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Energy Smart House Architecture for a Smart Grid

Energy Box System Solution Proposal

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Energy Smart House Architecture for a Smart Grid

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”Deus quer, o Homem sonha e a obra nasce”

Fernando Pessoa

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Andreia Melo Carreiro

Resumo

O consumo de electricidade nas residências tem vindo a crescer de forma contínua ao longo das últimas décadas, tornando-se um problema para as empresas do sector eléctrico, para os consumidores e para o meio ambiente. Os sistemas de medição existentes não são suficientes e têm limitações no fornecimento de informação adequada em tempo real sobre o consumo, a micro geração e o armazenamento de energia (em particular em veículos eléctricos). Também não estão preparados para lidar com custos da energia variáveis, num contexto de um mercado com preços dinâmicos que dependem do mix energético.

A rede eléctrica do futuro – a Rede Inteligente – terá de ir para lá da medição ao nível da residência e evoluir para a medição ao nível de cada equipamento individual. Por um lado, os consumidores (que também podem ser produtores) sofrem, regra geral, de uma falta de informação relativamente ao impacto de cada equipamento específico e relativamente aos comportamentos necessários para reduzir o seu consumo. Desconhecem também o real impacto, a nível económico, da energia consumida, produzida ou armazenada em cada momento. Por outro lado, os operadores de distribuição ou de transmissão enfrentam frequentemente perturbações na sua rede, devido a não conseguirem prever, com precisão, a produção de energias renováveis – que são, por norma, recursos intermitentes – e, em paralelo, prever ou influenciar o consumo dos seus consumidores. Cria-se, assim, uma ineficiência no uso dos recursos disponíveis.

Nesse contexto, o objectivo da presente tese é o de criar uma proposta de arquitectura para um sistema de gestão energética que seja inteligente, autónomo e responsivo à procura – a Energy Box – baseado numa infra-estrutura de Tecnologias de Informação e Comunicação (TIC), que tem como principal objectivo ajudar os consumidores finais a alcançar poupanças de energia e reduções de custos, sem perda de qualidade nos serviços de energia prestados.

A cooperação entre uma casa inteligente e uma rede inteligente é uma abordagem encorajadora que, com a ajuda das TIC, pode melhorar as capacidades da rede inteligente de energia.

Palavra-chave:

Tecnologias de Informação e Comunicação (TIC), Casas Inteligentes, Redes Inteligentes, Eficiência Energética, Resposta da Procura

Abstract

Electricity consumption in homes has been steadily increasing for the last few decades. This trend presents some problems for utilities, for customers, and for the environment. The existing metering systems have significant shortcomings when provisioning the adequate real-time information on the consumption, the micro generation, and the energy storage (particularly, in electric vehicles). They are also not prepared to handle the costs in a context of dynamic pricing, which depends on the generation mix.

The electric grid of the future – the Smart Grid – will need to go beyond the home meters, and zoom in on individual appliances' consumption readings. On one hand, customers (who may also be "prosumers" – that is, simultaneously producers and consumers), generally have a lack of information regarding their appliances and regarding the behaviors they need to adopt in order to lower energy consumption. They also lack the knowledge of the real economic impact of the energy consumed, generated or stored at each moment. One the other hand, the distribution or transmission system operators are often facing disturbances in their grids because they cannot predict precisely the output of many renewable energy sources – which are mostly intermittent resources – and, in parallel, predict or influence the consumption of their customers. Inefficiency thus arises in the use of resources.

In this context, the aim of the thesis is to create an architecture proposal for an intelligent and autonomous demand-responsive energy management system – the Energy Box – based on a fully interactive Information and Communication Technologies (ICT) infrastructure, the main purpose of which is to help end-users achieve energy savings and cost reductions, without loss of quality in the energy services provided.

The cooperation between a smart-home and a smart-grid is a promising approach which, with the help of ICT, can fully unleash the capabilities of the smart electricity network to provide energy services to end-users in a more efficient way.

Keywords:

Information and Communication Technologies (ICT), Smart House, Smart Grids, Energy Efficiency, Demand Response.

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Acronyms

6LoWPAN	IPv6 over Low power Wireless Personal Area Networks).
AC	Alternating-Current
ADR	Automated Demand Response
AEB	Aggregator Energy Box
AMR	Automated Meter Reading
API	Application Programming Interface
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
DC	Direct-Current
DG	Distributed Generation
DOE	Department of Energy
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
DVD	Digital Versatile Disc
EB	Energy Box
EISA	Energy Independence and Security Act
EMC	Electro-Magnetic Compatibility
EMS	Energy Management Systems
ETSI	European Telecommunications Standards Institute
EU	European Union
EV	Electric Vehicles
GHz	Giga Hertz
HA	Home Automation
HAN	Home Area Network
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Information and Communication Technologies
ID	Identifier
IEA	International Energy Agency
IEB	Individual Energy Box
IEEE-SA	Institute of Electrical & Electronics Engineers – Standards Association

IETF	Internet Engineering Task Force
IPv4	Internet Protocol version 4
IPv6	Internet Protocol Version 6
IT	Information Technology
Kbps	Kilobits per second
LAN	Local Area Network
M/411	Europe Standardization Mandate
M2M	Machine-to-Machine
MAC	Media Access Control
MAN	Metropolitan Area Network
Mbps	millions of bits per second
MHz	Mega Hertz
NB-PLC	Narrow Band Power Line Communications
ND	Nation Distributor
NIST	National Institute of Standards and Technology
OECD	Organization for Economic Co-operation and Development
P2P	Peer-to-peer
PAN	Personal Area Network
PQ	power quality
PV	Photovoltaic
PLC	Power Line Communication
R&D	Research & Development
RF	Radio Frequency
RH	Relative Humidity
SEP	Smart Energy Profile
SOA	service-oriented architecture
TCP	Transmission Control Protocol
TSO	transmission system operator
TV	Television
UART	Universal Asynchronous Receiver Transmitter
UDP	User Datagram Protocol
V2G	Vehicle-to-Grid
VDR	Video Disk Recorder

VEE	Validation, Estimation and Editing
VPN	Virtual Private Network
WAN	Wide Area Network
WPAN	Wireless Personal Area Networks
WSN	Wireless Sensors Networks

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1. Introduction

1.1. Context

The European Union is committed with the 20-20-20 targets to reduce carbon emissions by 20%, to improve energy efficiency by 20%, and to increase the share of renewables to 20%, by 2020. According to Organization for Economic Co-operation and Development (OECD) and International Energy Agency (IEA), the energy efficiency improvement and renewable energy increase are seen as the critical priorities to reach the 20-20-20 goal [1]. Both measures call for changes in the electric system [2], with the transformation of the current power grid system into a future power grid system generally designated as Smart Grid [3].

Currently the power grids only transport electricity between the generation and the end-user (industrial, commercial and residential customers). The future grids will follow an information centric approach in parallel with the energy transportation [4] (Figure 1).

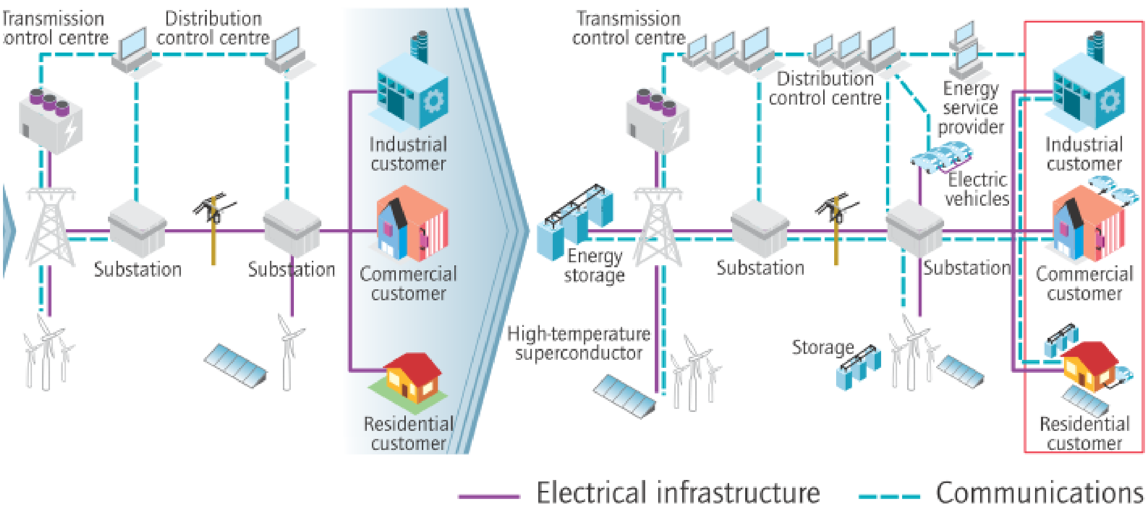

Figure 1 – Smarter Electricity System from present to future. Source: IEA data and analysis, 2011

Information associated with electricity systems and customers is the main reason to call the future energy grids Smart Grids [5]. This information will be provided by the use of smart meters and technologies, which must be able to cope with the challenges associated with electric vehicles, renewable energy sources, and storage systems, among others [4] [8]. The adequate usage of information will allow the management of peak loads, contributing to flattening the aggregated demand curve by matching forecasted demand growth with the current portfolio of generation resources. The result of these actions may contribute to avoid the construction of new generation units and/or the reinforcement of the grid infrastructures and equipment, providing new energy services and increasing the efficient use of the grid with a better integrated planning [3].

In this context, the Smart Grid is a system that delivers electricity from suppliers to consumers using Information and Communication Technologies (ICT) spending megabytes of data to move megawatts of electricity more efficiently, saving energy, ensuring reliability and affordably [4].

The principal characteristics of the Smart Grid are [7]:

- The interaction between the customer and the Utility;
- The customer can be a prosumer[1], accommodating generation and storage options;
- Creation of a new electrical market, enabling the development of new products and services for the customer;
- Optimize asset utilization and operate efficiently improving load factors, outage management performance, lowering system losses and reducing capital cost;
- Anticipate and respond to system disturbances, detecting and analyzing potential problems;
- Smart Grids are expected to operate resiliently against attacks and natural disasters.

In this way, Smart Grids integrate several properties including transmission and distribution infrastructures, information network, end-use systems and associated distributed energy resources. The trend towards the Smart Grid deployment is expected to gradually convert a centralized, “producer controlled” network into a decentralized, consumer-interactive network that should be supported by monitoring systems [5].

However, these improvements may lead to some problems associated with the integration of ICT with the current physical infrastructure and still unknown ways how

[1] *Who consumes electricity from the grid, from own production and can also sell electricity to the grid*

the utility and customer will interact. This lack of integration also raises some security issues that should not be ignored [4]. In this context, the National Institute of Standards and Technology (NIST) in the USA have been working on a framework and roadmap for Smart Grids interoperability [9]. The NIST framework defines a conceptual model presented in Figure 2 that is divided in 7 domains: Transmission, Distribution, Markets, Bulk Generation, Operations, Service Providers and Customers [6].

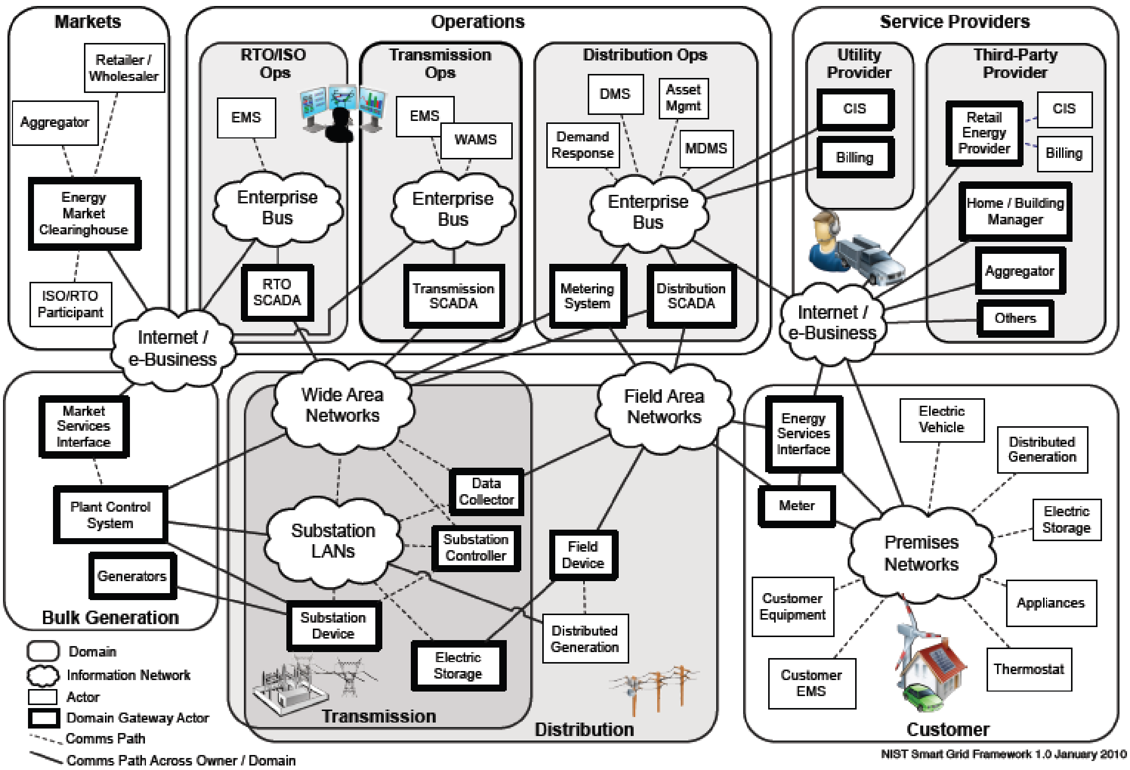

Figure 2 - The NIST Conceptual Model [6]

This work will be mainly focused on the residential sector in the Customer Domain. While the electricity consumption in the industrial sector has remained almost constant during the last decades, in the residential sector the electricity consumption has been steadily increasing.

The main reasons for these different trends are twofold. On the one hand, electricity consumption has been traditionally a well identified problem in the industrial sector, since it translates into higher costs. Therefore, huge investments have been devoted to develop Energy Management Systems (EMS) that reduces dramatically such consumption and, in turn, such costs. On the other hand, electricity consumption in households is not individually very significant; its true impact arises when it is summed up over millions of homes. In addition, the widespread utilization of new types of loads and the requirement of higher levels of comfort and services have also driven such increases in the electricity consumption in the residential sector [7].

Indeed, the electricity consumption breakdown in EU households was recently characterized [8], showing clearly the increasing importance of electronic loads, which represent more than 21% of the overall consumption [12].

Given those increasing consumptions, in-house monitoring and control systems with sub-metering capabilities are needed to provide to the users information about unwanted consumptions. With this information available, the users could take actions to reduce these consumptions such as replacing appliances by more efficient ones or shutdown appliances with high standby consumptions [22].

Furthermore, in a Smart Grid context, the customer, besides being a consumer, could be also a prosumer, since the presence of electricity microgeneration sources in households is steadily increasing and the penetration of Electric Vehicles (EV) is expected to growth in the next few years [3].

In this way, Electric Vehicles (EV) represent a new demand for electricity in the customer side and a possible storage medium that could supply power utilities [15]. The potential of Vehicle-to-Grid (V2G) can be expanded by adjusting charging times to off-peak power and avoid on-peak charging to reduce the necessity for extra generation distribution capacity [33] [34].

In this context, Demand Response (DR), perceived as an instrument to manage electricity customer in response to grid conditions, is needed, to enable customers to contribute to energy demand reduction during peak demand. This can be achieved using monitoring and control systems in houses, which are associated with consumption, local electricity generation and energy storage capabilities, that must be optimized in an integrated manner. DR is therefore a mechanism to encourage consumers to reduce such demand when is needed, and is designed to be fiscally and environmentally responsible, to answer to irregular and temporary peak demand periods, compensating the effects of the variability of renewable resources and reducing the electricity use when demand could outpace supply [4].

1.2. Objectives

This thesis presents a solution proposal for a novel energy smart home architecture able to monitor and control systems that meets the aforementioned requirements. The main goal of this architecture is to provide the foundation to reduce energy costs and CO_2 emissions by increasing the energy consumption awareness of the users, by acting automatically on the demand side (i.e., the appliances) and by coordinating electricity consumption, microgeneration and storage facilities while satisfying comfort requirements.

According to Figure 2 Figure 2 - The NIST Conceptual Model, the main focus of this project will be the Customer Domain; however, the Service Provider Domain, such as an Aggregator will also be a subject of study [6].

In the Customer Domain, an architecture based on ICT will be designed to support decisions. These decisions concern consumption, microgeneration and storage devices, and the relation between them within the Smart Grids context. This thesis will focus mainly on the consumption concerns.

In the Service Provider Domain, with focus on the Aggregator, an architecture based on ICT will be designed. The aggregator should allow the electricity distribution companies to balance the load and supply, considering the availability of the renewable energy resources which depends on external factors such as wind speed and direction or the amount of sunlight. The intermittent nature of the renewable resources leads, in general, to a sub-optimal use of the available resources [8] [9].

In this context, the main goal of this thesis is the design of an architecture solution of an automated demand response system. This system, called Energy Box (EB), a concept created by Livengood and Larson at MIT in 2009 [26]. The Energy Box System will be based on two main components: the local management (Individual Energy Box – IEB) and the aggregated management (Aggregator Energy Box - AEB).

