEM ARCHITECTURE

6.1 Overview

The main functionalities of the Signal Processing Units (SPU) are (Figure 14):

1) A functional and adaptable sensor that detects degrees of occupancy, temperature, radiation, illuminance, humidity, air quality in different types of inside/outside areas and transfers these parameters to the IAU for optimization.
2) A semi-automatic learning system that is managing abnormal signals, digesting and sending them to the Internet, so they can be analyzed manually by experts in order to retrain the system in an early stage of the EcoShopping project. Later on, an Internet-based semantic repository of signals will be built that provides processing packets to be downloaded to the system so it can learn from the experience of others to improve its capacities.
3) The sensing system will be based on a Hardware/Software platform easily adaptable and scalable to diverse buildings and spaces and, moreover, the compatibility to the existed BAM system (Figure 15) will be taken into account.

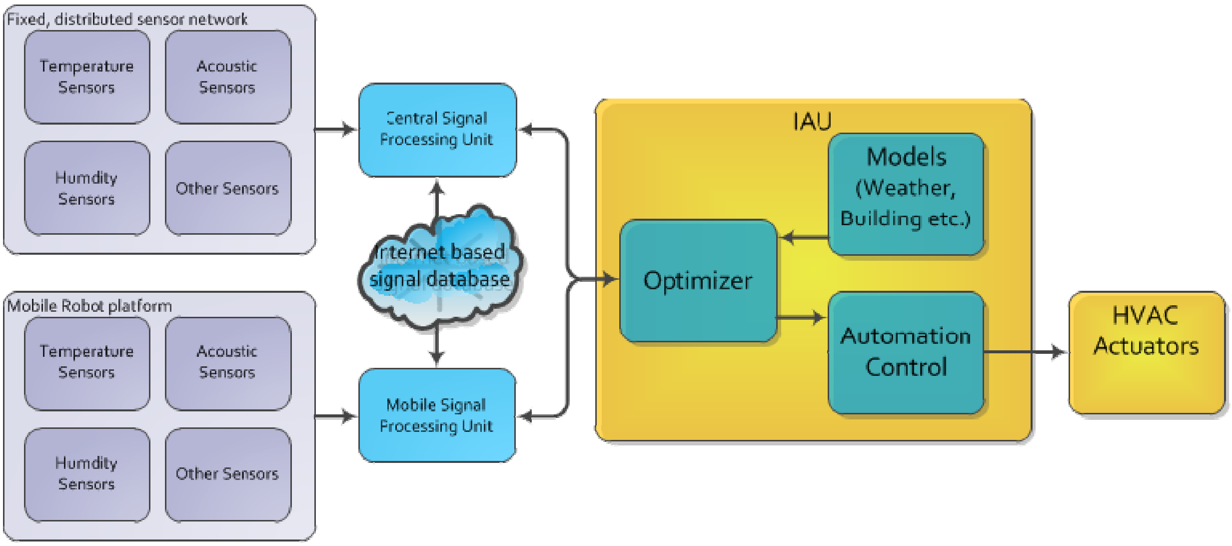

Figure 14. System Architecture and main functionalities of the IAU.

Regarding the SPU, innovations will also include:

- the integration of available technologies,
- the configuration and installation of the sensors network,
- the methods of signal processing,
- the algorithms and semantics of the acoustics events identification.

In order for intelligent algorithm to perform controlling, optimization, monitoring and reporting, first it needs to be implemented on suitable "intelligent" hardware platform. National Instrument's CompactRIO (cRIO) is programmable automation controller (PAC) that isflexible, reconfigurable control and acquisition system. It supports flexible hardware that can be used to implement intelligent control algorithm and wireless sensor network communication.

