FIEMSER: ENERGY EFFICIENCY IN SMART RESIDENTIAL BUILDINGS

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ABSTRACT

Buildings are responsible for up to 40% of energy use in most countries. However, there is a great potential to improve this figure, and ICT is one of the key tools to achieve it. This paper will present how the FIEMSER system will contribute to increase the energy efficiency in residential buildings through a double strategy: optimizing the operation of the building (energy demand, local generation and storage) and improving the behaviour of the building users. The FIEMSER system is an innovative Building Energy Management System (BEMS) for existing and new residential buildings that is been developed in the context of the Seventh Framework Programme (FP7). Current BEMSs have several weaknesses: predefined energy control strategies, lack of integration of the local energy generation with the building energy consumption, lighting system is completely decoupled from the HVAC system, based on wired control networks, limited interoperability, … FIEMSER system will define dynamic and holistic control strategies that take into account the current and future building operating conditions (building users activities, weather conditions, energy prices,…) and integrate the different energy related subsystems: HVAC, lighting, local generation and energy storage. The FIEMSER system leverages on the Service-Oriented Architecture (SOA) paradigm with the definition of modular service interfaces. This paradigm provides the necessary flexibility to adapt the system to the different configurations, integrate existing control protocols and emerging wireless ones, and support different GUI (Graphical User Interface). This paper will address the following questions: opportunities to reduce energy demand and increase local generation in residential buildings; operation scenarios; functional requirements of the FIEMSER system; the OSGI-SOA architecture that supports it and the associated data model.

Keywords: Smart Buildings, Energy Efficiency, Intelligent Control, Local Generation.

1. WHY THE FIEMSER SYSTEM AND ITS SCOPE

Buildings are responsible for up to 40% of energy use in most countries. This means buildings can make a major contribution tackling the climate change and increasing the efficiency of energy use. Even though many surveys show that it would be possible to reduce up to 30 percent in emissions from residential and commercial buildings by 2030 at a net negative cost. According to the United Nations Environment Programme, the construction sector has not realized these potentials. There are three key actions to achieving progress:

- **Use less energy**. Efficient lighting; more efficient electrical appliances and heating and cooling devices; improved cooking stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycle of fluorinated gases.

- **Make more energy locally**. Transforming a building from an energy consumption place to an energy generation place facilitates the integration of renewable energy sources (solar collectors, photovoltaic generators, wind mills, geothermal) and the efficient use of energy by generating heat and electricity at the place where they are needed, CHP - Combined Heat and Power (micro-turbines, fuel cells, sterling generators,...). This approach does not only increase the efficiency of the energy utilization process, but increases the performance of the energy systems avoiding transmission losses.
- **Share surplus energy** (through an intelligent grid). Active networks look for an active participation of customers in the management of the grid through a close interaction between Network operators, Customers and Suppliers. As result of this interaction, peak energy demands can be avoided and consequently, deferring the need to invest on the energy networks (transport and distribution) and expensive central power stations.

FIEMSER project focuses on the two first actions: "**Use less energy**" and "**Make more energy locally**". Although the project does not attack the third one, it provides the necessary conditions and platform to support the surplus energy sharing.

FIEMSER System is an innovative Building Energy Management System (BEMS) for existing and new residential buildings, which pursues increasing the efficiency of the energy used and the reduction of the global energy demand of the building, but without penalizing the comfort levels of the users.

Current BEMS operate according to predefined energy control strategies and always react in the same way, without taking into account changing conditions (for instance, the HVAC system is activated when a threshold value is reached and the associated control actions are predefined and don't take into account forecasted outdoor conditions, people in the building and their activities, etc.). At the same time, they don't integrate the local energy generation in the building with the energy consumption and the utility supply conditions. Now a day, energy generation and energy consumption are not coordinated, but are managed as two isolated systems.

Although some projects are addressing similar research topics (EnergyWarden Project, IntUBE Project, PEBBLE Project, DEHEMS Project…), FIEMSER initiates a new generation of BEMS that make their control decisions taking into account the current operation conditions and their expected evolution in a holistic way, with a tight coupling between energy demand and local generation systems.

