Università Politecnica delle Marche
Scuola di Dottorato di Ricerca in Scienze dell'Ingegneria
Curriculum in Ingegneria Meccanica e Gestionale

A User-Centred Methodology to Design and Simulate Smart Home Environments and Related Services

Ph.D. Dissertation of:

Andrea Capitanelli

Advisor:

Prof. Michele Germani

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14th edition - new series

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Acknowledgements

First of all, I would like to express my sincere gratitude to my advisor, Prof. Michele Germani, for having trusted in me, and, especially, for having encouraged me all the years of the PhD. Thanks for having involved me in several research projects, at national and international level, which have allowed me growing professionally and knowing many people in academic and corporate environment.

Big thanks goes to Eng. Fabio Ginesi that involved me in all the activities of the Homelab Consortium. Staying within the consortium has allowed me seeing many facets of the corporate life making me to acquire relational and management skills.

I also want to say a big "thank you" to all Professors, Researchers and Collaborators of the Design Tools and Methods for engineering research group, because before colleagues, they have been friends with whom was a pleasure to work. Furthermore, I want to extend my thanks to the people working in UNIVPM with whom I worked during these years, in particular, Professors and Colleagues of the Department of Industrial Engineering and Mathematical Sciences.

Finally, special thanks to my loved ones. They have always been close to me during my path. Really thank you, I care for you.

Andrea Capitanelli

Ringraziamenti

Prima di tutto vorrei esprimere la mia più sincera gratitudine al mio professore Michele Germani per avermi incoraggiato, motivato e soprattutto per avermi dato fiducia durante tutti gli anni del dottorato. Grazie per avermi coinvolto in numerosi progetti di ricerca, a livello nazionale ed internazionale, che mi hanno permesso di crescere professionalmente e di conoscere molte persone in ambito accademico e aziendale.

Un grande ringraziamento va all'Ing. Fabio Ginesi che mi ha coinvolto in tutte le attività del Consorzio Homelab. La permanenza all'interno del consorzio mi ha permesso di visionare molte sfaccettature della vita aziendale facendomi acquisire capacità relazionali, gestionali di progetto e dal punto di vista comunicativo in generale.

Voglio inoltre dire un grande "grazie" a tutti i professori, ricercatori e collaboratori del gruppo di ricerca di metodi e strumenti per l'ingegneria, perché prima che dei colleghi, sono stati degli amici con i quali stato un piacere lavorare. Inoltre, voglio estendere i miei ringraziamenti alle persone che lavorano nell'UNIVPM con cui ho collaborato in questi anni, in particolare i professori e colleghi del Dipartimento di Ingegneria Industriale e Scienze Matematiche.

Infine, un particolare ringraziamento va ai miei cari che mi sono sempre stati vicino in questo mio percorso. Veramente grazie, Vi voglio bene.

Andrea Capitanelli

Abstract

The advances in home automation and communication technologies offer several attractive benefits for the modern smart home, such as increased energy efficiency, improved residential comfort and reduced operative costs for the homeowner.

Data aggregation and sharing within the networks can be guaranteed by modern Internet of Things (IoT) approaches and supported by available Information and Communication Technologies (ICT) tools. Such technologies are evolving and the private houses are becoming technological places populated by a multitude of devices able to collect a huge quantity of data and to cooperate in an intelligent way to control different domains, from household appliances to lighting or heating and ventilation.

On one hand, the rising intelligence of smart devices makes a large amount of data available; on the other hand, data complexity creates difficulties in classifying, transmitting and interpreting essential data. Both aspects may drastically reduce the potential advantages and limit the diffusion smart devices. While in building automation proven solutions already exist, tailored applications for private houses and integration among heterogeneous devices and systems are still challenging due to the lack of standards and the variety of adopted communication protocols and data model schemas. Furthermore, even when the device connection and consolidation are achieved, making them cooperate in an interoperable way is another big challenge due to differences in usage paradigms, operation modes and interface integration. In fact, Smart Homes still lack of high interoperability and researches are often strongly technology-oriented and focused on single sub-system potentialities neglecting the expected benefits for the final users.

For this purpose, the presented research defines an information management model for the smart home environment to support design and simulation of its devices as well as the enabled services. Such a model considers different device typologies, their mutual relationships, the information flows and the user interaction modalities in order to properly model the environment and define its behavior. It supports the design of the smart home by simulating the devices' functionalities and estimating the expected performances.

Riassunto

I progressi nelle tecnologie di automazione e comunicazione all’interno degli edifici residenziali offrono molti interessanti vantaggi per lo sviluppo delle Smart Home, come l'aumento di efficienza energetica, il miglioramento il comfort per gli abitanti e la riduzione dei costi operativi per il proprietario.

L'aggregazione e la condivisione dei dati all'interno delle reti possono essere garantite dal moderno approccio denominato Internet delle cose (IoT) e supportati dalle nuove tecnologie dell'informazione e della comunicazione (ICT). Tali tecnologie si stanno evolvendo e le abitazioni stanno diventando luoghi tecnologici popolati da una moltitudine di dispositivi in grado di raccogliere una grande quantità di dati e di cooperare in modo intelligente per controllare tutti i dispositivi connessi, come gli elettrodomestici, l'illuminazione, i sistemi di riscaldamento, ecc.

Da un lato, la crescente intelligenza dei dispositivi connessi produce una grande quantità di dati; dall’altro lato, la complessità di tali dati crea difficoltà di classificazione, trasmissione ed interpretazione delle informazioni utili. Entrambi gli aspetti possono ridurre drasticamente i potenziali vantaggi e limitare la diffusione dei cosiddetti dispositivi “smart”. Mentre a livello aziendale già esistono soluzioni di automazione affermate ed ampiamente utilizzate, le applicazioni per le abitazioni private sono ancora di difficile diffusione a causa della mancanza di standard di comunicazione e della presenza di dispositivi e sistemi altamente eterogenei e quindi di difficile integrazione. Inoltre, anche quando la connessione tra due dispositivi viene stabilita, renderli interoperabili è un’altra grande sfida a causa delle differenze nelle modalità di funzionamento e della difficoltà di integrazione dell'interfaccia. Infatti, le Smart Home non consentono ancora una elevata interoperabilità e gli studi fatti sono spesso fortemente orientati alla tecnologia e concentrati sulle potenzialità dei singoli sottosistemi, trascurando i benefici per gli utenti finali.

A tale scopo, questo lavoro definisce un modello di gestione delle informazioni per ambienti domestici intelligenti con lo scopo di supportare la progettazione e la simulazione dei dispositivi “smart” nonché dei servizi sviluppati. Tale modello considera diverse

tipologie di dispositivi, le relazioni esistenti tra loro, i flussi informativi e le modalità di interazione dell'utente per modellare correttamente l'ambiente e definirne il comportamento. Il modello sviluppato supporta la progettazione della Smart Home ed è in grado di simulare le funzionalità dei dispositivi con lo scopo finale di valutare i benefici dei servizi forniti.

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Chapter 1. Introduction

The recent advances in smart devices and communication technologies offer many opportunities to the creation of innovative smart environments and services. In particular, there is a strong interest about smart homes and energy-cost control services. Indeed, firstly the residential sector has been proved to be one of the most energy-intensive [1]; secondly, a lot of research recently focuses on smart device connectivity issues and information management models [2] as well as energy efficiency architectures and services for the smart home [3]. However, energy control is only one of the possible enabling functionalities; in fact, smart homes can make several intelligent objects cooperate each other to achieve higher performances and support the users' everyday life: higher safety, better comfort, improved quality of life, reduced operative costs, or assisted living functionalities.

In this context, smart home environments should be conceived according not only to the devices' technological features, but also to the needs and skills of home dwellings [4]. Contrariwise, the majority of the existing systems are usually strongly technology-oriented and focused on the single sub-system potentialities [5]. Consequently, they usually focus on the implementation of a specific technology instead of the achievement of the expected benefits for the final users. Furthermore, although numerous system architectures have been proposed, the simulation of their behavior is neither investigated nor detailed in literature. Some companies use simulation tools to optimize they own products, but when they are included in a smart home system they cannot be simulated properly.

In order to overcome these limitations, a smart home reference model has to be defined to represent smart environments and understand which functions a certain device is able to perform when connected to a certain network and what information generates and sends to other devices. Furthermore, a set of management rules is due for the intelligent management of all the devices [6].

For this purpose, this research presents an information management model for smart home environments to support design and simulation of its devices as well as the enabled services. Such a model considers different device typologies, their mutual relationships, the information flows and the user interaction modalities in order to properly model the environment and define its behavior. It supports designing a smart home by simulating the devices' functionalities and estimating the expected performances. Performances can be measured in different ways according to the users' needs and the use scenarios (e.g. operative costs, energy consumption, saved energy, saved costs, sustainability impact, user support).

A first tool (Modeling tool) allows modelling different smart home environments (set of devices and infrastructure) and use scenarios (location, user typology, user's preferences) and therefore simulating the interoperable home behavior for a certain life span (daily, monthly, yearly). Then, a second tool (Simulation tool) allows simulating the behaviors and performance of the modelled smart home environment to support designers and engineers. Such tools can be adopted in different design stages:

- During product design and first environment design, when the preliminary design of the devices is completed, the Modelling tool drives design optimization of the products (devices and environments). It models the contributions of each device and its interoperable behavior, virtualize the smart home network, choose the most proper set of devices to satisfy a specific user scenario, and highlights the most critical points to be improved;
- During environment validation and service design, when a specific set of devices is tested for different scenarios (uses' typology, family typology, location and state, etc.) and different services to calculate the achievable benefits for each use scenario, the Simulation tool verifies the performances of a certain smart home solution including both products and services by evaluating the achieved benefits and providing a preliminary feedback about the market response.

In particular, this work validates the general method by their application to the energy-related services with the aim to reduce energy consumption, global cost for final users and environmental impact. It demonstrates how the method is useful to develop efficient smart services and how the developed tools are able to simulate the effects of an energy-control service.

1.1 Research Objectives

Given the state of art analyzed in the initial phase of the research project and described in the introduction, some considerations have been made that guided the work in the three years of PhD at the Department of Industrial Engineering and Mathematical Sciences, Università Politecnica delle Marche.

- It is very useful to analyze, starting from a high-level perspective, the home environment. The high point of view permits to visualize simultaneously all the actors that interact each other inside the home and external parameters that influence their behavior.
- Given the large amount of data and devices, it is necessary to develop a general method for intelligently manage the flow of data generated in order to develop services that integrate multiple devices (Chapter 3).
- Our questionnaires and researches revealed that one of the areas of greatest interest is the services for energy efficiency and comfort for the user, so it was developed a software tool that facilitates the development and validation of services applied to this particular sector.

The decision to explore a particular field of application was also dictated by issues related to the companies involved in the research (Homelab Consortium), the time available and the high differences in the types of services that can be developed in the Smart Home (AAL, home security, personal security, comfort, etc.) that require treatments and very different skills. In particular, the general method was applied to the energy-related services in order to increase energy efficiency, reduce costs and environmental impact of the house. It is worth to notice that the general structure of the method that will be presented in Chapter 3 remains unchanged, but the developed tools and the cases study analyzed focus on energy-related services. In particular, for energy-related services, the simulation aspect is very important as it permits to evaluate a particular solution in early design phase of the home environment. Such a work led to the development of software with which companies can develop and simulate a connected product, professionals can perform simulations in the initial design phase to evaluate the best solutions to meet customer requirements, and consumers can assess which product (or product group) is more suitable for their lifestyle. So it was decided to implement the rules defined in the general methodology in a Smart Home simulation tool analyzing the developed solutions from energy, economic and environmental point of views.

The main goals of this research study are listed below:

- Definition of a Smart Home information management model that includes both technical features and user needs and skills;
- Design and simulation of Smart Home user-centered services specific for the use case under investigation;
- Creation of a knowledge base of the home environment that includes devices, user habits and external parameters;
- Development of a Modeling tool that guides the user towards the modeling of the Smart Home scenario and able to reproduce the real use case under investigation.
- Development of a Simulation tool with an architecture able to simulate the real behavior of a defined home environment considering all the actors and their interaction rules. It permits to evaluate the designed smart service in the defined use case.

1.2 Innovation Proposed

Considering the research objectives and the analysis of the state of art about methods and tools developed in the field of smart environments and, in particular, for the smart home, the main innovation proposed in this work are described below.

Smart Home can be defined as an "ecosystem" in which several intelligent objects cooperate each other to achieve higher performances and support the users' everyday life.

Despite this, the literature shows that existing researches are usually strongly technology-oriented and focused on the single sub-systems potentialities. In fact, the state of art is full of examples of prototypes of smart devices and of communication protocols, but it is poor of analyses with the expected benefits for the final users. The innovation proposed in this work includes the design of a smart home information management model that considers all the actors of the home environment and that support the design of user-centered services.

Furthermore, although numerous Smart Home services have been proposed, the simulation of their behavior generally focuses on the specific system under investigation without a high perspective that includes all the actors (devices, users' habits, and external variables) and their interaction rules.

For this purpose, this work introduced a new design approach that aims to develop knowledge-based tools with an architecture able to simulate the real behavior of a Smart Home service and to define the best system configuration for the specific use cases under investigation. One of the major enhancements is the development of an intelligent tool that permits to configure a real home scenario considering all devices and user habits to validate the developed services in day life situations. Furthermore, it contains an intelligent user interface that, when requested, it is able to automate and simplify the data entry process. It brings to main advantages: the execution of fast simulations and the possibility of being used by non-expert users.

Chapter 2. The Smart Home Environment

A smart home, or smart house, is a home that incorporates advanced automation systems to provide the inhabitants with intelligent monitoring and control over the building's functions. It has appliances, lighting, heating, air conditioning, TVs, computers, entertainment audio & video systems, security, and camera systems that are capable of communicating with one another and can be controlled remotely by a time schedule, from any room in the home, as well as remotely from any location in the world by phone or internet. The aim of a Smart Home is to provide services to its homeowners such as comfort, security, safety, energy efficiency (low operating costs) and convenience at all times, regardless of whether anyone is home.

A “smart home” should anticipate and respond to the needs of the occupants, working to promote services through the management of technology within the home and connections to the world beyond. For example, a smart refrigerator may be able to catalogue its contents, suggest menus, recommend healthy alternatives, and order replacements as food is used up.

Although many people will be vaguely familiar with the term “smart home”, few of them will have a very concrete understanding of what it means. It was first used in an official way as long ago as 1984 by the American Association of House Builders. This development is key to what is meant by smart homes. For a home is not smart because of how well it is built, nor how effectively it uses space; nor because it is environmentally friendly, using solar power and recycling waste water, for example. A smart home may, and indeed often does, include these things, but what makes it smart is the interactive technologies that it contains.

2.1 History of the Smart Home

The 20th century saw a big revolution in domestic technology, a revolution that culminated at the close of the century with the emergence of the concept of the “smart home”. At the beginning of the 20th century, most of the available domestic technology would have been easily recognized and used by people from a hundred years earlier. By the end of the 20th century, however, domestic technology had changed beyond recognition. The first major impetus for change was the introduction of electricity into homes in the first quarter of the century. This provided a new source of clean, convenient power for appliances and spurred the introduction of novel equipment for the home. The second major impetus was the introduction of information technology in the last quarter of the century. This opened up possibilities for exchanging information between people, appliances, systems and networks in and beyond the home, possibilities that are still being explored.

The Smart Home was born from the concept of home automation design that was already in the process of coding in the 80s in residential buildings. The engine for the home automation development is constituted by the revolution in informatics, microprocessors and telecommunications networks. At the same time, increasingly sophisticated automation processes, in the field manufacturing, are the basis of building automation and home automation applications through the transfer of control and automation systems used in the factories, with proper precautions, in the building and in its facilities. During the 70s and 80s, the first prototypes of technologically advanced household appliances were developed. In fact, in this phase it was generated the first passage from the electrical home to the electronics home; subsequently the progress in this sector will lead to the current conditions of integrated home with the opportunity to provide innovative service to the dwellers, and therefore the concept of smart home.

The first project of intelligent home, in which computer and electronics technology are deployed in large quantities according to a new way of living, is the Ahwatukee house built the years 1970/80.

In Europe, the most significant project of the same period was the DORIS operation, in Alsace, on behalf H.L.M. of Strasbourg. In the project, 42 units were made with the

“Synforic” system and based primarily on safety features, environmental comfort and remote alarms.

The Japanese research started with Next house between 1982 and 1985 by experimenting automation technologies with focus on energy rationalization and home comfort.

From 1984, the development of information technologies and electronic technologies grew up and the European ESPRIT [7] acts as the engine in the man-made environment sector with a series of integrated programs of information technology and industrial technology transfer measures.

In the area of building automation, in the 80s, the Europe was moving in the direction of systems and standards deriving from the French and German research mainly. The Italian solution arrived in 1985 with Merloni-Ariston appliances that used a technology based on a telephone-evolved console able to direct equipment information also on the power grid.

Since the 90s, first projects for elderly people with mobility problems were created and they brought to products and initiatives in the field of Ambient Assisted Living (AAL). Now, AAL is one of the most growing areas of interest for researchers and company working in the field of “smart technologies”. The goal is to create better conditions of life for the older adults through the use of information and communication technology (ICT).

Several applications and services have been developed over the latest years for making houses smarter in terms of danger prevention, energy consumption, waste recycling, environmental monitoring and other life improvement implementations.

Furthermore, the continuously evolution of Information and Communication Technologies (ICT) and the growing development of new smaller and technologically advanced devices led to the introduction of the concept of Internet of Things (IoT). The term “IoT” was coined by Kevin Ashton, co-founder and executive director of the Auto-ID Center (research consortium at MIT), during a presentation at Procter & Gamble in 1999 [8]. The Internet of Things is an evolution of the use of the network: the objects ("things") became able to communicate information about themselves and access information aggregated from other objects, also they are they are recognizable within the network and able to “learn” from the data they acquire from other objects.

As of the end of 2004, there were some 875 million internet users worldwide [9] and mobile phones were being used more and more as devices for internet access. This led to the creation of new applications and services hitherto unknown, through both 2G systems and subsequently 3G systems (now we have 4G). The internet and other data transmission services (e.g. SMS, MMS), initially the purview of the developed world, were also gaining market share in developing economies, boosting information and communication access and increasing demand for bandwidth. Today, we are heading into a new era of ubiquity, where the “users” of the internet will be counted in billions and where humans may become the minority as generators and receivers of traffic. Instead, most of the traffic will flow between devices and all kinds of “things”, thereby creating a much wider and more complex “Internet of Things”.

Internet-of-Things (IoT) gave numerous possibilities decentralizing the control of smart homes. Numerous sensors and developed systems or services can all communicate via smart devices like smartphones.