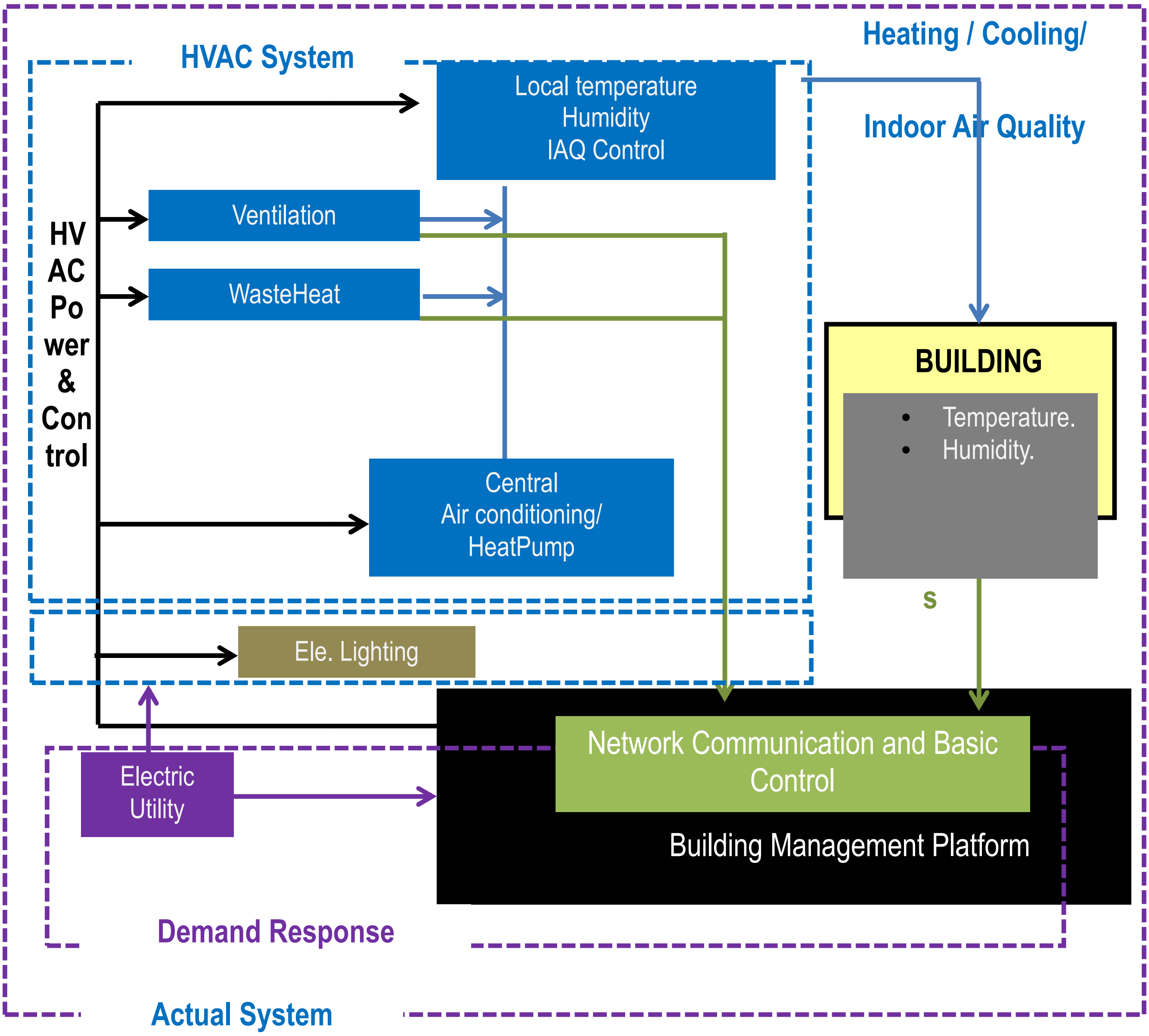

Figure 15. Actual BAM.

6.2 Fixed Sensor Network Architecture

The generic architecture of the fixed sensor network is described on *Figure* 16. . This architecture serves as a reference to the physical implementation of the fixed sensors network in the pilot facility and can be replicated to any other replication facilities where the Ecoshopping product will be installed.