The following diagram shows the global view of the FIEMSER system:

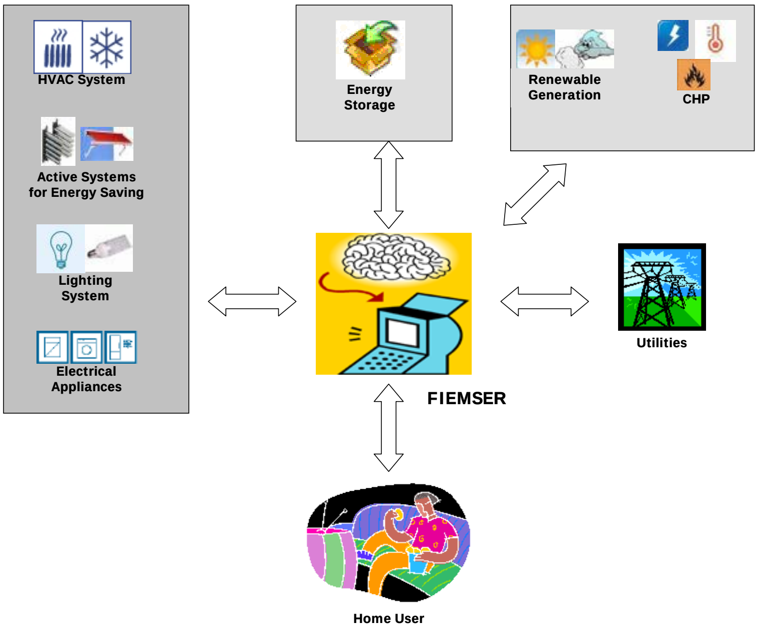

Figure 1. FIEMSER global overview

FIEMSER follows two main strategies:

- **Minimizing the energy demand from external resources**, through the **reduction of the energy consumption in the building** and the correct **management of local generation** (heat and electricity) **and energy storage** equipment to satisfy the energy demand of the building, and even provide the capability to export energy to the utilities when needed.
- **Interaction with the building user**, in order to increase the consciousness of the consumer about his energy consumption, providing hints to make punctual changes in his behaviour without major disruptions of his comfort conditions.

FIEMSER system will be validated in the two main climatic areas in Europe (Mediterranean and Continental) in 2012 by 6 months through its deployment in the KUBIK and the VERU experimental buildings. KUBIK is the TECNALIA's building test facility and its located in Bilbao (Spain). VERU is the Fraunhofer's building test facility and is located in Holzkirchen (Germany).

2. ENERGY SYSTEMS IN RESIDENTIAL BUILDINGS

When home users behaviour is analyzed from the perspective of energy demand, two types of energy demands are identified: direct and indirect energy demand.

- **"Direct energy demand"** means energy consumption that is typically related with electrical appliances, like washing machines, dishwashers, etc. These loads, are also known as **"shiftable energy demand"**. In this case, the energy consumption cannot be reduced, but it is subject to certain flexibility. The best action that can be done from a BEMS point of view is scheduling the energy consumption for the most profitable time (green energy is available, local generation is available, utility energy costs are lower …).
- **"Indirect energy demand"** means energy consumption that is typically related with lighting and HVAC systems. These loads are also known as **"curtailable energy demand"**. If the energy demand is not satisfied at certain instant of time, this energy demand is not consumed in another period. For example, when the user switches on a lamp for reading in the living room, he does not demand spending 100W in a light bulb, but 500 luxes, the comfort conditions for reading. Consequently, this demand can be satisfied in a different way, as opening the curtain without spending 100 w of electrical energy.

Energy efficient management at home also requires taking into account the interaction among the several energy systems in a building. HVAC and lighting systems are strongly interdependent. For example, closing a shutter increase the isolation of the building and reduce the cooling demand, but increases the artificial lighting demand.

In relation with the management of local generation, also two types of local generations have to be considered: intermittent and controllable.

- **Intermittent local generation** usually is related to renewable energy sources, such as wind and sun. These energy sources are dependent on weather conditions. The good point is that the "fuel" is free and CO2 emissions are zero. In this case, the BEMS should schedule the loads for maximizing the use of its own renewable generation.
- **Controllable local generation** usually is related to CHP - Combined Heat and Power (micro-turbines, fuel cells, sterling generators...). Although these generation units can be started at any time, their profitable operation requires a minimum operation time (they cannot be started to operate just for short periods) and the exploitation of both generated energies: electrical and thermal energy. From the perspective of the BEMS, a short-medium term scheduling is required and this scheduling has to be done taking into account energy consumption, energy storage capability and energy costs forecast. In some cases, CHP units are fed with biofuels, which are classified as renewables. In this case, additional benefits are due to the energy generation without CO2 emissions.