Although home automation has been around since the 1970’s, it did not achieve high market penetration due to high costs, proprietary communication standards, and reliance on installers/users with high-tech experience. Now we are at a turning point, because the advanced features, updates, user convenience, and data collection and analytics (e.g. tips to reduce energy consumption and costs) that could come from devices connected to the internet outweigh the cost of enabling Smart home products. Furthermore, new smart devices are increasingly easy to use and to install at home, in fact in many cases they are wireless devices without a wiring connection.

In this context, the key is interoperability between different manufacturer’s devices. In fact, the users would prefer the integrated management of smart objects inside the home, but the current offer is not yet able to respond adequately to this need [10]. Nowadays, the majority of the commercial solutions are vertical, not integrated with each other and even less with products from other suppliers. The interoperability (the ability to "talk" easily between devices from different manufacturers) arises then as a crucial condition for the development of the Smart Home market.

2.2 The challenges of communication: the interoperability requirement

In a building that can be defined “smart” many functions are controlled by one or more systems based on automation, electronics and telecommunication sciences containing instrumentation equipped with easily understandable and manageable user interfaces. The keywords in intelligent buildings are integration and interoperability between systems. Such systems are already quite established for tertiary markets (banks, offices and technology centers). However, for the housing market, we are still looking for effective solutions that realize concretely the objectives of integration and interoperability and that are more easily saleable in a market not ready to spend for this kind of technology and much less aware of the opportunities. In functional terms, what matters is that the home automation system is able to control and monitor all the functions of in real time (building, plant systems, user interaction, external events) considering all interactions and optimizing the overall performance according to the defined criteria.

Currently, designers and developers of home automation systems, for the choice of technology to be used, refer generally to individual homogeneous development "packets". The companies operating in the home automation market, in fact, offer a single standardized solution package, whose specifications refer to devices, programming languages, media to use for communication, communication protocols, message encoding, etc. Therefore, current systems do not communicate with each other, presenting proprietary technologies and communication protocols with a strong coupling hardware (HW)-software (SW). Furthermore, company policies mean that there is typically a lack of openness to developers and third-party vendors: little or no documentation available, non-replaceable devices, inability to add devices and sensors not provided by the manufacturer. In this scenario, it would be desirable the possibility for the user to choose the devices regardless of the standard they belong, without the need to know the technical specifications of his/her system, and drawing only the possible benefits.

2.2.1 The communication network

The creation of an interoperable system able to mutually control the devices and properly manage all data of each smart product requires the physical device connection (wired or wireless) to the Home Area Network (HAN) and the communication infrastructure to deliver all the collected data and make them available to other systems (e.g. for data analysis, for user monitoring, for remote control).

The physical device connection can be implemented in various ways as each device has different capabilities in terms of distance, speed and volume data transfer. The list below shows the physical media used in the smart home.

- Powerline: it consists of the existing house wiring that supplies all the electrical devices and exploits the principle of the Power Line Communication (PLC) technology. Since every home already has it, the power line is convenient and does not require any additional wiring [11]. Communication standards for power line are X10, HomePlug and LonWorks.
- Phone line and other wiring: it includes all the other wirings of the smart home, such as twisted pair, coaxial cable, fiber optic and others. They allow managing wide bandwidth data, as required by the entertainment system, the computer, etc. Some wired communication standards are Ethernet, USB, HomePNA.
- Wireless: it is a network that use electromagnetic waves to connect devices and send/receive information. It is practical, because it allows connecting numerous devices in an easy way and also including devices not connectable by a physical cable. Well-known wireless communication standards are ZigBee, Wi-Fi, Bluetooth.

It is worth to consider that each device has different requirements in terms of connections and communication protocols and a residential gateway is required.

2.2.2 The residential gateway

All the effort made until now to ensure interoperability have not yet had the desired effect on the market. The technological difference between the different apparatuses hinders the interoperability; consequently, to overcome these problems, the research has progressively focused to the development of technologies to ensure the interoperability of different products. It is in this context that is introduced a device called Gateway. It represents the link between each device connected to the HAN and is able to manage traffic information. It also serves as a bridge between the home and internet connecting the HAN with other external management systems [12]. Thanks to the gateway, the user (e.g. homeowner) can interact with the systems directly by an internal Graphical User Interfaces (GUI) or indirectly via computer and/or smartphone (both locally and remotely). Therefore, he/she can monitor home conditions, controls the devices and be informed about specific data. Even utilities and companies can access some data transmitted from the smart home, according to the privacy policy, for supporting some specific services (e.g. remote technical assistance). Figure 1 shows a scheme of the proposed architecture.

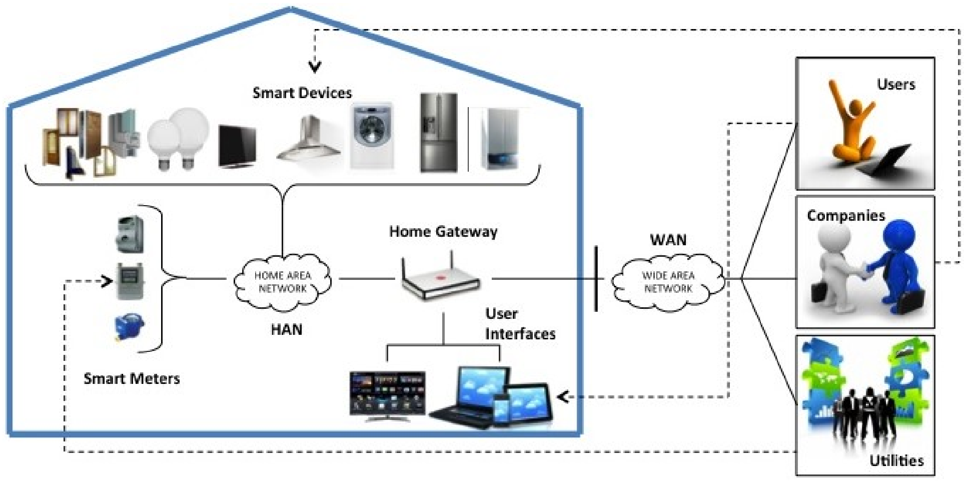


Figure 1: Example of Smart Home system architecture.

2.2.3 The communication protocols

The commercial development of home automation is therefore limited to the huge variety of specifications and standards, which do not allow an easy communication between devices from different manufacturers. On several fronts, it is working to eliminate this problem, in fact, several research institutions and government agencies have developed frameworks for the management of networks in intelligent environments.

The main interoperability framework are listed below:

- Open Services Gateway initiative (OSGi): it is created in 1999 [13] to define an open standard for the provision of services in interconnected environments such as the home and the car; so, it has been proposed to solve the problems of interaction between different types of middleware and service delivery methods.
- The Application Home Initiative (TAHI): it is created in 2000 [14] by different industries and groups of technicians who have worked together to provide interoperability guidelines for smart environments.
- Energy Conservation and Homecare NETwork (Echonet): it is a consortium that has recently proposed specifications developed to directly control the home automation devices and to connect them through a gateway device [15]. The specifications provide the use of APIs and standard protocols to promote the development of applications and define an open architecture.
- Intelligent Grouping and Resource Sharing (IGRS): it was formally established in 2003 by five of the largest computer companies in China, managed by the Chinese Ministry of Information Industry [16]. This standard was proposed to promote an intelligent consortium of manufacturers, a resource sharing and a collaboration services through information and communication devices to improve their interoperability and usability.
- Digital Living Network Alliance (DLNA): it is an international collaboration between the computer industry and the mobile equipment companies (over 250 companies) with the aim to develop a common standard for the communication of multiple audio

devices and video in local network [17]. The specifications are largely based on existing standards, such as the Internet UPnP standard for the devices connection and TCP/IP for the resource sharing.

These protocols have been developed over the years and they are already used in the market of connected products, but they failed to definitively resolve the interoperability issues of the smart home. Probably, it will be necessary to wait five years before devices from different home IoT ecosystems can carry out complex tasks like setting up the whole house. IDC analyst Michael Palma said: "I think we're going to see a lot of frustrated people trying to expand whatever they have invested in so far". Nevertheless, important companies have recently entered the home IoT market that have developed communication protocols that can be the standards of tomorrow.

- AllJoyn: it is based on software developed by Qualcomm [18], AllJoyn is now an open-source framework administered by the AllSeen Alliance [19]. Members include Microsoft, Cisco Systems, Panasonic and Sony. AllJoyn provides tools for the entire process of connecting and maintaining devices on a Wi-Fi network. Manufacturers can use the AllJoyn framework to create their own custom apps for onboarding devices onto a Wi-Fi network, complete with control and notification services.
- OIC: The Open Interconnect Consortium includes Intel, Samsung, Dell and Cisco [20]. Through an open-source project called IoTivity, people with other technologies, including competing ones like AllJoyn, can introduce plug-ins that let OIC products work with other types of gear.
- HomeKit: This software framework developed by Apple is designed to let users control home devices directly from an iPhone over Bluetooth or Wi-Fi [21]. It can also tie into an Apple TV for access when the iPhone is not in the house. Other smart-home platforms can connect with HomeKit through systems like the Insteon Smart Hub Pro. However, Apple controls the HomeKit ecosystem and approves the products that can use it.
- Brillo and Weave: These two software components have been called "Google's answer to HomeKit". Brillo is a power-efficient IoT operating system based on

Android [22], and Weave is middleware similar to AllJoyn and OIC that lets devices identify each other and their capabilities. Weave can work with OSes other than Brillo, and it can use at least three different networking protocols: Wi-Fi, Bluetooth Low Energy and Thread, the system spearheaded by sister company Nest [23].

2.2.4 Towards the Internet of Things paradigm

According to the IoT paradigm, objects become intelligent when they are localizable and they can acquire, process and exchange data. The Smart Home & Building applications are particularly important in the IoT scenario, since they represent the link between the individual (the citizen, the consumer) and the higher levels of adoption of IoT paradigm (Smart City, Smart Grid).

Among the most established fields of application, there are "simple" solutions, with objects with one specific function and that only marginally reflect the openness and accessibility that characterize the IoT. Examples of this solution are: intrusion detection and video surveillance (in Smart Home, Smart Building and Smart City), fleet management (Smart Logistics), traceability of "valuables" (such as biomedical equipment), maintenance of devices and systems (Smart Asset management), monitoring of the traffic through cameras or conductive coils and the location of the vehicles used for public transport (Smart City Smart & Environment).

In addition to the consolidated areas, there are also more mature solutions closer to IoT paradigm, characterized by a greater accessibility of the objects and, in some cases, by the presence of local data processing. Some of these solutions are: the smart meters for the measurement of electrical consumption (Smart Metering), home automation solutions for energy management, services for dwellers safety, the management of environmental scenarios, mobile information services and GPS box for the location of private vehicles and the recording of the parameters of guide (Smart Car).

The objective of full interoperability in Smart Home ecosystems responds to the idea of achieving the accessibility of the home “node” from external devices and fully integrate it into the IoT world.

2.3 Smart Home services

This section presents how Smart Home technologies can be adopted to provide consumer services by managing the information within an interoperable smart home environment. The service described in the following paragraph can offer benefits to several subjects: consumers, utilities, manufacturing companies as well as governments and public entities. Consumers have the possibility to save money and improve the quality of life since they worry no more about product assistance, they have home consumptions monitored and constantly verified, and they are safer without any change to their lifestyle. Many customized applications can be developed to incline people towards smart homes and solutions of the future. Furthermore, customers can agree with the companies to provide a specific service: for instance, they could have free assistance in exchange of continuous feedback. In this way, industries can have direct and reliable product and service evaluations without additional costs. Furthermore, both consumers and companies can choose which data to be monitored, how to be informed and when to receive information according to their own purposes. About utilities (e.g. energy, water, etc.), they can improve their current advantage from smart meters by a better management of the entire network. The electrical utilities can also benefit from the integrated Dynamic Demand Control (DDC) technology, and nor companies nor users have to pay for it. Utilities can also encourage this solution rewarding users by free electrical supply or cost reduction. Finally, governments and public entities can benefit from Ambient Assisted Living services, which improve elderly people wellbeing, limit their stay in medical centers, and reduce social costs in general. Obviously, also the environment takes advantages from the reduction of the resources’ consumption.

2.3.1 Home Energy Management

The actual growing world energy demand and the high attention to environmental impact reduction are generating a strong convergence of scientific, industrialists and politicians interests towards the use of Information and Communication Technologies (ICT) to support a more efficient use of the energy resources. The residential sector is one of the most energy-intensive reaching about 25% of global energy consumption [24]. It is difficult to understand the real energy use in residential buildings suggesting the development of technologies and services to monitor and improve home energy performances. In addition to this, the energy consumption in the home environment are closely related to the specific case under investigation, in fact it imposes the analysis of the particular application scenario and the target users to extract parameters able to describe the building behavior

Furthermore, Technical development in the energy market makes distributed generation and storage more affordable to consumers, enabling climate neutral electricity consumption. However, balancing supply and demand becomes more of a challenge for the electricity grid, a problem that can be solved, but one that requires attention. Technical development of solar panels, batteries, and so on, is key for energy efficiency, but equally important is the rapid development in the IoT, enabling the technologies and rules to manage these systems and definitely create the Smart Grid.

In the light of this development, Home Energy Management (HEM) services can play an important role to help consumers manage their electricity consumption. In fact, Smart Homes pushes a radical technological change where objects cooperate each other creating a continuous flow of information that can be used to support real-time decisions, optimize the systems energy performances and offer new energy services.

Currently, Home Energy Management Systems (HEMS) is on the spotlight, in fact, sustainable energy is high on the political agenda; companies and researchers are looking into this field, and there have been many pilot projects and proof of concepts. Despite this, there are still barriers for the consumers.

There is not yet a single standard definition of HEM or an agreed-upon description of HEMS or the functionalities and categories of products included within them.

Roth and Sache [25] define HEMS as “any device or system in the home used to: control an energy consuming device, identify or diagnose energy savings opportunities, or provide information to occupants to influence how they consume energy”; this definition was also used by Ford et al**.** [26] and Rosenberg and Liecau [27].

Home Energy Management technologies have the primary purpose of enabling residential users to manage home energy use by reducing consumption [28], [29], [30], or shifting/reducing peak demand [26]**.** The dwellers or the smart system (automatically) can select and implement a strategy for the best energy use. It brings benefits such as a better understanding of their energy consumption, information about how energy is used at home and tips for the energy and costs reduction.

Smart Homes and the service of HEM can give are numerous benefits to the users [31]**.** Benefits of HEMS from the consumer perspective include the money saving, the dwellers comfort and safety, remote maintenance, etc. All these service could be related to HEM in a cooperative system. The importance of these non-energy benefits is starting to be evident in products on the market; an example is the “Nest” thermostat that permits to save energy, but it also offers an innovative way for the ambient temperature management providing greater comfort to the inhabitants [23]**.**

As described above, HEM services are able to bring benefits to the consumers and to the stakeholders. HEM technologies can be divided in two main groups divided for kind of service provided that are “systems for energy monitoring” and “systems for energy management”.

The “energy monitoring” group includes technologies able to provide information on energy usage (specific or general) back to the energy user. The two primary services that are offered to the user by this kind of technologies are feedback and prompts.

- Feedback refers to the process of giving people information about their behavior that can be used to reinforce behavior and/or suggest behavior change [32]**.** In the context of home energy management, feedback specifically refers to information about household energy use and is often referred to as energy feedback [33]**.** Karlin et al. (2014) define energy feedback “as information about actual energy use that is collected in some way and provided back to the energy consumer". The provision of energy feedback (i.e., information) has been identified as a key defining functionality of HEMS; Van Dam et al. (2009) define HEMS as "intermediary products that can visualize, manage, and/or monitor the gas, water, or electricity use of other appliances or of a household as a whole."

Many times, domestic energy use is invisible to the user, so energy feedbacks are very important. Hence the importance of feedback in making energy more visible and more amenable to understanding and control. Feedbacks could be direct or indirect. Direct feedback includes information received via the consumer's computer, via smart meters combined with in-home displays. Indirect feedback includes more informative and frequent bills containing historical and/or comparative information on energy consumption. Many projects used energy feedback to promote energy efficiency and previous studies identified over 200 feedback product [26], [32]. However, there are significant differences in approaches, project goals and scientific methodology employed in developing the pilot projects, so the results should be read with caution. The EEA Technical report N° 5/2013 [34] suggests that up to 20 % of energy savings can be achieved through different measures targeting consumer behavior. The following table provides an overview of the savings achieved from different interventions (Figure 2).

Intervention	Range of energy savings
Feedback	5–15 %
Direct feedback (including smart meters)	5–15 %
Indirect feedback (e.g. enhanced billing)	2–10 %
Feedback and target setting	5–15 %
Energy audits	5–20 %
Community-based initiatives	5–20 %
Combination interventions (of more than one)	5–20 %

Figure 2: Summary of savings achieved from different interventions.

- Prompts are another form of information that HEM can provide; they send targeted or timed suggestions to the energy user that enable them to more actively manage demand. Prompts could be in the form of pricing tariffs, economic incentives or actionable advice. They can help users to shift the appliance time of use, increase the efficiency with which actions are performed, or swap one activity for another less energy-consuming one that provides the same service. Unlike simple energy feedback, prompts can provide not just consumption detail, but also payment option, energy tips and information on pricing.

The other "energy management" group includes technologies with the ability to modify the energy consumption of a household appliance. Two primary services offered by this kind of technologies are the remote control and rule-based control.

- Remote control the situation in which a user can controls the appliance operations inside or outside the home via a user interface. This allows the user managing that appliances energy demand in real-time from a remote location; the request can be transmitted to the appliance via an internet connection. This kind of control is manual, because the user spontaneously has to perform the action.
- Rule-based control is often termed automation, because it includes the systems management made by a computer control unit that can be a central control unit or distributed control units (one for each device o group of devices). The devices scheduling is a rule-based control and refers to the creation of priorities or settings to manage household appliances ahead of time [32], [35]. The scheduling priorities can be defined manually by the user (e.g. in case of power overload the first device automatically turned-off is that defined by the user) or set dynamically by the control unit (e.g. the scheduling of household appliances to maximizes the self-consumption of renewable energy produced) [36].

  Optimization is a type of rule-based control in which usage or historical data is analyzed and used in algorithms, such as machine learning, to create a more effective demand pattern within the constraints set by users, and thus improve output and efficiency [37].