The definition of the architecture for the IEB is the first step to design the EB system. This architecture will focus on the ICT required for the local management level inside the house. The IEB will react to grid stimuli (namely dynamic pricing) as individuals that only know the reality inside the house, including the integration of multiple sensors and actuators as well as communication protocols [10].

The second step will relate to the aggregated management at the grid level through the AEB. This level will have the responsibility to maintain the balance and fairness in the offers and requests of energy from the grid.

The last step will consist in the design of an architecture to integrate the IEB and AEB levels. This architecture should define the communications between both components and provide a platform for near real time actuation and information exchange [10].

To achieve this goal, two main research questions arise:

1. **What is the most adequate architecture based on ICT for an in-house demand-responsive energy management system?**

   The aim is to find how the household appliances will communicate with the IEB, how to actuate and control devices, how to communicate with microgeneration and storage systems and what kind of meters and sensors should be used to monitor the electricity associated with consumption, microgeneration and storage.

2. **What is the best way to optimize the bidirectional information flow between the AEB and the IEB?**

   This question will focus on the optimization of the communication channels between the AEB and the IEB. Problems such as the format of the messages to exchange, taking into consideration security concerns, as well as whether the architecture should be two- or three-tier should be addressed. With two tiers, faster and direct communications can be ensured, but internet is required in each home; with 3 tiers, an intermediary level of communication is required to avoid the need of external (played by customer) internet connection. This decision will have impact on the performance and final solution cost.

This thesis will focus on a solution proposal architecture based on ICT for an in-house demand-responsive energy management system, taking in consideration only the consumption concerns.

1.3. Text Organization

The remainder of the Master thesis is structured as follows:

- Section 2. goes through a brief presentation of the state-of-the-art of the technologies. Some related projects are also described.
- Section 3. presents the framework of the research, presenting the main issues analyzed in this thesis, namely energy efficiency and conservation, distributed generation, energy storage and communication technologies.
- In section 4. the system requirements are presented at general level and at the in-house, machine-to-machine and aggregator energy box domains.
- Section 5. presents the global energy box system architecture, also divided on the same domains.
- Section 6. summarizes the thesis, emphasizing its main conclusions and proposes the future work.
- Annex A describes the application protocol, providing examples of the basic functionalities, message structure and message repertoire.

2. State-of-the-art

The Institute of Electrical and Electronics Engineers - Standards Association (IEEE-SA) is currently one of the associations gathering research efforts leading to the standardization of smart grids interoperability. Among others, the main research topics are: networking, security and integration of distributed resources [11].

IEEE is working closely with the NIST, which is developing a standards roadmap, since NIST was assigned with the "primary responsibility to coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability of Smart Grid devices and systems (…)" under the Energy Independence and Security Act of 2007 (EISA) [3]. This agreement was established because Smart Grids need to urgently have protocols and standards.

Figure 3 displays the high level conceptual model created by NIST related to the interaction of actors in different Smart Grids Domains (Markets, Operations, Service Provider, Bulk Generation, Transmission, Distribution, and Customer) through secure communication flow and electrical flow.

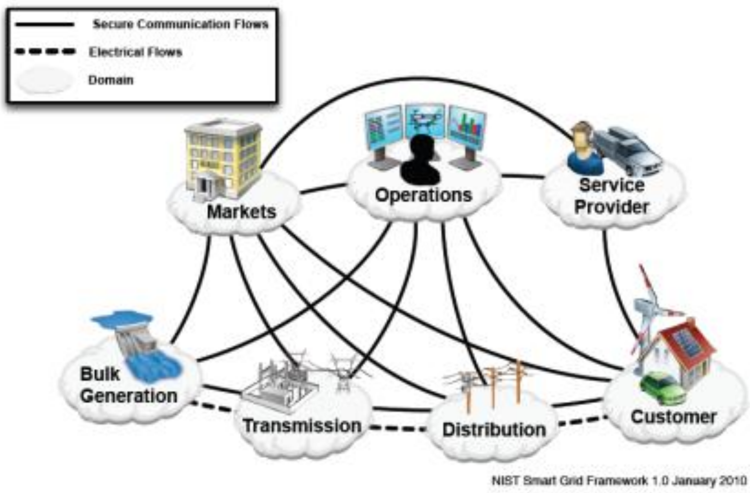

Figure 3 - High Level conseptual module (NIST) [6]

Also in Europe, Smart Grids have received a lot of attention. The idea of future grids in Europe is described in detail in the European Technology Platform Smart Grids and the Strategic Deployment Document [12], which presents the required changes in the electric systems to promote transformation towards Smart Grids.

Following this approach, the European Commission has issued the Europe Standardization Mandate (M/441) to the three European Standardization bodies CEN [13], CENELEC [14] and ETSI [15] to define an open architecture for utility meters and services. This architecture should take some actions including an upcoming mandate on standardization and the development of a system that can operate across boundaries of generation, transmission, distribution and customer (consumer or prosumer) systems addressing key issues such as price, security and sustainability [1] [3].

Standards, in this context, consist in technical specifications and rules for products and systems with the goal of enabling the deployment of smart metering and smart control systems, to secure interoperability, protect the customer and safeguard the system reliability [10]. The M/411 refers that for smart metering systems, for which there are currently approximately 110 applicable technical standards available. Nevertheless, those standards are not described in a detailed way regarding open architectures that can cover the complete requirement range. The M/411 should also guarantee interoperability of technologies and applications within the European market.

The projected open architecture places the smart meter gateway as a central device in the house. This gateway can be part of any central device meter (electricity, water, gas or heat) or work as an isolated device. Moreover, an open interface is required to be defined in order to specify the communication with smart meter in-house and home automation services to connect with a public network of services providers, with different kinds of facilities.

Nowadays significant improvements regarding energy efficiency have been achieved in appliance technologies, but the end-use electricity consumption has still increased, particularly in buildings. Some of the reasons for such increase are associated with a higher degree of basic comfort and level of service and amenities as well as with the widespread utilization of new types of loads [21].

Therefore, improving energy efficiency in European households/services sector has become a very important goal for the European Commission, which has committed the Member States to convince the society and provide them with the means to reduce energy consumption, create a culture of energy efficiency, and promote the construction of green buildings with local distributed generation.

Recently, significant R&D efforts have been carried out in this area and there are currently a few commercial solutions available [7]. However, some of the available systems do not have sub-metering capabilities and thus do not provide users with real-time information about the individual consumption of appliances. The control capabilities provided to the users and the communication services to allow information sharing between users and utilities are also scarce. As result, such systems do not guarantee the required conditions to operate DR programs [8]. However, DR services are an important emerging aspect of the Smart Grid, with very good results in terms of energy savings in some case studies, but with only very limited examples, due to the lack of technology [9].

In addition, there is an absence of systems that include monitoring for both consumption, generation and storage, providing services and information to the users and to the utility, thus ensuring the global optimization of the system at the house.

To contribute to solve those problems, several EU R&D projects are currently underway, dealing with different components of this issue, such as:

- Management and control of renewable technologies – e.g. Energy Warden (www.energywarden.net);
- Measuring and analysis of building energy profiles – e.g. IntUBE (www.intube.eu);
- Energy management systems for residential buildings – e.g. Fiemser (www.fiemser.eu);
- Embedded systems for increasing energy efficiency in buildings – e.g. eDIANA (www.artemis-ediana.eu);
- Monitoring of energy consumption and comfort levels – e.g. Dehems (www.dehems.eu);
- Profiling and managing the energy consumption of appliances at home – e.g. AIM (www.ict-aim.eu);
- Consumption information to increase energy awareness – e.g. BeAware (www.energyawareness.eu)
- Optimization of loads to perform generation-consumption matching – e.g. Pebble (www.pebble-fp7.eu);
- Intelligent monitor and control of electricity systems – e.g. E-Energy (www.e-energy.de);

- Communication between smart devices, users, and the utility – e.g. NOBEL (www.ict-nobel.eu), BeyWatch (www.beywatch.eu), and SmartHouse/ SmartGrid (www.smarthouse-smartgrid.eu);
- Aggregation and forecasting of energy demand and supply – e.g. MIRABEL project (www.mirabel-project.eu).

However, the ENERsip project (www.enersip-project.eu) addresses this topic holistically, providing a comprehensive solution to monitor and control consumption and generation infrastructures, which includes not only the required M2M[2] (Machine-to-Machine) communications infrastructure, but also the IT system and user interfaces. In addition, the ENERsip platform includes an in-house monitoring and control system, which can be used with all types of buildings and appliances; whereas other projects target households that already have smart meters, smart control, and automation [67].

Next generation homes will have two more components to add to the smart grids: microgeneration and storage [9]. The end-user will be able to generate and storage energy changing his/her relationship with the grid. The sale of electricity will no longer be an exclusive of the Utilities, the end-user will also have the possibility to sell electricity to the grid. To improve the grid efficiency, a demand responsive system is required, associated with advanced metering. This system should be able to manage the load [24].

Current discussions in Europe have been emphasizing the need for an Automated Demand Response infrastructure to achieve a sustainable and efficient grid considering the interaction between each house and the grid [17]. Unfortunately, despite all the efforts and initiatives there are no significant developments towards a standard definition [18].

On the other side of the Atlantic, the Lawrence Berkeley National Laboratory through the Demand Response Research Center has advanced a proposal for an OpenADR protocol that would standardize communications between houses and the grid [19]. A novel architecture is needed to model the structure of a system and describe the entities and their interactions within the system, with a very large range of communication networks that can be ensured by a diversity of network technologies, such as HAN[3] (Home Area Network), Enterprise LAN[4] (Local Area Network), WAN[5]

[2] *Refers to technologies that allow both wireless and wired systems to communicate with other devices of the same ability*

[3] *Home Area Network is a residential local area network*

[4] *Local Area Network is a computer network that interconnects computers in a limited area*

(Wide Area Network), PAN[6] (Personal Area Network), MAN[7] (Metropolitan Area Network), VPN [8](Virtual Private Network), among others [20].

The integration of ICT into the Smart Grid is a key element to create a well-defined Reference Architecture [21]. This integration should provide extended applications management competences over an integrated secure, reliable and high-performance network. This should result in a new architecture with many stakeholders, applications and networks that need to interoperate [20].

The architecture definition is really an important issue, because it is a guide to decision making on how to achieve a functional fit within a system, in this case with respect to the interaction between in-house and the aggregator in the new grid infrastructure.

The creation of a service-oriented architecture (SOA) in residences requires adopting wireless sensor networks (WSN) to manage all appliances in the framework of a smart house concept [30] [31] [33] [34].

The WSN enables the monitoring of electricity use in consumption, generation and storage devices, at the same time that can autonomously operate in households' appliances dynamically changing ambient conditions and consumer loads [21; 22; 23]. With the focus on energy efficiency, the smart home concept has recaptured special care for the academy and industry because it is needed to find the way to relate the three domains of consumption, microgeneration and storage [24] [25].

There is a plethora of communications standards for smart metering and sub-metering (i.e., in-house monitoring and control networks or HAN) [10]. In general, wireless solutions are preferred vis-à-vis wired ones, since they reduce deployment and maintenance costs and allow higher flexibility. This is not the case for PLC (Power Line Communication), since PLC[9] does not require the deployment of additional infrastructure; however, PLC presents problems related to EMC[10] (Electromagnetic Compatibility) and low to medium voltage conversion. NB-PLC (Narrow Band Power Line Communications) partially solves those problems, but it may present bandwidth

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[5] Wide Area Network is a telecommunication network that covers a broad area
[6] Personal Area Network computer network used for communication among computer devices
[7] Metropolitan Area Network is a computer network that usually spans a city or a large campus
[8] Virtual Private Network is a method of computer networking that allows users to privately share information between remote locations
[9] Power Line Communication is a systems for carrying data on a conductor also used for electric power transmission
[10] Electromagnetic Compatibility is the ability of a system to perform satisfactorily in its electromagnetic environment without introducing intolerable interference into anything in that environment

problems. Standing out among the wireless technologies is IEEE 802.15.4[11], since it is defined to minimize power consumption and cost in applications with low data rates and no latency constraints.

According to Gartner [35], the communication between in-houses the grid level can be roughly divided into two major groups: RF (Radio Frequency) and PLC. The PLC communication is usually preferred by incumbent electricity operators for the communication infrastructure. On the other hand, RF solutions are often preferred by independent meter operators, telecommunications companies and consumers associations because these solutions keep better separation between the electricity infrastructure and the ICT infrastructure. [37]

There are two WPAN[12] possibilities to run on top of IEEE 802.15.4: ZigBee [13] or 6LoWPAN[14] (IPv6 over Low power Wireless Personal Area Networks). While 6LoWPAN seems to be the most appropriate solution in the long run, ZigBee definitely represents the more mature solution that can be deployed nowadays. Indeed, the ZigBee Smart Energy Profile (SEP) 2.0 already includes 6LoWPAN in the ZigBee stack. However, 6LoWPAN still presents some problems: instead of enabling seamless end-to-end communications based on IPv6, gateways and tunnels would still be required along the current IPv4-based communications infrastructure. Thus, strictly ZigBee is used within the hereby presented in-house monitoring and control network.

In this way, the Energy Box System aims to create a novel ICT architecture for an energy smart house integrated with the smart grid, filling the gaps existing in the European Projects mentioned, related to architecture design combining the in-house management systems and the communication with the grid.

The inclusion of microgeneration and storage devices in this architecture, as well as, the interaction with the grid mediated by an aggregator, should contribute to ensure the matching between demand and supply. In this way, ICT architectures based on Smart House infrastructure, interacting with smart grids, enables the aggregation of houses as intelligent networked collaboration, instead of seeing them as isolated passive units in the energy grid [27].

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[11] "*standard which specifies the physical layer and media access control for low-rate wireless personal area networks*"

[12] *Wireless Personal Area Network is a network for interconnecting devices centered around an individual person's workspace, in which the connections are wireless.*

[13] *ZigBee is a specification for a suite of high level communication protocols using low-power digital radios based on an IEEE 802 standard*

[14] *IPv6 over Low power Wireless Personal Area Networks is the name of a group in the internet area internet engineering task force*

3. Framework

In this chapter the main issues related with this thesis are described, namely the three main vectors in a smart grid context, the energy efficiency, the distributed generation and the energy storage. Also the communication technologies that can be used in order to provide services to ensure the optimization of such vectors are described.

3.1. Energy Efficiency and Conservation

As described in the introduction, over the last few decades, worldwide energy demand has increased due to industrial development and global economic growth, resulting in a simultaneous increase in global energy costs and in environmental impacts. Although significant improvements regarding energy efficiency have been achieved in appliance technologies, the end-use electricity consumption has still increased, particularly in Buildings (Figure 4). Some of the reasons for such increase are associated with a higher degree of basic comfort and level of service and amenities, as well as with the widespread utilization of new types of loads [38].

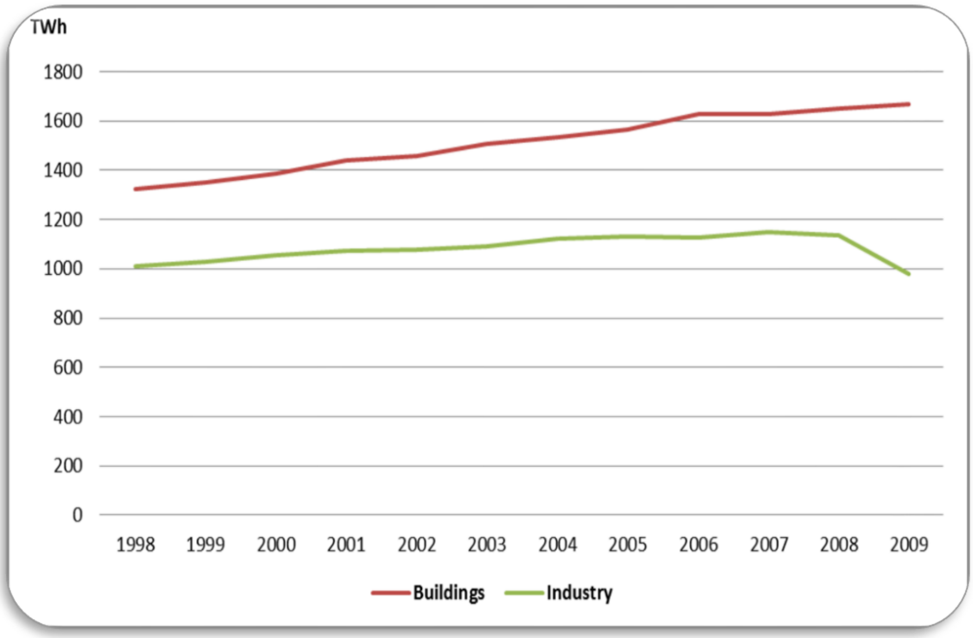


Figure 4 - Electricity Consumption in Europe [38]

The breakdown of consumptions in EU households was recently characterized in the REMODECE project [39]. Figure 5 shows the distribution of yearly electricity consumption for a typical (average) European household. Cooling (refrigerators and freezers) is the group of appliances requiring the largest share of the electricity consumption within a household, representing about 28% of the total electricity consumption. Lighting represents the second largest with 18% of the total electricity consumption. Clothes washing and drying represents about 16%, personal computers and accessories 12%, cooking 11% and television 9%. Air conditioning loads require about 2% of the household electricity consumption, while other appliances such as vacuum cleaners, radios and chargers represent about 4%.

