Friendly Intelligent Energy Management System for Existing Residential Buildings

Authors: Marc Bourdeau[1], Juan Perez[2], Jorge Viñuela Cañon[3]
[1] *Centre Scientifique et Technique du Bâtiment (FR), marc.bourdeau@cstb.fr*
[2] *TECNALIA (ES), juan.perez@tecnalia.com*
[3] *Acciona (ES), jorge.vinuela.canon@acciona.es*

Short Abstract

The paper develops the work achieved so far in the FIEMSER project, a EC-funded R&D project launched at the beginning of 2010 and aiming at the development of an innovative energy management system for existing and new residential buildings (BEMS), which pursues the increase of 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.
The paper starts with a reminder about the context, the incentives and objectives of the project, and presents the progress beyond the state-of-the-art. It then introduces to the technical description and modelling of the different loads, local energy sources and energy storage systems that are potentially manageable by the FIEMSER system in residential buildings, then continues with the technical specification of the system, including typical scenarios, a first approach of the graphical interface, the functional system requirements, as well as the non functional requirements. The functional requirements mainly rely on the description of 8 Use Cases, corresponding to the core system activities.
The paper concludes with further work planned during the 3 year duration of the project, and some perspectives for the experimentation and deployment of the FIEMSER system in real conditions.

1. Background and objectives of the work

It is well known that the building sector is the largest resource consuming sector. Residential and tertiary buildings are responsible for about 35% of the EU's total final energy consumption and GHG emissions. This means that the sector offers the largest single significant potential for cost effective energy savings.

In order to achieve progress and reduce primary energy consumption of buildings, there are three key alternatives: *use less energy*, *produce more energy locally (especially through renewable energy systems)*, and *share or store surplus energy (by taking advantage of the energy grid or storage systems)*.

The EC-funded FIEMSER R&D project that started in February 2010 typically addresses the two first alternatives previously mentioned to reduce primary energy consumption of buildings, although it will also provide the necessary framework to take into account connection to the grid.

The main objective of this project is the development of an innovative energy management system (BEMS) for **existing and new residential buildings,** which pursues the increase of 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. In order to achieve this goal, two main strategies are followed:

- **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 equipments to satisfy the energy demand of the building, and even provide the capability to export energy to the utilities when needed.

- **Enhance the interaction with the building user**, in such a way as to increase the consciousness of the consumer of his energy consumption and CO_2 emissions, providing hints to make punctual changes in his behaviour without major disruptions of his comfort conditions.

As shown in the diagram below, the FIEMSER system will manage in parallel the reduction of the energy demand of the building (HVAC, lighting, electrical appliances …) and the scheduling of the local generations (renewable generation and CHP) to achieve a greater energy and economic efficiency. It will take into account, on the one hand, "**direct energy demand**" or "**shiftable energy demand**", corresponding to energy consumption that is typically related with electrical appliances, like washing machines, dishwashers, etc., and can be subject to a certain flexibility; and, on the other hand, "**indirect energy demand**" or "**curtailable energy demand**", that is typically linked to the energy consumption of lighting and HVAC systems, and can't be postponed to last demanding periods.