2.3.2 Ambient Assisted Living (AAL)

The elderly population is rapidly increasing; this fact pushes to take advantage of available technologies to improve their wellbeing and support a correct lifestyle. Numerous home automation systems have been proposed and many smart objects have been designed with the aim to communicate important information for elderly assistance. However, there are strong barriers to their implementation mainly due to the information management issues and the lack of high-level overall system design. The fragmentary nature and the extreme "verticalization" of the proposals identified in the literature highlights the most important limitation of these solutions: the absence of an open and common platform that permits the development, implementation and growth of services; in other words the absence of the characteristic of interoperability. An AAL system has to collect necessary data derived from direct observation of interaction between the elderly and the appliances and such information can be collected without additional costs. Data can be used to monitor user's habits or to remotely control some devices that, for example, could be too difficult to activate for an elderly. It finally has to allow investigating how aged people live daily and capture alarming signals to make them live safe. Thus, elderly can feel more independent and improve their quality of life. In the same time, they are monitored continuously and relatives will be advised immediately, if they need help. Such a service can be enhanced by identifying possible health issues or preventing dangerous situations thanks to dedicated post-processing applications.

Major challenges in the field of Smart Homes [38] and the Smart Cities [39] are the following: meet the needs of users, improve security and to be able to monitor their state of health, Elderly, disabled and vulnerable people in general can benefit greatly by smart environments [40], [41]. However, many factors until now have limited its development. First of all, the lack of an adequate level of interoperability and of a common platforms such as to support the development of interoperable systems and platforms. Different efforts have been made in the past, in particular through pilot projects developed in the United States, Europe and Asia, through which it is tried to introduce inside the home intelligent technologies for monitoring vulnerable people (Project SmartBo [42], ProSafe

Project [43], the Aware home [44], [45]. Although these projects were based on innovative technologies, most of them were considered as demonstrators of technology that simply provide data obtained from the processing of an insignificant number of sensory measurements. They were also evident interoperability limits of the systems as well as the integration of the data collected. In more recent project, it is tried to improve the product interoperability, but this continue to be a big issue [46], [47]. This suggests that much work remains to be done to address fundamental issues that allow full monitoring of the inhabitants, from a large number of devices and sensors, heterogeneous and still little interoperable with each other.

The monitoring of the health conditions of individuals is one of the largest fields of application study in the world of healthcare. The vital signals generally used are the ECG (electrocardiogram), the oximeter, the body temperature, the heart rate and the blood pressure. Each of these parameters requires a dedicated sensor or a dedicated measuring system. In [48] a collection of current solutions that integrate these measures for the domestic monitoring of health status is presented. State of the art contains various solutions, but each of them still have some disadvantages, which prevent a wide application, or that is specific for a particular application or case. For example, [49] shows a portable remote assistance system that can measure vital signs, but it is intended for the monitoring of patients with heart failure and the total cost is quite high. A modular high-performance system based on sensor network is the Codeblue [50]. It is a hardware and software platform able to coordinate and communicate with a number of wireless medical devices providing the data measured by a pulse oximeter, ECG, blood pressure monitor and motion sensors along with the ability to make the patient's location. However, this solution is specific to manage emergencies in clinical areas (such as hospitals or clinics) and not usable for home remote monitoring. From other side, there are systems such as the LifeGuard [51], which is a platform capable of integrating different types of sensors such as ECG, respiration, oximetry and blood pressure. This platform has a high capacity for integration, but it only allows local storage of the acquired data and therefore requires further development, in order to do remote monitoring. The projects and the cited systems are complex or still research projects. While simpler systems already on the market are specific to particular types of user and have a limited number of measured parameters or they are not interoperable. Very interesting results have been demonstrated by the introduction of non-contact measurement systems based on the use of vision systems such as optical (mainly laser [52]) and electromagnetic [53]. In [52], the vital signals are properly measured without the contact with the subject. Some commercial solutions based on electromagnetic waves in the UWB (ultra-wideband) for indoor monitoring are also available.

2.3.3 Safety and Security

Smart Home security means that the Home and the Dwellers are protected from external intrusion. Personal security practices would be ensuring doors are locked, alarms activated, windows closed, extra keys not hidden outside and many other routine tasks, which act to prevent a burglary. A household security system integrated with a home automation system can provide services such as remote surveillance of security cameras over the Internet, or central locking of all perimeter doors and windows. Smart Home safety is the achievement of proper living conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of dwellers. It also refers to the awareness and education of risks and potential dangers in and around a home, which may cause bodily harm, injury, or death to those residing in and around the physical structure of a home. The basic tenets of home security include:

- Surveillance (seeing what is happening inside and outside your home);
- Sensors (knowing when there is movement, water, fire or smoke in your home);
- Locks (securing your home with physical barriers);

The Internet of Things has made it easier than ever to set up a smart home in which you can remotely control your door locks, lawnmowers, lights, thermostats, vacuums, and even pet feeders. A smart home security system connects to the home Wi-Fi network so it is possible to monitor and control the dwellers' security using smartphone or other devices. Entry-level systems typically include a couple of door and window sensors, a motion detector, and a hub that communicates with these devices using one or more wireless protocols such as Wi-Fi, Z-Wave, Zigbee, or a proprietary mesh network. Typically, it is possible to provide other sensors to coverage the entire house and build a comprehensive system that includes door locks, garage door openers, indoor and outdoor surveillance cameras, lights, sirens, smoke/CO detectors, water sensors, and more.

Security cameras are an essential component to a home security system. Visible cameras deter burglars and recorded footage can help you recover items after a break-in and prosecute the perpetrators. Internet connected cameras let you see both the interior and exterior of your home from anywhere, helping you avert or mitigate disasters and keep an eye on inhabitants, as well as prevent theft. There are many options when it comes to adding surveillance around your home: from wireless Wi-Fi capable cameras that can be remotely accessed and controlled from your smartphone or tablet, to covert cameras that capture video and images from a hidden location, to complete DVR kits that can handle and record video from several camera locations.

Sensors help extend your home security system into all corners of your home. With the ability to detect motion and a wide array of potentially threatening environmental conditions, sensors are a crucial component of your system. Today sensors not only detect problems and sound an alarm, but if they are connected to your home's Wi-Fi, they can alert you wherever you are. Motion sensors are simple, slim devices that attach to your window or door and emit a loud noise if someone tries to open them. They are perfect for that window or door that should never be opened. Motion detectors differ from motion sensors by sensing when a person or animal is moving in a space, rather than knowing when an object is opened or closed. They offer an excellent deterrent for prowlers and when there is a power socket nearby, they can be set to make a noise or turn on a light when someone passes through an area. Environmental sensors are other important devices. Every home should have a smoke alarm and a carbon monoxide detector. These basic sensors have been proven to save lives. More advanced environmental sensors include the ability to detect moisture levels, humidity and temperature. Connected devices can often pair with other products to expand their functionality. For example if you have a Nest Protect sensor, it can communicate with a Nest Thermostat, which will shut off the furnace if it senses smoke. Another smart solution for home safety is a water sensor. Water sensors (e.g. Wally Water Leak Detection System [54]) will detect water leaks and changes in humidity and temperature and alert you via WiFi, helping you avoid or mitigate disasters caused by burst pipes or overflowing dishwashers. Smart lights is a security method with a light set on a timer to come on and off at certain times, giving the appearance that someone is home when they are not. A home that appears occupied is far less likely to be targeted for theft. An open door is an open invitation, so locking the home is clearly the first step in security. However, locks are also inconvenient, especially when you have your hands full of groceries, or your mother needs to get in to feed the cat and you forgot to leave her a key. **Electronic locks** are relatively new in the security space and there are a variety of different levels of "smart" locks. Keypad is simple and useful to avoid endlessly handing out keys; a keypad entry provides a safe and secure way to allow entry to multiple trusted people without cutting multiple keys. It will be also possible to change the code if it is necessary to revoke someone's access without changing the locks. Smart locks do not require a physical key (although most still work with one). Instead, they use the smartphone to authenticate access, normally via Bluetooth. This technology allows sending digital keys to visitors or other people that need to grant temporary access. Additionally, smart locks allow locking and unlocking the door remotely. Doorbells are also getting smart and these once insignificant devices are poised to play a growing role in home security systems, in fact, the concept behind this service is very solid. When someone rings your doorbell, your phone will ring and a built-in-camera will show you who is at the door. Two-way communication can let you talk to the person, giving the illusion you are at home even if you are halfway around the world.

2.3.4 Remote maintenance and Device remote control service

Some Smart Home devices has a particular function that permits to backs up dweller's service and support claims, e.g. in case of technical problems, the product contacts the producer support team and, if it is necessary, it allow them remote access for technical checks. Classic corrective maintenance can be replaced by a more accurate smart preventive and predictive approach. In fact, companies and users can obtain mutual benefits: companies can monitor specified parameters to prevent a failure and observe the appliance behavior to improve the product itself; contemporarily customers can have a continuous assistance, a reduction of product failure and downtime and finally a lower global consumption. Furthermore, users may receive real time indications if their product care is not appropriate. Contrariwise, currently users may not observe a malfunctioning for a long time while the product consumptions increase.

Device remote control is different from the Remote maintenance; in fact, it is a crucial aspect to guarantee people safety and comfort. It means that the user, and not the producer, can manage his/her product from any place. It is much related to the service dedicated to the user comfort, but it involves also energy and AAL services. Smart Home systems offer the possibility to regulate lighting, heating, security systems, entertainment electronics and many other devices.

2.3.5 Comfort

The ability to integrate different systems, with its endless possibilities for customization, significantly improves the home livability. The goal of Smart Home is, in fact, to control each device with the touch of a button, as well as to have full control of the home, even remotely. The convenience of an automated system is also expressed in the possibility to program specific functions at fixed times or to store scenarios. It means a set of commands that are activated simultaneously and designed to meet the needs of a particular condition (for example, the “night” scenario can turn off all the lights, close the shutters and the activation of the burglar alarm system). Comfort is a purely subjective sensation perceived by the user at home or in certain service conditions and indicates the "level of welfare" perceived. From this definition, it is clear that the comfort is something that depends on the individual person; it is not an objective and absolute thing. Consequently, a system that aims to improve the comfort of the user must necessarily be adaptable and customizable to meet the needs and habits of that particular user. Smart Home services that create comfort cannot be considered in all respects a category of its own, while they form a cross-category that intersects the categories described above (Energy, Health, Security, Safety, etc.). For example, comfort can result from a correct regulation of the rooms' internal temperature and then we talk about environmental comfort that inevitably is linked to the heating energy consumption. The feeling of safety and security within the home can cause a sense of comfort and, in this case, it is linked to the security services. In this section some of the most important services of the Smart Home are discussed; their primary objective is to simplify and improve the lives of users. One of the most important functions of the Smart Home that bind to user comfort are the scenarios. What is a scenario? A scenario is a set of commands programmed by the user in advance that are executed sequentially with a single keypress. Therefore, the user does not send many requests to individual devices, but with a single command activates all. An example is the film scenario: pressing a strategically well-positioned button next to the sofa (or by the smartphone), the living room becomes like a cinema: the TV is turned on, the shutters are closed and the lights are dimmed.

Automatic temperature control of indoor environments is another important feature that the Smart Home can offer. In this case, the comfort binds with energy management, and the two subjects should be treated as one. This service has the aim to offer to the inhabitants a comfortable environment by thermo-hygrometric point of view, but the goal the system must manage a series of systems that must be balanced to achieve. Such systems include: the automatic regulation of heating systems, the control of temperature and internal humidity, the energy monitoring, the efficient management of the installations in use, etc.

Some examples of automatic temperature control are the following. In the morning, the shutters in the rooms with east facing go down to reduce the temperature; in the afternoon, instead they give shade to the exposed west rooms. In winter, when the user is not at home, the interior environment temperature is lowered and it is then raised before his/her return (the same principle, but on the contrary in the summer).

Other services related to comfort are the management of lighting systems based on different situation at home, the handling of audio and video systems, a variety of devices controlled via app, etc.

Generally, one of the main aspects that allow them to Smart Home to be comfortable is the presence of automatic devices that facilitate the dwellers' life. Starting from simple on/off of a remote device, via the activation of multiple devices with a single command, up to the full automation In the last case predictive algorithms are involved, which based on the user's habits know autonomously what is needed in a precise moment.

The integration of home automation devices still needs improvement, but over the years, it will have a satisfactory integration of all devices in the Smart Home, that is a key issue for the services related to the user's comfort.

2.4 The Market of Smart Home and the Internet of Things Paradigm

A Smart Object (SO) is any everyday object with the ability to communicate with the user and with other OS; it is often equipped with sensors. In the coming years, it is expected a boom in the market for these devices, which are the "building blocks" of the Internet of Things (Figure 3).

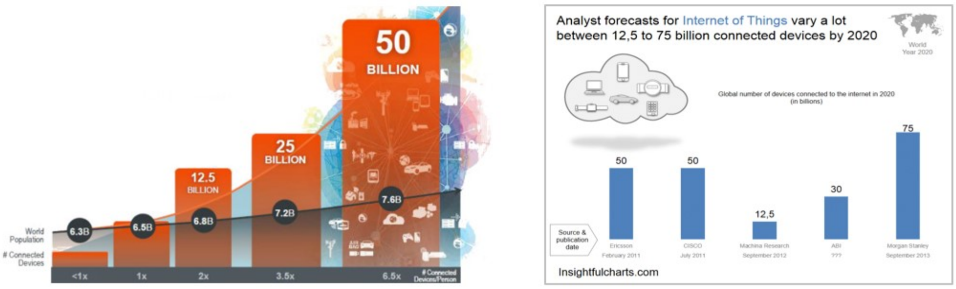


Figure 3: Expected trend for the IoT Market.

The IoT's fields of application are various and outside the boundaries of the home environment, ranging from the vital signs monitoring of a person to the complete control of his/her physical activity, from the home security to the ambient air quality monitoring. For convenience, the devices on the market can be divided into the following three categories: Home, Lifestyle and Health.

The Home category includes, on one hand, all those devices (cameras, thermostats, environmental sensors, smart plugs, smart lamps, etc.) that enable domestic environment monitoring, on the other, the actuation devices that electrically execute an operation based on the information produced by the sensors. In 2013, sales of wireless devices for the smart home increased up to 17,230,000 units and they continued to grow until now. It is expected to reach half a billion of unit in 2018 [55]. According to the study of Juniper Research [56], revenues generated by the Smart Home services will reach 71 billion dollars in 2018 and 80% of them will be generated from entertainment services. The Strategy Analytics [57] has made even more optimistic forecasts for the same year by estimating that the worldwide revenue of the Smart Home market will reach $100 billion. A search of Berg Insight AB says that North America is the most advanced area for solutions for Smart Home (3.5 million systems installed by the end of 2012) while the European market is further back (1.06 million systems by the end of 2012). However, in both geographical areas an important growth rate is expected for next few years.

The field of IoT includes also devices for lifestyle and healthcare. The Lifestyle category includes devices for the person's well-being, the most of them are wearable devices and 90% of these are smartwatch, smart band and activity tracker (or similar). According to the study provided by IDC (International Data Corporation), the offer of such devices is constantly growing and it is sold 72.1 million of wearable devices at the end of 2015, i.e. 173.3% more than 26.4 million units sold in the year 2014 [58]. The volume of business has become important and it is expected to grow reaching the forecast of 155.7 million devices sold in 2019.

The Health category includes all those devices that allow medical monitoring of a person's vital parameters (heart rate monitors, blood glucose meters, blood pressure monitors, etc.). Currently there are 17,000 applications on the market for Mobile Health (mHealth). According to a study of "research2guidance" [59], such applications for smartphones will enable the mHealth industry to reach 500 million users. A research of "Lux Research" has predicted that the mHealth market will grow from $ 5.1 billion of 2013 to 41.8 billion dollars in 2023.

In particular, telemedicine systems and services are evolving with the aim to allow the remote assistance of vulnerable users. According to a study conducted in 2014 by IHS, patients using telemedicine devices will increase from 0.4 million in 2013 to 7 million in 2018, generating a gain for the market of 4.5 billion dollars [61].

As evident from the above lines, the Smart Home is already a reality, from toothbrushes connected, to household appliances and heat regulation. However, it is evident that there is still a large gap to be filled to get a mass adoption of such devices. Privacy and costs have historically been the most significant barriers to the spread of the OS, but a number of new obstacles have emerged raising concern among consumers. Two of the main obstacles are the products usability and interoperability.

The key is in the services that will be offered and in the accessibility that users will have to such services and products. The surveillance cameras and locks connected to the smartphone are among the most popular devices; in fact, in the world, a burglary is made every 14 seconds and 56% of them are through the entrance doors. Space heating accounts for 48% of energy consumption in a typical house, then it is clear why the connected thermostats are high on the list of the most popular products of 2015. Recent researches show that, in considering the purchase of one SO, consumers give more importance to the facilitated use than to the technical innovation; moreover, most of them said that they do not feel competent in selecting and using these technologies. Nevertheless, in a recent questionnaire proposed by our working group (sample of 200 users), about 50% of respondents said that they planned to buy one SO in the short term. The same finding was also confirmed by an analysis conducted in 2015 on a sample of American users from Icontrol Networks Inc [60].

The same research points out that the majority of consumers want their devices would be able to perform certain functions autonomously and not just to complete action on the request. This property requires a device adaptation to the habits and needs of the particular user through the use of suitable sensors and the analysis of collected data. These functions and services are developable in an integrated ecosystem of products, where each of them performs a specific function and shares the information generated with the others.

Certainly, the scenario just described highlights the necessity of tools able to guide the consumer towards the choice of products and to clearly show how these objects can provide services to him/her.

2.5 The Actors of the IoT World

The constant evolution of ICT and the consequent fragmentation of the current market for Smart Objects have created considerable difficulties for companies in the development of products able to act into an integrated system that provides more services to the customer. The lack of common solutions has often led companies that work in the field of the Internet of Things (IoT) to develop and promote its products independently. Consequently, this market, in a short time has greatly increased the number of manufacturing companies and the number of devices available to the consumer, but which usually offer the same services. In addition, these market peculiarities mean that, currently, there is no single communication standard for Smart Objects field. Consequently, the customer has to choose between very similar devices, but that often have different operating logic, generate data in different formats and use different communication interfaces.

Faced with these problems, at global and European level, there are adopting collaborative approaches between the manufacturers of hardware, software and systems integrators. All this led to the establishment of consortiums in order to have more strength in a highly competitive market, by developing and promoting open communication protocols and logical common management. The major consortiums at European level that in recent years have developed integrated solutions for the Smart Home are Qivicon (DE) [62], Energy@Home (IT) [63], Homelab (IT) [64] and Agora (FR) [65]. Currently, at global level there are many interests in the new communication frameworks, which aim to make interoperable all connected devices. In this context, the major players are Allseen Alliance (AllJoyn) [66], Apple (Homekit) [67] and Google (Weave) [68], to which have joined and are joining more and more partners.