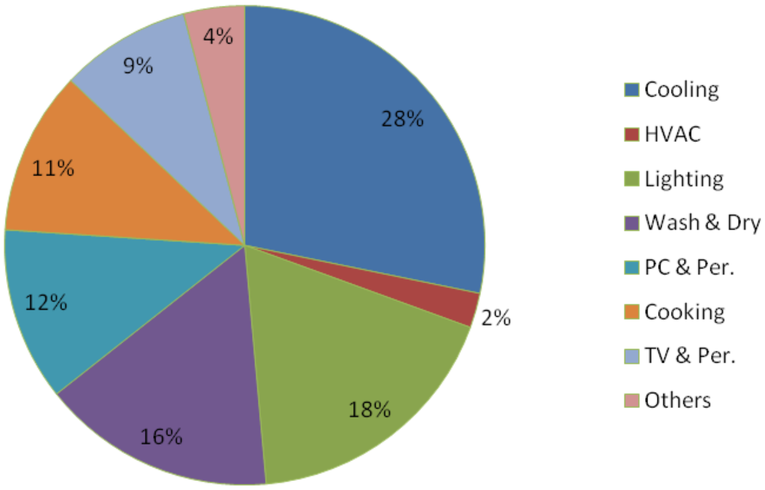


Figure 5 - Distribution of yearly electricity cnsumption for a typical EU household [38]

The baseline load consumption of EU average household is also quite high, near 200 W, mostly due to the cooling appliances and the HVAC (Heating, Ventilating, and Air Conditioning) loads, as shown in Figure 6. In the EU, the average standby electricity consumption is about 180 kWh per household per year, which according to some literature between 7-11% of the total annual electricity consumption per household [23]. According to the IEA (International Energy Agency), by 2030, 15% of the total appliance electricity consumption in Europe could be due to standby functions. As can be seen, washing and drying appliances have a high consumption at peak hours, although in general they may be shifted to other periods. Near real-time monitoring and control system are needed to provide the consumer with tools to be aware and to reduce such stand-by consumption [7].

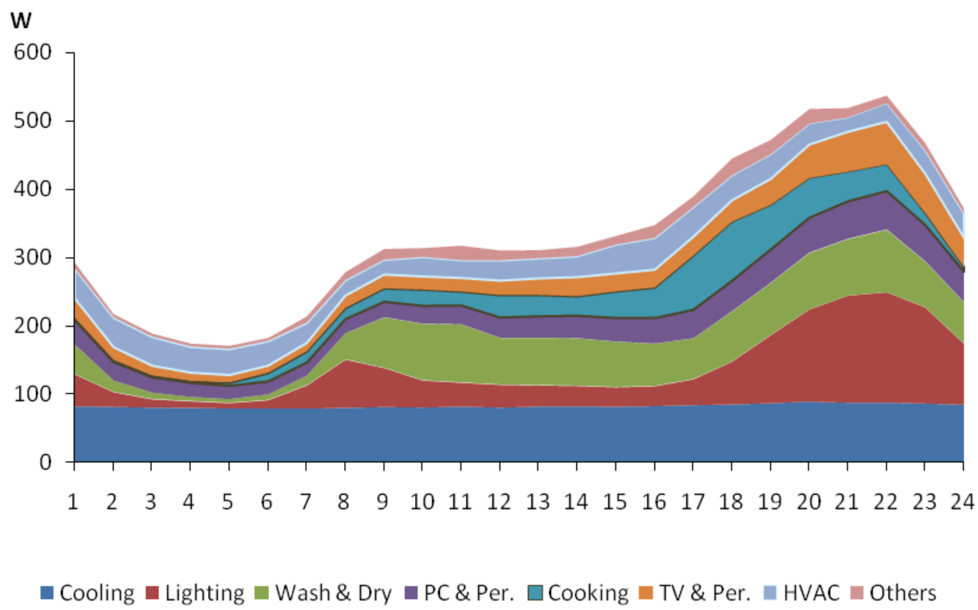


Figure 6 - Daily accumulated consumption in group of appliances for a typical household [39]

Thus, actions to reduce the energy consumption and optimize it in residential buildings are needed, namely energy efficiency and energy conservation actions.

Energy efficiency should be associated with technology that produces the same end services while using less energy [40]. This technology is continuously changing because a device that was energy efficient 30 years ago is probably not energy efficient today. Energy efficiency programs have become increasingly popular as global warming has become more of a threat. As many people in the industry say, “the cleanest energy is the energy never used”.

Although energy conservation is frequently confused with energy efficiency, it is fairly unlike. Both include, in general, a reduction of energy use but accomplish that goal in different ways. Conservation includes generally cutting waste of energy. Energy conservation has not been as popular as energy efficiency because it is frequently related with sacrifice. For utilities, it is also much easier to measure the impact of installing an energy efficient device because the energy savings do not depend on human behavior [40].

Thus, to achieve energy savings there are two possible options: technological change (energy efficiency) or behavior change (energy conservation). Both options can be promoted by demand-side management and demand response programs.

3.1.1. Demand Side Management

The Demand Side Management (DSM) concept was defined by Gellings in 1980 as the planning and implementation of activities based on sustainable development promoting the rational use of energy and increasing the energy efficiency to reduce the impacts related with global warming.

Perhaps the most widely accepted definition of demand-side management is the following: "Demand-side management is the planning, implementation, and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility's load shape, i.e., changes in the time pattern and magnitude of a utility's load. Utility programs falling under the umbrella of demand-side management include: load management, new uses, strategic conservation, electrification, customer generation, and adjustments in market share" [42].

This definition of DSM focuses upon the load shapes implies an evaluation process that examines the value of programs accordingly[45]. The incentives for more efficient use of electricity should be concerns of general interest:

- National economy: Reduce imports of primary energy;
- General Population: Reduction of air pollution and environment degradation, conservation of fossil resources and maximize consumer welfare;
- Utility: Avoid or delay investment needs;
- Prosumer: To induce a more rational consumer behavior in the energy use and consequently reduce cost while improving lifestyles.

In general, demand-side management embraces the following critical components of energy planning [43]:

- Demand-side management will influence customer use. Any program proposed to influence the customer's use of energy is considered demand-side management.
- Demand-side management need realize certain objectives. To create a "desired load shape change" the program must promote the success of certain goals, i.e., it must result in reductions in average rates, advances in customer satisfaction, achievement of reliability targets, etc.
- Demand-side management will be assessed against non-demand-side management options. It needs that demand-side management options be

compared to supply-side options. It is at this stage of evaluation that demand-side management becomes part of the integrated resource planning process.

- Demand-side management identifies how customers will respond. Thus, demand-side management encompasses a process that recognizes how customers will respond not how they should respond.
- The value of demand-side management is influenced by load shape.

Integrated Resource Planning (IRP) as can be seen in Figure 7 and how it fits in the whole process.

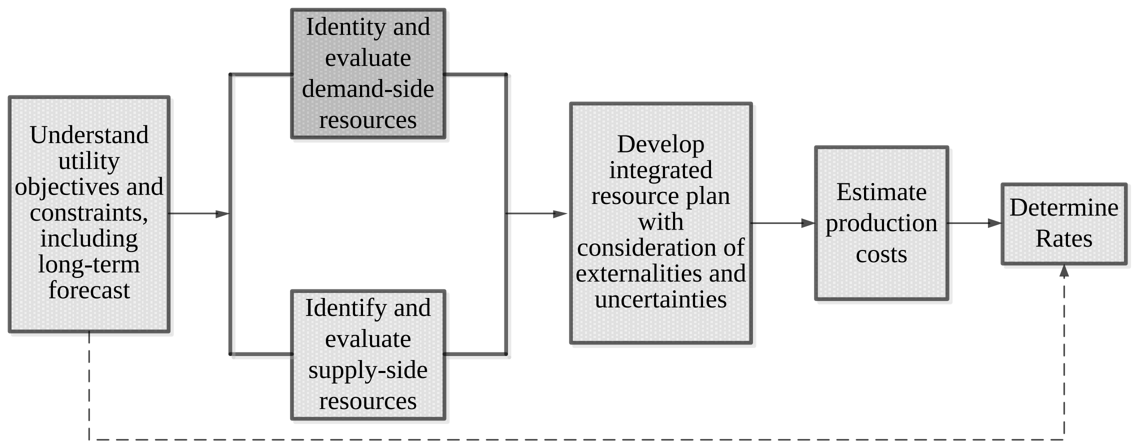


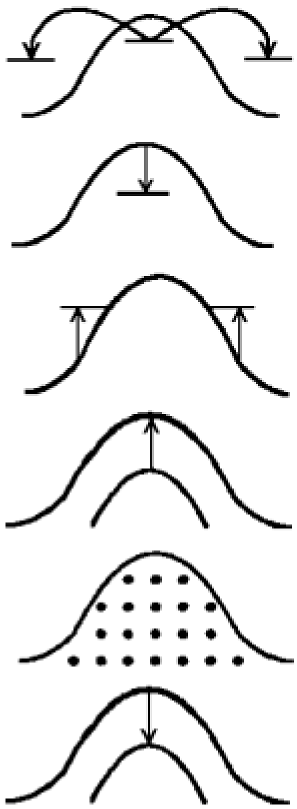
Figure 7 - How DSM fits into integrated resources planning [43]

These types of programs are intended to overcome two major obstacles that hinder the penetration of more efficient technologies: lack of knowledge among consumers and the high initial cost.

Through the implementation of DSM programs it is possible to achieve three categories of goals [28] [29]:

- Strategic – Guidelines for long-term planning that includes improvement of financial flows, rising incomes and improving the relationships with prosumers;
- Operating – Specific actions to reduce or postpone investment in capacity generation through a more efficient use of installed capacity, minimize the environmental impact or provide consumers with cost control;
- Flexibility - Conditioning the load curve;

The Utilities that engage in DSM programs use different strategies for the load curve management, as can be seen in Figure 8:



Load shifting – The deviation of the load-peak is usually obtained through variable rates by time of day or by promoting thermal storage devices.

Peak clipping – Reducing the load during peak periods is usually obtained by direct control of loads of the consumer or stimuli tariff.

Valley Filling – The increase of load during the off-peak periods is obtained by stimuli to the use of electricity in off-peaks periods.

Strategic Load Growth – The strategic growth of consumption seeks to encourage new uses for electricity, perhaps conquering the market to other fuels, by promotion of efficient equipment.

Flexible Load Shape – This is a concept related to reliability. Load shape can be flexible – if customers are presented with options as the variations in quality of services.

Strategic Conservation – is obtained through incentives to use more efficient energy use, for example the incentive to use more efficient equipment.

Figure 8 - Elements of the DSM Planing Framework [42]

In conclusion, the DSM encourages the end-user to be more efficient in the energy use, using more efficient technologies and behavior. A smart grid ensures the right means to provide to the consumer stimuli to adopt actions to achieve energy savings, enabling real-time monitoring of energy consumption and costs.

3.1.2. Demand Response

Demand Response (DR) is a particular situation of the demand-side management, as described in Figure 8 with the Flexible Load Shape. DR is the ability of the consumer react “automatically” to prices depending on the time, due to a signal of a contingency (which varies in amplitude and duration) to reduce or switch loads.

The DR occurs naturally in most markets, because the suppliers have flexibility to increase or reduce prices based on a variety of market factors. Consumers respond to these prices by adjusting the consumption or looking for alternative appliances with more efficient energy consumption. [46]

With the DR technologies it is possible to direct or indirectly force a consumption reduction in critical situations, in a short time. In the past, the electric system has been planned and operated under the supposition that the supply system must meet all customers' energy use, and that is not possible to control the demand [11]. However, that supposition is starting to change due to the creation of opportunities for customers to manage their energy use in response to signals (prices or load contracts).

The idea behind DR is that if the marginal peak load price is higher than the value that a consumer gets out of the services derived from the electricity, he would be willing to modify the demand, if paid the peak price or slightly less instead. A grid operator can obtain an economic benefit paying to a customer to reduce the consumption instead to paying a power producer to supply more output, because in peak periods the generation cost can be very high [11].

Traditionally the DR technologies were typically used to attend to economic concerns. However, nowadays they can be used to improve the system reliability, reducing instantaneously the energy consumption to prevent the most unbalanced situations, like the problems that result from the large space conditioning consumption on days with reduced wind velocity. As more customers practice automated price-responsive demand or automatically receive and respond to directions to increase or decrease their electricity use, system loads will be able to respond to, or manage, variability from wind power generation [11].

In conclusion, the DR encourages the end-user to make short-term reductions in energy demand in response to a price signal. The smart grid ensures the communication between consumer and utility enabling the DR programs implementation. In a context with high intermittent local generation, the DR is an important tool to ensure the grid reliability.

3.2. Distributed Generation

Distributed generation (DG) can be defined as a source of electric power connected to a distribution network or a customer site. Technological advances now permit power generation systems to be constructed in reduced dimensions with high efficiency, low cost, and least environmental impact [47].

Distributed generation can function as an additional to electricity generated by enormous power plants and distributed through the electric grid. Located at a customer's site, DG can be used to manage energy service needs for power quality and reliability [48] [47].

Distributed generation technologies can be divided into two different categories according to availability: firm and intermittent power. The firm power technologies are those that enable the power control of DG units that can be managed as a function of the load requirements. Firm DG plants can be utilized as backup, working only in situations of grid unavailability, in periods of high consumption (when the electricity is more expensive), working continuously, or dispatched to meet the variable load in an optimal manner [11].

Most of the distributed generations are non-dispatchable renewable resources, without control of the produced energy. Such resources are also intermittent, having a random generation character. Examples of this kind of technology are wind power or solar power that only produces energy when the wind or the sun is available. These technologies can be installed aggregated with energy storage that, by filtering the energy generation fluctuation, enables the management of the delivered energy by the combined system.

In this section, only the components related directly with the thesis will be described, namely, the renewable microgeneration integrated in buildings (Photovoltaic Panels and Wind Turbines).

Microgeneration consists on small-scale devices to generate electricity, at kilowatt level, which can be installed in buildings and namely in households. The use of microgeneration in residential buildings (mainly PV power) is increasing and must be optimized with the local consumption, to increase the grid efficiency. Since they are intermittent sources, new tools are needed to predict and monitor such generation and ensure the optimization of generation and consumption in a smart grid context.

3.2.1. Photovoltaic Panels

Photovoltaic (PV) solar panels are made up of cells connected together that convert light radiation into electricity. The PV cells produce direct-current (DC) electricity, which must then be inverted for use in AC systems.

Insolation is a term used to describe available solar energy that can be converted to electricity. The factors that affect insolation are the intensity of the light and the operating temperature of the PV cells. Light intensity is dependent on the local latitude and climate and generally increases as the site gets closer to the equator [49].

Photovoltaic systems produce no emissions, are reliable, and require minimal maintenance to operate. They are currently available from a number of manufacturers for both residential and commercial applications, and manufacturers continue to reduce installed costs and increase efficiency [49].

Distributed PV systems that provide electricity at the point of use are reaching widespread commercialization. Chief among these distributed applications are PV power systems for individual buildings. Interest in the building integration of photovoltaics, where the PV elements actually become an integral part of the building, often serving as the facade or exterior weather skin, is growing worldwide.

A building integrated photovoltaics (BIPV) system consists of incorporating photovoltaics modules into the building envelope, such as the rooftop or the frontage (Figure 9). By simultaneously serving as building envelope material and power generator, BIPV systems can provide savings in materials and in electricity costs.

BIPV may be used in many different assemblies within a building envelope:

- Incorporated into the facade of a building, complementing or replacing traditional glass.
- Incorporated in the external layers of the wall of a building façade.
- Used in roofing systems, providing a direct replacement for different types of roofing material.
- Incorporated in skylight systems, in which part of the solar light is transmitted to the inside of the building and the other part is converted into electricity.

Figure 9 – Photovoltaic roofing [50]

The photovoltaic panels cause low disruption because they are installed outside the house or on the roof. Due to recent changes in planning regulations, they are even easier to install than ever before. At houses, the PV systems are directly connected to the grid, not requiring a battery to store the energy.

3.2.2. Wind Turbines

Wind Turbines have been used for many years to harness wind energy for mechanical work, as in, pumping water.

Wind energy became a significant topic in the 1970's during the energy crisis. Wind turbines, basically windmills dedicated to producing electricity, were considered one of the most economically viable choices within the renewable energy portfolio. Today, attention has remained focused on this technology as an environmentally sound and convenient alternative. They are currently available from many manufacturers and improvements in installation cost and efficiency continue [51].

Wind turbines are packaged systems that include the rotor, generator, turbine blades, and drive or coupling device. As the rotor turns, its speed is altered to match the operating speed of the generator. Most systems have a gearbox and generator in a single unit behind the turbine blades. As with PV systems, the output of the generator is processed by an inverter that changes the electricity from DC to AC. Modular solutions that can be integrated in the building are already available.