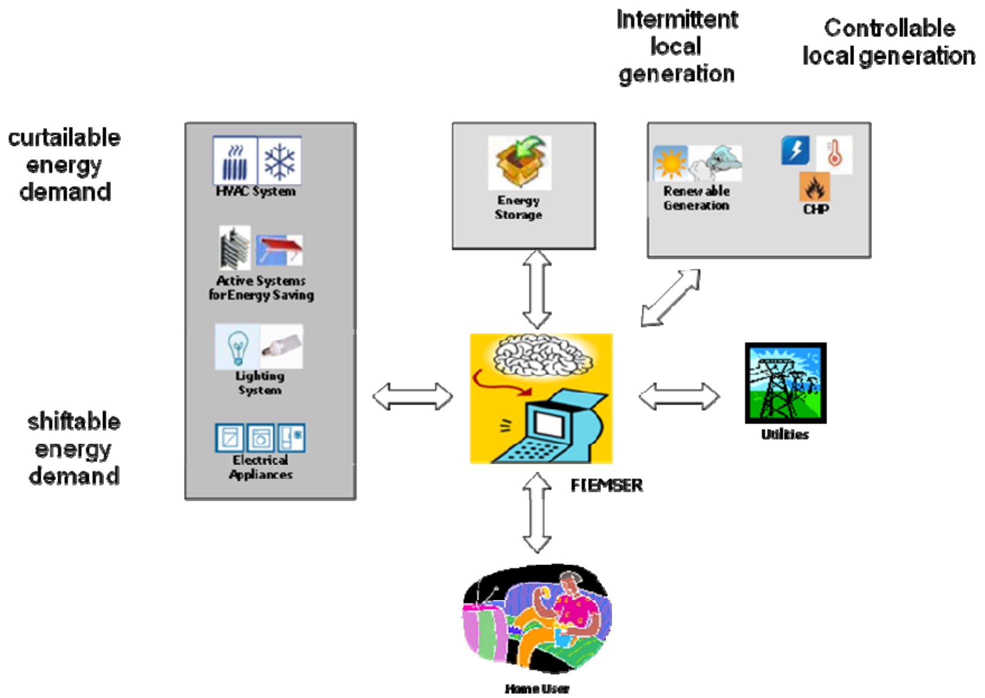

Figure 1 – Conceptual view of FIEMSER

In relation with the management of local generation also two types of local generations are considered in FIEMSER: intermittent and controllable. **Intermittent local generation** is usually related to renewable energy sources, such as wind and sun. These energy sources are dependent on weather conditions. In this case, the FIEMSER BEMS should schedule the loads for maximizing the use of its own renewable generation. **Controllable local generation** is usually related to CHP - Combined Heat and Power (micro-turbines, fuel cells, sterling generators...), that allows the simultaneous generation of usable heat and power (usually electricity) in a single process. In other words, it utilizes the heat produced in electricity generation rather than releasing it wastefully into the atmosphere. CHP is sometimes referred to as co-generation.

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 generation, energy storage capability, and energy costs forecast.

FIEMSER will automatically optimize in near real time the energy consumption of the building and the operation of local generation in order to minimize the energy cost of the building and CO2 emissions without reducing the comfort level of the home users. Nevertheless, home user decisions will always have higher priority than FIEMSER strategies. Consequently, user awareness about the energy performance of the building and the requirements of the home user will have to be taken into account. In order to satisfy this requirement, FIEMSER will develop a ubiquitous user interface that will be accessible from desktop computers, mobile devices (smartphones, PDAs…) and through the digital TV.

Deploying this system in existing buildings requires a wireless control network that makes possible the placement of sensors and actuators with a minimum impact in the building and minimum installation costs. FIEMSER wireless control network will be based on the emerging standard 6LowPAN (IPv6 over Low power Wireless Personal Area Networks), the International Open Standard that brings IP even to the smallest of the devices - sensors and controllers. It will make easier the integration of FIEMSER with the current housing monitoring and control standards, as KNX, LonWorks, BACnet, ModBus…

2. Progress beyond the state-of-the-art

From the energy management point of view, two main weaknesses of current BEMS are:

- They operate according to predefined energy control strategies. For instance, HVAC and lighting systems are activated when a threshold value is reached and the associated control actions are predefined. Consequently, systems always react in the same way, without taking into account changing conditions (current and forecasted outdoor conditions, people in the building and their activities, etc.). In the same way, other very relevant energy consumers, as electrical appliances (washing machine, dishwashing…) are controlled only taking into account a predefined operation schedule.
- There is a lack of integration of the local energy generation in the building with the energy consumption and the utility supply conditions. Nowadays, energy generation and energy consumption are not coordinated, but are managed as two isolated systems. Until recently no energy management systems have been installed and the main purpose, of the ones that have a system like that installed, is to provide a centralized control capability of the energy consuming resources but without specific energy efficiency algorithms. What means that the functionality of the installed BEMS is to know the status of the energy generators (on/off) of a building and to provide the capability for switching them on or off from a centralized location. Moreover, this kind of management systems only can be programmed using proprietary programming languages.

FIEMSER innovates with respect to the current BEMS functionality by developing a **holistic energy management strategy** which takes into account the current building operation conditions (occupant needs and comfort conditions, operation of electrical appliances, lighting, temperature, humidity, …, local generation, energy costs) and their **expected evolution in the next hours** in relation with the outdoor and indoor conditions (weather evolution, building/environment energy transfers, occupancy and activities planned by end-users), local generation and energy storage capabilities, utility supply conditions (day ahead hourly pricing, real time hourly pricing, …) in order to minimize building energy demand, energy cost and CO2 emissions. Moreover, FIEMSER addresses the energy efficiency of the building by **looking at the thermal and electrical energy at the same time**, and by considering not only passive but also active components of a building that can contribute to the use/generation of energy. Active devices mean not only PV, CHP, and wind, but also shading devices or windows, which being active modify significantly the heat exchanges with the environment and the degree of lighting within the affected areas of the building.