The scenario that is shaping up for the coming years will be attended by a wide range of interoperable products, but which would have the right integration systems to offer services optimized to the needs of the individual user. In this context, appropriate modeling and configuration systems will be required for companies to develop and simulate application scenarios, for professionals to be supported in the design and installation phase and for users to have a tool that helps them during the purchase.

Besides big companies and real giants of technology (Apple, Samsung, Sony, LG, etc.), in recent years, many small companies have appeared in this market, often created as start-ups and born from university research. These small companies often lack financial resources, skills and vision needed to look out in a global market. This condition reveals a further requirement and business opportunity that involves collaboration with external actors that provide the opportunity for manufacturers to give visibility to their products and reach new markets.

Chapter 3. A methodology to Design Smart Home Services

The evolution of communication technologies and the increasing intelligence of consumer electronics have stimulated the rapid growth of services and applications in smart home environments. Indeed, nowadays it is possible to take advantage of the large amount of information available every day about personal actions as well as events taking place at home or outside to provide comfort to home dwellers. The home is not more a place where a number of appliances carry out specific tasks, but becomes a distributed environment where many entities work together and exchange a huge quantity of data. Theoretically, the smart home has all the necessary information to execute automatic tasks and provide services to support the dwellings' life. However, there are mainly two open issues: the design complexity of the whole interoperable systems and the management of the huge amount of data by correlating information and services. On one hand, smart homes are usually designed by merging heterogeneous sub-systems and make them connected, without caring about real device interoperability or desired service functions and without following a high-end logic. In smart home different layers of operation governed by physical media, home networks and different communication protocols can enable sub-systems automation and management. However, the involved sub-systems are strongly heterogeneous and work with different specifications and protocols. Managing these different sub-system risks to be the main scope and, as a consequence, design is usually technology-driven and not at all user-centred. On the other hand, connectivity generates an impressive quantity of information, which, however, is difficult to control and risks to be unexploited. Data management complexity leads to bad information management and difficulties in capturing and effectively transmitting essential data [5]. It often causes inefficiencies and meaningless interpretations and can drastically reduce the potential benefits and discourage the application of ICT supporting tools within a safe place as own home. Furthermore, interoperability is hard to achieve due to the sub-system isolation and the lack of attention to joint execution of tasks from the system developers [69].

Consequently, designing interoperable and easy-to-use Smart Home System (SHS) is still an open task.

For this purpose, designing a smart home means not only to install several technologies developed separately and collect data from each of them, but also to provide user-centred services able to guarantee the desired functionalities through the selection and integration of the most appropriate sub-systems thanks to an interoperable architecture. In fact, a good smart home system should identify which data support a certain function and exploit the necessary information to create ad hoc service for the specific purpose and context of use. During the smart home design, it is essential to classify all the device information and monitored parameters according to the final application, and to properly select those technologies able to satisfy the users' need. In this context, the users' involvement is fundamental to achieve high quality and usable solutions (Nielsen, 1993). Indeed, it has been demonstrated that generally people's perception of system qualities mostly depends on how they interact with it: how easily they understand the way it works, what they feel about it, how much it serves their purposes and fits in the context of use [70]. The success of the proposed solution, in particular a service, is mainly due its ability to predict the user behaviors and meet his/her needs by providing what he/she exactly is wanting. In traditional product design, the involvement of end-users since the first design stages is essential to generate good and usable solutions [71]. A fortiori, it should be for complex systems like the smart home.

This work proposes a methodology to support the design of smart home environments and the system information management to realize device interoperability, which is necessary to provide services for the home dwellings. Indeed, such a method supports the selection of the smart devices on the basis of the context of use and the necessary services, and the intelligent management of the system information in order to make devices really interoperable and provide tailored facilities. The method allows cataloguing commonly spread home devices and all the generated information, and configuring the system functionalities according to the desired services. Furthermore, this methodology is adopted to support the design of additional services tailored for specific user profiles based on their effective needs.

The most relevant research contributions in smart home design concern the following aspects:

- Adoption of information-oriented perspective to analyze and classify the smart home information;
- Adoption of a user-centred approach by investigating the users' needs and service requirements and involving them in system design;
- Definition of a general information management model able to easily represent the significant information categories and their correlation with the device classes and functionalities;
- Exploitation of a general model to realize user-centred service by means of an interoperable device network, where heterogeneous devices cooperate by a shared information management models.

3.1 State of art of Smart Home Design

3.1.1 User-Centred Design in the Smart Home

The User-Centred Design (UCD) approach typically entails involving users in the design and testing of a system to collect their feedback, impressions and suggestions for design improvements. An UCD model as described by Buurman [72] advocates a design process that involves users in order to match the product to the user requirements and to increase its practical use. This process is suitable especially for those systems that are easier to understand and use and directly impact on the users' behaviors and quality of life. Brown and Mulley's research demonstrated that UCD shortens overall development time and costs by reducing the number of changes required in the later stages of the design process which results to better quality solutions (Brown and Mulley, 1997).

Many definitions of smart home have been proposed [73], but it is basically a house that has highly advanced automatic systems for lighting, temperature control, multi-media, security, window and door operations, and many other functions. A smart home appears "intelligent" because its computer systems can monitor so many aspects of daily living. For instance, the refrigerator may be able to inventory its contents, suggest menus, recommend healthy alternatives, and order groceries. In this context, adopting an UCD approach is fundamental for the development of a smart home system, which has many interactive products (e.g. video recorders, hi-fis, washing machines, heating controllers) with intelligence embedded (e.g. sensors, controllers, actuators) and where the development of connected products and services has the great potential for even greater complexity and problems for the domestic user. It should also be remembered that in a domestic set-ting, users are often in a relaxed mode and do not want to spend long periods reading handbooks and trying to understand complex consumer products. Therefore, a UCD approach helps to apply principles of interface design to home systems to ensure that people with a wide range of characteristics and abilities can use them successfully [74].

For applying UCD, the first step is to identify the target users of the smart home as the user population that will affect the specifications of the equipment, interfaces, devices and related services. In this direction, a recent study explored the smart home experience and highlighted the main characteristics of smart home users. Indeed, a good design should allow the system to operate in a flexible and accommodating manner, without causing conflict amongst different users. Furthermore, device interoperability must be completely transparent to the final users. Usually, the smart home is designed according to the householders and family members, which are the most interested users. However, other user group could be considered according to the specific application: visitors, system installers and maintainers, or service providers. They diversely interact with smart home products and services, and different requirements. Some studies explored smart home design in the past years, but they usually focused on specific aspects of the design, in particular on the user interfaces. Some works investigated adopted a UCD approach to guide the development of assistive devices and interfaces [75] for specific diseases like dementia [76]. Several studies focused on special user classes like elderly and disabled [77]. A recent example of UCD tools application concerned the development of consumer health technologies [78].

Generally, UCD principles are adopted to design single items or system interfaces, not to design the entire smart home sys-tem. However, understanding the users' needs and their conceptual model towards a specific context is a precursor to developing a system with appropriate requirements, usefulness, information quality and interface quality; all of which are paramount to the success of SHS.

3.1.2 Smart Home Interoperability

From a technological point of view, a smart home is defined as a special home where all the sub-systems are interconnected and acquire and apply the knowledge about the home dwellers to achieve comfort and efficiency (i.e. to save energy, to reduce operating costs and to improve safety, comfort and multimedia services) [79]. In this context, sub-system interconnections are guaranteed by the rapid growth of residential gateways that allows intelligent solutions managing all the devices connected to the home area network (HAN) and integrating different items [80]. For a SHS, interoperability means the ability of systems, applications and services to work together reliably, to exchange information and to use the information and resources exchanged. The creation of an interoperable system able to mutually control the devices and properly manage all the data of each device class requires the physical device connection to the HAN and the communication infrastructure to deliver all the collected data and make them available to other systems (e.g. for data analysis, for user monitoring, for remote control).

A considerable amount of new solutions for the smart home automation has been recently developed. They mainly differ from the adopted communication protocols and architectures. Different layers of operation governed by standards and middleware equipped with different communication protocols enables automation and management of the home sub-systems. The physical device connection can be implemented in various ways as each device has different capabilities in terms of distance, speed and volume data transfer: they can be based on power lines, phone lines or other wired connections, and wireless communication. Power line technology consists of the existing house wiring that supplies all the electrical devices and exploits the principle of the Power Line Communication (PLC) technology. Since every home already has it, the power line is convenient and does not require any additional wiring [11]. Communication standards are X10, Konnex (www.knx.org), Lon Works (www.echelon.com) and HomePlug (www.homeplug.org).

Phone line and other wiring include all the other wirings of the smart home, such as twisted pair, coaxial cable, fiber optic and others. They allow managing wide bandwidth data, as required by the entertainment system, the computer, etc. Some wired communication standards are Ethernet, USB (www.usb.com), HomePNA (www.homepna.com) or CAT5 that are commonly used for audio, video and data communication in smart home environment. Wireless technologies use electromagnetic waves to connect the devices and send/receive information. It is practical because it allows connecting numerous devices in an easy way and al-so including devices not connectable by a physical cable. Well-known wireless communication standards are Zigbee (www.zigbee.org), Wi-Fi (www.wi-fi.com), Bluetooth (www.bluetooth.com).

There are also some proprietary systems designed for Home Automation purposes: examples are SCS by Bticino and Legrand (www.legrand.com, www.bticino.it), Vimar By-Me (www.vimar.it), and C-BUS of Schneider Electric (www.schneider-electric.com). As a consequence, a unique and shared smart home standard does not exist yet and tools for the high-level coordination of the smart house, independently from the existing architecture, are still missing. It entails managing the sub-system heterogeneity and diversity, which is in charge of residential gateways.

From the interoperability perspective, three levels of integration can be recognized inside a generic smart home: basic connectivity level, network interoperability and syntactic interoperability. The first level provides a common standard for data exchange to establish a communication link. Basic connectivity tiers are represented by Ethernet, Wi-Fi, and PPP. The network interoperability enables message exchange between the system entities across a variety of networks inside the SHS. Examples of common standard are Transport Control Protocols (TCP), File Transfer Protocols (FTP), Internet Protocols (IP). The final tier, syntactic interoperability concerns the agreement of rules that manage the structure on encoding information exchanges and allows two or more components to work together. The availability of common rules is fundamental to make devices produced by different manufacturers interoperable. In order to so this, specific message content structures should be provided, such as Simple Object Access Protocol (SOAP) (www.w3.org/TR/soap) or Representational State Transfer (REST) [81]. Consequently, smart home system design is particularly challenging due to the huge amount of data to be managed and the degree of complexity of the devices' integration in the home area network.

3.1.3 Smart Home Service System

In order to design a system framework able to provide and control services for the smart home users, the last level of interoperability called syntactic is fundamental. Indeed, the introduction of the smart appliances within a home network re-quires understanding which functions a certain device is able to perform when connected to the network, what information can be sent and which commands received, according to a common syntactic language. In this context, the CECED (European Committee of Domestic Equipment Manufacturers) faced the device interoperability issues with the CHAIN (Ceced Home Appliances Interoperating Network) platform (www.ceced.org). It defines the protocol for connecting appliances in a single multi-brand system designed for control and automation of key services in a home: e.g., remote control of appliance operation, energy or load management, remote diagnostics and automatic maintenance support to appliances, downloading and updating of data, programs, and services from the Web. It established a preliminary application profile for home connected and also promoted the standard CENELEC (European Committee for Electrotechnical Standardization) (EN 50523-1 e EN 50523-2). However, it is centered on electronic devices and communication standard among devices, while the users' perspective is not considered.

About SHS research, the design activity is fragmented and focused on single smart technologies neglecting the system overall vision [69]. When services are analyzed, they are studied separately without caring about real service integration and common system platform and data management. Actually, the majority of projects all around the world are focusing on the energy issue [82]. The most significant are: Smart Energy 2.0 (www.zigbee.org/SmartEnergy), Energy@home (www.energy-home.it), EEBus (www.eebus.org), E-Energy (www.e-energy.de), ADDRESS (www.addressfp7.org), REserviceS (www.reservices-project.eu). They all focus on network energy management through data exchange with smart grids and they introduce standard rules for the information exchange between the users and the utilities. Furthermore, such systems are usually finalized to provide a specific benefit or service such as monitoring, analyzing and estimating the energy consumption [83]. However, they do not define a standard data management tool for high-level purposes.

About services, on one hand numerous research studies have been conducted about house occupant characterization and behavior modelling, mining and simulation of typical consumption profiles, rule-based management systems for reducing consumptions and feedback interfaces able to persuade users to modify their habits [84]. Furthermore, some projects focused on data elaboration and data mining to realize services for different purposes, such as supporting manufacturing enterprises cooperation like MSEE - Manufacturing Service Ecosystem (www.msee-ip.eu), creating person-centric immersive environments like SM4All - Smart Homes for All (www.sm4all-project.eu), or proving support to elderly people disabilities like HOPE - Smart Home for Elderly People (www.hope-project.eu). Although they are user-centred, they do not care about devices' interoperability and rule definition for information exchange between multiple partners. On the other hand, they tend to neglect other types of services that can be connected to the smart home exploiting the same technological infrastructure. Thus, there is a lack of an overall vision and a strategic roadmap for future developments. Recently TAHI (The Application Home Initiative) is working specifically on interoperability issues for the home (www.theapplicationhome.com), but the interactions between the home dwellings and the system companies (e.g. Energy utility, technical service providers, etc.) are not considered.

For this aim, a UCD approach is necessary since it supports the design of services able to bring benefits to the subjects involved and select the most appropriate system architecture where each sub-system is integrated with the others in order to achieve the customers' satisfaction. However, considering the state of art, the application of a structured UCD approach to smart home system is still limited and not oriented to services. Recently, several services related to devices remote control have been proposed, but there are some open issues regarding their implementation on the white goods [85]. Also appliances remote maintenance concept is studied to provide benefits for both users and companies, but it has been considered as a concept independently of any architecture and available tools capabilities [86].

A basic model for a smart home service system has to consider that each device has different requirements in terms of connections and communication protocols and a residential gateway is required. Such an object represents the link between each device connected to the HAN and is able to manage traffic information. It also serves as a bridge between the local network and the external one (internet) and allows connecting the HAN with other management systems [12]. The gateway allows the proposed tool to leaning on the existing architecture. Such a tool supports the identification of the most appropriate technologies to be installed in order to satisfy the user needs. The user (e.g. homeowner) can interact with the system directly by a Graphical User Interfaces (GUI) or indirectly via computer and/or smartphone. The latter works both locally and remotely. Finally, the system should support the user to monitor home conditions, control the devices and be informed about specific data (e.g. device consumptions), as well as the utilities and manufacturing companies to access data transmitted from the smart home, according to the privacy policy, and to provide specific services (e.g. remote technical assistance). The idea to design and create such an integrated system offers a new way for companies to carry out market analysis and service tailoring, which are still ignored in the majority of manufacturing contexts.

3.2 The Method for Smart Home service Design

The present research aims in supporting smart home system design for sub-systems cooperation and user-centred services. It proposed a high-level system design, which requires user-centred principles to achieve the user's needs satisfaction and adopts a knowledge-based approach to support the information management and the design of the technological system. A similar approach has been already adopted in complex system design, for instance to manage human interactions in extended enterprise [87] or to benchmark virtual reality tools for specific purposes [88], [89], however it represents a novelty in smart home system design.

The proposed method consists of 7 steps (Figure 4):

1. Investigation of the users' needs: the smart home users are firstly analyzed and described according to their demographic characteristics, technical skills, and human behaviors. Then, they are involved in focus groups and submitted to interview and questionnaires to highlight their needs in terms of product and service functionalities;
2. Specification of the related service requirements: the users' needs are translated into users' requirements by applying requirement elicitation techniques like brainstorming and serious games [90]. Such techniques are used to make the users act as players in a simulated environment, which is supposed to reflect realistic processes and reproduce a variety of service functionalities in order to evaluate their relevance for the specific context of use;
3. Smart home information analysis: it concerns the classification of the devices into a set of homogenous classes and the analysis of all the information generated and exchanged by the considered devices. The devices' classification considers the commonest smart home devices grouped in classes according to the typology, the set of treated data, the home interaction modalities and the user interaction ones. Five main classes have been identified and investigated (Meter, Consumer Electronics, Household Appliances, Environmental Control, and DHW and HVAC). Subsequently, the information flow generated by the devices involved is organized into a set of significant categories according to their main function.
4. Identification of a general information management model for the smart home: it is based on the correlation between the information categories and the device classes and the mapping of their specific functioning by a correlation matrix, which represents the core of the general information model.
5. Definition of a set of intelligent rules and tasks to perform the service functionalities: this step describes the actions that the single device or the group of devices have to perform to generate the desired service. In particular, it is described in detail in a temporal sequence of tasks with the aim to have a complete map of actions in a high point of view for the designer.
6. Design of the tailored services and the system rules: all the interactions inside the smart home can be modelled by considering all the possible information flow in and

out the involved devices. Practically, there is a merge of the correlation matrix with the set of intelligent rules. Such models are defined by Business Use Case (BUC) diagrams [91] and UML diagrams (www.rational.com): BUC allows easily representing how the user interact with the system functions, items and services, while UML diagrams detail the model according to different levels (State diagram, Activity diagrams, Use Case diagrams). In this way, system actions are defined according to GET purpose (read and obtain information) and EXECUTE purpose (react and execute some commands);

7. Design of the smart home system: after having defined the general information model, services to be provided and devices to be involved, the system is designed by benchmarking the necessary sub-systems and technologies, and defining the general architecture and the partners' ecosystem able to realize the desired functionalities as well as an effective information management and device interoperability. The technological benchmarking exploits Quality Functional Deployment (QFD) techniques [92] to identify the most appropriate tools to realize the basic system connectivity and the network interoperability of the smart home.