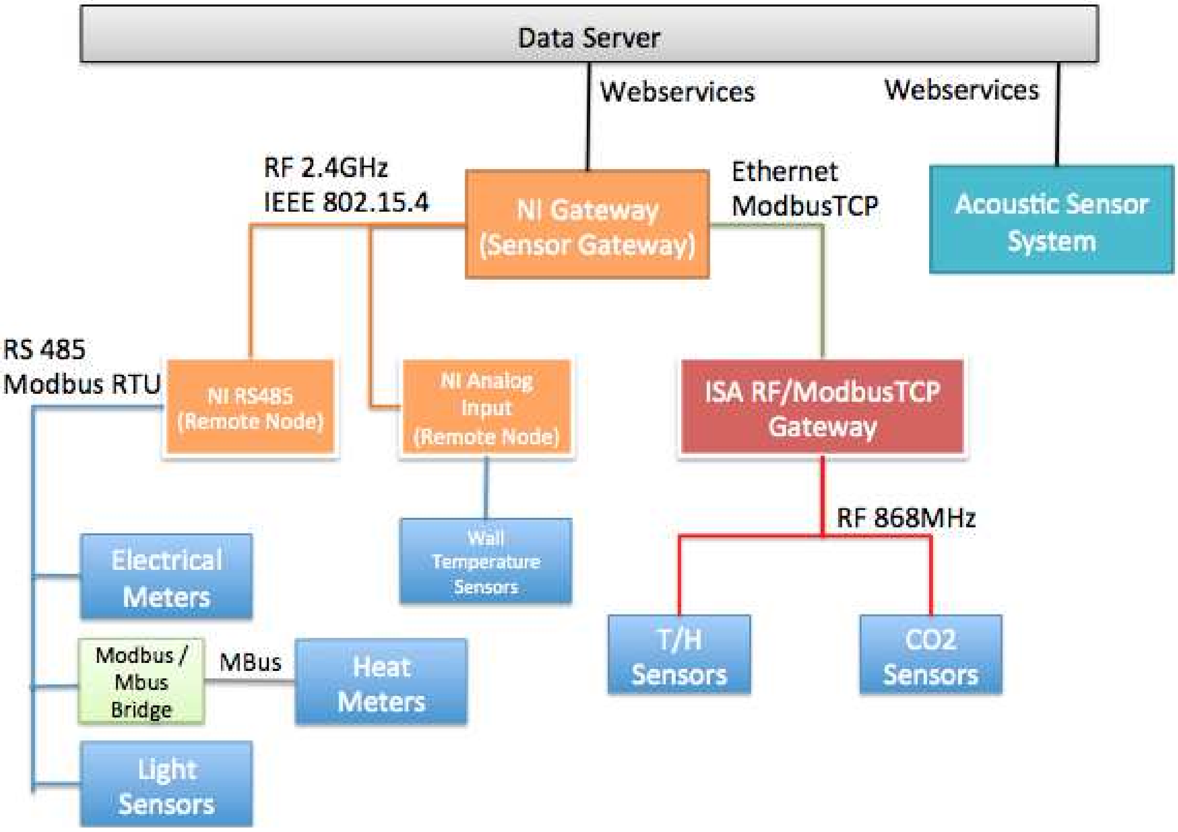

Figure 16. Fixed sensors network architecture diagram.

This architecture is based on a National Instruments backbone, composed by a central gateway (Sensor Gateway) and one or more remote nodes needed for integrating the sensors. The remote nodes communicate with the Sensor Gateway using a 2.4 GHz IEEE 802.15.4 wireless network. The Acoustic Sensor Network module communicates the acquired values directly to the Data Server using the specified Webservices.

The main specifications of the Sensor Gateway to be used in the Ecoshopping fixed sensor network are represented in the next tables (from Table 7 to Table 14) and figures (From Figure 17 to Figure 29).

Table 7.Sensor Gateway (NI 9792 Programmable Gateway)

 *Figure 17.*NI 9792 Programmable Gateway.	Main specifications: • Industrial grade • 533 MHz processor • Dual Ethernet ports • 2.4GHz IEEE 802.15.4 wireless network • Capability to communicate with 36 distributed remote nodes • Integrated web server

One or more Remote Nodes will be used to read information from the sensors installed on the field. Several types of remote nodes are available to be used with the Sensor Gateway. In the

Ecoshopping project it is expected to use RS485 Remote nodes, to read values from the Modbus RTU sensors, such as electrical meters, light meters or heat meters through a Modbus RTU to MBus protocol bridge. The Remote Nodes to be used in the Ecoshopping system are:

Table 8.*Remote Nodes*

 *Figure 18.* NI 3231 RS485 Remote Node.	Main specifications: • Industrial grade • Programmable, autonomous interface to serial sensors, instruments or control boards • One RS485 port and two digital I/O lines • 2.4 GHz IEEE 802.15.4 radio that provides up to 300 m outdoor range • Low-power operation with up to 3-year battery life
 *Figure 19.* NI 3202 Analog Input Remote Node.	Main specifications: • Industrial grade • Four analog input channels • Four digital I/O lines • 2.4 GHz IEEE 802.15.4 radio that provides up to 300 m outdoor range • Low-power operation with up to 3-year battery life

6.2.1 Electricity energy monitoring

For reading the energy consumed by the facility, electrical meters will be used. The used electrical meters will analyse the relevant electrical circuits on the facility electrical boards and provide the information on the Modbus RTU interface which will be connected to the RS485 Remote Node (NI 3231). Several electrical parameters such as consumed active energy, consumed reactive energy, voltage, current, frequency or power factor are provided by the electrical meter on the Modbus interface in the respective Modbus registers. The electrical meters make use of suitable current transformers to analyse the measured circuit and compute all the provided measurements. *Figure* 20. describes the electrical diagram of the electrical meter connections to measure an electrical circuit.