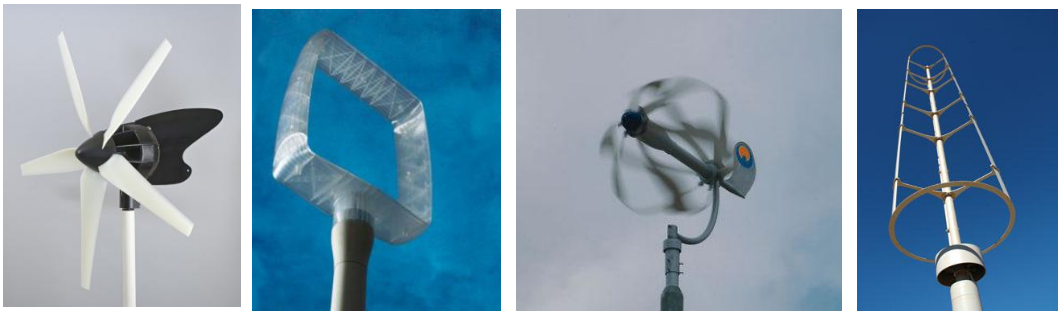


Figure 10 - Energy types of rotors [68]

3.3. Energy Storage

Energy storage in electric energy generation systems enables the adjustment between the energy generation and demand. Energy storage has essential position in the electric sector, because the energy demand has variations hourly, daily and seasonally. Additionally, the energy generation from renewable energy sources has significant variations, either in the short term (few seconds) or the in long term (hourly, daily and seasonal).

Energy storage is an appropriate option to make possible the large-scale integration of intermittent renewable sources, because the energy produced by intermittent renewable sources can be transferred in time to be released in low generation or high consumption times. Thus, energy storage is a crucial resource in a smart grid that includes microgeration from intermittent renewable resources. [52]

There are already small-scale units available, which can be used in residential buildings as individual or community energy storage, with decreasing costs. Such technologies are mainly based in supercapacitors and several types of batteries. One particular case of the batteries use is within electrical vehicles, which is the only storage option considered in the Energy Box Project.

The Vehicle-to-Grid (V2G) concept is associated with bidirectional grid interface, where plug-in electric vehicles, such as electric cars (BEVs) and plug-in hybrids (PHEVs), communicate with the power grid to sell demand response services by either delivering electricity into the grid or by throttling their charging rate [53].

These vehicles can be recharged during off-peak hours at cheaper rates while helping to absorb excess nighttime generation. This happens because the batteries of the electrical vehicle can function as a storage system connected to the grid [43].

To work in V2G power systems, each vehicle must have three required elements:

- A connection to the grid for electrical energy flow.
- Control or logical connection necessary for communication with the grid operator.
- Controls and metering onboard the vehicle.

In a smart grid, the charging of the battery can be optimized and the stored energy can be used to ensure the matching between the local generation and energy consumption.

3.4. Communication Technologies

Wired and wireless technologies have been evaluated for application in House Domains. As wired technologies Ethernet and PLC has been considered due to their wide acceptance whereas ZigBee, Z-Wave and 6LoWPAN have been selected for candidates in a wireless environment.

3.4.1. Wired Communication Protocol

Regarding to the wired solution, the study will be focused on the Ethernet and PLC technologies.

3.4.1.1. Ethernet

Wired LANs use Ethernet and network adapters. They usually also require central devices, such as, hubs, switches or routers to accommodate and link nodes. As far as installation is concerned, the solution is less practical since cables must be run between each node of the network or to a central device. In regards to costs, as cable, hubs and switches are very inexpensive, wired solutions are advantageous. The main benefit that can be referred is the improved reliability of such solutions in carrying data, offering also superior performance [54].

Ethernet is a local area technology, with networks traditionally operating within a particular home or building, with connecting devices in near immediacy. At most, Ethernet devices can have 90 meters of cable between them without active equipment in the middle, making it impractical to connect geographically dispersed locations. Modern advancements have considerably increased these distances, allowing Ethernet networks to span tens of meters. It is today the most widely deployed network technology in the world, having evolved according to the maturation of the computer networking in order to encompass new technologies [54].

Originally, Ethernet consists of communication over a single cable shared by all devices in the network, thus enabling the communication between all of them. Historically, this medium has been coaxial copper cable running at 10Mbit/s, but today it has been replaced by Ethernet hubs and/or switches to reduce installation costs, increase reliability, and enable point-to-point management and troubleshooting. Regarding the Ethernet protocol, it specifies a set of rules for constructing the frames sent through the network, such as a minimum and maximum length for frames and the inclusion of both the destination and source addresses [54].

Whenever a device sends a message, all devices connected to the network receive and examine the frame, check the destination address and will only examine its content in the case of the frame being for itself. Ethernet also offers the possibility of sending a broadcast, thus transmitting a frame to all nodes of the network that, in turn, will receive and process the message. Despite the significant changes in Ethernet, the frame formats have been kept so that different generations of Ethernet can be readily interconnected [54].

Regarding the physical implementation of the technology, Ethernet repeaters are used to take the signal from one Ethernet cable and repeat it into another cable. Repeaters can detect improperly terminated links from continuous collisions and, in that case, they stop forwarding data. They alleviate the problem of cable breakage enabling functional segments to continue working in case of a cable breakage. Multiport Ethernet repeaters are also known as “Ethernet hubs”.

Some limitations of the Ethernet technology are listed below:

- Length of the shared cable: there are practical limits to the size of the Ethernet network;
- Weakening of the signal while travelling along the cable;
- Scrambling of the signal due to electrical interference from neighboring devices;
- Waiting time for the network to be quiet before sending frames.

Because Ethernet is a wired technology and due to the limitations presented, Ethernet is not the best solution to apply in the home network of the Energy Box System, since it can compromise the performance of the system and the internet services are needed.

3.4.1.2. PLC

PLC is being standardized in IEEE P1901-2010 Standard for Broadband over Power Line Network: Medium Access Control and Physical Layer Specifications.. PLC technology is able to carry data via the electrical supply network which means that the physical medium used for data transmission is the conductor also used for electric power transmission. PLC thus enables to extend an existing local area network through the electric plugs, only requiring for that purpose the installation of specific units. Those units include a transmitter capable of generating modulated RF carrier signals and thus adding the communication signal to the AC power line signal and, on the other hand, a receiver unit capable of separating the communication signal from the AC power component signals [54].

The principle of PLC consists in the transmission of a radio frequency communication signal of a few hundred Hz to a few tens MHz together with the alternating power, having frequencies of 50 to 60Hz. This signal is transmitted via the power infrastructure and can then be received and decoded remotely. Any PLC device located on the same network can receive the signal.

Nowadays, there is a particular interest in PLC for automatic meter reading industry because it enables to obtain fresh data from all metered points in order to better control and operate the system mentioned above. For example, the technology can be used by electric utility companies to provide information to a central station that communicate command signals to devices located at the sites of electric energy consumers.

Although being a wired solution, PLC is more attractive than the said hard-wired communication systems which require dedicated communication wiring. With PLC, the transmission medium already exists thus reducing the installation complexity and cost [55].

On the other hand, PLC technology presents the disadvantage of the distribution power lines being susceptible to electrical noise and interference such as spikes and noise, and the need to avoid introducing radio-frequency (RF) interference into the lines. Specifically, the equipment connected to the indoor power line can generate noise or lower the impedance of the power line, which can result in an increase in the error rate to cause communication failures in the power line communication. Furthermore, power lines inherently attenuate RF signals heavily, and are not designed to support efficient transfer of higher frequency signals. When serious attenuation or distortion is generated in the PLC channel due to a load having a poor channel property, the communication quality is considerably deteriorated. The main failure scenarios are due to [54]:

- Interference from nearby systems giving raise to many signals in the same bandwidth so that the modem may not be able to determine a specific frequency;
- Signal attenuation by active devices such as relays, transistors and rectifiers that create noise in their own system;
- Signal attenuation by passive devices: transformers and DC-DC converters attenuate the input frequency signal almost completely.

3.4.2. Wireless Communication Protocols

3.4.2.1. ZigBee

ZigBee (IEEE 802.15.4) is a low data rate, low power consumption, and low cost technology for Wireless Personal Area Network (WPAN). It is intended to be simpler and less expensive than other WPAN [54]:

- Because ZigBee can activate (go from sleep to active mode) in 15 msec or less, the latency can be very low and devices can be very reactive. As ZigBee can sleep most of the time, average power consumption can be reduced radically, extending the battery lifetime.

- In general, the ZigBee protocols minimize the time the transceiver is ON thus reducing the power use. In beaconing networks, nodes only need to be alive while a beacon is being transmitted.

ZigBee specification has been developed by the ZigBee Alliance, which is an association of companies that works together to enable reliable, cost-effective, low-power, wirelessly networked, monitoring and control products based on an open global standard [57].

The ZigBee Alliance is responsible for standardizing the network and the application layer in order to provide interoperable data networking, security services, and a range of wireless home and building control solutions. ZigBee supports three different network topologies [54]:

a. **Star Topology** establishes communication between devices and a single central controller, called the PAN coordinator. The PAN coordinator may be mains powered while the devices will most likely be battery powered. Applications that benefit from this topology include home automation personal computer (PC) peripherals, toys and games. After a full-function device is activated for the first time, it may establish its own network and become the PAN coordinator. Each start network chooses a PAN identifier, which is not currently used by any other network within the radio sphere of influence. This allows each star network to operate independently.

b. **Peer-to-peer (P2P) Topology** has also one PAN coordinator and in contrast to star topology, any device can communicate with any other device as long as they are in range of one another. A peer-to-peer network can be ad hoc, self-organizing and self-healing. Applications such as industrial control and monitoring, wireless sensor networks, asset and inventory tracking would benefit from such a topology. It also allows multiple hops to route messages from any device to any other device in the network. It can provide reliability by multipath routing.

c. **Cluster-tree Topology** is a special case of a peer-to-peer network in which most devices are full-function devices and a reduced-function device may connect to a cluster-tree network as a leave node at the end of a branch. Any of the full-function devices can act as a coordinator and provide synchronization services to other devices and coordinators.

3.4.2.2. 6LowPAN

6LoWPAN (IPv6 over Low power Personal Area Networks) is an open standard supported by open-source code that lets developers use the Internet Protocol (IP) between wireless IEEE 802.15.4-compliant devices. The IETF (Internet Engineering Task Force) has set up a 6LoWPAN working group to oversee such a standard. The 6LoWPAN IETF group problem statement document is RFC4919 and the baseline protocol specification is RFC4944 [54].

The 6LoWPAN WG has defined encapsulation and header compression mechanisms that allow IPv6 packets to be sent to and received from over IEEE 802.15.4 based networks. IPv4 and IPv6 are the work horses for data delivery for local-area networks, metropolitan area networks, and wide-area networks such as the Internet. Likewise, IEEE 802.15.4 devices provide sensing communication-ability in the wireless domain. The inherent nature of the two networks though, is different [54].

The targets for IP networking for low-power radio communication are the applications that need wireless Internet connectivity at lower data rates for devices with very limited form factor. Examples could include, but are not limited to: automation and entertainment applications in home, office and factory environments. The header compression mechanisms standardized in RFC4944 can be used to provide header compression of IPv6 packets over such networks [55].

IPv6 is also use on the Smart Grid enabling smart meters and other devices to build a micro mesh-network before sending the data back to the billing system using the IPv6 backbone. Some of these networks run over 802.15.4 radios, and therefore use the header compression and fragmentation, as specified by RFC4944.

3.4.2.3. Z-Wave

Z-Wave is a proprietary wireless mesh networking open standard that allows a wide array of devices in and around the home to communicate among them and to be monitored and controlled remotely. The technology is developed by Zensys, and it is supported by the Z-Wave Alliance, an international consortium of manufacturers that provide interoperable Z-Wave enabled devices [54].

Z-Wave is a low-power wireless technology designed specifically for remote control applications. Unlike Wi-Fi and other IEEE 802.11-based wireless LAN systems that are designed primarily for high-bandwidth data flow, the Z-Wave RF system operates in the sub Gigahertz frequency range and is optimized for low-overhead commands such as ON-OFF (as in a light switch or an appliance) and raise-lower (as in a thermostat or volume control), with the ability to include device metadata in the communications [36] [55].

Because Z-Wave operates apart from the crowded 2.4 GHz frequency, it is largely impervious to interference from common household wireless electronics. This freedom from household interference allows for a standardized low-bandwidth control medium that can be reliable alongside common wireless devices.

As a result of its low power consumption and low cost of manufacture, Z-Wave is easily embedded in consumer electronics products, including battery operated devices such as remote controls, smoke alarms and security sensors. Z-Wave is a mesh networking technology where each node or device on the network is capable of sending and receiving control commands through walls or floors and use intermediate nodes to route around household obstacles or radio dead spots that might occur in the home [56].

Z-Wave devices can work singly or in groups, and can be programmed into scenes or events that trigger multiple devices, either automatically or via remote control. Some common applications for Z-Wave include [60] [61]:

- Remote Home Control And Management
- Energy Conservation
- Home Safety And Security Systems
- Home Entertainment

3.4.2.4. Wi-Fi (802.11)

A Wireless Local Area Network (WLAN) based on Wi-Fi IEEE 802.11 standard is a flexible data communication system implemented as an extension to or as an alternative for, a wired LAN within a building or campus. Using electromagnetic waves, WLANs transmit and receive data over the air, minimizing the need for wired connections. Thus, WLANs combine data connectivity with user mobility and enable movable LANs through simplified configuration [54] [63].

The WLAN configuration may be grouped into three types [58] [62]:

a. **Peer-to-peer (P2P) WLAN** configuration is an independent WLAN that connects a set of PCs with wireless adapters. Any time two or more wireless adapters are within range of each other, they can set up an independent network. These on-demand networks typically require no administration or pre-configuration. The main disadvantage of this type is very short distance communication; thus access points can extend the range of independent WLANs by acting as a repeater effectively doubling the distance between wireless PCs.

b. **Infrastructure WLANs** allows multiple access points link the WLAN to the wired network and allow users to efficiently share network resources. The access points not only provide communication with the wired network but also mediate wireless network traffic in the immediate neighborhood. Multiple access points can provide wireless coverage for an entire building or campus.

c. **Microcells** and **Roaming Wireless** use cells, called microcells, similar to the cellular telephone system to extend the range of wireless connectivity. At any point in time, a mobile PC equipped with a WLAN adapter is associated with a single access point and its microcell, or area of coverage. Individual microcells overlap to allow continuous communication within wired network.

Wi-Fi standards are developed by the IEEE to differentiate between various technology families. Wi-Fi products are identified as 802.11, and are then further identified by a lower case letter that identifies which specific technology is in operation, such as 802.11a/b/g/n. There are five Wi-Fi generations of products available, and more standards are in the works for adding future features and enhanced performance and security. Each generation is defined by a set of features that relate to performance, frequency and bandwidth. Each generation also furthers security enhancements and may include other features that manufacturers may decide to implement. Table 1 summarizes main features of currently available 802.11 technologies [59].

Table 1 - 802.11 Current Available Technologies, Main Features

Wi-Fi Technology	Frequency Band	Bandwidth or maximum data rate
802.11a	5 GHz	54 Mbps
802.11b	2.4 GHz	11 Mbps
802.11g	2.4 GHz	54 Mbps
802.11n	2.4 GHz, 5 GHz, 2.4 or 5 GHz (selectable), or 2.4 and 5 GHz (concurrent)	>100 Mbps

3.5. Security Issues

In this section, first a wide overview of the security concerns in the Smart Grid is provided. Then, the main security mechanisms provided by the communication technologies described above are presented.

3.5.1. General Considerations

Today's power grids already comprise a wide variety of digital devices and complex control systems. However, future smart power grids will be more "wired" (or "wireless") in order to optimize the use of available resources by controlling them in a more flexible and dynamic way based on network status awareness. This combination of traditional utility systems with public communications infrastructure brings new potential security threats [64].

Securing the Smart Grid is a major issue taking into account that it will imply a huge market where lot of money and business interests will be at stake and that it will carry really sensitive information both from the utility and from the customer point of view [65].

In particular, it is especially important for such systems to be secure and robust against cyber security threats. Since this kind of threats are posed by human beings who are able to learn and change their methods over time, security in this context means by nature a dynamic and ever-changing process [64].

Although throughout this section security features provided by different communication technologies will be analyzed, cyber security is not only about technology. In fact, cyber security is primarily about people, processes and technologies [64].

The complete system delivered to a utility must provide different types of security:

- It must be secure by design, e.g. secure architecture, robust threats analysis, reduction of vulnerabilities.
- It must be secure by default, e.g. keeping permissions under a strict control, turning off unused features.
- It must be secure in deployment, e.g. providing the users with training and documentation, management of detection, defense and recovery.

The relationship between security and reliability in the Smart Grid is also relevant, since these two concepts are not always aligned. The huge amount of information about different components of the entire system that the smart power grid will make available to the utilities is highly useful for managing reliability, but protecting such information means an additional challenge from a security perspective. Nevertheless, analyzing this information properly may be also useful in order to detect security holes and prevent attacks [64].

The relationship between security and performance is another important point to be taken into account when designing the Smart Grid security architecture. In this sense, security measures must ensure the security level required by the system, which must be established in advance during the design phase, impacting its performance as less as possible [64].

Finally, interoperability of utility systems has lately emerged as a priority. Therefore, it is important to ensure that security measures do not come at the expense of interoperability.

4. System Requirements

This sections specifies the requirements for the Energy Box System, that aims to create an architecture of an intelligent system allowing the end-user to manage efficiently his/her electricity usage and the utility to improve the operation of the grid, by remotely monitoring, controlling and coordinating microgeneration, storage (with the use of electrical vehicles) and consumption in each residence.

The architecture should provide the end-user to better manage their energy consumption, microgeneration and storage to achieve energy savings. Secondly, it will give the utility information in near real-time about the status of the network and the local generation-consumption matching, which will help to operate the grid more efficiently.