The global consumption of an average European home is summarized in the following pie chart. This chart shows that the energy saving system must consider in priority the house heating (boiler with tank – 62,1 %), the air conditioning (14%) and lighting (4%). The energy saving from all the other house appliances is secondary regarding their part of consumption.

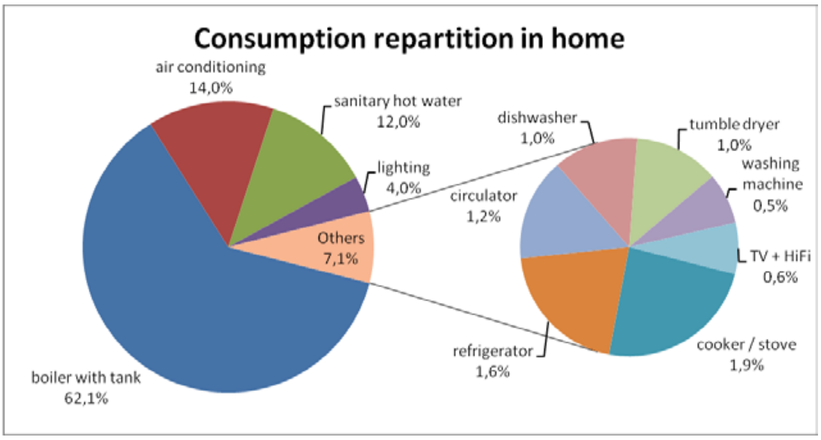

Figure 2. Main energy consumption at home

At the same time, the energy efficiency of house heating, air conditioning and lighting systems is very related with their operation conditions. However, the energy efficiency of the rest of the home equipment (washing machine, refrigerator) is more related with their design process than with their operation conditions.

Concerning electricity generation in residential buildings, the renewable energy sources, photovoltaic and small wind turbine stay the only local energy sources if there is no production by micro-CHP.

From the thermal energy point of view, thermal solar system and possibly heat pump could be very interesting, because they act directly on the heating part, which is the biggest energy consumer. These thermal generation units are usually supported by boilers.

3. OPERATION SCENARIOS

In Europe, several types of residential buildings coexist: detached house, semi-detached house, multi-dwelling building… Each type of building implies a different ownership model and determines the possibility of sharing energy generation and storage systems and a common BEMS.

FIEMSER has defined two operation scenarios: “Isolated Home Scenario” and “Multiple Dwellings Scenario”.

The “Isolated Home Scenario” focused on a four people family, which is composed by two children and their parents, that lives in an isolated house. Its main characteristic is that there is a “one-to-one” relation between the home to be controlled and the FIEMSER system. At the same time, the energy consumption, local generation and energy storage systems have a unique and common owner.

The “Multiple Dwellings Scenario” focused on how the facility manager of a building block takes advantage of using the FIEMSER system and how FIEMSER interacts with each dwelling resident. Its main characteristic is that the FIEMSER System has to manage several independent apartments (each apartment has a different owner), which are the main energy consumers in the building, and some common services, usually local energy generation and storage systems.

Consequently, FIEMSER System has been developed according to a modular architecture that allows adapting the system to the specificities of each operation scenario.

The description of both scenarios allowed us to identify the main functional requirements of the FIEMSER system and to estimate its potential energy saving in each scenario, in order to fix a reference price for the future FIEMSER system commercialization.

4. SYSTEM FUNCTIONALITY

BEMS are based on three main functional modules: interaction with the building, control logic and user interface. FIEMSER also follows this general approach, but goes a step forward in the functional requirement of each module.