Besides, FIEMSER innovates with respect to the current approach of existing BEMS by aiming at the **distribution of the intelligence** in such a way that there is not a centralized decision point but a central coordination over several intelligence controllers. From this perspective the kind of information that FIEMSER treats will not be limited to on/off signals but will send complex information (forecasts about prices, temperatures, wing, solar radiation…) and operation restrictions (maximum power consumption during certain periods) to be communicated to the intelligent distributed devices with the objective of optimising the overall energy efficiency.

Regarding communication networks, most building monitoring and control equipment used today is built on top of a wired infrastructure. During building construction, cables and monitoring devices are deployed and connected to a central monitoring system. Such systems are very reliable but have severe drawbacks. First, the deployment of cables is cost intensive and adds to the overall construction cost. Second, a cable-based infrastructure is not very flexible and building re-configuration (e.g. re-partitioning of office spaces) is difficult and cost intensive. Third, in addition to the aforementioned limitations, it is as well very difficult and expensive to retrofit an existing building with a state of the art building management system. To overcome these problems, wireless building monitoring and control systems are currently proposed and developed. These, however, introduce different new challenges: battery replacement, data losses, unstable communication. To introduce a wireless monitoring system, the communication network must be dependable. Data from and to the sensors/actuators must be transported timely and reliably. A monitored building condition must be reported in time. A subsequent reaction in form of a command message to an actuator must be delivered with a similar predictable quality. Current wireless sensor networks do not provide this feature.

FIEMSER innovates in this respect by developing a dependable and energy efficient sensor network in order to allow a successful deployment of a WSN for building monitoring. Moreover, FIEMSER will develop a flexible sensor node software that can be dynamically adjusted and provide a software layer allowing interoperability with existing control communication systems on the market, like KNX To achieve this, FIEMSER will investigate the usage of **6LowPAN** (IPV6 over low-power personal area networks) aimed at defining header compression mechanisms that allow IPv6 packets to be sent to and received from over IEEE 802.15-based networks.

Finally many recent reports about energy efficiency in buildings stresses that building's occupants behaviour is one of the most important aspects to achieve energy efficient buildings. Recently several FP7 R&D that try to change building's occupants behaviour have been approved, as BeAware[1] (Boosting Energy Awareness with mobile interfaces and real-time feedback), DEHEMS[2] (Digital Environmental Home Energy Management System) or Beywatch[3] (Building Energy Watcher). From the perspective of the building occupants, all these projects mainly focus on metering energy consumption and advising them in real-time about energy consumptions that are higher than the expected ones through different mobile devices like PCs, PDAs or smartphones. FIEMSER extends this approach by the integration in the energy management system the most common, friendly, multigenerational and multicultural communication device, the TV.

3. Profiling of energy-related devices

In order to have a better understanding of the different kinds of energy generation, consumption and storage devices potentially in use (energy being electricity or thermal energy), an analysis of residential buildings fulfilling a double role of consuming energies and, also, producing and storing energies, has been made as a first task for the specification of the FIEMSER system.

Firstly main loads in home, from water heater to leisure devices, have been identified and a brief technical description of each of them has been provided, including the average energy consumption with a consumption profile during a normal day and/or a year. In addition, this part contains some data useful for the control and the future algorithm of FIEMSER system.

This has been complemented by an analysis of the local energy sources which can be used to decrease (with the objective to nullify) the power consumption from the grid. This led to a technical description of the sources, architecture of classical power grid and a profile of the energy production if available. Like for energy loads, some pieces of information have been added regarding the control aspects.

A third part addressed the energy storage systems. After a brief technical description, this part provides energy storage capacity and amount of energy deliverable, and if available a classic architecture used with each type of storage device.

This work gives precisions about all appliances in an average European home, detailing from a technical point of view the main devices which could be managed by the FIEMSER system. But first of all, it gives an order of magnitude on the average consumption of each device, and shows which ones are the most important for energy saving (see chart below). In particular, the chart clearly shows that the energy saving system must consider in priority the house heating (rooms and water) and the air conditioning. The energy saving from all the other house appliances is secondary regarding their part of consumption. This kind of information gives the main way for energy management in the FIEMSER algorithms, and provides helping indications for the start of the project.