4.1. General Requirements

In this section, the user requirements are defined. Each requirement is referred with a unique identifier composed of three letters and a sequence number. Most information on the description of each requirement was obtained from datasheets of device manufacturers.

To achieve the Energy Box System goals the architecture needs to provide means for monitoring and controlling the most significant energy consuming elements in the house, as well as of those associated with microgeneration (solar panels and wind turbines) and storage (with the use of electrical vehicles).

The services are focused to provide information to end-users to facilitate their decision-making, taking into account different comfort requirements, the intelligent behavior of the environment, overall demand, user presence, etc. The user may interact with the system, including remote access, but the use of Internet is required. Services like real-time information of consumption, generation and storage, reports on historical data, or ecological footprint, are some examples of the type of information that can be provided by the Energy Box System

These services imply different requirements to be fulfilled by the Energy Box System, which are identify in the next sections.

4.1.1. In-House Requirements

In this chapter the requirements related will all the components inside the house will be defined. These main components are the Individual Energy Box, the Sensors and the Intelligent Plug Socket.

4.1.1.1. Individual Energy Box (IEB)

The requirements in this section relate to the Individual Energy Box. There are four sections that categorize the requirements: general, user interface, communications and quality requirements.

Code:	**IEB-001**
Name:	Energy consumption and microgeneration measurement.
Description:	There should be support for measurement of energy consumption and energy microgeneration.

Code:	**IEB-002**
Name:	Energy Storage Management.
Description:	There should be support for management of energy storage (within electrical vehicles).

Code:	**IEB-003**
Name:	ADR
Description:	There should be support for integration with ADR system provided by AEB.

Code:	**IEB-004**
Name:	In-House Decision Support.
Description:	The system should be able to decide which devices should be actuated regarding initiation of specific Demand Response action.

Code:	**IEB-005**
Name:	Temperature control.
Description:	The system should be able to control the temperature of the rooms when temperature control devices such as HVAC are configured in the system.

Code:	**IEB-006**
Name:	Temperature measurement.
Description:	The system should be able to measure temperature in multiple rooms of the house.

Code:	**IEB-007**
Name:	Humidity control
Description:	The system should be able to control the humidity of the rooms when humidity control devices such as dehumidifier are configured in the system.

Code:	**IEB-008**
Name:	Humidity measurement.
Description:	The system should be able to measure humidity.

Code:	**IEB-009**
Name:	Archive data
Description:	There should be a local archival to provide data of energy profiles and forecasting.

Code:	**IEB-010**
Name:	Forecasting of the energy consumption, microgeneration and storage.
Description:	There should be intelligence to provide forecasting of energy consumption, microgeneration and storage.

Code:	**IEB-011**
Name:	Energy consumption profiles.
Description:	Each major consumption device should have a consumption profile associated with it. The system should be able to create and maintain these consumption profiles.

Code:	**IEB-012**
Name:	Energy microgeneration profiles.
Description:	Each energy microgeneration device such as photovoltaic panels or wind turbines should have a microgeneration profile associated. The system should be able to create and maintain these microgeneration profiles.

Code:	**IEB-013**
Name:	Data Privacy.
Description:	The system should be able to receive data privacy configurations. On data privacy restricted, the system should never send that data to the external servers or utilities. The data privacy should be activated only for devices individual profiles and not for global aggregated measurements.

Code:	**IEB-014**
Name:	Aggregated Management.
Description:	The IEB should promote the management of aggregate consumption through the monitoring of the individual consumption value of a set of appliances, enabling their intelligent remote control, always taking into account the directives set by the householders.

Code:	**IEB-015**
Name:	Device Management.
Description:	There should be the possibility to add and remove devices (sensors, actuators...) to the system.

Code:	**IEB-016**
Name:	Anomaly detection.
Description:	The system should detect and report abnormal energy consumption and/or generation in the distribution network.

Code:	**IEB-017**
Name:	Aggregation of data in time.
Description:	There should be support for data aggregation in larger periods of time (i.e. the system should be able to aggregate multiple readings of every minute in one reading related to a period of 1 hour). The supported aggregation should be: 1 minute, 15 minutes, hourly, daily and monthly.

Code:	**IEB-018**
Name:	Aggregation of data by groups.
Description:	There should be support for data aggregation within groups of devices (i.e. the aggregated consumption of refrigeration devices or the aggregated consumption of household appliances).

Code:	**IEB-019**
Name:	Interface with AEB.
Description:	The system should be able to report and interact with AEB interface. The communications with this interface should be encrypted.

Code:	**IEB-020**
Name:	Remote control.
Description:	The system should provide remote control of devices though communications with AEB.

Code:	**IEB-021**
Name:	Appliance performance monitoring.
Description:	The system should detect appliances that are consuming too much energy.

4.1.1.1.1. IEB – User Interface

This section will describe de requirements of the user interface of IEB. This interface will define how the user will configure and interact with the IEB.

Code:	**IUI-001**
Name:	Security.
Description:	The web interface should implement security mechanisms to ensure authentication and encryption.

Code:	**IUI-002**
Name:	Metering Data.
Description:	There should be a web user interface that provides access to metering data.

Code:	**IUI-003**
Name:	Consumption categorization.
Description:	There should be a web user interface that provides detailed access to consumption data, detailed by consumption from network/grid and generation from local microgeneration.

Code:	**IUI-004**
Name:	Device consumption.
Description:	There should be a web user interface that provides detailed access to consumption data, detailed by consumption device.

Code:	**IUI-005**
Name:	Storage levels.
Description:	There should be a web user interface that provides access to the current status of the storage devices associated with the system.

Code:	**IUI-006**
Name:	Device Configuration.
Description:	There should be a web user interface that provides easy configuration of all supported devices (consumption, microgeneration, storage, temperature, humidity, IR, etc...).

Code:	**IUI-007**
Name:	Data Privacy Configuration.
Description:	There should be a web user interface that provides easy configuration for data privacy.

Code:	**IUI-008**
Name:	Device Classification.
Description:	There should be a web user interface to classify all the connected devices in groups.

4.1.1.1.2. IEB - Communications

This section will define the communications requirements of the IEB. The IEB will communicate with all the devices inside the house as well as with the M2M system.

The high level communications requirements for the system to perform all the needed functions are:

Code:	**ICM-001**
Name:	Short range communications.
Description:	The system should have an IEEE 802.15.4 and ZigBee HA compliant interface to support short range communications with in-house devices.

Code:	**ICM-002**
Name:	Mid-range communications.
Description:	The system should have an IEEE 802.11 a/b/g/n compliant interface to support mid-range communications with M2M system.

Code:	**ICM-003**
Name:	IR Communications.
Description:	The system should have an IR interface to support actuation on house appliances that provide IR interfaces.

Code:	**ICM-004**
Name:	Communication failure detection.
Description:	The system should detect communication failures between configured devices AEB.

Code:	**ICM-005**
Name:	Network rearrangement.
Description:	The system should provide automatic mechanisms to configure network devices.

Code:	**ICM-006**
Name:	Security.
Description:	The system should implement security mechanisms to enforce authentication and encryption of communications.

Code:	**ICM-007**
Name:	IP Communications.
Description:	The system should support IP based communications in the IEEE 802.11 interface for connecting to the infrastructure concentrator the neighborhood level (M2M).

4.1.1.1.3. IEB – Quality Requirements

This section will define the system quality requirements. These will ensure quality of data and functionalities of the IEB.

Code:	**IQA-001**
Name:	Power outage prevention.
Description:	The system should never lead the house to a power outage. The algorithms and all the decisions should ensure that the main quality requirement is secured.

Code:	**IQA-002**
Name:	Archive Data
Description:	The system should be able to store data needed for profiles and forecasting for at least 1 year.

Code:	**IQA-003**
Name:	Consumption Measurement Rate.
Description:	The system should perform the energy consumption metering at a rate of 1 reading per minute.

Code:	**IQA-004**
Name:	Generation Measurement Rate.
Description:	The system should perform the energy generation metering at a rate of 1 reading per minute.

Code:	**IQA-005**
Name:	Temperature and Humidity Measurement.
Description:	The system should perform the temperature and humidity measurements at a rate of 1 reading every 15 minutes.

Code:	**IQA-006**
Name:	Communications Reliability.
Description:	The communication channels should use protocols that ensure data delivery. This requirement should be applied to in-house communications and external communications.

Code:	**IQA-007**
Name:	Communications Reliability 2.
Description:	The system should be able to support network failures for at least 12 hours. On network failure the system should be able to perform all the critical tasks.

Code:	**IQA-008**
Name:	Forecasting range.
Description:	The system should be able to forecast at least 1 day of energy consumption and microgeneration with help of generated profiles.

4.1.1.2. Sensors

There will be a set of sensors working inside the house. This section will define the requirements of each one of the sensors.

Code**:**	**IHS-001**
Name:	Temperature Sensor
Description:	There should be a sensor to measure the temperature.

Code:	**IHS -002**
Name:	Temperature Accuracy
Description:	The temperature sensor defined in IHS-001 should have a minimum accuracy of +/- 0.5ºC.

Code:	**IHS -003**
Name:	Temperature Range
Description:	The temperature sensor defined in IHS-001 should have a minimum working level of -10ºC and a maximum working level of 50ºC.

Code:	**IHS-004**
Name:	Humidity Sensor
Description:	There should be a sensor to measure the humidity.

Code:	**IHS-005**
Name:	Humidity Accuracy
Description:	The humidity sensor defined in IHS-004 should have the minimum accuracy of +/- 4.5%RH.

Code:	**IHS-006**
Name:	Humidity Range
Description:	The humidity sensor defined in IHS-004 should have a minimum working level of 10% and a maximum working level of 90%.

Code:	**IHS-007**
Name:	Comfort Sensors Operating Environment
Description:	The sensors defined in IHS-001 and IHS-004 should work either in indoor environments as in outdoor environments.

Code:	**IHS-008**
Name:	Comfort Sensors Low Battery Alert
Description:	The sensors defined in IHS-001 and IHS-004 should have a low battery alert.

Code:	**IHS-009**
Name:	Comfort Sensors Networking
Description:	The sensors defined in IHS-001 and IHS-004 should be fully compatible with IEEE 802.15.4 and ZigBee HA compliant.

Code:	**IHS -010**
Name:	Comfort Sensors Power Supply
Description:	The sensors defined in IHS-001 and IHS-004 should be powered by batteries.

Code:	**IHS-011**
Name:	Clamp sensor
Description:	There should be a monitoring sensor that connects the meter to the consumer unit. Any power that is used in a house will pass through this cable.

Code:	**IHS-012**
Name:	Clamp sensor networking
Description:	The Clamp sensor should have a ZigBee network interface.

Code:	**IHS-013**
Name:	Clamp sensor sampling frequency
Description:	The sensor defined in IHS-011 should be able to sample current at a minimum frequency of 1 Hz.

Code:	**IHS-014**
Name:	Clamp sensor transmission
Description:	The sensor defined in IHS-011 shall transmit its measurements in a minimum period of 30s. The sensor shall have a minimum transmission range of 30 m in-house.

Code:	**IHS-015**
Name:	Clamp sensor operational ranges
Description:	The sensor defined in IHS-011 has a voltage range from 100 V to 400 V and a measuring current range from 50 mA to 95 mA.

Code:	**IHS-016**
Name:	Clamp accuracy and memory
Description:	The sensor defined in IHS-011 should have higher accuracy than 90% and enough memory to log 2 minutes of data.

Code:	**IHS-017**
Name:	Clamp Power Supply
Description:	The sensor defined in IHS-011 should be powered by 3 X AAA batteries or 1.5 V DC Supply.

4.1.1.3. Intelligent Plug-Socket

The requirements of the main actuators devices considered within the Energy Box System are described in this section.

Code:	**IHA-001**
Name:	Intelligent Plug-Socket
Description:	There should be a device that can be connected to a power socket and intercept (sensing) the power signal. The device should allow the connection / disconnection of the appliance to the electric power through it.

Code:	**IHA-002**
Name:	Intelligent Plug-Socket Sensing
Description:	The sensor defined in IHA-001 should be able to measure current and power.

Code:	**IHS – 003**
Name:	Intelligent Plug-Socket Amperage Limit
Description:	The sensor defined in IHA-001 should be able to sense current values of 16A and have a safety relay.

Code:	**IHA-004**
Name:	Intelligent Plug-Socket Networking
Description:	The sensor defined in IHA-001 should have a ZigBee network interface.

Code:	**IHA-005**
Name:	Infrared Gateway
Description:	There should be a device that can actuate on appliances via infrared.

Code:	**IHA-006**
Name:	Infrared Gateway Networking
Description:	The device defined in IHA-005 should have a ZigBee network interface.

Code:	**IHA-007**
Name:	Infrared Gateway Actuation
Description:	The device defined in IHA-005 should be able to receive orders to actuate via Infrared on appliances.

Code:	**IHA-008**
Name:	Infrared Gateway Power Supply
Description:	The device defined in IHA-005 should be powered by DC 12 V

Code:	**IHA-009**
Name:	Infrared Gateway Reading
Description:	The device defined in IHA-005 should be able to read IR signals.

4.1.2. Machine-to-Machine System (M2M)

The M2M system will provide communications between the IEB in residences and the AEB in the utility. This system will allow that each house does not need to have an internet connection to communicate with AEB.

This section will provide the requirements for the M2M system.

Code:	**M2M-001**
Name:	Local area communications.
Description:	The system should have an IEEE 802.11 a/b/g/n interface to provide communications with IEB's. This interface should support TCP/IP communications.

Code:	**M2M-002**
Name:	Wide area communications.
Description:	The system should have an Ethernet interface to connect to a modem that provides communications through internet with AEB.

Code:	**M2M-003**
Name:	Message routing.
Description:	The system should be able to connect IEB with AEB performing message routing between these devices.

Code:	**M2M-004**
Name:	Security.
Description:	The system should provide security in communications enforcing authentication and encryption of communications.

4.1.3. Aggregator Energy Box (AEB)

Code:	**AEB-001**
Name:	Communications.
Description:	The system should have an Ethernet interface to provide connections to the Internet. This interface will allow the IEB to communicate with the AEB.

Code:	**AEB-002**
Name:	Security.
Description:	The system should provide security in communications enforcing authentication and encryption of communications.

Code:	**AEB-003**
Name:	Failover and High Availability.
Description:	The system should implement the mechanisms needed to provide

	failover and high availability. The system should not be down more than 15 consecutive minutes.

Code:	**AEB-004**
Name:	Load Balancing.
Description:	The system should be scalable and implement load-balancing mechanisms to distribute load among multiple instances.

Code:	**AEB-006**
Name:	Demand and supply analysis.
Description:	The system should analyze the demand and supply patterns and to identify deviations in order to optimize the configuration of the electric grid taking into account contextual information and the near real-time information coming from meters and sensors.

Code:	**AEB-007**
Name:	Grid balance.
Description:	The system should be able to detect fairness deviations in the grid in order to regulate load balance towards more advantageous times of day/week/month.

Code:	**AEB-008**
Name:	User behavior induction
Description:	The system should be able to influence the costumer to increase or decrease the energy consumption, sending signals to the user based on energy price.

Code:	**AEB-009**
Name:	Data storage.
Description:	The AEB should store and process data transferred from each IEB and from the Utility.

Code:	**AEB-010**
Name:	Remote load management.
Description:	The AEB should provide remote load management operation in order to best match all prosumers' needs.

5. Global Energy Box System Architecture

The main goal of this section is to design an architecture solution of an automated demand response (ADR) system. This system, called Energy Box (EB), will be based on two main components: the local management (Individual Energy Box – IEB) and the aggregated management (Aggregator Energy Box - AEB).

The definition of the architecture for the IEB is the first step to design this system. This architecture will focus on the ICT required for the local management level inside the house that allows managing efficiently the available energy resources, and so saving energy, by monitoring, controlling and coordinating the consumption, microgeneration, and storage. The IEB should react to grid stimuli (namely dynamic pricing) as individuals that only know the reality inside the house, including the integration of multiple sensors and actuators as well as communication protocols.

The AEB should have the responsibility to maintain the balance and fairness in the offers and requests from the grid. The step will consist in the design of architecture to integrate the IEB and AEB levels. This architecture should define the communications between both components and provide a platform for near real time actuation and information exchange. In order to define a fine-grained architecture the system has been divided into 2 different domains (Figure 11):

- In-House Domain(IEB):
    - Consumption;
    - Microgeneration;
    - Storage;
- Grid Domain (M2M System and AEG);

The work performed during this thesis was focused mainly on the architecture definition of the in-house system (IEB) on the Consumption Domain.