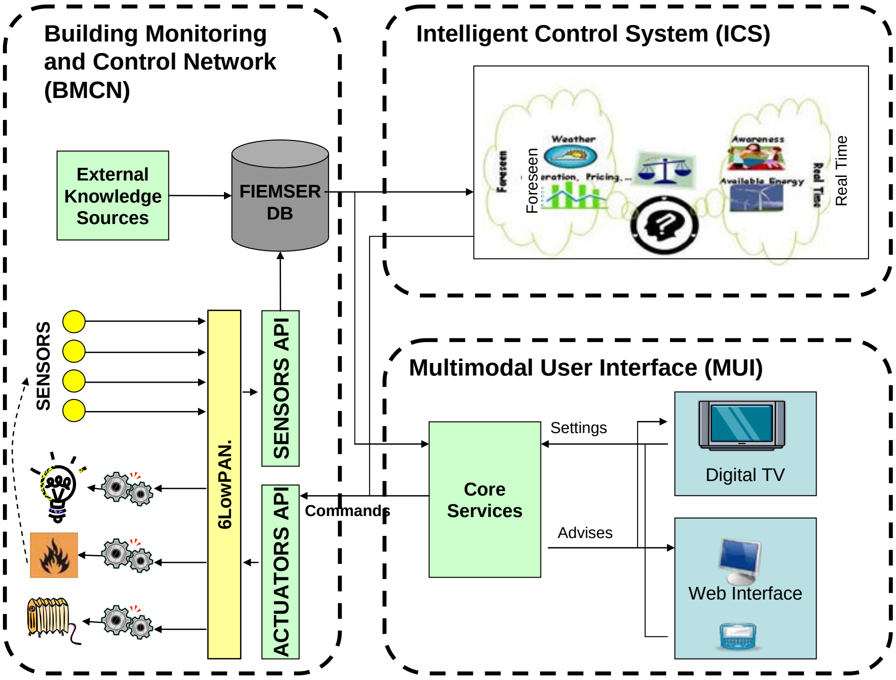

Figure 3. FIEMSER functional modules

Following, the main functionality of each FIEMSER module is detailed:

- **Building Monitoring and Control Network (BMCN)**. The main functionality of this module is to provide a wireless monitoring and control network that is interoperable with already existing control protocols. This functionality can be detailed in the following functional requirements:
  - Wireless communication to sensors and actuators in order to make easier FIEMSER's deployment in existing buildings.
  - Node energy efficiency, in order to provide long lifetime for battery operated devices.
  - Interoperability with exiting control protocols, as KNX, ModBus, ZigBee, 6LowPan...
  - Transmission reliability (the number of packet successfully received over the total transmitted) also when dealing with unreliable communication mediums and in the presence of interfering appliances such as microwaves and motors, which are common at home.
  - Scalability, in order to guarantee sufficient reliability and coverage in different size and density of the network and with different traffic conditions.
  - Security, in order to avoid unauthorized accesses and protect the network and the network-accessible resources from unauthorized access.
  - Integrate external data sources in the monitoring process. For example, weather forecast services.
- **Intelligent Control System (ICS)**. The main functionality of this module is to operate the building with the minimum energy demand from external energy networks and minimizing the energy bill. This functionality can be detailed as the following functional requirements:
  - Forecasting the energy demand of the home for the next period (from the current time to 24:00). The energy demand is calculated taking into account home architecture (e.g., facades, wall isolation), HVAC, hot water and lighting installations, operation of the mechanisms to reduce building energy demand (e.g., blinders, windows, …), day type that provide information about daily activity in the home and comfort settings and the weather forecast. This forecasting will be done trying to achieve the minimum energy demand to satisfy comfort conditions.
  - Forecasting the intermittent local renewable energy generation in the building. This local energy generation is calculated taking into account the characteristics of the renewable energy generation systems (e.g., surface, orientation, efficiency) and weather forecast (e.g., sun radiation, wind speed).

- Scheduling the operation of the energy storage and generation systems and reallocating shiftable loads (e.g., washing machine). The schedule is done taking into account the forecasted energy demand, forecasted intermittent local renewable energy generation, generation capability of controllable local generation units (e.g., μCHP, boiler), current state of the energy storage systems and energy prices.
- Monitoring the execution of the energy consumption, storage and generation plan. In order to detect deviations from the initial plan and generating a new plan when needed, the energy demand and generation of the building is monitored, as well as, the weather forecast and the energy prices.
- Operating loads, generators and energy storage systems and mechanisms to reduce home energy demand according to the schedule. The ICS sends one by one the operation orders when they have to be executed.
- Monitoring home users behaviour in order to suggest more energy efficient behaviours, but keeping the same comfort level. This analysis is based on the analysis of the current energy loads, comfort settings, home architecture (e.g., facades, wall isolation), HVAC, hot water and lighting installations, operation of the mechanisms to reduce building energy demand (e.g., blinders, windows,) and current and short term forecasted environmental conditions (e.g., temperature, sun radiation, wind direction and speed).