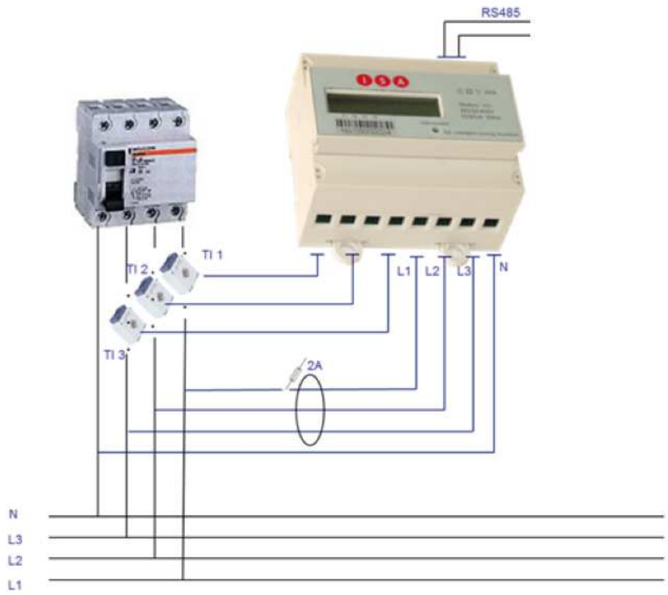

Figure 20. Electrical meter diagram.

For the electrical circuit metering, the ISA iMeter electrical meter or any 3rd party electrical meter with identical characteristics acquired from the market can be used. For this deliverable the ISA iMeter was considered to be used and the following table illustrates the main characteristics for this electrical meter.

Table 9.Electrical meter (iMeter).


Figure 21.iMeter electrical meter.
	General Characteristics:
	• Communication: Modbus over RS485 (Modbus RTU)
	• Voltage rating: 230 VAC (phase to ground voltage)
	• Number of measured circuits: 1 triphasic or 3 moniphasic
	• Mechanical fixing: DIN Rail montage
	• Measured variables:
	  o Instant active, reactive, apparent power
	  o Accumulated active, reactive, apparent energy
	  o Instant power factor on each phase
	  o Instant Frequency
	  o Instant voltage on each phase and inter-phases

6.2.2 Heat energy monitoring

For measurement of delivered/consumed heat energy, heat meters will be used in the project. By analysing the fluid (commonly water) flow rate, flow temperature and return temperature, the heat meter is capable of computing the produced heat energy by a boiler or the delivered heat energy to a radiator or other heat consuming device or devices.

The most common protocol available to read information from heat meters is the M-Bus protocol. To integrate the measurements performed by the facility's heat meters, a protocol converter (usually known as a bridge) has to be used to convert the M-Bus protocol used by the heat meters into the Modbus RTU,which can be easily read by the RS485 Remote Nodes (Figure 22).

Figure 22. Usage of the M-Bus to Modbus converter for heat meters reading.

The Kamstrup Multical 402 heat meter (or any other similar heat meter) having a M-Bus communication interface may be used for the purpose of monitoring the heat energy. The following table describes the main characteristics of the Kamstrup Multical 402 heat meter.

Table 10.Heat Meter (Kamstrup Multical 402)

 *Figure 23. Kamstrup Multical 402 Heat meter.*	General Characteristics: • Communication: M-Bus (slave, wired) • Measured parameters: o Heat energy o Flow meter o Flow temperature o Return temperature • Power supply: D-Cell battery • Authonomy: 12 years • Water temperature range: 15..130ºC

The bridge to be used to convert the M-Bus communication into a Remote Node readable Modbus RTU is the ADF HD67029M-485 device. The device's main characteristics are described in the following table.

Table 11.M-Bus to Modbus RTU protocol converter.

 *Figure 24. ADF HD67029M-485.*	General Characteristics: • Communication with iHub: Modbus/RS485 • Communication with heat meter: M-Bus • Power supply: 15..21 VAC; 18..35VDC • Data rates M-Bus: Up to 38400 bps • Data rates Modbus: Up to 115200 bps • Mechanical fixing: DIN Rail montage

6.2.3 Light level monitoring

For light level monitoring a light sensor will be used. This light sensor has the capability to provide by Modbus RTU the light intensity of a specific point in Lux unit. This sensor can be connected directly to the RS485 Remote Node by the Modbus RTU communication interface. For this purpose, the Ocean Controls KTA-275 Modbus Light Sensor or similar can be used. The following table describes the main characteristics of the Ocean Controls KTA-275 sensor.

Table 12.Light level sensor


Figure 25. Ocean Controls KTA-275 Ligh Sensor.
	General Characteristics:
	• Communication: Modbus RTU
	• Measured parameters:
	    o Light level in Lux
	    o Range from 0 to 16384 Lux

6.2.4 Air quality parameters monitoring

Air quality parameters will be acquired from ISA iPointTH and iPointCO2 set of sensors. These sensors are capable of measuring air temperature, relative humidity and CO2 concentration and transmit the measured values over a ISM 868MHz radio. The temperature and humidity sensor is battery powered which reduces the positioning restrictions for the sensor; the CO2 concentration sensor is not suitable for being powered by batteries so it is mains powered.