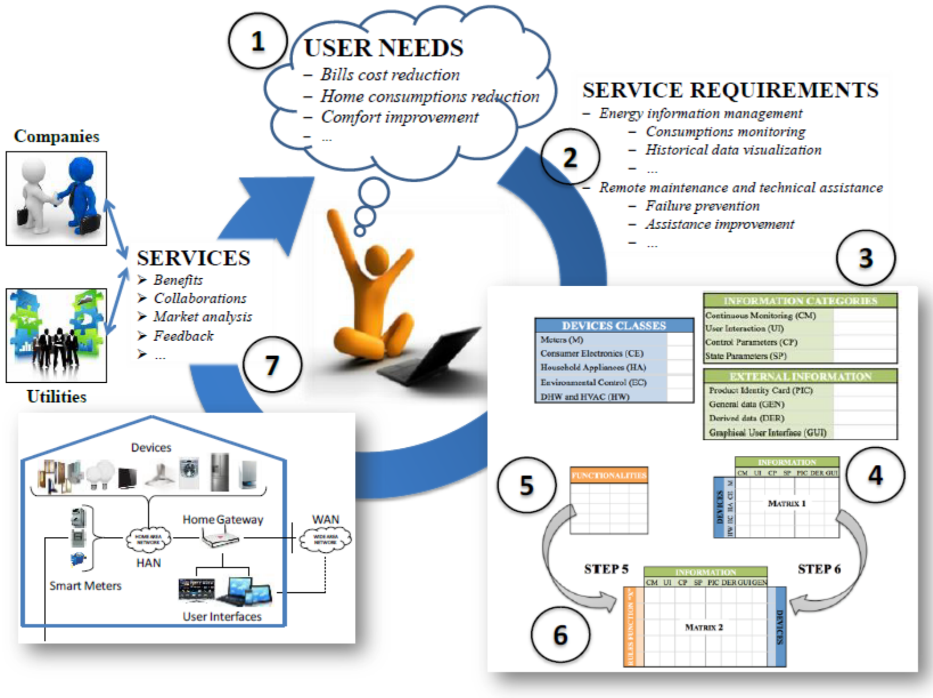


Figure 4: User-centred design method for the smart home.

3.2.1 STEP 1: Investigation of the users' needs

The design of the high-level system requires a holistic and user-centred approach and focuses on the service user's needs satisfaction to support the design of an intelligence-based information management tools. For this reason, the first step concerns the analysis of the user's needs in relation with a specific context of use (e.g. elderly people living alone, young married couple with an active lifestyle, a family with two little babies, etc.). Such an analysis is carried out by involving sample users and investigating their habits and behaviors by different techniques such as interviews, questionnaires, and brainstorming sessions. At the end, a list of users' needs for the implementation of useful services supporting people in the specific context of use are defined. The most exploited investigation techniques were interviews and questionnaires, in particular, the questionnaires have allowed gathering a significant amount of useful information, since they can be administered simultaneously to many people. So, the questionnaire is useful in the first phase, where the it is needed a survey from a high point of view; then, in a second phase, it can be exploited the potentialities of the interview that requires more time, but that permits to mine more detailed information.

The questionnaire's construction phase is a particularly important moment for the planning of the evaluation survey. In fact, this instrument shall be designed in order to induce respondents to disclose their real preferences for the good in question. The main design aspects are the following: the structure of the questionnaire, the choice of the size of the sample of users, the choice of the various techniques for answers and questions, the way in which the questionnaire is administered and the results analysis.

The survey technique through a questionnaire was chosen, because they are already used in many research fields such as sociology, psychology, marketing, ensuring over the years a high degree of reliability. In fact, the questionnaire permits to transmit the information in a clear and simple way, collecting information on the qualitative and quantitative variables under investigation. For this questionnaire, 5 main steps were identified:

- First Phase: design of the questionnaire's conceptual model;
- Second phase: construction of the questionnaire;
- Third phase: administration of the questionnaire in closed user groups;
- Fourth phase: administration of the questionnaire to the selected users classes;
- Fifth phase: Analysis and verification of the collected data.

In the first phase, the evaluation object has to be detected through the establishment of a list with all the required information, by defining some operational concepts as key points of the survey. For example, in our work they were:

- Knowledge, attitude and use of technology;
- Analysis of the requirements: survey on the spread of technology and the priority in the purchase of a smart product;
- Supply-Demand analysis and evaluation hypothetical market;
- Desired services.

The next step is the translation of the needed information in a series of understandable questions for the interviewee. Questions should be set in order to motivate the participants, avoiding possible misunderstandings. In the questionnaire drafting, there were adopted some general criteria regarding the structure: Introductory section, Evaluative section and Final section. Other criteria define some basic rules:

- It is necessary to adopt a logical sequence of topics: the questionnaire has to be set up to facilitate the passage of the respondent from one topic to another;
- It 'good to provide sets of questions relating to the same subject in succession avoiding to return on previously treated arguments, while is being addressed other issues;
- It is necessary to prevent that a question affects the answer of the following questions;
- The simplest questions should be placed at the beginning of the questionnaire;
- The most delicate questions should be placed at the end of the questionnaire.

3.2.2 STEP 2: Specification of the related service requirements

The second step consists in the identification of the smart home functionalities able to satisfy the identified user's needs. Some general aspects like energy, comfort, security, safety and product care are considered as well as standard functions related to the system management and possible preset scenarios. The search of such functionalities is done by analysis the state of art of IoT solution and the new product on the market. This analysis involves both academic research and commercial products with the aim to include a global perspective of the services eligible in the Smart Home environment. The final scope is to create a knowledge base of functionalities that can be easily linked with the users' needs and skills. In this ways, it is possible to provide "the right service to the right user". Another important aim is the creation of clear rules that have to be the basis for a tool that, in the future, would be able to automatically link the questionnaire results (STEP 1) with the required functionality (STEP 2). These functionalities have to be updated constantly, as the Smart Home solutions are evolving year per year. Table 1 shows examples of functionalities for each category investigated in the present research.

Energy	Devices scheduling Home historical consumptions analysis
Comfort	Heating automatic regulation Home environmental conditions monitoring

Security	Leaks detection Intrusion detection
User safety	Mobility monitoring Fall detection
Product care	Device remote maintenance Product use analysis
System management	Scenario creation Device installation
Scenarios	"Out of home" "Holiday"

Table 1: Smart home functionalities categories.

3.2.3 STEP 3: Smart home information analysis

Step 3 aims to provide an overall vision of the smart home in order to create a general information management model. For this aim, smart home devices are identified and displaced in five homogenous classes (Table 2) according to typology, treated data and home interaction modalities. Renewable energy systems are included in the meters category as the information provided by the dedicated meters, neglecting the specific system parameters. It refers to the device classification cataloguing. Hereafter, the considered classes of devices are described:

- **Household Appliances (HA)**: this class includes the major household appliances grouped as cooling (refrigerator and freezer), cooking (oven, hob, hood) and laundry (washer, dryer, dishwasher). Within this category, there are some of the most complex devices characterizing a modern house. To be interoperable, they require a microcontroller [82], which manages the processes during the automatic operation mode as well as the remote control mode. They need a communication node installed on board or located outside to be connected to a home network, for instance the "Ultra-Low cost Power-line" (ULP) [93]. This solution, developed by Indesit Company Spa (www.indesitcompany.com), is cheap and also contains the Dynamic Demand Control (DDC) technology [94];
- **Meters (M)**: this class includes electricity, gas and water meter, whose data are communicated to the homeowner through the home network and/or to the utilities through the smart grid. Control and safety systems (e.g. electrical safety, gas leaks, water leaks) are included in this category. Thanks to the control parameters, it is

possible to detect gas or water leak in real time and, consequently, shut off the corresponding meter remotely. Obviously, possible short circuit and electrical overload are monitored;

- **Consumer Electronics (CE)**: this class includes entertainment systems (e.g. TV, game console, audio equipment and players) and small household appliances (e.g. coffee makers, electronic cutters or graters, toasters). They typically have low and constant energy consumption and can be easily switched off/on by a remote control without any preventative measures. For this category the power consumption can be simply monitored as well as its usage (e.g. when and how long they are used; state of devices to allow a remote control);
- **Environmental control (EC)**: this class comprehends very common components such as lighting, doors, windows, window curtains and shutters, and security system items. All of them can be control by similar functions, as turn on/off, intensity regulation, opening and/or closing control, opening regulation. This category also includes the alarm system that considers the intrusion detection sensors for doors and windows. Information is typically used for remote control and interaction analysis. In particular, thanks to motion sensors for automatic light switching, it also possible to localize users and detect an abnormal behaviors by recording the user movements. It may be useful for AAL scopes to improve safety and human health;
- **DHW and HVAC (HW)**: this class includes Domestic Hot Water devices (DHW), Heating, Ventilation and Air Conditioning devices (HVAC), and all the devices and sensors related to their functioning, even when located in different areas or on other devices (e.g. sensors of indoor/outdoor temperature, humidity sensors, etc.).

Device class	Description
Household Appliances (HA)	It includes different classes of devices such as refrigerator and freezer, oven, hob, hood, washer, dryer, and dishwasher, which are enhanced by a microcontroller to manage automatic operation mode and a communication node to make them connected (e.g. Ultra-Low cost Power-line (ULP))
Meters (M)	It includes electricity, gas and water meters, whose data are communicated through the home network and/or the smart grid in real time and can be remotely controlled. It can include also control and

	safety systems (e.g. electrical safety, gas leaks, water leaks)
Environmental Control (EC)	It comprehends common classes of components such as lighting, doors, windows, alarm system and sensors, window curtains and shutters, which can be grouped because they can be controlled by similar functions (e.g. turn on/off, intensity regulation, opening/closing control)
DHW and HVAC (HW)	It includes Domestic Hot Water devices (DHW), Heating, Ventilation and Air Conditioning devices (HVAC), and all the devices and sensors related to their functioning (e.g. sensors of indoor/outdoor temperature, humidity sensors)
Consumer Electronics (CE)	It includes a wide range of devices from entertainment (e.g. TV, game console, audio equipment and players) and small household appliances (e.g. coffee makers, electronic cutters or graters, toasters), which are characterized by constant and low energy consumption, and off/on switching.

Table 2: Smart home device classification.

Data model classification considers four main categories (Table 3): they allow eliciting the relations between the information generated by the smart home devices and their functions. All relevant information has been classified and exploitation rules investigated. In this context, several classification criteria are possible, so the proposed cataloguing represents a good way according to the research goals but it cannot be considered exclusive. Four categories have been defined as follows.

- **Continuous Monitoring (CM)**: this category includes all the information continuously monitored when the appliances are turned on. Some data are sent to the utilities automatically and are not visible to the user, whereas other data may always be visualized by user interfaces. They mainly consist of resources' consumption data (e.g. energy, water, etc.) and are used for services addressing both the customers and the utilities;
- **User Interaction (UI)**: it refers to all the information regarding the user-product interaction. Generally, data are aggregated and used for statistics analysis with the final aim to define significant user profiles or frequently events (e.g. wrong actions, selected options, etc.). Data are usually sent when required and they are used mainly for marketing analysis and customer care investigations by the producer companies;
- **Control Parameters (CP)**: this category comprises all the data collected to supervise the device or user security, so they mainly refer to the functional device parameters.

They are analyzed and compare with the target parameters to predict a hypothetical problem or to detect dangerous conditions. Generally, they are forwarded to companies or service providers when a specific threshold is exceed;

- **State Parameters (SP)**: it refers to information regarding the device state or a particular stored scenario, which are both read when the remote control has to be executed. Such data are used by the system for remote control and de-vice state control.

The model also considers four extra categories of data (Table 4) that are not directly generated by the devices but provided by external entities (e.g., utilities, manufacturing companies), elaborated by the system or sent by the users by means the Graphical User Interface (GUI).

- **Product Identity Card (PIC):** It refers to device reference information provided by the manufacturing company (e.g. datasheets, standard consumptions, etc.). They are fundamental for the products care and do not depend on the smart home.
- **General data (GEN):** It refers to data generated by external entities (e.g. building typology, occupants' characteristics, economic indicators, fees of utilities, climatic conditions) that contribute to define the analyzed scenario.
- **Derived data (DER):** It refers to data derived from post-processing elaboration and statistics analysis (e.g. average time of use, average expenditure over the time, use frequency), which can be used for realizing specific service functionalities. They are considered external as they are usually produced by partners' elaborations and software systems.
- **Graphical User Interface (GUI):** It refers to data generated by the users as remote settings of the proposed smart home functions (e.g. on/off, close/open, show details, set parameters, etc.).

Information category	Description
Continuous Monitoring (CM)	It includes consumption information that is continuously monitored when the devices are turned on (e.g. energy, water), which can be used to provide a feedback to users and VE companies
User Interaction (UI)	It refers to all the information regarding the user-product interaction and characterizing the users' behaviors (e.g. selected options, duration of use, time of use, frequency). Such data are used for statistical analysis and user behaviors investigation
Control Parameters (CP)	It considers the functional parameters of the home devices, which are continuously analyzed and compared with target parameters. Such data are used to predict problems, detect conditions, and supervise device functionality and user security
State Parameters (SP)	It refers to all information regarding the status of home devices, which is used to monitor a particular scenario or to carry out device remote control

Table 3: Smart home information categories.

Information category	Description
Product Identity Card (PIC)	It refers to device reference information provided by the manufacturing company (e.g. datasheets, standard consumptions, etc.). They are fundamental for the products care and do not depend on the smart home.
General data (GEN)	It refers to data generated by external entities (e.g. building typology, occupants' characteristics, economic indicators, fees of utilities, climatic conditions) that contribute to define the analyzed scenario.
Derived data (DER)	It refers to data derived from post-processing elaboration and statistics analysis (e.g. average time of use, average expenditure over the time, use frequency), which can be used for realizing specific service functionalities. They are considered external as they are usually produced by partners' elaborations and software systems.
Graphical User Interface (GUI)	It refers to data generated by the users as remote settings of the proposed smart home functions (e.g. on/off, close/open, show details, set parameters, etc.).

Table 4: Smart home external information categories.

3.2.4 STEP 4: Identification of a general information management model

This step concerns the identification of a general information management model for the smart home, which is fundamental to map devices and functions available in the smart environment. Such a model arises from two main considerations:

- The number and variety of sensors and devices usually installed at home, which require managing a large amount of information and understanding the explicit and tacit relationships with other devices;
- The complexity of the services, which implies identifying logical rules able to support the design and running of the user-oriented services. In order to do that, the model must properly select, interpret and process the necessary information. Only in this way, the complexity of the system and the costs can be reduced and the benefits can be higher than the expense.

The information model is based on the correlation between the device classes and the information categories: in particular, for each class, information managed is defined according to its function and role. The described information categories are matched with device classes and a correlation matrix is populated with available data (Table 5). For household appliances, since the class is wide and varied, we limit the application scenario to probably the most common devices (washing machine, fridge-freezer, dishwasher, etc.) and we classify the information provided by it. However, some data may be used also for less used white goods. Also the DHW and HVAC class includes numerous devices and systems with different technologies, so the considered data do not includes special function of a particular producer.

Such a correlation directly support system and service design: when a certain user need is defined and a specific requirement elicited (e.g. automatic control of the curtains to maintain a fix degree of brightness inside the room), the matrix allows defining which parameters have to be controlled and by which device. At this point, an information model is required to exactly define which commands are involved and which rules have to be adopted. Figure 5 shows the smart home information model in another perspective. Such a methodology support the creation of a virtual smart home environment where devices' data are managed and they interoperate in a single ecosystem. Furthermore, it brings to the creation of a collaborative system for supporting dynamic virtual enterprise, similarly to recent experiences in product collaborative design [88].

The proposed model can be adopted to provide services for customers, manufacturing companies and utilities. The washing machine represents a good example. The customer can monitor the machine consumptions to have feedback on his/her habits and/or product functioning or to verify if an anomaly occurs. At the same time, companies can analyses how users interact with the product and which are their habits (e.g., washing programs or functions are selected more frequently). Thus, it is possible to know if a specific feature has less successful than expected. On the other hand, the users' favorite cycles analysis can support the definition of a new function. In fact, the products are generally optimized according to the standards and the customer habits, but real data can confirm or rebut such preliminary statements. At the same time, technical assistance and customer service departments can analyses cycle execution and verify if the performances are the desired ones by comparing actual data (i.e., control parameters as cycle time and consumption, vibration and noise level, etc.) with threshold parameters. Finally, utilities can read consumption data for each user or user profiles and can optimize the fee or the agreement, also by defining new conditions advantageous for the customers as well as for themselves. Similar information may be considered for the other products of the laundry class. About other household appliances, different data can be monitored but the approach remains the same. For example for cooking, data will be: cycle, programs and temperature of cooking and the selection of specific functions for the oven; regulation of gas or power intensity for the hob; presence of the cooking smokes; filtering system efficiency; fan speed for the hood, etc. Also energy and security parameters are considered, whereas there are not the state parameters because, for this class, the remote control is not feasible in safety. For fridge and freezer, the characteristic information will be: temperature of the compartments, parameters of the compressor, the evaporator and the condenser and the opening doors to observe also the behavior of an aged person. Information regarding other devices such as security, lighting and doors/windows can be useful to increase the people safety and comfort. If a threat is detected, a notification alerts the user through a computer, a smart phone or an audible alarm. The information is also exploited for Ambient Assisted Living (AAL). An example may be represented by the information of the temperature in a home where an elderly person living alone, if the temperature in the home passes a threshold value, a family member or the hospital is immediately alerted. Another example can be done about the energy management of the house. The smart system can push the user towards the best action to reduce consumptions by observing the average temperature of the rooms recorded during the year and how the user has interacted with the devices. This service could be very useful considering that the majority of the energy home consumption is due to space heating/cooling [95].

	Correlation Matrix	**INFORMATION CATEGORIES**			
		Continuous Monitoring (CM)	**User Interaction (UI)**	**Control Parameters (CP)**	**State Parameters (SP)**
DEVICE CLASSES	**Meters (M)**	Gas consumption Power consumption Water consumption	Shutting on/off gas Shutting on/off water Shutting on/off power	Electrical overload Short circuit Gas flow rate Gas pressure Water flow rate Water pressure	Electric meter ON/OFF Gas meter ON/OFF Water meter ON/OFF
	Consumer Electronics (CE)	Power consumption	Delay start Turning off time Turning on time	Volume	ON/OFF Standby
	Household Appliances (HA) e.g. washing machine	Grid frequency Power consumption Water consumption	Delay start Eco wash on Easy iron on Extra rinse on Intensive wash on Pre-wash on Rinse hold on Set program Set spin speed Set temperature Set time to finish Turning on/off time Weight estimation	Cycle time Cycle phases time Detergent level Door lock Drum lock Drum speed Filter occluded Motor efficiency Motor speed Noise level Vibration level Phases consumption Resistance Water level Water conductivity Water pressure Water temperature	ON/OFF Open/Close door Cycle phase running Detergent presence Load presence
	Environmental Control (EC)	Electricity consumption Ambient light level Video surveillance	Interaction time User in the room Scheduled switch on/off Set light Brightness Interaction time Scheduled opening Scheduled closing Activation time Deactivation time	Burnt out bulb Intrusion detected	Light ON/OFF Light Brightness Open Close Opening rate Alarm system ON/OFF
	DHW and HVAC (HW)	Room temperature Outdoor temperature Room humidity Power consumption Gas consumption Air flow rates Water temperature for space heating Water temperature (DHW)	Scheduled power on/off Set point temperature Set fun speed Interaction time Set water temperature (for space heating or DHW)	Dirty air Quality of the fume Chimney temperature Chimney draft High/low room humidity High/low room temperature Temperature between rooms Low air flow rates High/low pressures in the pipes Supply/return water temperature in pipes	System ON/OFF Standby

Table 5: Correlation matrix between system information and device classes.