- **Multimodal User Interface (MUI)**. The main functionality of this module is allowing the resident setting his comfort preferences and aware him about more energy efficient behaviours. This functionality can be detailed in the following functional requirements:
  - Accessible through the most common devices for home users: desktop computer, smart phone and Internet-connected TV.
  - Accessible when residents are at home and also when they are outside.
  - Advice about energy efficient home operation through the most appropriate active user interface.
  - Provide access to the current and historic home sensors and actuator values.
  - Allowing building operation.
  - Provide access to energy performance indicators, in terms of kWh and Euros.
  - FIEMSER System set up: sensors and actuator, data sources, reference values…
  - Setting user preferences, as home usage profile for each day type, comfort conditions…

5. SYSTEM ARCHITECTURE

Most of the BEMS available in the market are developed having a well defined core technology, due to the underlying legacy system. The approach of the FIEMSER system is very different, because it leverages on the Service-Oriented Architecture (SOA) paradigm with the definition of modular service interfaces. This approach provides flexibility when it is necessary to include new devices in the FIEMSER system domain.

Most of the legacy BEMS systems were based on PLC (Programmable Logic Controller) or similar, architectures in which some I/O extensions are deployed all over the domain to be managed. These I/O extensions are connected to some central device, namely the PLC, which stores both the data and the control routines. FIEMSER's approach is to define interfaces/gateways connecting flexibly to typical legacy systems that could be found in building domain, and in addition create a "light" family of devices that could be integrated on the system through wireless connectivity links.

The FIEMSER platform is based on the OSGi framework SOA deployment platform. For each external component an OSGi bundle will be developed to allow its integration with the entire platform. These bundles are developed by using the JAVA language.

The event-based development and Web Services approach avoid adding development constraints on external components. By this way we can use the best technology for each concern and integrate it through an OSGi bundle.

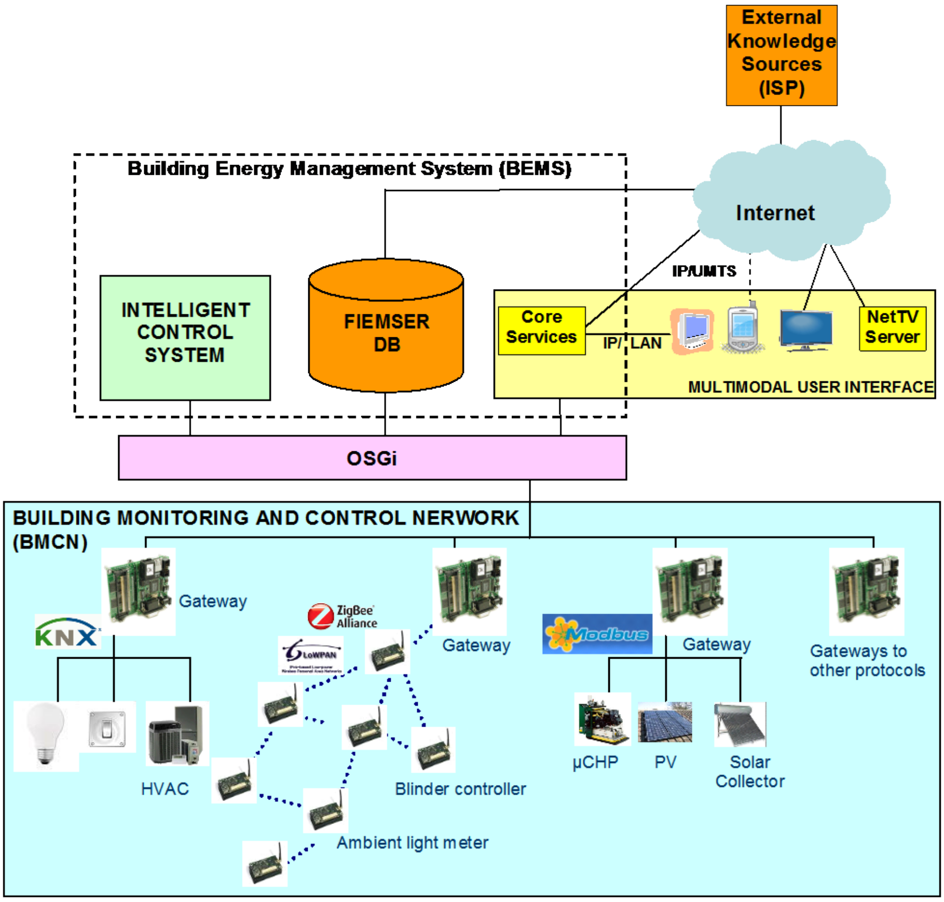

Figure 4. FIEMSER Architecture

The FIEMSER System software architecture is based on four main components:

- **Building Energy Management System (BEMS)**. It is the core of system and manages the information that is collected from the building and the external knowledge sources and decides the actions to be done. It has three main submodules:
  - **FIEMSER DB**, which stores the information that is managed by the system. This is a key submodule in this architecture, its acts a whiteboard that allows sharing information among the different FIEMSER modules.
    Some details of Database's OSGi bundle architecture:
    - <u>*OSGi bundle:*</u> By wrapping the database API in an OSGi bundle, we ensure the seamless integration of this module in the rest of the FIEMSER platform.
    - <u>*ORM (Object-Relational Mapping) framework*</u>: FIEMSER data are strored in MySQL, a relational database. Consequently, we need to use a tool to perform the object mapping. We will use Hibernate, one of the best frameworks in the JAVA world, which benefits from maturity and a very important developers community.
    - <u>*DAO (Data Access Object):*</u> As its name implies, the role of this layer is to unify access to data. In this way, it is easy to provide several ways to access data as through Web Services or events.
  - **Intelligent Control System (ICS)**, which makes the control decisions. The integration of the ICS component with the rest of the FIEMSER platform is done through the communication module, that can be exploited in three sub-modules:
    - <u>*Service Access Abstraction Layer (SAAL).*</u> This layer provides an unified access to the services that are provided by the rest of FIEMSER modules and activate the ICS services that are requested by them.
    - <u>*Synchronous Interface (SI)*</u>**,** which accesses to the services that are provided by the other FIEMSER modules and offers the ICS services to the other modules. This communication mechanism will be implemented through Web Services.

- *Asynchronous Interface (AI)*, which will generate the events to be attended by the other FIEMSER modules and will react to the ones that are sent to it from the other FIEMSER modules.
- **Multimodal User Interface (MUI) – Core Services**, which provide a unified interface to the different end-user's devices to interact with the rest of the FIEMSER system. This component is a Java-based server application whose API interfaces may be called by the Intelligent Control System, the Database or the Building Monitoring and Control Network.

- **External Knowledge Sources**. They provide information about the external building operation conditions (e.g., weather forecast, dynamic energy prices, etc.) as Internet Service Providers (ISP). External knowledge sources are integrated in FIEMSER as external Web Services, according to the standard SOAP based Web Services Protocol Stack.
- **Building Monitoring and Control Network (BMCN)**. It allows collecting information from the sensors that are installed in the building and sending orders to the actuators to change the behaviour of the home. The BEMS manages all the building sensors and actuators according to the "Internet of Things" approach as FIEMSER will establish a reference control protocol to interact with them via IP. Nevertheless, the architecture has been designed in such a way that different control protocols can be integrated through the development of the corresponding gateway. In the scope of the project, three main protocols are supported:
  - **KNX**, as the main control protocol for buildings in Europe.
  - **6LowPAN + ZigBee**, as the main wireless communication protocol for low energy consumption communication networks.
  - **MODBUS**, as the main control protocol for local energy storage and generation systems.

  The architecture of this component will follows a layered approach with the following layers:
  1. **Sensors and Actuators Interpreter API Layer:** Bundles in this layer exports the Discovery, Data, and the Configuration & Notification services by mediating between the other components in FIEMSER and the specific sensing and acting infrastructure.
  2. **Hardware Abstraction Layer:** While the API layer is hardware agnostic and only deals with abstract device capabilities, this layer deals with differences in network and protocol capabilities of the hardware devices connected to this component