[1] http://www.energyawareness.eu/beaware
[2] http://www.dehems.eu
[3] http://www.beywatch.eu

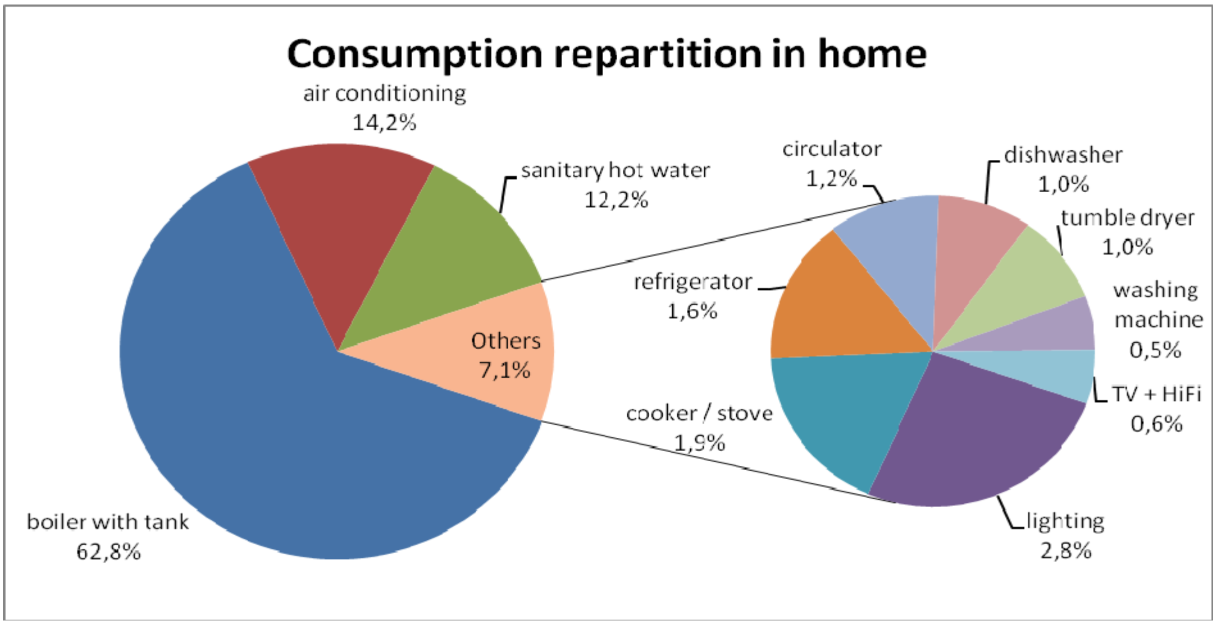

Figure 2 – Global consumption of an average European home

4. System Specification

One of the first works achieved in FIEMSER was to functionally and technically specify the envisaged system. This was realized by first defining scenarios that introduce FIEMSER requirements, then describing main functional system requirements and detailing them through the description of Use Cases.

A set of 8 Use Cases have been identified:

1. Process for updating the control system when a new device connects to the network (UC#1)
2. Accessing to the home settings by the user (UC#2)
3. Building monitoring and control actions (UC#3)
4. Generation of a day ahead schedule of resources utilization (UC#4)
5. Monitoring of the execution of a schedule and the reaction to events (UC#5)
6. Activation of an immediate energy consumption situation by the user (UC#6)
7. Performance index calculation (UC#7)
8. Accessing to performances information by the user (UC#8)

The overall functional schema, with the associated UCs, is presented in Figure 3 below.

In this schema, processes are identified as blue boxes. Main input and output data (red boxes and lines) are mentioned for each process (these data being described into more details in the corresponding Use Case). It should be noted that some processes will be run in a cyclic mode, whereas some others will be started by the end-user or triggered as a post-condition of other processes (blue arrays). Those cyclic processes are identified with the icon in the functional diagram.