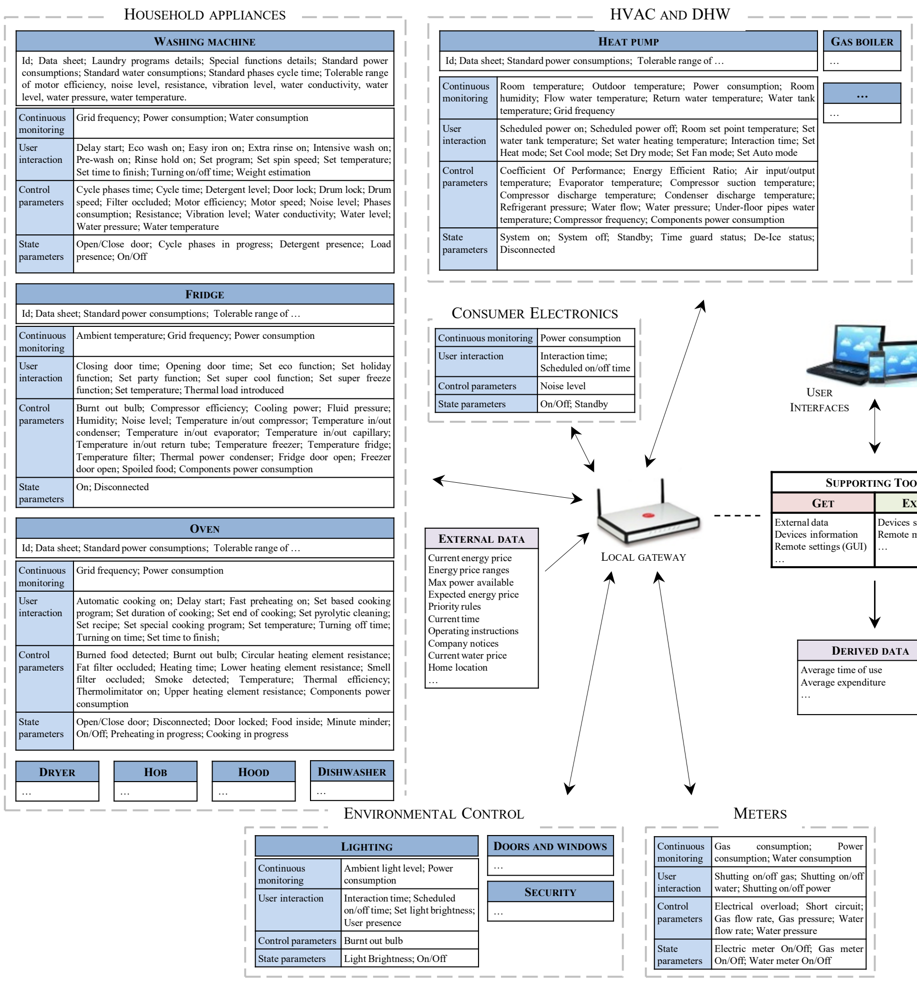


Figure 5: The smart home information management model.

3.2.5 STEP 5: Definition of a set of intelligent rules and tasks to perform the service functionalities

This step involves the definition of a list of rules that have to be performed to provide a service. In this step, the actions that the single device or the group of devices have to perform are designed with the aim to generate the desired service. In particular, the actions are described in detail in a temporal sequence of tasks, because a complete map of actions in a high point of view for the designer is requested. In this part of the design process, the rules are general, because they have to be the same for devices of each producer and particular functions of particular product are not supported. Once the general rules are defined, it can be designed the particular set of rules for the single use case (it can be a particular user's necessities or a special function installed by an individual producer).

An example is shown in the figure below (Figure 6) and it represents the basic rules for the automatic scheduling of a household appliance during a single day:

DEVICE SCHEDULING	
RULES	If the parameters are conform with the start condition, Then do next step. Else send the message to user.
	Calculate the latest time for the cycle start according to the user setting and considering a tolerance.
	Schedule the device start to minimize the energy expenditure for the user considering the other devices scheduling and according to the priority rules and user needs.
	Turning on the device at the scheduled time.

Figure 6: Example of the general rules to schedule a smart device.

The figure 6 includes a sequence of rules for the device scheduling. For a better understanding, the next figure (Figure 7) associates the rules for the smart scheduling services with the washing machine device in a practical example.

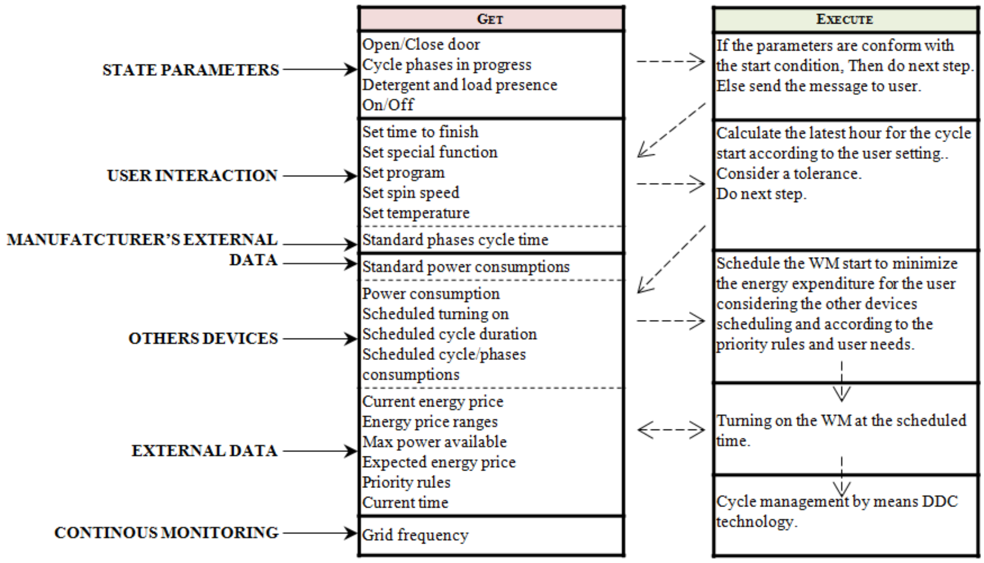


Figure 7: Rationale to schedule the washing machine start.

In this example, it is clear that this step defines when an information is requested (temporal parameter), from which device and what action has to be performed. All the data at the logic level are defined, but it is still necessary to contextualize the scheme in a real environment.

3.2.6 STEP 6: Design of the tailored services and the system rules

This step is the core of the methodology as it allows understanding what devices can be used to realize a certain service function, which data have to be managed and how each specific device will collect data from the other devices and will make data available for the interoperable system.

The service is realized by applying the selected functions of the general information management model to the specific appliance chosen by the user. All data are listed in a scheme that represent the logics behind the service; they are classified considering also the external information categories. Only data and events related to the selected function are kept for the case study, while other information is not shown. The rules (STEP 5) to perform the service are listed on the left, whereas the relations between devices and rules are specified on the right. It is worth to notice that this step shows how the proposed model easily defines the rules to manage a set of tasks to carry out the service.

These rules are specific are valid for all devices of a same category, because the goal is to create a standardized model for a certain device, but at the same time, they are automatically customizable for the particular devices selected by the user. It means that a service can be simulated with different typologies of devices and boundary conditions. For example, in the service of “device scheduling”, it can be selected a single washing machine or all the household appliances at home, but the general rules will be the same (for devices in a same category). Obviously, each user can obtain different benefits from this service in relation to his/her habits. At the end of the analysis, a user’s benefits evaluation can allow comparing different scenarios of use depending on the specific users’ habits and behaviors and assessing the advantages of such an approach. The following scheme shows the STEP 6 applied to the “scheduling service” for a washing machine (Figure 8):

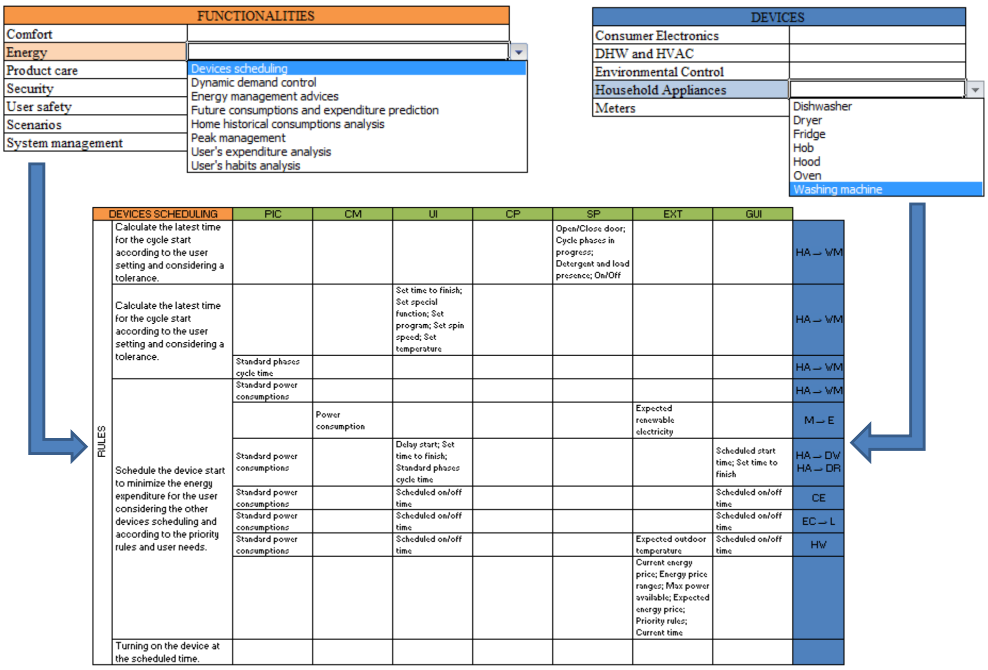


Figure 8: Simulation of the information management model for the “Washing Machine scheduling service”.

3.2.7 STEP 7: Design of the smart home system

The STEP 7 of the service design process refers to the definition of sub-systems and technologies that are necessary to promote the service. The Smart Home is not only a technological place, but also a “real” ecosystem, so in a high point of view it is possible to map the general architecture and the partners’ able to realize the desired functionalities as well as an effective information management and device interoperability. This step aims to guide the user through the configuration process of the home environment in a simple and intuitive way; practically, it allows the physical configuration of the Smart Home. The information is obtained from the same database used for the above steps, but with step 7, the service design process is completed with all the physical components for creating a true home automation system. This tool allows performing an advanced search for home automation devices necessary for the installation of the system, filtered by the compatibility constraints (e.g. the communication protocols). This last step can be performed manually, but it requires a dedicated informatics application to became usable by a non-expert user. To do this, one of the future developments will be the creation a configuration tool of the smart home. The user will have the ability to configure their own home through a graphical design tool made available on a dedicated platform. The tool will also allow characterizing the home in order to assess any states of incompatibility in the arrangement of objects; in this way, the user will have useful information in order to establish the degree of coverage of the devices with wireless connectivity. Once the configuration process is completed, this application will be able to provide different types of output:

- Visual output, it includes the plan of the home made by the addition of smart devices. At the end of the configuration process, it will be possible to see how this system works configured. Through a simple interface block, it permits to create scenarios that show the behavior of the devices based on the type of event that happens. This virtualization component is critical to fully understand the performance of the configured system and to make the user aware of the product (system) that could buy.

- Functional output, it provides information about the connections between the various components and their installation, it is useful to prepare guidelines for the operator who will be assigned to the installation.
- BOM of the home automation system, which is the shopping list needed to implement the system designed with the defined Smart Home configurator.
- Analysis of benefits for the user, in terms of comfort, cost savings, energy, and security of the house and of the person. In this way, the user can estimate the real benefits quickly and intuitively.
- Projects comparison, after the configuration of two or more projects the web platform will be able to make comparisons across the significant indices in order to compare in an immediate way the solution and define the most convenient for the user.

The figure below (Figure 9) shows an example of a configurator realized by the Design Tools and Methods group of the Department of Industrial Engineering and Mathematical Sciences of the Università Politecnica delle Marche (UNIVPM). It would be a good starting point to realize the tool just described as it contains part of the desired functionalities also if currently it does not consider smart devices.

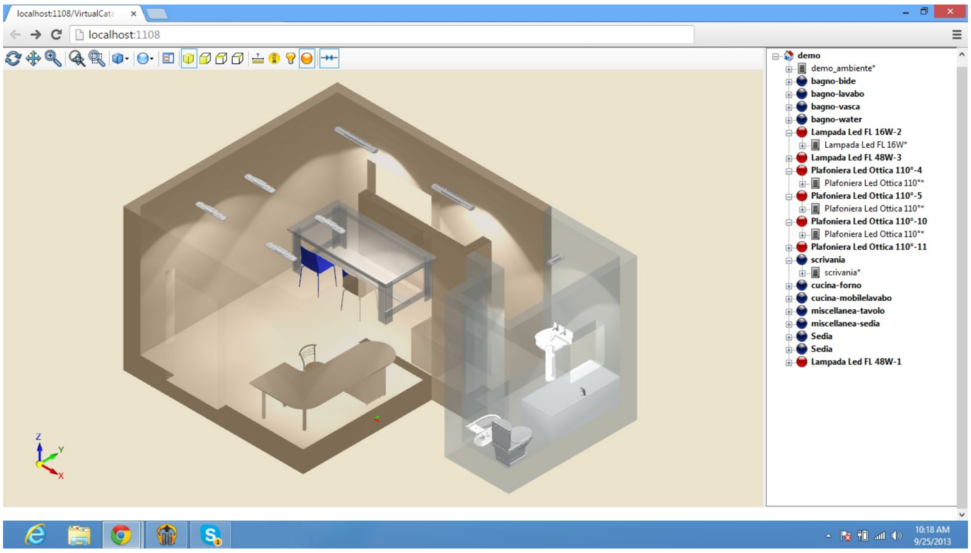


Figure 9: Example of the configurator already realized in the UNIVPM.

3.3 Case Studies

The washing machine scheduling service

This section presents how the proposed approach can be implemented to design the "Washing Machine scheduling service" as a practical case and to estimate the effective benefits on two different scenarios of use. The methodology is used to model the "Device scheduling" function and to apply that to washing machines in order to create a dedicated service to be simulated on practical use scenarios. The first part of the case study shows how the user can easily select the desired service function as well as the devices involved, and how the system visualizes the data model and identifies the rules to perform the selected functions in practice. In the second part the proposed rules are validated on two application scenarios by estimating the potential benefits of the optimized energy-control service in terms of energy saving, costs reduction and user satisfaction.

The "Washing Machine scheduling service" is realized by applying the device scheduling functions of the general information management model to the specific appliance i.e. washing machine.

In the model, the first step consists in choosing the field of interest and selecting the desired function, in this case "Device scheduling" of the "Energy" category. The second step concerns the selection of devices involved in the selected function. There are five device classes related to the energy category and each device class contains a group of devices. In this case, the Washing Machine is selected. Next steps is the creation of Matrix 2 (Figure 8), which introduces a set of intelligent rules for energy management services that are correlated with data, devices, and events. All data concerning the washing machine operation are listed and classified considering also the external information categories. Only data and events related to the selected function are kept for the case study, while other information is not shown. Furthermore, data from other devices strictly necessary to perform the function are treated as well as already present about the machine. The rules to perform the "Device scheduling" are listed on the left, whereas the relations between devices and rules are specified on the right. It is worth to notice that this step shows how the proposed model easily defines the rules to manage a set of tasks to carry out the intelligent scheduling.

These rules are specific for the device under investigation but they are valid for all washing machines, homes and users, because the goal was to create a standardized model for a certain device. Obviously, each user can obtain different benefits from this service in relation to his/her habits. The user's benefits evaluation allows comparing different scenarios of use depending on the specific users' habits and behaviors and assessing the advantages of such an approach.

Remote maintenance and technical assistance service

For this service the "Control parameters" information category is considered to evolve the concept of maintenance by directly interacting with devices at work. In fact, corrective maintenance can be replaced by a more accurate preventive and predictive approach. For instance, companies and users can obtain mutual benefits: companies can monitor specified parameters to prevent a failure and observe the appliance behavior to improve the product itself; contemporarily customers can have a continuous assistance, a reduction of product failure and downtime and finally a lower global consumption. Furthermore, users may receive real time indications if their product care is not appropriate. Contrariwise, currently users may not observe a malfunctioning for a long time while the product consumptions increase. An example of tool rationale related to the washing machine remote maintenance is shown in Figure 10. A similar overview could be provided also for the other services.

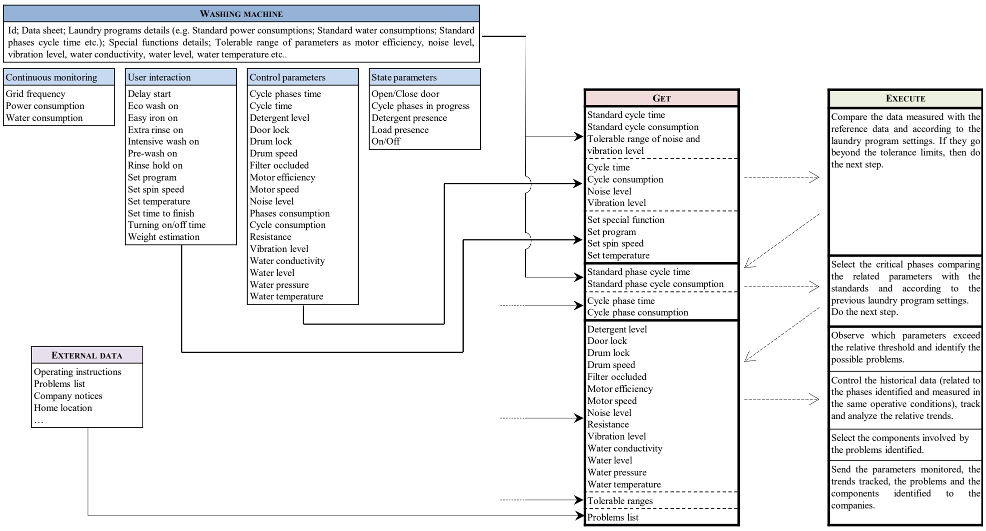


Figure 10: Tool rationale related to the remote maintenance service.