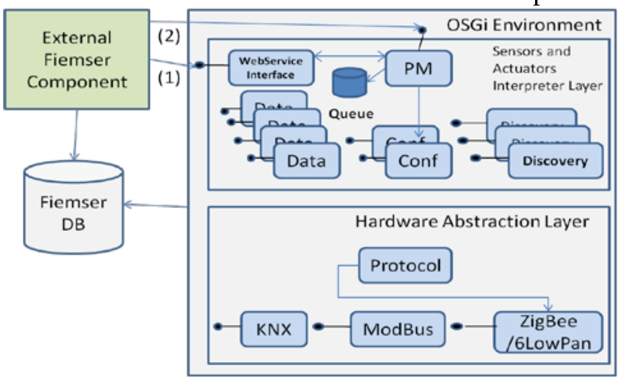

Figure 5. BMCN OSGi based layered architecture

- **Multimodal User Interface - End-User Devices**. They make the link between the end-user and the BEMS. Three types of end-user's devices are supported:
  - **Desktop Computer**: It is a standard PC that is installed in the same place that the BEMS. They are connected trough the LAN (wired or wireless).
  - **Smart Phone**: It accesses to the BEMS from anywhere, an consequently, the connection between them is done through the Internet UMTS connection of the Smart Phone.
  - **TV**: It is an Internet-connected TV solution that is installed in the same place that the BEMS. The Internet-connected TV solution may require a link to an external server through an Internet connection.

6. DATA MODEL

The FIEMSER architectural design has been complemented with the data modelling of the information exchanged between the main parts of the system.

Data models are defined for information coming from outside (weather conditions, electricity prices, gas prices…), data to be exchanged between the main components of the architecture, and data to be exchanged with loads, generators and storage devices.

This modelling activity takes into account previous work and other approaches like: IFC and gbXML data models for the building sector, as well as work done in other related R&D projects, as EnPROVE, EnergyWarden, ENERsip, IntUBE, PEBBLE, SmartCoDe, BeyWatch, BeAware…

Based on this analysis and the functional specification of the FIEMSER system, a complete UML FIEMSER data model, with more that one hundred classes, have been defined. This data model covers data categories/packages that are described in the next table:

Data Category	Content
• Environmental and contextual data	• Location, climate zone, shadowing, building orientation, etc. • Weather data, energy prices, etc.
• WSN-related data	• Sensors & Actuators (location, characteristics, configuration data…) • Data collected from sensors (equipments operation, building usage) • Log of activations (control orders sent to actuators)
• User preferences	• Usage profile, definition of scenes, including comfort set-points and use of appliances • Control rules and energy strategy
• Resources scheduling data	• Scheduling of resources
• Advices	• Orders, and associated advices, created as a result of an event, usually associated to an action of the user and some other actions suggested by the system
• Energy performance indicators	• Log of consumptions • Performance indicators
• Energy-focused BIM (Building Information Model)	• Space organisation / Envelope & partition (characteristics) • Home equipments (appliances, generators, storages…) (location, type, characteristics…)
• User Access Rights	• User rights regarding the access to FIEMSER functionalities

Table 1: FIEMSER data model categories.

Special attention was paid to the interoperability with architectural CAD tools and building energy simulation tools. The two main standard data models in EEB (Energy Efficiency in Buildings), IFC and gbXML, were analyzed. Finally, the gbXML data model was selected as reference data model for the FIEMSER System development. gbXML, which results from a bottom-up approach, focuses on building thermal load properties. It is then simpler and easier to use and more efficient than IFC to integrate with thermal analysis software, thus allowing quicker implementations. The XML basis (data model in XML Schema and data format in XML) provides flexibility and extensibility, and data can be easily processed by XML parsers. Besides, gbXML is integrated with CAD, design and simulation tools (REVIT, SketchUp…). The limited features in terms of geometry (compared to IFC) are not an obstacle for FIEMSER since we are addressing buildings with standard geometrical features. Nevertheless, this does not mean that we will ignore the BuildingSMART community in our further work. Indeed, it is planned that our modelling work will be disseminated (as a proposal for possible standard extension), not only towards the gbXML community, but also towards all relevant standardisation bodies, including BuildingSMART.

7. CONCLUSIONS

This paper summarizes the achievements of the FIEMSER project during its first execution period. These achievements can be summarized in:

- a detailed analysis of the energy consumption, generation and storage systems at home, and the most common sensors and actuators to control them,

- the functional specification of an intelligent BEMS that adapts its control strategy to the building operation conditions and its user interface to the current resident activity,
- the architectural design to deploy requested functionalities, and
- the data model that support the data flows.

Currently, FIEMSER partners are working in the implementation of the system.

For further information about the FIEMSER System, please visit the project web site (http://www.fiemser.eu), where the FIEMSER project public deliverables ("D1 - Energy generation, consumption and storage in buildings", "D4 - System Architecture", "D5 - FIEMSER data model" and "D9 - Interface Modules") are available, or contact us.

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