In order to integrate the values provided by these sensors into the Ecoshopping platform, a 868MHz radio to Modbus TCP protocol bridge from ISA will be used. Figure 26. depicts the integration of the iPointTH and iPointCO2 into the platform by the usage of the RF/Modbus TCP protocol bridge.

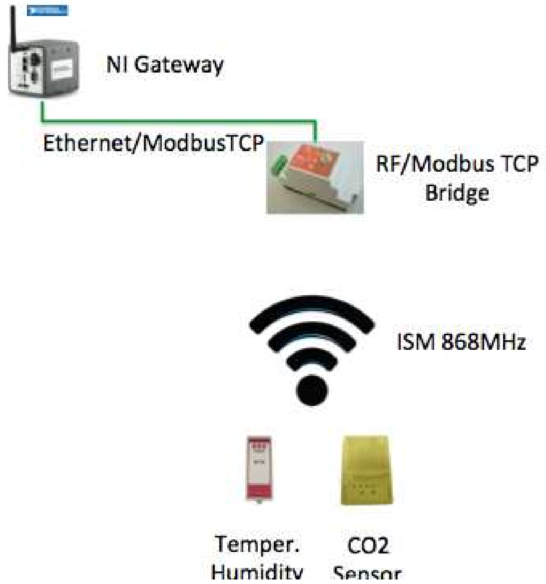

Figure 26. Integration of temperature, humidity and CO2 sensors.

The following table containing the main characteristics of the iPointTH and iPointCO2 air quality sensors.

Table 13.*Air quality sensors.*

 *Figure 27.* iPoint TH device.	General Characteristics: • Communication: ISM 868MHz • Power supply: 2xAAA 1.5V batteries • Sampling interval: 15 minutes • Measured variables: o Air temperature in ºC o Air relative humidity in %
 *Figure 28. iPoint TH device for iHub.*	General Characteristics: • Communication: ISM 868MHz • Power supply: 230VAC • Sampling interval: 15 minutes • Measured variables o Air CO2 concentration in PPM

The described air quality sensors are suitable for using in indoor environments.

6.2.5 Wall temperature monitoring

For monitoring of the wall temperatures, a contact temperature sensor has to be used. Two distinct parts compose this sensor: a thermometer platinum based resistor (i.e. PT100) and a resistance value transducer. The measured temperature affects the resistance of the sensor, which is sensed by the transducer and transformed into a analog value of current ranging from 4…20mA. The equivalent temperature values for the 4 and 20mA are configured in the transducer. The current value is then read by the Analog Input Remote Node and, by knowing the transducer configuration, converted into Celsius degrees.

Table 14.Wall temperature sensor.

 *Figure 29. PT 100 Temperature probe.*	General Characteristics: o 4..20mA output o Configurable temperature range

6.2.6 Example of architecture implementation

The Figure 30. depicts an example of the proposed architecture implementation, indicating the communication protocols and sensors/meters.