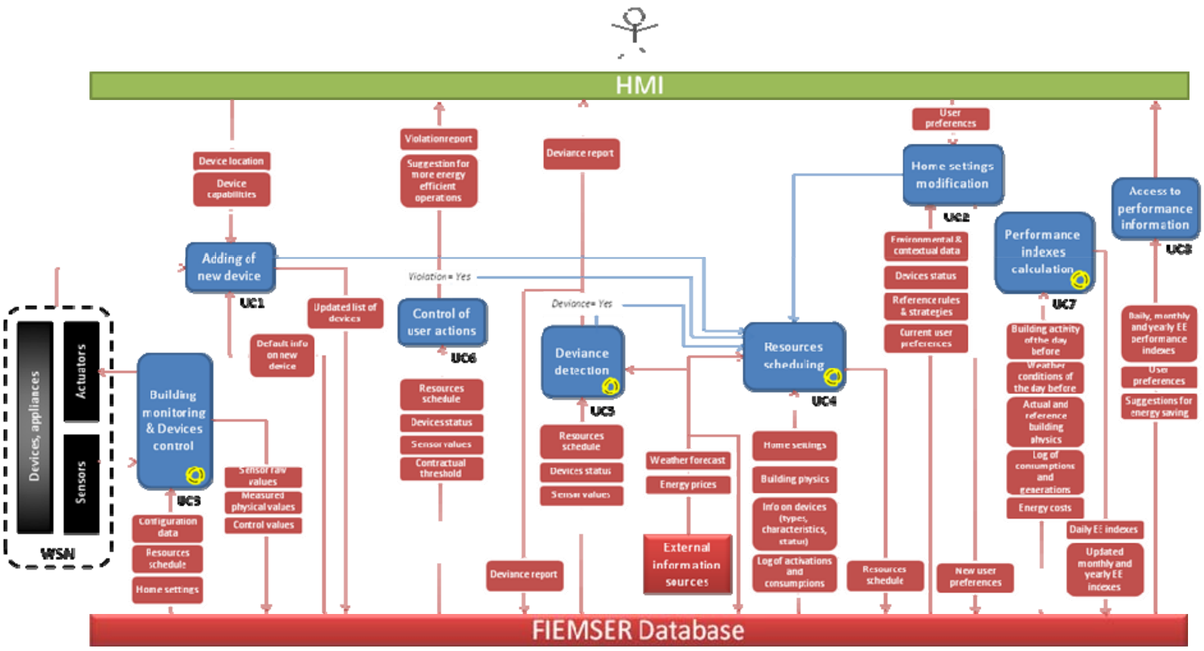

Figure 3 – Overall functional schema

The FIEMSER Database plays a central role in this functional architecture. It contains (but not only) all the data collected from the sensors and external sources, and exchanged between the FIEMSER components. As for the HMI (Human-Machine Interface), it can be implemented on various display devices: a standard PC screen, a TV, or a smart phone, depending on the location the end-user will access to the system.

Complementary to the Use Cases, the energy management algorithm (used by the intelligent scheduler described in Use Case #4), the interaction between all FIEMSER elements and devices, the communication mechanism and the interaction between the system and the end-user (GUI), have also been specified.

Non functional requirements, including hardware requirements, system upgrading, installation and maintenance, and system configuration, are also important issues that have been addressed for a proper running system.

It should be stressed that all the functional (and non functional) system requirements specified have been aligned to provide the end-user with a non intrusive system.

As an example of non-functional requirements, an overview of FIEMSER Hardware is depicted in Figure 4 below:

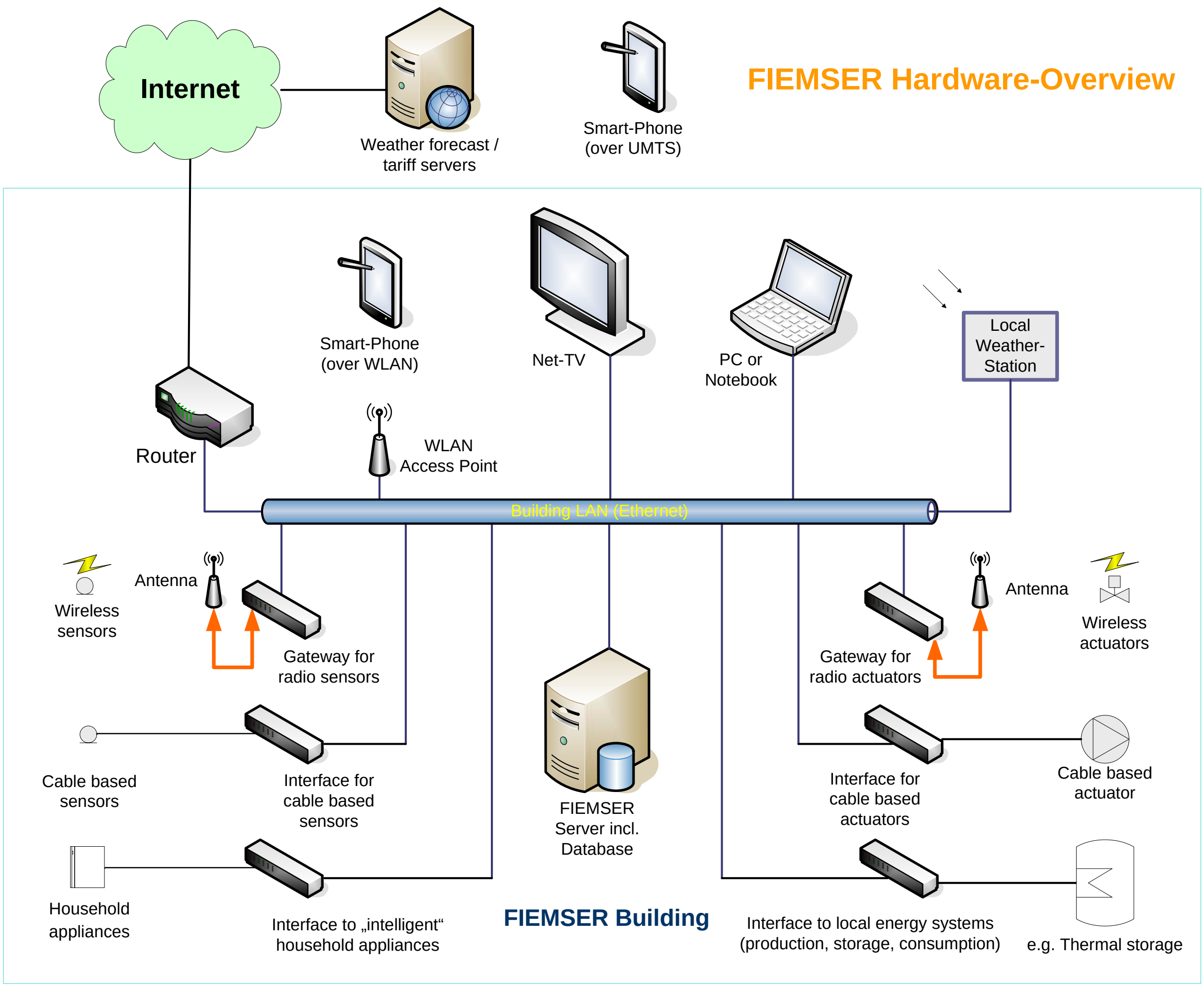

Figure 4 – Overall hardware architecture

5. Further work

During the next 27 months of the project, the work will mainly consist in defining and developing the main components of the FIEMSER system (the monitoring & operation tool, the intelligent control system and the multimodal user interface), achieving the system integration, and validating the system in real life conditions in two main climatic areas in Europe: the Mediterranean climate and the Continental climate.

FIEMSER's performances in Mediterranean climate will be validated in the KUBIK building. KUBIK is a 3-floor + cellar experimental building that is located in Spain, at TECNALIA's facilities. This building is fully monitored and includes local generation units and energy storage units.

FIEMSER's performances in Continental climate will be validated in the VERU building. The VERU experimental building is a test facility for energy and ergonomic investigations. VERU is a 3-floor experimental building that is located in Germany. As well as measuring consumption for heating, hot water, air-conditioning and ventilation, the various ergonomic aspects of lighting solutions are investigated.

6. Conclusion

This paper introduces a research work that started this year and will contribute to the reduction of primary energy consumption and GHG emissions of new and existing residential buildings by developing innovative building management systems which will decrease the overall energy demand (for lighting, domestic appliances and HVAC, whatever electricity or fossil energies are used), and make optimized use of available energy sources and storages. The first months of the project have concerned the collection of requirements and the first specifications of the system that should be able to interface with existing BEMS already in place.

Till the end of the project, planned in February 2013, efforts will be put on the development of needed system modules and even more importantly, the validation of the FIEMSER approach in two testing facilities in Spain and Germany.

For further information, please visit FIEMSER's website: http://www.fiemser.eu

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