Chapter 4. Smart Home and Environmental Sustainability: The Energy-related Services

The actual growing world energy demand is generating strong attention to the energy efficiency and to the environmental sustainability. The residential sector is one of the most energy-intensive reaching about 25% of global energy consumption [24]. Furthermore, it is difficult to understand the real energy use in residential buildings suggesting the development of methodologies and tools to monitor and assess their energy performances. Such an analysis requires defining all the actors, their interaction rules and the intelligent management of a large amount of data. In addition to this, the energy performances of the home environment are closely related to the specific case under investigation, in fact it imposes the analysis of the particular application scenario and the target users to extract parameters able to describe the building behavior. They are related to the technological characteristics of the systems, to the external environment (e.g. external temperature, solar irradiation, etc.) and to the user needs and habits. It introduces some complexities, because many of these data are difficult to find and to predict. Another cause of complexity was introduced by the information and communication technologies (ICT) that creates new relationship between home devices fostering the spread of smart systems. In this scenario, simulation tools have been developed to grasp the real energy performance of a building, but they require a high level of detail for the input data, which are often difficult to find. Otherwise, other tools are built for much simplified simulations and typically addressed to inexperienced users neglecting the real complexities of the system.

For this reason, this chapter presents the application of the proposed methodologies (Chapter 3) to energy-related services. The design approach for this particular services typology involved the development of knowledge-based tools with architecture able to simulate the real behavior of the building considering all the actors and their interaction rules, but at the same time containing the features that allow them to be used in fast simulations or by inexperienced users. One of the focuses is the development of an intelligent user interface that, when requested, is able to automate and simplify data entry process. It is particularly useful when the user does not know the necessary input data for the simulation, e.g. energy consumption profiles, detailed features of the building, etc.

4.1 The Energy Simulation of the Home Environment

Nowadays, energy simulation tools are increasingly essential for analysis of building energy performances and for the evaluation of best design solutions. The simulation process enables a faster design process, allowing comparing a wider range of solutions and a clear understanding of the consequences of a design decision. One of the major applications of the buildings simulation is the energy efficiency evaluation, since they are energy intensive.

Recent climate changes and the progressive reduction of fossil energy resources have raised a growing awareness of the need to reduce energy consumption and to use more sustainable energy sources [96]. Energy efficiency has therefore become a mandatory requirement for buildings [82], both for environmental conservation and for economic reasons, given that, according to recent estimates [97], buildings are responsible for about 39% of the annual primary energy consumption and in particular 25% due to residential buildings [98]. Numerous efforts have been made to reduce energy consumption and promote alternative sources of production. Very often, however, these two aspects are handled individually while they should be analyzed in an integrated perspective from the early design stage to enable more efficient energy management.

In this regard, simulation tools can be very useful and effective to perform overall energy assessment of the building by improving the result quality and reducing the times of the design phase. However, it is difficult to predict the real energy use in residential buildings, because it requires considering a large number of variables to contextualize and to understand the system as a whole [99]. All these variables are related to each other creating the home environment and its simulation requires defining all the “actors”, their interaction rules and the intelligent management of a large amount of data. In these years, specific simulation tools have been developed to grasp the real energy performance of buildings, but only highly experienced users, such as professionals or researchers, can use them, as they require a high level of detail of the input data. Generally, these tools are designed to simulate specific technical aspects of the building (the building envelope, the heating system, the renewable energy systems, etc.), but they fail to provide a comprehensive view of the home environment as an integrated ecosystem of actors that interact each other and with the external environment.

However, in an early design stage, it is useful to simulate the home environment in a comprehensive way (including devices, user habits and external variables) from a high-level perspective, without the need to analyses in detail individual systems. Once a global energy photograph is obtained, if necessary, the design of the individual components (with high level of detail) will be done. In fact, in the early design stage, the designer must make quick assessments of different design alternatives to understand how these have an impact on other systems and, very important, whether they are compatible with dweller's habits and needs [100].

In fact, the energy performances of the home environment are closely related to the specific case under investigation imposing the analysis of the particular application scenario and the target users to extract parameters able to describe the building behavior. They are related to the technological characteristics of the systems, to the external environment (e.g. external temperature, solar irradiation, etc.) and to the user needs and habits. It introduces some complexities, because many of these data are difficult to find and to predict.

Furthermore, in the analysis of complex systems with many variables to consider, it is impossible to find a single best design solution, because every good solution will have both advantages and disadvantages. Also in the analysis of a residential environment, many design drivers that can be considered sometimes go in contrast with one another forcing the designer to search for a compromise solution. Examples of these design criteria are: the power consumption, costs, environmental impact, the user's needs, comfort, etc.

In this context, the basic requirement is to have simulations tools able to perform a complete simulation of the building environment, but it is clear the need to integrate them with features helping the user to do correct analysis and find the best solutions. On one hand, it is useful to integrate the simulation tools with a knowledge base to support the user in data management (especially in the data entry process) and, on the other, it is convenient to combine them with multi-objective optimization tools to find and compare the best solutions with a holistic assessment of the simulated environment.

For this purpose, our design approach contain a knowledge-based simulation tools coupled with a multi-objective optimization tool with the aim to find best design solution in home environment. The first tool is built in Matlab environment with an architecture able to simulate the real behavior of the building considering both thermal and electrical model and the user habits. In addition to this, it includes features that allow it to be used in fast simulations or by inexperienced users. The optimization phase is made with the software Modefrontier linked with the simulation tool, such that they can be used as a single ecosystem able to simulate and optimize the required design criteria.

The focus is the definition of the best system configuration for the specific use cases under investigation optimized for the whole energy consumption, costs and environmental impacts.

The method relies on an integrated dynamic model that incorporates a “Modeling tool” for the use case design and systems configuration and a “Simulation tool” that contains the algorithms for the home environment simulation with the energy, cost and environmental impact evaluation. An “Optimization tool” can be linked to the “Simulation tool” and it permits to define the design criteria and evaluate the best solution.

4.2 State of Art of Building Energy Simulation Tools

The building energy simulation has been addressed extensively in the literature [101], [102]. It offers many possibilities to optimize the design of the buildings from the perspective of cost and energy efficiency; however, the results may be interpreted wrongly if operational parameters and analysis objectives are not defined clearly. In this context, specific simulation tools have been developed to grasp the real energy performance of a building. Each of them has different characteristics and application purposes in terms of complexities and area of analysis [100]. One of the most famous program is Energy Plus Simulation Software developed by the U.S. Department of Energy [103]**.** It is able to perform building energy analysis and thermal load calculation exploiting DOE-2 [104] and BLAST simulation engines. Another example is HAMLab, a collection of models and tools suitable in Matlab and/or COMSOL environment made by the Eindhoven University of Technology [105]. The strength of the previous two software is in the building envelope simulation and the heat and vapor flows modelling. TRNSYS is a tool developed by the Solar Energy Laboratory of the University of Wisconsin Madison [106]; it has a modular structure with a set of packages that allows representing the building and the HVAC/R systems. MODELICA [107] is a non-proprietary, object-oriented, equation based language released by Lawrence Berkeley National laboratory that is able to model various complex physical systems in different fields. It is popular for its open source library for building energy analysis and control simulation. TRNSYS and MODELICA libraries are very suited for the HVAC/R system simulation. Environmental System Performance-research (ESP-r) [108] is a tool developed by the Energy Systems Research Unit of the University of Strathclyde in Glasgow. It is a powerful tool for dynamic energy simulation of buildings and it is able to perform also lighting and acoustic analysis. As the other software described above, its limit is the difficulty of being used by those not familiar with the thermos-physics of the building. Thermal Analysis Software (TAS) [109] is a program for building thermal simulation in dynamic conditions; it is powerful in the simulation of ventilation flows, in fact, it includes a separate module for the computational fluid dynamic (CFD) analysis. The drawback of these simulation tools is that they require detailed input data that are often unknown in the early design stage and that make difficult the building simulation in comprehensive way [110]**.** Furthermore, long calculation time and the data entry process, which often takes place by programming languages, do not allow making quick evaluation between various design alternatives that is a key issue. In building performance simulation, the integration between BES tools and optimization algorithms/software has been proven to be a very effective and convenient approach to support designers in the analysis and in the identification of the optimal configuration. In fact, although the iterative trial-and-error research process (driven by designer expertise) could be a useful method to investigate alternative design options, it is time-consuming and practically impossible due to the difficulty in exploring a large number of combinations. In last years, many researches have addressed the issue of energy simulation and optimization in building environment. Such researches are usually focused on specific aspects of the building design and they often exploit the calculation engine of the above-mentioned software. Some studies focused on simulation and optimization of the building envelope parameters, so they are useful to architects and civil engineers during the architectural design process. Sahu et Al. [111] proposed a methodology to allow a quick energy efficient design for air-conditioned building in tropical climate. Genetic algorithm was used as optimization tool for design and the optimum solution, given by GA, was processed and validated through the building simulation software TRNSYS. Delgarm and Al. [112] suggested an approach for the simulation based multi-objective optimization problems, which addresses the optimization of the building energy performance. In this study, a multi-objective particle swarm optimization (MOPSO) algorithm is coupled with EnergyPlus software to find solutions that improve the building energy performance. Al-Homoud [113] coupled a direct search optimization technique (Nelder–Mead method) with ENERCALC energy simulation to optimize the thermal design of buildings with intermittent occupancy. Other researches address the issue of the renewable energy resources (RES) design and management with the aim to maximize energy efficiency and cost benefits for dwellers and utilities [114]. These researches involve also the issue of smart grid that are linked to the way in which the distributed energy is produced in private small plants [ref.]. Ghiaus and Jabbour [115], in order to optimize the total cost of a hybrid PV/diesel generator system, used Design of Experiments based on simulations in TRNSYS. Li et Al. [116] conducted a thermo-economic optimization of a trigeneration system in an urban residential area in Beijing. The optimization was conducted through a genetic algorithm toolbox implemented in Matlab. Chabaud et Al. [117] proposed an approach to energy resources management for residential microgrids. TRNSYS has been used to model the thermal behavior of a grid-connected building equipped with energy production and storage systems. HVAC is an important subsystem of the building environment, in fact several studies focused on the developed of tools for HVAC design and simulation. Between these researches, it is possible to distinguish tools with different purposes, e.g. pipe/duct sizing, equipment sizing and selection, energy performance analysis, etc. Congradac and Kulic [118] minimized chiller energy consumption through artificial neural networks, trained with data collected from a real chiller, and genetic algorithms. EnergyPlus software was used to perform the energy simulation. Lee and Cheng [119], through the integration of EnergyPlus tool with a hybrid optimization algorithm, found the optimum water supply temperature of a chilled water system. Fong et Al. [120] proposed a simulation-optimization approach for the efficient energy management of HVAC. They minimized HVAC energy consumption coupling a dynamic simulation, performed through TRNSYS software, with evolutionary programming. Besides topics described above, other studies have focused on aspects that secondarily affect the energy consumption in buildings, but which are equally important to perform efficient simulations. These works proposed innovative solutions to model the user comfort, the occupancy behavior, the daylight conditions, etc. Moreover, different studies have tried to enlarge the analysis taking into account multiple perspective. Chantrelle et Al. [121] developed a multi-criteria tool for the optimization of buildings renovation considering costs, energy use and comfort. The optimization was performed using a Genetic Algorithm (NSGA-II) and TRNSYS and COMIS simulation software. Fesanghary et Al. [122] developed a methodology to tackle multi-objective building optimization based on harmony search algorithm and EnergyPlus simulation. Their aim was to minimize the life cycle cost and carbon dioxide equivalent emissions of the buildings. Bambrook et Al. [123] analyzed a detached house in Sidney in order to reduce its heating and cooling requirement to the point where no heating and cooling system is necessary. This building was optimized with respect to life cycle cost. They coupled the BES software IDAICE with the optimization program GenOpt 2.0. Ascione et Al. [124] developed an approach for performing the buildings optimal-cost analysis, based on the multi-objective optimization of energy demand and thermal comfort. The optimization is reached through the implementation of a genetic algorithm and is based on the integration of EnergyPlus and Matlab. Many design approaches and simulation tools have been developed in these years; each of them focuses in certain specific aspects of the building environment, but they are not developed to take into account the home environment in a global perspective considering all the actors involved. However, all these aspects interact each other and depend from user habits and external events, so there is the need for an integrated simulation tool to take all aspects into account [125] in order to define quickly the best design solutions for a particular user living in a particular geographic area.

4.3 The Methodology Applied to the Energy-related Services

The methodology applied to the energy-related services inherits the structure of the general methodology presented in the Chapter 3, but for this particular type of service, it includes the concept of simulation. Also in this case, it is structured in a sequence of steps to follow that permit to reach the desired goal.

The first step of the methodology refers to the data research and identification that is the first analysis of the home environment. This can be done with different techniques and the objective is to define all the actors and to understand how they act inside and outside the home. At the end of the research process, data must be classified and organized into an appropriate structure that includes also relationship between the identified entities.

The second step includes the specification of services requirements that is the logics design of the energy-related service that will be simulated and tested in virtual environment. It has the aim to produce a list of services eligible in the Smart Home environment.

The third step includes the Smart Home modeling that is the contextualization of the home environment. After the data research and processing, it is possible to design a knowledge base able to manage the found data. The knowledge repository contains data and formalized rules such as design variables, devices properties, dimensioning rules, component features and functionality. The Knowledge base (KB) guarantees technical feasibility for a large range of connections within the specific home design context. The core of the methodology is the design of a tool that permits to configure, simulate and evaluate the home environment and the energy-related services (fourth step). In this work, the tool was divided in two sub-programs that are the Modeling tool and the Simulation tool. The Modeling tool allows generating the use scenario created by the user that includes devices, user habits, and relationship between them and with external entities. It has an interactive interface able to adapt the detail of the input data on the base of the user needs and skills. The Modeling tool interacts with the KB that includes a set of constraints, rules and possible layout of the user interface. Furthermore, it is able to retrieve data not provided by the user from statistical data found in the first step.

The Simulation tool translate the use scenario into a system architecture creating the virtual model of the real environment, i.e. electric model, heat model and the water fluxes inside the home. It permits to simulate Smart Home services that can be tested and improved (for companies) and, once the logic is developed, evaluated in the particular cases under investigation (consumers and designers). At the end of the simulation, it generates a complete results report. The produced reports permits to evaluate the benefits of a simulated service (fifth step).

The Figure 1 shows the scheme of proposed methodology.

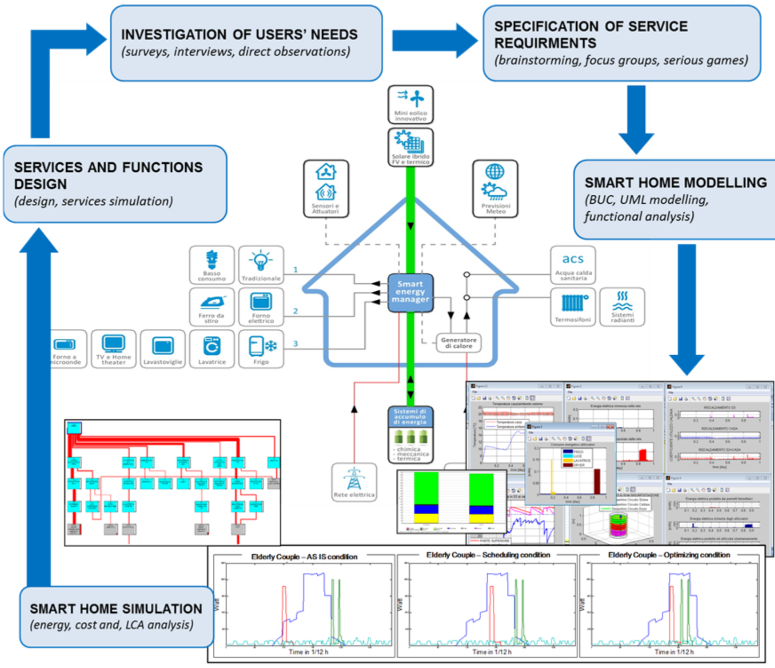


Figure 11: Methodology applied to the energy-related services.

The next sections will not show all the steps of the methodology since they follow the same structure described in the chapter 3. Instead, they will present activities that for energy-related services are particularly important in respect to other services. These activities are the initial data research and processing and the modeling/simulation tools design.

4.4 Data Research and Processing

Between the aspects that influences the simulation results, there are the input data. Consequently, it is necessary to pay close attention to their definition, as they can be decisive in making a correct building energy simulation. For example, the heating and electrical devices can have the real work cycles different from those set in the simulation; the user who will live in that building may have habits and needs completely different from those assumed in the calculation.

In general, the input data are essentially composed of the following elements: horizon of time, building thermo-physical characteristics, elements of the systems, load profiles, climate data, control strategies of the plants, national/regional regulations and other simulation-related parameters. For greater understanding and simplicity of description, we define three main data classes (or" actors") that include parameters related to the elements described above and all the other parameters. These classes are: devices, users habits and external variables.

The simulation of residential environments is based on the collection and elaboration of data related to dwellers, devices and events. The creation of a knowledge base allows designing and simulating the real operating conditions of the home environment in order to accurately estimate the benefits of different solutions. In this work, the data collection was made by studying the state of the art and by the direct involvement of users, which are fundamental to collect accurate information concerning the following aspects:

- Home devices, which concerns the identification and the characterization of the home energy devices for typology and operating mode (e.g., energy profile, age, use frequency, selected options, etc.). The devices analysis is useful to understand the most significant data related to the products functioning.
- Dwellers typology, it refers to the identification of the users' habits and needs, i.e. how and when the consumers use each device (e.g., number of people at home, year of birth, job, etc.). Such an analysis is carried out at first, by consulting reports of researches at European and international level [126], [127], [128] and then, directly involving users by different techniques such as interviews and questionnaires.

- External parameters, it refers to data generated by external entities (e.g. building typology [129], climatic conditions, fees of utilities, etc.) that contribute to define the analyzed scenario. They are not directly linked with the users' behaviors.

At the end of the research process a substantial amount of data are collected, which are essential for the building simulation, but they must be first selected and then organized into an appropriate way. In this context, a sensitivity analysis must be carried out to understand what parameters are more or less important, which of them can be considered constant, which ones instead vary and compared to what. One of the key points is a proper data management that must be associated with a proper architecture to guarantee a correct information exchange. It means the selection and the classification of the devices, the analysis of their data model, the aggregation of the necessary data according to the desired service functions, and finally the definition of a set of rules to coordinate device operations according to user preferences and external events.