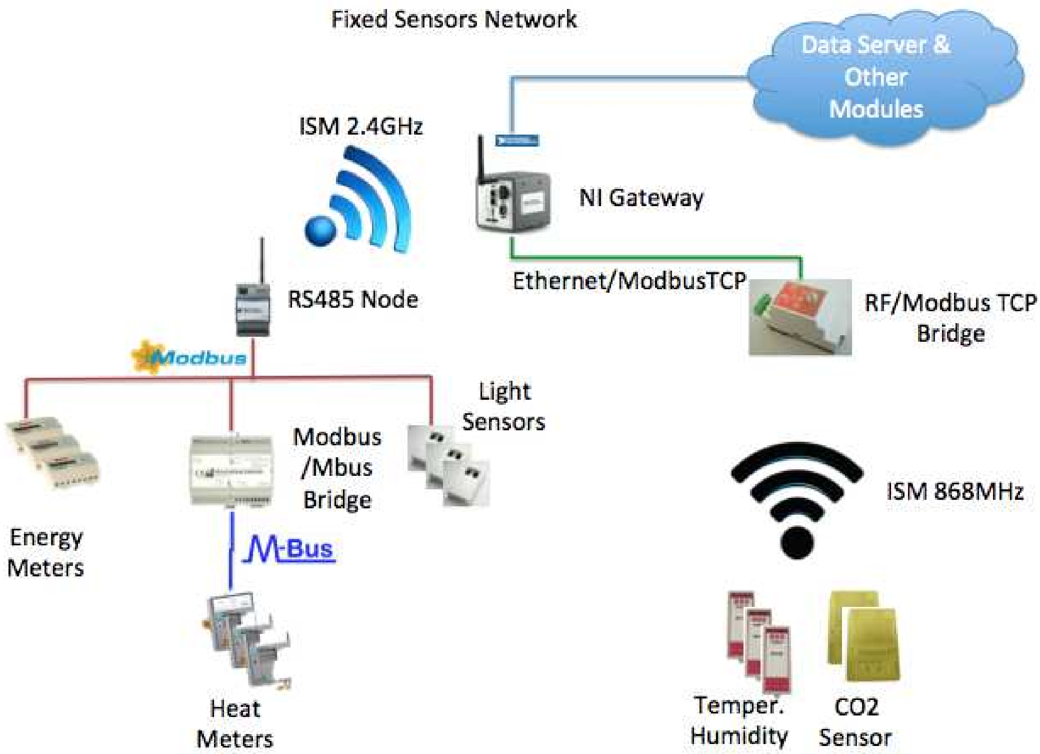

Figure 30. Example of fixed sensor network implementation.

6.3 Acoustic sensor network architecture

Isosynchronous multi-channel audio-streaming is usually achieved using proprietary networks like ADAT or MADI. The main objective of this contribution is to stream audio data from spatially distributed modules to a host using standardized Ethernet networks. The synchronization is achieved by using a network protocol for industrial clock distribution – Precision Time Protocol (PTP). To ensure maximal clock accuracy, the system is implemented on FPGA, using finite-state-machines instead of a processor.

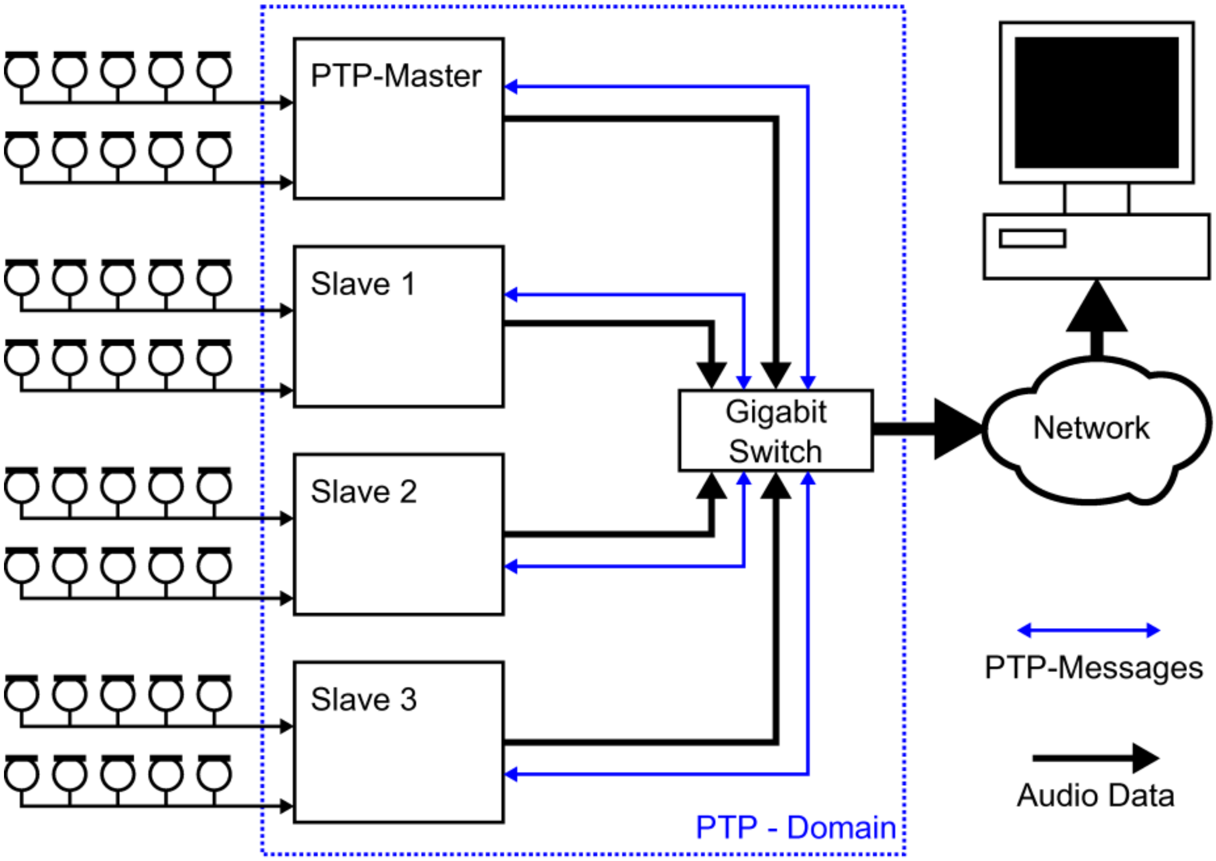

Figure 31. Basic structure and network topology.