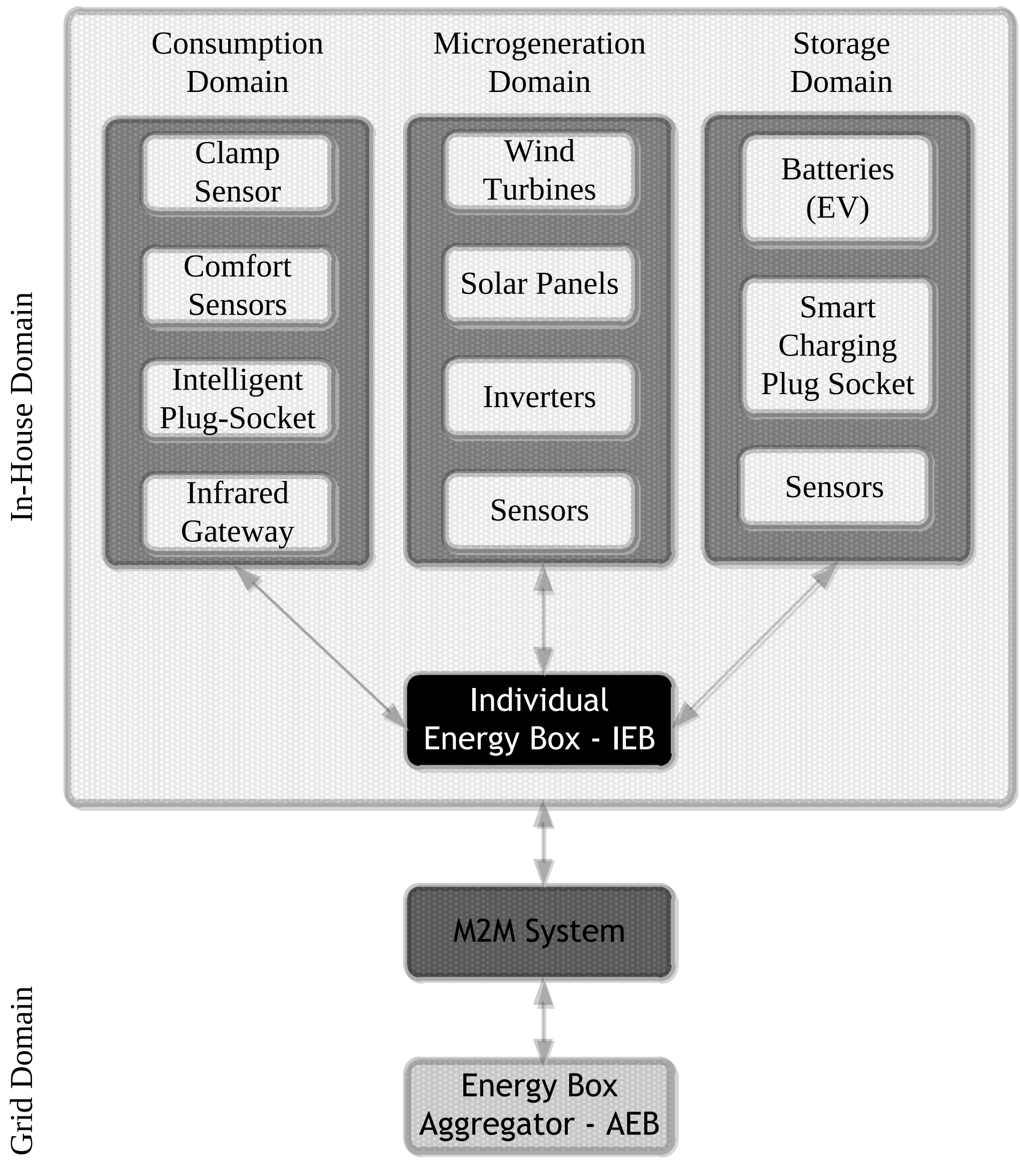


Figure 11 - Global Energy Box System Architecture

The in-house monitoring and control system described in this section is located at one of the edges of the Energy Box System and it represents the Consumption Domain within In-House Domain. The In-House Domain also comprises the Microgeneration Domain and Storage Domain, which represent the local energy microgeneration and storage facilities.

The Microgeneration Domain is composed of microgeneration sources, inverters and sensors. The microgeneration sources can be photovoltaic panels and wind turbines. The Storage Domain is composed of batteries of an electrical vehicle (EV), smart charging plug-sockets and sensors. The Storage Domain allows the storage of excess energy over a time period and its release in another time period. Therefore, it represents an important element of the Smart Grid, since it allows the transfer of energy over time optimizing the system to compensate the unpredictability and variability of the renewable energy sources.

The Energy Box System will be able to give to the prosumer a range of information services about their energy consumption, microgeneration and storage and the associate economic and environmental impact.

This information flow should be provided at different levels of granularity, starting from the aggregated data at the whole house level down to the detailed information about each individual appliance. It will also be possible to select different levels of time-based aggregation – from minutes and hours to days and months. In addition to the basic energy monitoring functionality, the possibility to compare the actual energy consumption with the expected one should be included, for instance, based on historical data. Any deviations should be reported to the user. Analysis at the appliance level will help to detect those devices with a significantly degraded performance.

Finally, a set of the energy management services will be looking continuously for opportunities to reduce energy consumption by inducing specific changes in the users' habits, daily operation (equipment schedules), appliance upgrades or replacements. The outcome of such analysis will be a list of specific recommendations.

In a context of electricity dynamic pricing, which is foreseeable in the future, it will be important for each-end user to have the ability to respond quickly to dynamic changes, such as near real-time prices or demand response events. This leads to the need of a continuous 24/7 control of electrical loads [26].

The Demand Response functionality will help to minimize electricity consumption, while taking into account user preferences, weather conditions, daily occupancy patterns, and inputs about dynamic prices. The user should be able to specify individual devices or groups of devices to be included in the automated demand response programs, and consequently, these devices will be directly controlled by the IEB that will ensure the end user's cost is minimized.

Through this section, the main features of the each domain will be described in order to provide a more detailed overview of the Energy Box System, with focus on the In-House Consumption Domain. Annex A describes the application protocol, providing examples of the basic functionalities, message structure and message repertoire.

5.1. In-House Domain

The In-House Domain comprises the entire infrastructure associated with energy smart houses. Within this paradigm, houses do not only consume energy, but they also generate it by using energy microgeneration sources (solar panels and wind turbines) and could store energy with the use of EVs. Therefore, the In-House Domain can be further subdivided into consumption, microgeneration and storage domain (Figure 12).

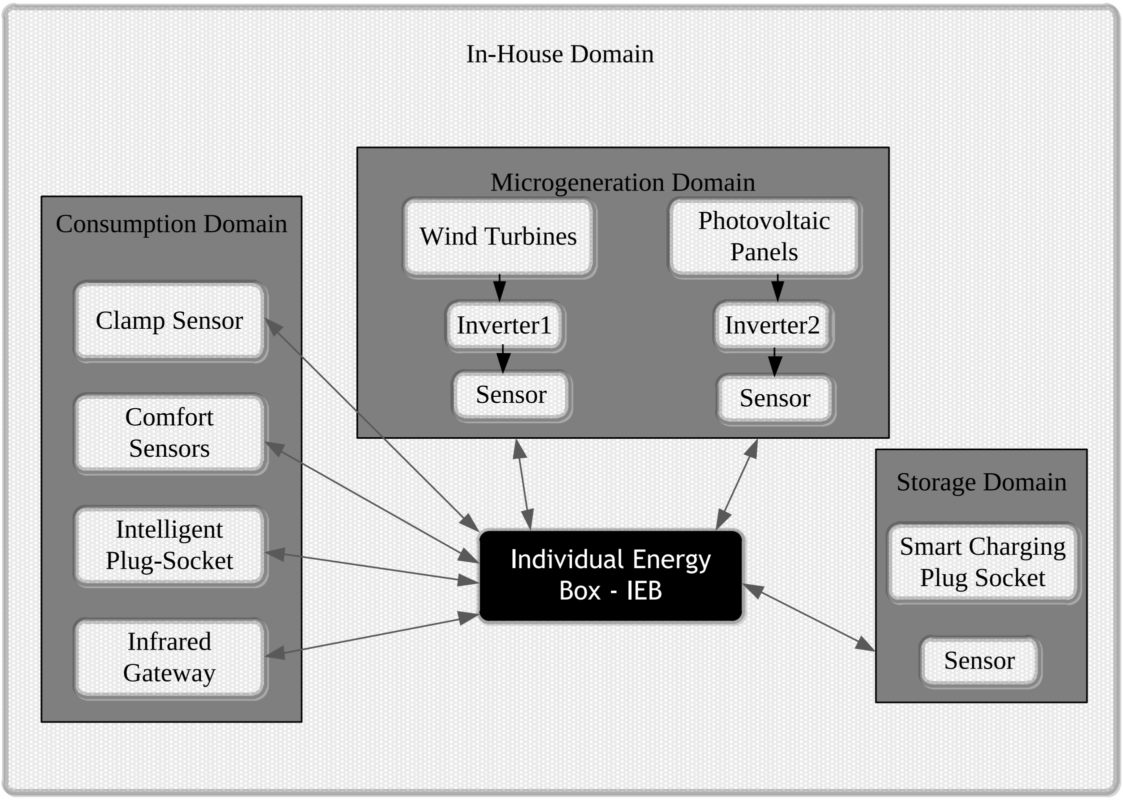


Figure 12 - In House Domain Global Architecture

The IEB represents the interface between the in-house and the rest of the grid and it allows bidirectional communication. Therefore, there will be at least one IEB associated with each house. The IEB will communicate with the sensors (Clmap and Comfort) and actuators (Intelligent Plug-Sockets and Infrared Gateway) belonging to their own network by using short-range communication technologies, either wired or wireless.

5.1.1. Consumption Domain

The In-house Consumption Domain focuses on the specification of the in-house energy consumption infrastructure, including the interoperability of existing energy-efficiency protocols, legacy appliances, and the communications channels with the remaining modules within the Energy Box System, as can be seen in Figure 13 - In-House Energy Consumption InfrastructureFigure 13.

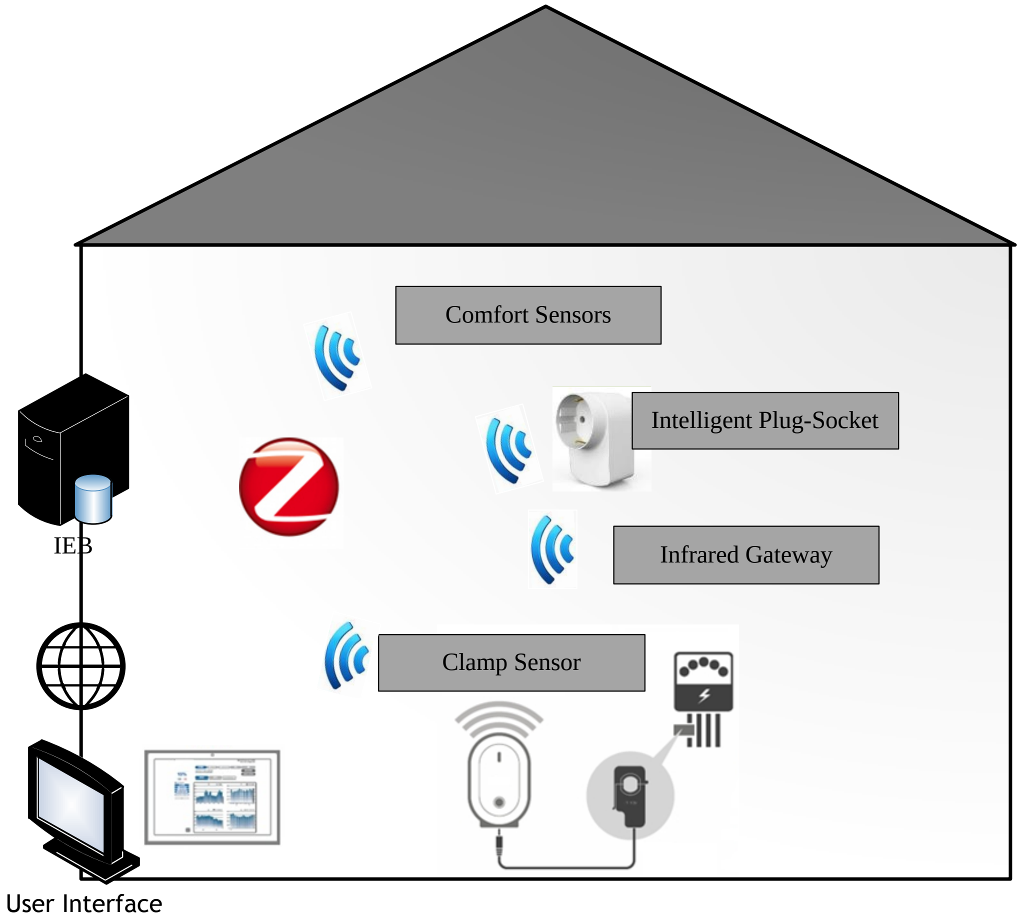


Figure 13 - In-House Energy Consumption Infrastructure

The in-house Consumption Domain architecture is described in this section, including an explanation of how all the components work together inside the house and how they interface with the rest of the system.

Figure 14 presents a diagram of the communication between the Individual Energy Box, the peripherals, and the upper layer.

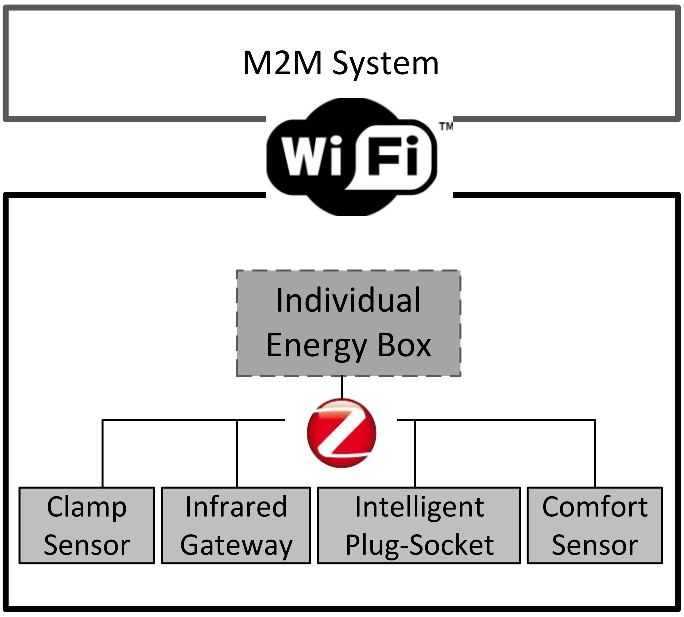


Figure 14 - In-House Energy Consumption Architecture

The IEB is the main gateway of communications inside the house and should support two different wireless technologies: ZigBee and Wi-Fi (IEEE 802.11).

The Wi-Fi network interface will communicate with the M2M System to send and receive all the information to and from the AEB. The use of the Wi-Fi interface reduces the costs of the solution for the provider and for the client since there is no need of having one internet connection for each IEB, aggregating the communications of multiple IEB into one internet connection on the M2M system.

The ZigBee network interface will be used to communicate with all the peripherals inside the house, such as clamp sensor, infrared gateway, intelligent plug-socket and comfort sensors. All these peripherals periodically send information to and receive information from the IEB.

Regarding wireless protocols, the main recommendation for the House Domain is to use ZigBee, since it addresses the needs of remote monitoring and control and sensor network applications, which typically have very low bandwidth requirements (20–250 kbps). It enables the deployment of large-scale low-power networks, and devices can run for years with inexpensive batteries. ZigBee provides low power requirements, network scalability and reliability.

Therefore, ZigBee is the most suitable current wireless solution for the In-House Domain. In particular, the preference within ZigBee goes towards a particular ZigBee stack profile, the ZigBee PRO.

The ZigBee PRO presents a set of advantages, when compared to the traditional ZigBee:

- **Network scalability** - the ZigBee PRO's improved support for larger networks offering more management, flexibility and performance choices;
- **Fragmentation** - is a new ability to divide longer messages and enable interaction with other protocols and systems;
- **Frequency agility** - provides the networks with the ability of changing channels when interference occurs;
- **Automated device address management** - is optimized for large networks with added network management and configuration tools;
- **Group addressing** - offers additional traffic optimization needed in larger networks;
- **Wireless commissioning** - enhanced with secure wireless commissioning capabilities;
- **Centralized data collection** - tuned specifically to optimize information flow in large networks.

The high level of security requirements in the Energy Box System leads to the usage of ZigBee PRO with High Security Mode. This is recommended even at the expense of reducing compatibility, since this security mode is not compatible with the full ZigBee feature set.

The ZigBee’s underlying layer (IEEE 802.15) WPAN is standard and is intended for use in embedded applications requiring low data rates and low power consumption. It can be implemented in mesh networks relying on several topologies.

ZigBee could also be used for the communication between a group of IEB and the M2M System in a scenario where all of them are deployed within the same building. However, Wi-Fi (IEEE 802.11) is the most likely solution for the communication between IEB and M2M System, since it provides higher bandwidth and coverage.

5.1.1.1. Clamp Sensor

The Clamp Sensor collects the global in-house electric current using a non-intrusive method. With the data collected by the clamp and with an adequate recognition algorithm it is possible to processes and analyze variations in consumption, and translating them into the discriminated electrical consumptions of different rooms and appliances [66]. In order to achieve this goal, the recognition algorithm should analyze the changes in electrical power absorbed by the house and use supervised machine learning techniques to enable the assignment of each load “signature” to the specific domestic appliances.

The Clamp sensor presents a clear advantage as a bridge technology, enabling the identification of consumptions of each individual appliance without an intrusive and costly infrastructure of individual meters for every appliance. In the future, individual appliances might have their own embedded meter and communication circuitry.

5.1.1.2. Comfort Sensor

The comfort sensors measure different environmental variables, such as temperature and relative humidity, which are taken into account when achieving energy savings without compromising the user comfort levels.