Figure 31 depicts the general system structure of the fixed acoustic sensor network. The microphone-arrays are clustered in groups of up to 10 microphones at a single slave. Each microphone node needs a power supply. Currently up to seven microphone-arrays –slaves- can be used within a dedicated acoustic sensor network. However, the network protocol could be modified to manage up to 20 slaves. A single slave within a sensor network needs to operate as master system.

Data transfer and synchronization using PTP-messages is realized with Ethernet connections using a dedicated gigabit-Ethernet switch. This Ethernet switch exclusively manages the acoustic sensor network data traffic. Although, it would technically be possible, no additional data traffic on the gigabit-switch is wanted, to ensure the optimal time synchronization between all slaves.

The unprocessed audio data is send to the audio-processing-unit using, e.g., the existing building Ethernet network.

6.4 Control system architecture

Building Automation and Control Systems (BACS) control and supervise mechanical systems in buildings. Mechanical systems may include heating, cooling, air-conditioning, ventilation, lighting, blinds and shutters, security, fire alarms, and more. The purpose is to provide a comfortable and safe indoor environment in an energy efficient way. The BACS is normally fully automatic and executes control sequences, control strategies, alarm and supervisory tasks, and data logging. Building managers and occupants use the system. This is usually either to change the automatic operation (e.g. changing the temperature setpoint in an office room), or to investigate the status of spaces or equipment connected to the system (e.g. checking the inlet and outlet temperatures of a heating plant).

General control system architecture is shown in Figure 32. . Information for the various sensors will be sorted in Ecoshopping Database. Some critical information from the sensors can be relayed directly to Automatic Control and Monitoring (cRIO) system to improve usability. Different actuators for HVAC and all other systems will be controlled by Automatic Control system. Models will use information from Ecoshopping Database and also use it to store their output data. Output data from models and other data will be used by the Optimizer which will suggest best strategy for the minimum impact and minimum cost. User control over the usage of Optimizer in the system will be added.

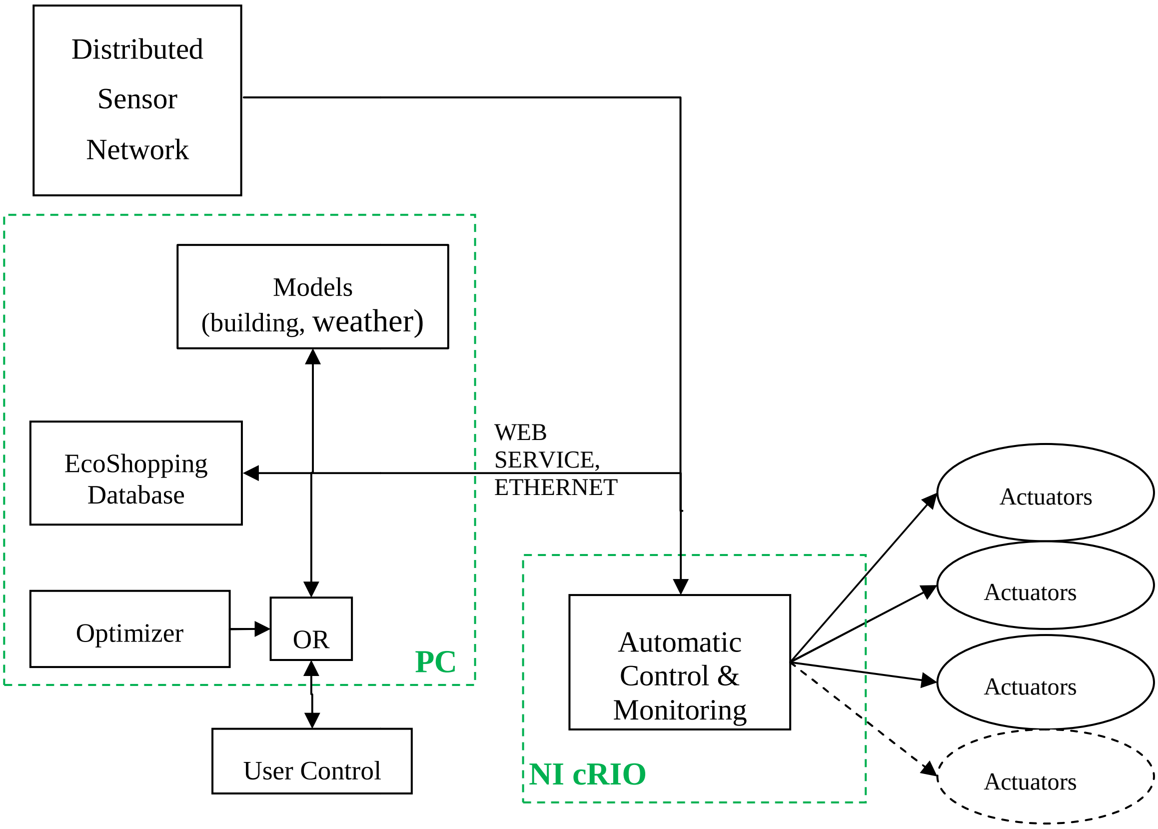

Figure 32. Control system architecture.

7. Conclusions

The final goal of this task is the specification of the EcoShopping IAU system, which is in the core of the EcoShoppingtool development utilised in Hungarian demonstator. The purpose of this firstphase of the system requirements work was to describe the IAU system and toidentify the requirements, do the specification of the different modules and define the system architecture for the EcoShopping IAU system.

The main results are:

- Description of the EcoShoppingIAU system,
- Definition of the System Requirements for EcoShopping IAU system,
- Definition of the System Specification for EcoShopping IAU system,
- Definition of the System Architecture for EcoShopping IAU system.

7.1 Summary of achievements

The main results presented in this report are the description of the system requirements, system specification and system architecture for EcoShopping IAU system.

- Description of the EcoShopping IAU system including the fixed sensor network, the mobile sensor network and the control system
- Listing of the standards which should be considered when developing the EcoShopping IAU system
- Description of the EcoShopping relevant communication between building and IAU
- Description of the communication between the (fixed and mobile) sensor networks and the control system
- Description of the system architecture to be adopted when considering IAU systems

7.2 Relation to continued developments

This document describes the basis for the EcoShoppingIAU development. The final IAU will be developed later in this task. This initial document includes some general info of EEPOS IAU requirements, specification and architecture to be implemented in T5.2, T5.3, T5.4, T5.5, T5.6 and T5.7. This is the most important document when developing the final version of IAU system.

On the other hand the final IAU has output to WP3, WP4 and WP6. In other words the final IAU is in the core of the EcoShopping project affecting EcoShopping tools development and related demonstration. And if possible these requirements, specification and architecture can have a role when developing other retrofitting intelligent automation units at the European level, which may lead to a standardization action on this matter.

7.3 Other conclusions and lessons learned

The definition of system requirements, specification and architecture is a rather heavy process since different modules have different communication and storage necessities. Furthermore the unification of such different requirements may sometimes be a challenge. Also due to the complexity of the system which involves experts with different expertise, makes the specification process specially challenging regarding the harmonisation of the descriptions of each module into a coherent and clear system description.

8. ACRONYMS AND TERMS

AED............................Acoustic Event Detection

API. .... Application Programming Interface

ASHRAE..................... American Society of Heating, Refrigerating and Air-Conditioning Engineers

BACnet........................ Building Automation and Control Networks (communications protocol)

BAM...........................Building Automation Management

BEM .... Building Energy Management

CAD .... Computer-aided design

CAE............................ Computer-Aided Engineering

CAM........................... Computer-Aided Manufacturing

CE............................... European Union EMC & Safety Compliance Declaration

CEBus......................... Consumer Electronics Bus

cRIO ....CompactRIO hardware platform

DALI ....Ligthing control network-based systemsfor building automation.

DCV45 .... Demand Controlled Ventilation

DMPC......................... Deterministic MPC

Demko .... European Union Product Safety

Ex .... European Union Hazardous Locations

EIB .... European Installation Bus

EHS .... European Home Systems Protocol

EPBD.......................... Directive of Energy Performance of Building

FPGA..........................Field-programmable gate array

HBS .... Home bus System

HVAC.........................Heating Ventilation and Air Conditioning

IAU.............................Intelligent Automation Unit

ICT .... Information and Communication Technology

I/O...............................Input/Output

JSON .... JavaScript Object Notation

KNX .... a home and building automation standard

LonWorks....................Local operating network, a networking platform used for control

MPC ....Model Predictive Control

PC............................... Personal Computer

PLCs .... Programmable logic controllers

PTP .... Point-to-Point communication

RBC .... Rule-Based Control

SCADA .... Supervisory Control and Data Acquisition

SMPC .... Stochastic MPC

SPU.............................. Signal Processing Units

UDP .... User Datagram Protocol

9. References

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10. APPENDICES

This deliverable does not have further documents associated.