5.1.1.3. Intelligent Plug-Socket

The Intelligent Plugs-Socket is an actuator, which is associated with “dumb” devices, such as refrigerators or electric water heaters, acting upon the appliance power supply by cutting it off or turning it on. There is a unique device ID, associated with each Intelligent Plug-Socket device, allowing its unambiguous identification within the system. Once the device ID gets into the system, the IEB will then be ready to start acquiring data from it.

5.1.1.4. Infrared Gateway

The Infrared Gateway aims to control IR controlled devices by interpreting messages received from the IEB. This Infrared Gateway device allows the end-user to remotely control, via a web interface, their home equipment without the necessity for line-of-sight for IR controlled devices.

The Infrared Gateway should allow the control of infrared-based “smarter” devices, such as HVAC or TV equipment, by relaying binary commands that are converted into IR sequences understandable by the appliance.

The Infrared Gateway should use ZigBee communication interface, exposing its functionalities and interact with the Energy Box System. The Infrared Gateway should have two different components: The Local Hardware and the Remote Software.

The Local Hardware resides within the house, receiving a stream of binary codes via the ZigBee interface and generating the appropriate Infrared signals, according to standard Infrared timing protocols.

The Remote Software should run in the IEB, providing a web accessible interface in which the users can select the brand and model of their appliances. The software retrieves the appropriate binary sequence codes to the selected appliance from a public database of remote control configuration files, locating the relevant commands to be controlled by the system and fetching the corresponding binary commands.

The Infrared Gateway enables the remote turning on or off of Infrared controlled appliances. Thus, the Infrared gateway represents a key element of the system herein presented, allowing the control of a wide range of appliances. A very important benefit is the remote control of HVAC systems, which represents one of the main opportunities to reduce the electricity consumption within households. Again, the Infrared Gateway will constitute an important technology bridge. In the future, appliances are expected to have their own communications and actuation circuits, allowing them to communicate directly with the home EMS.

The Infrared Gateway box can be composed by two main modules (Figure 15), one ZigBee module and one IR module, each one being responsible for part of the device behavior. The IR module is the master and besides managing the IR actions, like capturing IR data or transmitting IR information, it coordinates the ZigBee module activities.

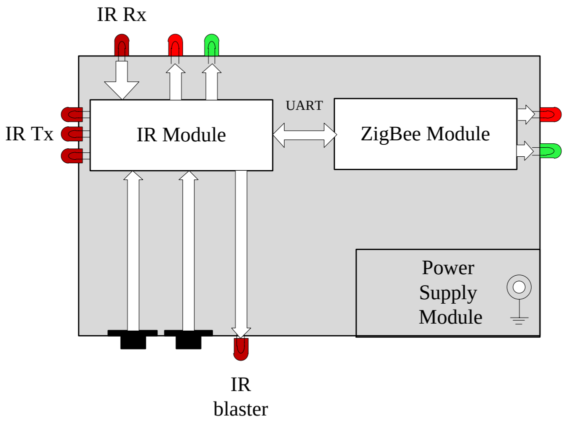


Figure 15 - Infrared Gateway Device Architecture

Both modules communicate and synchronize their actions through a serial communication as it is illustrated in the Figure 15.

5.1.2. Consumption Domain Principal Interfaces

- Clamp Sensor and IEB

The Clamp Sensor will be able to measure the global energy of the in-house consumption infrastructure and all the information will be processed in the Clamp Module (Figure 16). It will be plugged to the electrical network and will monitor the current electrical signatures of the appliances.

The Clamp Sensor should give a continuous reporting of the monitored electrical appliances consumption to the IEB via ZigBee PRO / IEEE 802.15.4 using the feature set of the Smart Energy Profile. Furthermore, the IEA run the recognition signature modules with the data collected by the Clamp sensor, analyze and characterize the consumptions.

- Comfort Sensors and IEB

Comfort sensors measure different environmental variables that may be taken into account to maintain the comfort level saving energy and money, such as temperature and humidity. These sensors will also send the gathered information to the IEB via ZigBee PRO / IEEE 802.15.4. The communication will be bidirectional and asymmetric, in terms of traffic pattern. Most of the information will flow from the Sensors to the IEB, since they are sources of data. However, the IEB may need to place requests in real-time to the Sensors.

- Intelligent Plug-Socket and IEB

The Intelligent Plug-Socket should be associated to "dumb" devices, such as refrigerators or electrical heaters and will act on their power supply by cutting it off or turning it on. Therefore, they will receive commands from the IEB, but they will also send information regarding the connected appliance individual consumption to the IEB.

- Infrared Gateway

The Infrared Gateway will allow controlling the status of infrared based "smarter" devices, such as HVAC, TV, DVD, VDR box or Hi-Fi equipment. The Infrared Gateway will receive commands from the IEB and it will also send requests to the IEB associated with a User Interface.

5.1.3. Individual Energy Box Interfaces

The IEB commands all in-houses blocks and enables the bidirectional communication with the grid. The IEB is equipped with multiple hardware interfaces and multiprotocol features, in order to communicate with in-house devices (e.g. using ZigBee) and with the M2M System (e.g. using Wi-Fi).

The IEB is the main communications gateway inside the home. It is equipped with multiple hardware interfaces and it supports two different wireless technologies: IEEE 802.15.4/ZigBee and Wi-Fi (IEEE 802.11). The Wi-Fi network interface is used to communicate with the M2M System, in order to exchange information upstream with the remainder of the platform. The ZigBee network interface is used to communicate downstream with all the in-house peripherals, such as sensors and actuators.

The components' functionalities are implemented by several internal functional modules. Figure 16 shows the internal organization and main functional modules of the IEB, which are described below.

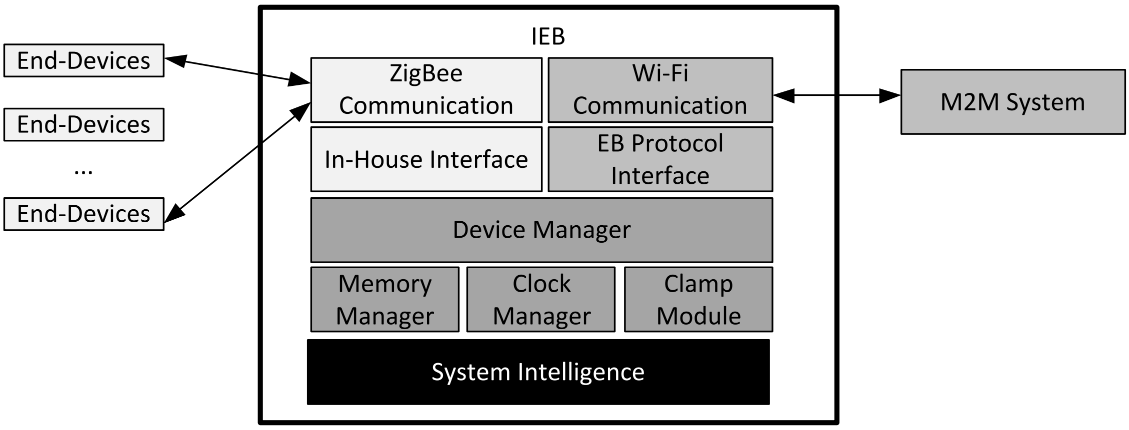


Figure 16 - Internal Functional Modules IEB

a) Intelligence System Module

This is the module where the intelligence of the system resides. It is responsible for processing all the data regarding energy consumption, microgeneration and storage, and enabling an efficient use of available resources anytime. This module should be able to provide a set of services to the end-user, such as:

- Information related to consumption, microgeneration and storage;
- Discrimination of the electrical appliances load in each house;
- Recommendation to change appliances for more efficient ones;
- Demand response management;
- Appliances Control;
- Historical data.

b) In-House Interface Module

The In-House Interface Module is responsible for abstracting external devices' specificities and communication protocol details to the rest of the Energy Box System internal modules, mainly to the Device Manager module, interfacing internally with the ZigBee Communications Module. This latter module is responsible for managing and coordinating the In-House ZigBee Network, assuring all the communications between the IEB and the different in-house devices.

c) EB Protocol Interface Module

The Energy Box Protocol Interface Module is used for managing the communication between the IEB and the rest of the Energy Box System. It implements the M2M System Protocol, and it interfaces with two internal modules: The Device Manager Module and the Wi-Fi Communications Module.

d) Wi-Fi Communication Module

The Wi-Fi Communications Module is responsible for managing the link and network layers of the Wi-Fi interfaces, adjusting the configurations of the mentioned layers to ensure connectivity with the external network.

e) Device Manager Module

The Device Manager Module manages the IEB, and it acts as a hub between the M2M System, the end devices and all other internal IEB modules. This module is responsible for controlling and configuring all in-house end-devices, relaying commands and binary files to devices, and requesting, receiving and processing samples from the sensors.

The Device Manager Module interfaces with the following modules:

- **Memory Manager** – Used to store the IEB's and all the configured devices' configurations and retrieved samples. The memory manager module is responsible for managing all the memory (volatile and non-volatile memory) of the IEB for storage of its internal configuration;
- **Clock Manager –** Used to acquire timestamps for events and retrieved samples and to trigger several interval time-based actions;
- **Clamp Module** – Used to process all the samples extracted from the Clamp sensor. This module should process the data acquired by the Clamp Sensor, and when certain pre-configured conditions are matched indicating the change of an appliance state (On/Off).

5.1.4. Microgeneration Domain

The Microgeneration Domain should be able to monitor and control remotely elements installed in the energy generation facilities within houses.

The Microgeneration Domain comprises energy microgeneration equipment (photovoltaic panels and wind turbines), inverters and sensors, as shown in Figure 17.

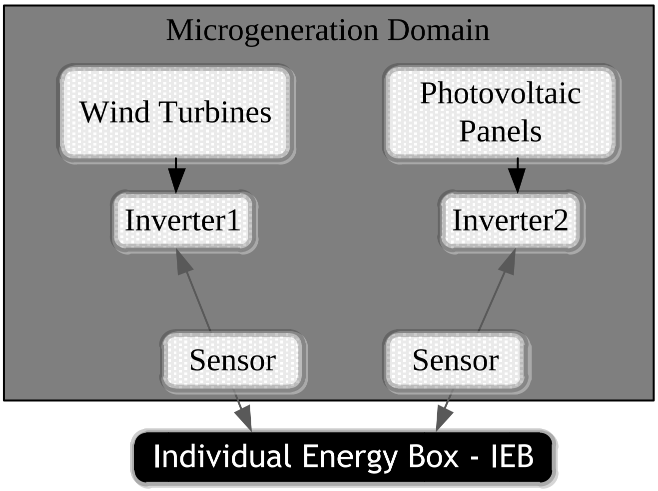


Figure 17 - In-House Energy Microgeneration Infrastructure

The main objective of the sensors is to measure variables related to electricity generated by the microgeneration sources in order to provide the information to the IEB to better manage the use of the electricity generated, controlling the electricity sold to the grid, as well as the electricity consumed in the house [54].

As mentioned previously, the IEB is equipped with multiple hardware interfaces and multiprotocol features in order to communicate with in-house microgeneration devices and with the M2M system.

5.1.4.1. Inverters

The main functionalities of the inverter are listed below [54]:

- The inverter makes the conversion into AC current before being injected in the electrical grid.
- The inverter is also in charge of monitoring of the photovoltaic panel and wind turbines to work at its maximum power working point.

Therefore, the inverter should be able to alert about any event if configured properly in advance.

5.1.4.2. Sensors

The sensors collect data related to the electrical energy generated, measuring a set of parameters related to the electricity produced by photovoltaic panels and wind turbines.

Therefore the sensors can integrate a weather station, which can include:

- Temperature (inside the house and outside the house);
- Humidity (inside the house and outside the house);
- Wind direction and speed;
- Rain gauge;
- Solar radiation;

The sensors should transmit the collected data to the IEB.

5.2. M2M System Infrastructure Architecture

This section will focus on the definition of the M2M system architecture design in accordance to the requirements and considering the existing technologies constraints.

As mentioned previously, the EB System is divided into two main domains: In-House Domain and Grid Domain, as can be seen in Figure 18.

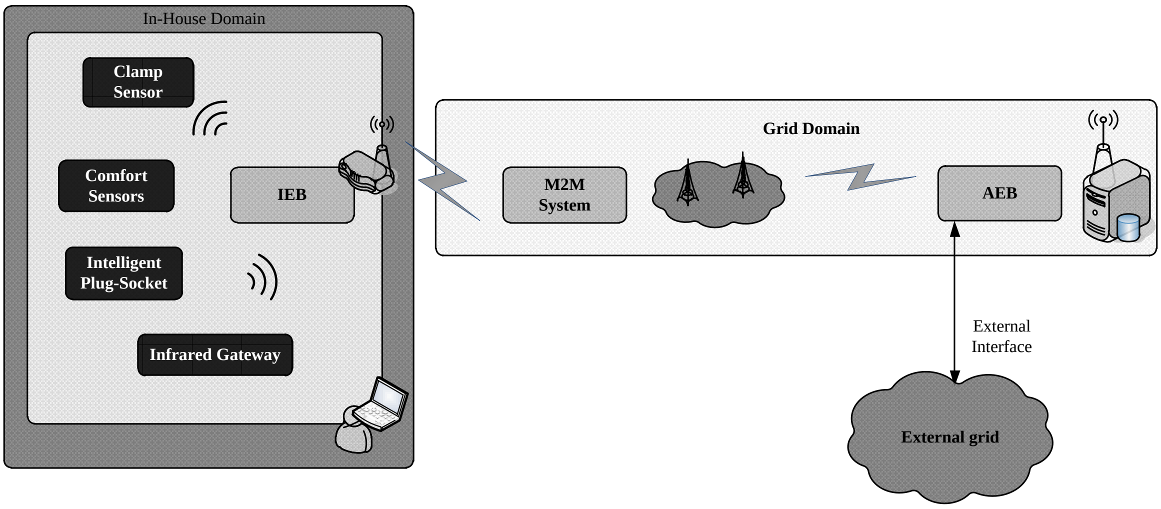


Figure 18 - Energy Box System Global Architecture

The M2M system is the infrastructure responsible for bidirectional communications between the IEB with the AEB, using primary broadband TCP/IP connection and backup channels (3G connections) for a reliable communication between both. The backup channels can be used only if needed and for really important information, such as alarms. The existence of this M2M system will enable a solution where the end user does not need to have an internet connection, reducing the cost of the overall solution.

The M2M System is responsible for securing the communication within this segment and can be divided in 3 layers as can be seen in Figure 19.

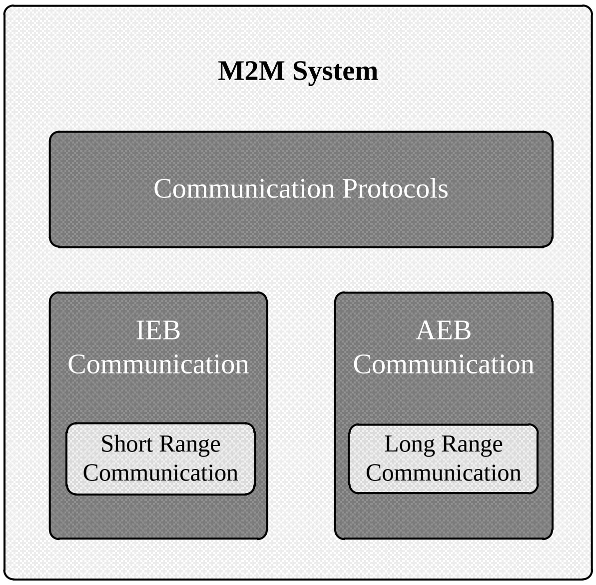


Figure 19 - M2M System

The Communication Protocol layer provides services to external agents. This block provides access to the system via TCP/IP protocol between IEB and AEB.

The IEB communication layer provides access to the different IEB through the available short range communication channel.

The AEB communication layers provide primary and backup channels of communication with the AEB.

The system tightly relies on a hybrid and hierarchical M2M system, which fits the typical communications architecture for the Smart Grid [54]. It is hybrid, since it is based on different communication technologies, depending on the specific requirements of each communication segment. It also hierarchical, due to the fact that there are specific devices which manage the communications within each communication segment [54].

5.3. Aggregator Energy Box

The Aggregator Energy Box can aggregate data related to the consumption, generation and storage of several IEB and ensure the connection between the customer and the Utility by representing a single entity that purchases electricity from or sells electricity to the Utility. The AEB can therefore increase the system impact by ensuring a large level of energy consumption and generation that can be regulated by the Utility.

The AEB intends to optimize the network operation, which means to anticipate and prevent any abnormal situation possibly resulting in electricity black-outs. The AEB wants to manage the distribution system in reliable, secure, safe, and economic manner. Therefore, it is needed to control the power quality in the network by balancing electricity generation and consumption at any time, and be willing to reward prosumer who in practice contribute to this goal.

The AEB collects all the consumption, microgeneration and storage data coming from the In-House Domain. It processes and enriches that data with additional information, such as consumption and generation forecasts or electricity prices and rates, and it enables an efficient use of the available resources at any given moment, by taking the appropriate decisions based upon the information that has been collected.

The AEB consist on several functional modules as can be seen in Figure 20 and described in this section.

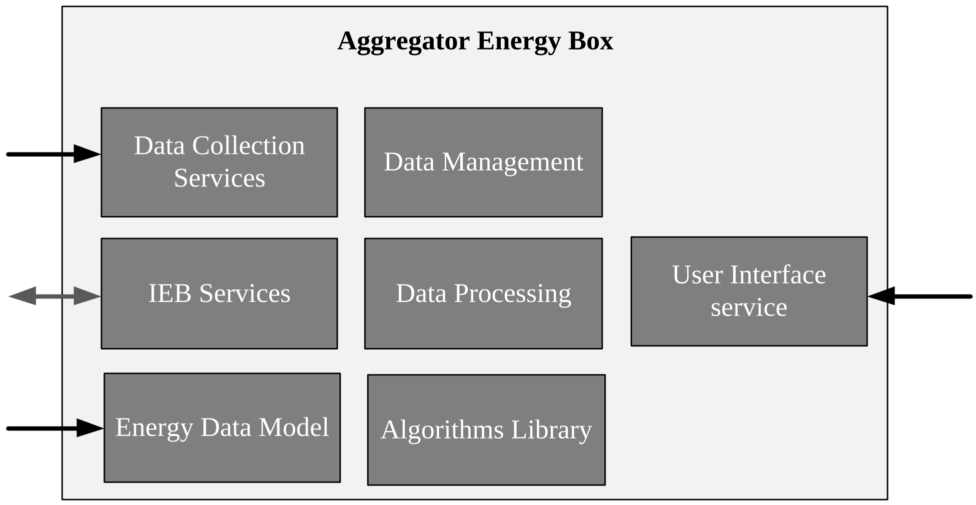


Figure 20 - Aggregator Energy Box Main Components

Data Collection Service – This module provides an input interface for M2M System, which serves as an interface the House Domain. The core functionality provided by this module consists of a method interface, which requires measured data and identification of the source inputs.

Data Management – This module offers a set of data management services that enable creating, editing, removing and listing of additional data needed by the AEB. Data management services are responsible for input data validation as well as for removing any data associated with a previously removed record (for example, the data management service allowing to delete a measurement point has to guarantee a safe removal of the measurement point's measured data history). Another functionality provided by the data management module is the management of the underlying data repository or database. This includes computing performance metrics, physical and logical size, identification of redundant or obsolete data and consequent removal and data consistency check.

Data Processing – This module is in charge of all required measured data processing tasks. The second part of general support services is implemented in this module, which consists of: Data Validation, Estimation and Editing (VEE), Data Cleaning and Data Aggregations. This module represents the central access point to the data stored in the underlying database. The input data requested by the invoked algorithms are supplied by this functional module.

Energy data model - This module is used for predicting the energy consumed in a given set of houses, as well as for predicting energy generated locally by renewable energy sources (solar and wind power).

Algorithms library - This module works as a repository of algorithms and makes them available to the data processing module by means of service interfaces. The repository keeps track of registered services, which represent algorithms in the underlying database and supports registering, modification and removal of an algorithm service.

IEB services - This block provides means of communication with IEB. The functionality of this block is therefore focused on interfacing with the M2M System.

User Interface services - This module works as an entry point for the Web Interface, enabling the access to the archive data, configuration and management.

6. Conclusions & Future Work

6.1. Conclusions

This thesis presents a proposal for a new energy architecture for a smart-home, capable of monitoring and controlling systems with an eye on the reduction of costs and emissions. That goal is achieved by increasing the energy consumption awareness of the users, by acting automatically on the demand side, and by complementing the energy consumption with local generation, demand response, and storage resources.

The main technologies and methodologies that can be used in such architecture were analyzed in order to define the requirements of the system at the in-house, machine-to-machine, and aggregator energy box levels. Based on the defined requirements and analyzed technologies, the most adequate architecture based on ICT for an in-house demand-responsive energy management system was designed. Such architecture ensures the communication between the appliances, the micro generation and storage systems, and the individual energy boxes. It also ensures the control of appliances and the monitoring of the energy consumption.

In spite of presenting and analyzing requirements and architecture for all the domains, this thesis was mainly focused on the Consumption Domain. Thus, more details were presented about its specific components. The interfaces and the application protocol have been presented, with examples of the basic functionalities, message structure, and message repertoire, demonstrating that all the requirements of the Consumption Domain are achievable with the proposed architecture.

The proposed architecture is a solution to the problems that electric utilities are facing due to the increase of consumption in households and the increasing penetration of local generation. The proposed solution also benefits the end-user, by providing tools to decrease electricity consumption and optimizing the consumption schedule as well as ensuring a good match between local generation and consumption, through energy storage – where electrical vehicles play a key part –, and demand control, through demand response technology. Such impacts ensure benefits both to consumers and utilities, decreasing costs and environmental impacts and increasing the grid’s reliability and the home’s comfort levels.

6.2. Future Work

As described before, this thesis was mainly focused on the Consumption Domain; thus the future work should have more focus on the generation and storage domains, analyzing their components, interfaces, and protocols. More details on the Service Provider Domain are also desirable, including the control strategies to ensure a smooth micro grid operation. To test the architecture and services, a simulation of a real grid with real consumption and generation data would be important to evaluate the proposed architecture and services.

Thus, a software model based on algorithms to enable the matching between demand and supply should be designed. This model should consider renewables as intermittent sources, dynamic pricing, and prosumers, in order to achieve a "load follows supply" strategy. The "load follow supply" strategy consists of adapting the consumption diagram to the electricity generation availability, by influencing the end user with compensatory benefits.

Some examples will help to illustrate the challenges at stake at these two levels: Example 1: after a low price broadcast, all IEB will try to take advantage of this low price and turn on some appliances in the home; at a wider level, this will create undesired oscillations in the grid level; the responsibility of the AEB is then to avoid these situations and minimize the interference of the IEB decisions on the grid conditions. Example 2: currently in Portugal, there are periods where the renewable generation output is higher than the load; this excess of generated electricity comes mainly from wind power; in other periods, wind power generation can have very significant decreases in a matter of minutes; therefore, the utility needs power plants operating in spinning reserve to compensate such fluctuations; the AEB should minimize these inefficiencies with a model that can induce or reduce load on demand, while guaranteeing supply when needed.

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8. Annex A: In-House Consumption Application Protocol Specification

In order to specify a protocol that fits the requirements presented in Chapter 4, the definition of the protocol will be taken in a three-stage approach.

This section defines the application protocol for supporting the required functionalities for the In-house Consumption Domain System.

8.1. Application Protocol

The application protocol should be built on top of UDP/IP protocol to help scalability and complexity.

This section defines the set of functional applications that the communication protocol will need to support, along with the required data structures that will be transferred.

8.1.1. Basic Functionalities

The following basic application functions have been identified as the basis for the communication protocol.

8.1.1.1. Network management

Regarding the management of the network, the following functionalities have been identified:

a) IEB Identification: The initialization of the IEB will be done manually through the AEB, resulting that the protocol only needs to support the IEB Identification capability;

b) Add Device: Addition of sensors, Intelligent Plug-Sockets and Infrared Gateway to the network may be initiated by the IEB.

c) Remove Device: Removal of sensors, Intelligent Plug-Sockets and Infrared Gateway from the network may be initiated by the IEB;

d) Configure Device: Configuration of sensors, Intelligent Plug-Sockets and Infrared Gateway may be initiated by the IEB, according to parameters defined by the householders through a portal.

e) Network/Link Status: The status of each of the independent links shall be known by the IEB.

8.1.1.2. Data and Event Collection

The functionalities regarding the data collection process, instantaneous data readings, accumulated values or device statuses, are summarized as follows:

a) Automatic Report of Readings: The IEB shall be able to periodically check each device connected to it and automatically report about the device's state and readings;

b) On-demand Reading: It shall also be possible for the IEB to request the state and readings of a specific device or set of devices;

c) Automatic Report of Events: The IEB shall be able to report whenever a relevant event occurs, such as a device having a low battery level or some device being turned off.

8.1.1.3. Clock Synchronization

The timeline for the AEB and the IEB shall be synchronized; therefore the following functions are required:

a) Clock Read: There must be a way for the AEB to know the local time of the IEB;

b) Set Clock: It shall be possible for the AEB to set the time and date of an IEB.

8.1.1.4. Command Transmission

As one of the main goals of the system is to be able to act upon remote devices, there is the need to perform those actuations. A single functionality was identified:

a) Send Command: There is the need to transmit commands from the AEB to the IEB. These commands may serve several purposes, such as the actuation of appliances (turn ON/OFF) or controlling generation devices (turn ON/OFF, sun-trackers, safe operational modes, etc.) in order to optimize the energy use.

8.1.1.5. File Transfer /Data Block Transfer

To accommodate for more complex device configurations that require variable-length configuration files it is also required the ability to transfer files. In order to have a limited-size protocol, this functionality assumes the form of:

a) Data Block Transfer: It is necessary to allow the transmission of variable-length data blocks from the AEB to the IEB.

8.1.2. Message Structure

It is assumed that the protocol is based on the request-response communication paradigm even though it considers some notification messages that require no response. In order to support these two operating modes, there are three top-level containers in the protocol:

1. **Request** container, which is the basis for every message in which a device queries another;

Tag Name	Request
Attributes	time – number of milliseconds since Jan 1, 1970 0:00 UTC msg-id – message identifier to be used for mapping to the correct *response* operation – “get” or “set”

2. **Response** container, which is the basis for every message in response to a ‘request’ message;

Tag Name	Response
Attributes	time – number of milliseconds since Jan 1, 1970 0:00 UTC msg-id – message identifier to be used for mapping to the correct *request*

3. **Notify** container, which is the basis for every message that does not require a response.

Tag Name	Notify
Attributes	time – number of milliseconds since Jan 1, 1970 0:00 UTC

8.1.3. Message Repertoire

This section presents the protocol messages identified from the required application functionalities.

8.1.3.1. IEB Identification

There is the need to identify the several elements in the network and this is done using a “deviceIdentification” message.

This message (the response) shall be automatically generated by the IEB, as a notification message, after the IEB connects to the network back office. Additionally, it may be required for an IEB to identify all devices connected to it by sending a request with the attribute “query-subdevices” set to “yes” and the response shall contain the identification of one or more devices.

Tag Name	deviceIdentification
Initiated by	IEB
Request operation: *get*	query-subdevices – may be “yes” to request the identification of all elements connected to the destination IEB
Response / Notification	ID – Endpoint identifier, globally unique type – type of device (IEB, sensors, intelligent plug-socket, Infrared gateway) firmware – Firmware/Software version hardware – Hardware version protocol – Protocol version

The “deviceIdentification” message may be used to identify M2M System or devices connected to a specific IEB. The firmware, hardware and protocol versions could be optional.

8.1.3.2. IEB Access Restriction

To remove an IEB from the network, it is required to notify the AEB that it should block connections from a specific IEB. The default behavior is to accept connection from all IEB; therefore it is required to have a message for adding and removing an IEB from the AEB block list.

Tag Name	accessRestriction
Initiated by	AEB
Request operation: *set*	iebID – IEB Identifier permission – "allow" or "deny"
Response	status – "OK", "Not OK" or "Unknown" details – Details of failure

Since the M2M System only needs to know which IEB to block, when it receives a message with permission set to "allow" it simply needs to remove that IEB from the block list.

8.1.3.3. Add/ Configure in-house devices

In order to control the devices interfacing with a specific IEB needs to be able to modify the configuration of a specific device, adding it if not previously configured. The message serves both the purpose of reading or setting the configuration, depending on the *operation* attribute of the request.

For configuring a new device or reconfiguring an existing one, It is required to perform a *set* operation.

Tag Name	deviceConfig
Initiated by	IEB
Request operation: *set*	deviceID – Device's identifier: The deviceID of 0 (zero) is reserved for the IEB comInterface – Communication interface of the device deviceType – Type of device defaultState – In case of devices capable of actuating, specifies the default state for the device, which shall be restored when some failure occurs (e.g. power failure on the IEB) variableID – Identification of variable to query. variableFormat – Format of data read from variable. Necessary to interpret the data from the variable. Possible values:

	uint64 – 64bit unsigned integer sint64 – 64bit signed integer float64 – 64bit floating point (IEEE754 double precision) uint32 – 32bit unsigned integer sint32 – 32bit signed integer float32 – 32bit floating point (IEEE754 single precision) uint16 – 16bit unsigned integer sint16 – 16bit signed integer float16 – 16bit floating point (IEEE754-2008 half precision) bit16 – set of 16 digital inputs uint8 – 8bit unsigned integer sint8 – 8bit signed integer bit8 – set of 8 digital inputs acquisitionPeriod – Period, in seconds, for acquisition of the variable value
Response	status – "OK", "Not OK" details – Details of failure

8.1.3.4. Remove IEB devices

In order to control the devices interfacing with a specific IEB also needs to be able to remove / unconfigure a specific device.

Tag Name	deviceRemove
Initiated by	IEB
Request operation: *set*	deviceID – Identifier of the device to remove
Response	status – "OK", "Not OK", "Unknown" details – Details of failure

8.1.3.5. Data Reading

To enable the reading of data from the sensors and actuators connected to the IEB, there is a specific message.

Since the IEBs are periodically acquiring data from each device, each acquisition generates an automatic notification message with the new readings. The AEB may also request a data reading on-demand, using the same message.

Tag Name	Data
Initiated by	IEB
Request operation: *get*	deviceID – Identifier for the device – The deviceID of 0 (zero) is reserved for the IEB variableIDs – Identification of variables to read (these variables must be configured). If this attribute is missing, read all the ones that are

	configured. startTime – Time of oldest sample to retrieve (optional support) endTime – Time of most recent sample to retrieve (optional support)
Response / Notification	deviceID – Identifier for the device deviceState – The current state/mode of operation of device, including the operating phase (e.g. ON, pre-wash). Each measurement is returned in a "reading" *tag* with the following attributes: time – Time of measurement (may be different from 'now') as the number of milliseconds since Jan 1, 1970 0:00 UTC variableID – Identification of variable value – Measurement values status – Status or Quality associated with the measurement, such as: "valid", "invalid", "incomplete sample period", etc…

For the on-demand data reading, two optional parameters were also specified for allowing access to historical data in a future implementation. If these parameters are absent, only the current reading is returned. If the parameters are specified all data readings between *startTime* and *endTime* shall be returned in ascending order of acquisition time, up to the size limit of the response message.

8.1.3.6. Events

The events are reported to the data, the only difference being that there are only the spontaneous notifications and the IEB cannot ask for events on-demand. The event messages are generated as soon as an event occurs.

Tag Name	Event
Initiated by	IEB
Notification	deviceID – Identifier for the device / endpoint – The deviceID of 0 (zero) is reserved for the IEB time – Time of event (may be different from 'now') as the number of milliseconds since Jan 1, 1970 0:00 UTC module – Module of device that originated the event eventID – Identification of event info – Event details / information

To be able to have an overview of the network status, the IEB needs to be able to check the connectivity up to a specific network element. The most obvious way to do this is to use the existing messages to determine that the all the links between origin and destination are OK.

8.1.3.7. Command device / change device mode

The actuation capability of devices is controlled using a specific message. This message provides the capability of acting upon one or more appliances and also allows some device specific actions to be ordered remotely, such as ordering a device to reboot.

Tag Name	Command
Initiated by	IEB
Request operation: *set*	deviceID – Identifier for the device – The deviceID of 0 (zero) is reserved for the IEB action – Required action (turn ON/OFF; suntracking mode; reboot; restore default configurations; etc…) value – value associated with action, e.g. voltage level for DAC.
Response	status – "OK", "Not OK" details – Details of failure

8.1.3.8. Read/Set Clock

To achieve the clock synchronization function it is required to be able to set the remote clock to a specific time by using this message.

Tag Name	Clock
Initiated by	IEB
Request operation: *set*	time – Time to set (may be different from 'now') as the number of milliseconds since Jan 1, 1970 0:00 UTC
Response	status – "OK", "Not OK" details – Details of failure

8.1.3.9. Data Block Transfer

To transfer variable-length data there is the need to split the data into a set of limited-size blocks of data before transmitting them. The following message shall be used to transfer each of these limited-size blocks.

Tag Name	sendData
Initiated by	IEB
Request operation: *set*	deviceID – Identifier for the device/endpoint to which the *file* is destined. The deviceID of 0 (zero) is reserved for the IEB module – Destination module within device name – Name of *file* being transferred; new *file* with same name as an existing one will overwrite the older one as soon as the corresponding *commitData* message is successfully processed totalSize – Total size of the *file* being sent offset – Offset, within the *file*, of the first byte in "data" data – Data bytes payload (encoded in Base64). This is not an attribute, but the contents of tag *sendData*.
Response	status – "OK", "Not OK" details – Details of failure

The IEB will receive these data blocks and will need to reassemble them to reconstruct the original data.

It shall not be assumed that the data blocks will arrive in a particular order. After transmitting all the data block segments, the AEB shall notify the IEB that the data blocks need to be reassembled and the new *file* shall replace any previous one with the same *name*, for the same *module* and *deviceID*. This notification shall be done using the following message.

Tag Name	commitData
Initiated by	IEB
Request operation: *set*	deviceID – Identifier for the device/endpoint to which the *file* is destined. The deviceID of 0 (zero) is reserved for the IEB module – Destination module within device name – Name of *file* transferred; new *file* with same name as an existing one will overwrite the older one totalSize – Total size of the *file* transferred crc – CRC-32 of the data transferred, in hexadecimal format (8 digits), used for validating the transferred file. This CRC-32 is determined from the original data, not the Base64 encoded one
Response	status – "OK", "Not OK" details – Details of failure

Only after this message has been successfully processed is it possible for a new file to overwrite an existing one. The usage of a CRC for validating the data transferred serves the purpose of identifying errors or failures in the transmission of specific data blocks.