In this study, the knowledge base includes all data related to the energy production, conservation and management (e.g., sources, utilities, renewable energy system, electricity grid, etc.), the building (e.g., location, number of rooms, thermal transmittance, etc.), users (e.g., energy profile, habits, preferences, etc.), household devices (e.g., typology, consumptions, functionalities, status, etc.) and the weather conditions (e.g., temperature, solar radiation, etc.).

The data collection is necessary to perform a correct simulation, because they permit to define the relationship between the "actors" of the home environment, but it is also helpful for the use case definition, since they allow improving the velocity and the accuracy of the data selection and data entry processes.

4.4.1 Analysis of Home Devices

The identification and the characterization of the home energy devices for typology and operating mode (e.g., cycle duration, energy profile, etc.) is one of the key points. In fact, the devices characterization is useful to configure the environment, to understand the most significant data related to the product functioning and to develop an efficient information management tool able to guarantee the devices interoperability. In particular, for home automation devices all the information characterizing the specific product and the additional devices required to guarantee its functioning and communication have to be considered. For example, they consist in resources consumption data (e.g., energy, water, etc.), functional parameters that are analyzed and compared with a set of target parameters (e.g. speed, rates, temperatures, etc.), functionalities and/or scenarios that can be selected by the user, communication requirements, etc..

For this aim, the literature and the datasheets of different manufactures' products are investigated. The collected data can be classified into a set of homogeneous categories to support the design and development of an effectiveness high-level rationale. In addition, brainstorming sessions and/or workshops with experts are necessary to revise, elaborate and validate the information model.

The first step included the state of art of the researches done in the field of the home consumption analysis. This analysis is crucial to understand which devices determine a high impact on energy consumption and how to determine the overall power profile. In particular, at the European level, some studies investigated the home energy consumption profile with specific measurement campaigns. These studies includes the analysis of single devices or group of devices, but generally, they consider an average energy consumption neglecting the users' typologies. In many cases, the analysis is divided per country highlighting some differences between the European countries. For our work, it is useful to start to consider the European studies as the energy consumption habits between different continents is completely different. For example, the habits of a US citizen are completely different between those of an EU citizen. Some significant studies in the field of the home energy-related devices are:

- EURECO (2002): The investigation field of Eureco project is the Demand Side Management of the specific electricity end-uses, in the residential sector. It describes the state and structure of the specific-electricity uses in the residential sector of four chosen country [130].
- MICENE (2004): It includes measures of energy consumption of electric energy in 110 Italian homes. In particular, it analyses the load curves of the major household appliances and lighting equipment [131].

- REMODECE (2008): The objective of the project is to perform a common analysis of the measurement campaigns of electricity consumption in households in European countries. The measurement campaigns were performed in at least 100 households per country (approximately two weeks per household), using monitoring equipment capable to monitor the energy demand every 1 or 10 minutes in a varying number of appliances per household [132].
- SMART-A PROJECT (D 2.3 of WP2, 2009): It aims at developing strategies how smart domestic appliances can contribute to load management in future energy systems. In order to do this, the project assesses the options for load-shifting by a variety of appliances across Europe and compares these with the requirements from energy systems both on the local and regional level [126].
- END-USE METERING CAMPAIGN IN 400 HOUSEHOLD IN SWEDEN (2009): The investigation field of this project is the Demand Side Management of the specific electricity end-uses, in the residential sector. The first objective of this campaign is to precisely describe the state and structure of the specific-electricity uses in the residential sector [127].

Other studies concentered more in other parameters, such as the devices shares sales also grouped for energy efficiency and other specific product parameters (e.g. the maximum load capacity for the washing machine). The Energy Efficiency Status Report of the JRC (2012) is an accurate study that treated this kind of information [133].

After the study of the state of art, the analysis continued with a questionnaire developed by our group of research with the aim to retrieve data not treated in the state of art and to confirm the information provided by the works analyzed. In particular, the results of this study are shown in the following paragraph as it includes a large part related to the users' energy consumption habits related to the common household appliances.

At the end of the analysis a huge quantity of data were collected and it was classified to have a knowledge base with the information of each devices. For a quick and efficient use, they were organized in sheet including tables and graphs belonging to the device. At this point, there were different values for the same parameters that were retrieved from different reports, so they were elaborated to have a single average and updated value that represent that parameter.

As many devices were considered, they were grouped for typologies in device categories. The most common devices that are considered in this work are included the following groups:

- Renewable-energy production devices, such as photovoltaic and thermal solar panel, wind power system, etc.;
- Hot water storage systems and electrochemical or mechanical system for electricity storage;
- Domestic Hot Water devices (DHW) and Heating, Ventilation and Air Conditioning devices (HVAC), which are characterized by a high energy consumption and a priority of operation;
- Major household appliances grouped as cooling (refrigerator and freezer), cooking (oven, hob, and hood) and laundry (washer, dryer, and dishwasher);
- Consumer electronic devices as entertainment systems (e.g., TV, game console, audio equipment and players) and small household appliances (e.g., coffee makers, hair dryer, toasters);
- Environmental control devices containing common components such as lighting, alarm systems and other home automation devices and sensors.

The Table 6 shows a selection of data obtained for the main home devices. In fact, it is not possible to present all data in this document, as it would require a separated paper.

List of parameters	*Processed data*	*MICENE*	*EURECO*	*REMODECE*	*SMART-A*
Dishwasher					
Annual energy consumption (kWh)	*230*	369	268	234	241
Cycle energy consumption (kWh)	*1,11*	1,45	1,35	1,13	1,19
Device average age(years)	*7*	6	6	-	-
Time of use (peak hours)	15-16, 21-22	22(fr/fs), 15(fr/fs), 10 (fr)	21-22, 15-16	-	20-21
Washing machine					
Annual energy consumption (kWh)	*198*	224	193	184	150
Cycle energy consumption (kWh)	*0,85*	-	0,78	0,68	0,89
Device average age(years)	*7*	6	6,5	-	-
Time of use (peak hours)	8-9, 15-16	10(fr), 15-16 (fr), 12(fs), 15-16(fs)	9-10, 15-16	-	8,2
Dryer					

Annual energy consumption (kWh)	*400*	-	400	347	251
Cycle energy consumption (kWh)	*2,5*	-	1,2	1,72	2,46
Device average age(years)	*afternoon slot*	-	5,9	-	-
Time of use (peak hours)	*6*	-	-	-	10, 21-22
Oven					
Annual energy consumption (kWh)	*110*	-	-	-	120
Cycle energy consumption (kWh)	*0,85*				0,89
Time of use (peak hours)	*18-20*	-	-	-	11, 18
Fridge-Freezer					
Annual energy consumption (kWh)	*330*	637	656	451	403,5
Required power when turned on (W)	*113*	64,8 (daily average power)	-	-	138,2
Time of use (peak hours)	*continosly*	Use almost constant, with small peaks of consumption at the door openings. *			
Device average age (years)	*7*	7,9	6,9	-	-
Air conditioner					
Annual energy consumption (kWh)	*500*	-	-	372	-
Required power when turned on (W)	*1000*	-	1530	-	1700
Time of use (peak hours)	*15-21, with peak at 17*	-	16-17	-	15-21
Water heater					
Annual energy consumption (kWh)	*1500*	-	1516	-	-
Daily energy consumption (kWh)	*4,4*	-	4,41	-	-
Average power required (W)	*1200*	1255	1255	-	-
Time of use (peak hours)	*7-9, 19-22*	9, 21	8-10, 20-22	-	-
Lighting					
Annual energy consumption (kWh)	*375*	375	375	487	-
Time of use (peak hours)	*evening slot*	*evening slot*	*evening slot*	-	-

Table 6: Statistics relating to common household devices.

Notes:

- "fr" and "fs" indicate the weekdays and the holidays; the distinction is necessary because some devices exhibit deviations of data between the one and the other;
- * the 25% of the refrigerator-freezer consumption depends on the frequency of opening of the doors.

These data are useful to evaluate the impact that each device has in total energy consumption of the house. Despite this, with the knowledge of the average statistical data of devices, it is not possible to reach the complete understanding of the home environment. In fact, the home energy profile varies not only depending on the devices present at home, but also with the influence that the user has to them. Each user has its own particular habits and needs, so there is the need to study this highly variable environment by going to understand the user behavior, simplifying where is possible.

4.4.2 Analysis of Users Needs and Habits

The analysis and management of a residential environment is based on the collection and elaboration of data related to dwellers, devices and events. In particular, the knowledge of users' habits allows designing and developing user-centred systems and services and simulating the real operating conditions of the home environment in order to accurately estimate the benefits of different solutions. In order to gain this knowledge, the first step of the proposed methodology is the investigation of users' profiles, needs and behaviors by exploiting several techniques such as questionnaires, interviews, brainstorming sessions, etc. The direct involvement of users in the analysis process is fundamental to collect accurate information concerning the following aspects:

- Family members (e.g., number of people, gender, year of birth, etc.);
- Building characteristics (e.g., location, typology, energy class, etc.);
- The use of household appliances (e.g., age, energy efficiency class, use frequency, selected options, etc.);
- Expectations of new smart home technologies and services (i.e., the effectiveness of existing services, new proposals, etc.).

According to the nuclear family characteristics, several users' classes can be roughly defined. After the user-product interaction analysis, these ones have to be revised and aggregated in order to define few significant classes with a similar consumption profile and simplify the simulation process without compromise the reliability and validity of results. Therefore, the output of this step is users classes with a characteristic energy profile referred to a "typical week".

The technique that has produced the best results in the users' analysis is the questionnaire, because it permitted to reach many people in a in a short time. The questionnaire was created in order to understand how consumers interact with the devices within the home. This procedure is described in this paragraph highlighting each step done.

Design of the questionnaire

The questionnaire was prepared and proposed on the web via the application "Modules" of Google Drive. It was shared through communication channels such as social networks and email; the responses were automatically collected in a private digital space. The survey included a first part of personal questions to identify and categorize the user typology, the second part concerned the user's habit of use of some selected home devices and, finally, the third part included questions regarding the knowledge of the smart home and the interest of its services. The questionnaire was developed on 21 pages. This decision was adopted to treat each appliance separately and to give to the respondent that does not have a particular appliance the opportunity to switch to the next page. The estimated time to complete the questionnaire is approximately 15 minutes. A general scheme of the questionnaire is shown below (Figure 12):

- Initial Introduction (p. 1)
- Information on the user, (p. 2)
- Information on the home, (p. 3)
- Use of home devices:
    - Dishwasher (p. 4-5)
    - Washing machine (p. 6-7)
    - Dryer (p. 8-9)
    - Oven (p. 10-11)
    - Fridge-Freezer (p. 12-13)
    - Cooking (p. 14-15)
    - Home heating (p. 16)
    - Air conditioner (p. 17-18)
    - Lighting (pg. 19)
    - Consumer electronics (p. 20)
- Home automation (P. 21)

Figure 12: Scheme of the questionnaire.

Results analysis: identification of users' classes

The aim of the questionnaire was to understand which are the most energy-consuming appliances used in the home environment and how different users use these devices. The responses from the questionnaire were automatically collected in a worksheet in Google Drive, which allowed their simple management and processing. The first phase of the study was the development of the answers; these have been differentiated according to the type of user. Respondents were assigned to different classes of users based on information, such as chronological age, the number of people at home, work situation and the number of hours in which there is someone in the house. Examples of the user classes are pensioner, single worker, House with 2 students, family with 3-4 people, young couple, etc. The classes of users emerged from the questionnaire were many, but some of these were composed by a small number of respondents. For these, it was not possible to reconstruct an overall picture to reflect the best use of the devices; furthermore, some users' classes were very similar in terms of user profile. Finally, for each of the identified classes, tables containing the results of the responses regarding the use of the considered appliances have been created. Below, there is the Table 7 concerning the dishwasher relatively to the user class "family of 4 people".

N° Respondents	**Weekdays**		**How old is your dishwasher?**		**Energy label class**	
31	**Annual washing**	**Every week**	<1	1	A+++	2
Who has it	218	4,2	1--3	5	A++	3
25			3--5	8	A+	3
	Mattina presto	0	5--8	5	A	1
	Prima di pranzo	1	8--15	1	G	1
	Dopo pranzo	4	>15	5	I do not know	14
	Metà pomeriggio	2				
	Tardo Pomeriggio	2	**Average time of the washing program**		**Type of the most used program**	
	Sera	18	30min	3	Automatic	1
	Notte	5	1h	7	Delicate	2
	Non la uso	1	1h 30	8	Economy	8
			2h	4	Intensive	1
			>2h	1	Classic	9
			I do not know	2	Quick	3
					I do not know	1

Table 7: Data of the Dishwasher for a family of 4 people.

<u>Results analysis: creation of selected users' classes</u>

Tables cited above allowed comparing how the different classes of users make use of household devices. Some of them have the same energy consumption profile, for this reason the classes with similar results were brought together in order to simplify the subsequent simulation phase without compromising the validity of the results. These considerations permitted to pass from the many classes to 5 significant user typology.

These classes' are listed below:

- Young single;

- Young couple;
- Elderly couple (>65);
- Family with 3-4 people;
- Family with 5+ people;

In this way, tables that represent the five new user classes are created and they are a mix of the original classes found with the questionnaire. This is possible as the classes joined had a very similar user profile. In the next chapters, there will be shown as the user can customize his/her own energy profile. In fact, the predefined user profiles can be used to speed up an energy simulation for non-experts, for statistical analysis and to facilitate the creation of a personal home energy profile.

Creation of the energy profile for each classes

The information obtained with previous analyzes were organized in tables and subsequently entered into a database in order to be usable in the simulation tool that have been developed in the work and that will be shown in the following pages. The following is an example of such tables (Figure 13); the formatting of the data has been modified to make it readable in this document. The table below is an extract of the defined table, for reasons of space not all devices al listed here.

ELDERLY COUPLE	DAYS	M	T	T	W	F	S	S
WASHING MACHINE	TIME START	-1	08:00	-1	10:00	-1	15:00	09:00
	TEMPERATURE	-1	40	-1	40	-1	40	60
DRYER	TIME START	-1	-1	-1	-1	-1	17:00	-1
DISHWASHER	TIME START	-1	08:00	-1	-1	20:00	-1	14:00
OVEN	TIME START	-1	-1	18:30	-1	-1	10:00	11:00
FRIDGE-FREEZER	TIME START	CONTINOUS OPERATING						
HOOD (DINNER)	DESCRIPTION							
	TIME START	18:30	18:30	18:30	18:30	18:30	18:30	18:30
	TIME END	19:30	19:30	19:30	19:30	19:30	19:30	19:30
	W	200						
HOOD (LAUNCH)	DESCRIPTION							
	TIME START	12:00	12:00	12:00	12:00	12:00	12:00	11:00
	TIME END	12:30	12:30	12:30	12:30	12:30	12:30	12:30
	W	200						
HOB (BREAFAST)	DESCRIPTION							
	TIME START	07:15	07:15	07:15	07:15	07:15	07:15	07:15
	TIME END	07:30	07:30	07:30	07:30	07:30	07:30	07:30
	W	1000						
HOB (LAUNCH)	DESCRIPTION							
	TIME START	18:30	18:30	18:30	18:30	18:30	18:30	18:30
	TIME END	19:30	19:30	19:30	19:30	19:30	19:30	19:30
	W	1000						
HOB (DINNER)	DESCRIPTION							
	TIME START	12:00	12:00	12:00	12:00	12:00	12:00	11:00
	TIME END	12:30	12:30	12:30	12:30	12:30	12:30	12:30
	W	1000						
HOB (MORNING)	DESCRIPTION							
	TIME START	09:00	09:00	09:00	09:00	09:00	09:00	09:00
	TIME END	11:30	11:30	11:30	11:30	11:30	11:30	11:30
	W	100						
HOB (EVENING)	DESCRIPTION							
	TIME START	18:30	18:30	18:30	18:30	18:30	18:30	18:30
	TIME END	22:00	22:00	22:00	22:00	22:00	22:00	22:00
	W	100						
DESKTOP PC (EVENING)	DESCRIPTION							
	TIME START	19:00	-1	-1	19:00	-1	-1	-1
	TIME END	21:00	-1	-1	21:00	-1	-1	-1
	W	100						
GAMING CONSOLE	DESCRIPTION							
	TIME START	-1	-1	-1	-1	-1	-1	-1
	TIME END	-1	-1	-1	-1	-1	-1	-1
	W	150						
PRINTER	DESCRIPTION							
	TIME START	-1	-1	-1	-1	-1	-1	-1
	TIME END	-1	-1	-1	-1	-1	-1	-1
	W	7						
COFFEE MAKER	DESCRIPTION							
	TIME START	13:00	13:00	13:00	13:00	13:00	13:00	13:00
	TIME END	13:15	13:15	13:15	13:15	13:15	13:15	13:15
	W	300						

Figure 13: Extract of week profile for an Elderly Couple.

4.4.3 Analysis of External Parameters

This step concerns the analysis of the more influential external parameters. The term "external parameters" include variables that influence the building energy profile, but that are not linked with the users' behaviors. It refers to data generated by external entities (e.g. building typology, climatic conditions, fees of utilities, etc.) that contribute to define the analyzed scenario. The building typology is one of the most important external parameter, because it influences directly the rooms heating consumption, but also other conditions as the users' lifestyle and the devices typology installed at home. According with the building typologies defined in the TABULA Project [129], it is possible to identify 4 main categories of residential buildings: Single Family House (SFH), Terraced House (TH), Multi Family House (MFH), Apartment Block (AB). Each of these categories differs in some aspects from the others. In this work, aspects that characterize each type of buildings in terms of energy performances were classified in order to create a database containing all data of buildings. It permits to associate the category of building to the construction type of it (as the envelope is formed), creating a correlation matrix that define a series of "standard" buildings typologies. Furthermore, it is possible to associate a specific type of buildings to a particular year of constructions and the average surface of each type of buildings is included in the database, in addition to this, it is possible to calculate the consumptions of a buildings starting from the energy class according to the national legislation. Another important external parameter is the geographical area that influences the building energy behavior with its climatic conditions. It includes variables as the external temperature and the solar irradiation, directly linked with the users' habits and the devices operations. In particular, for each considered city a list of important data are included to reproduce the climatic behavior of that area. Other external parameters are more related to the national's regulations and to the context of the local energy market. The fees of utilities is one of the most important as it affects the users' choices in the purchase phase (e.g. if the electricity has a high price, I will buy a gas boiler and not a heat pump) and the users' behaviors during the use phase (e.g. I will turn on the dishwasher when the electricity cost less). In this work, the price of the main energy sources are defined to calculate the cost of the energy consumed and to compare different home configurations to find the best of the particular user. In addition, the renewable energy sources are considered.

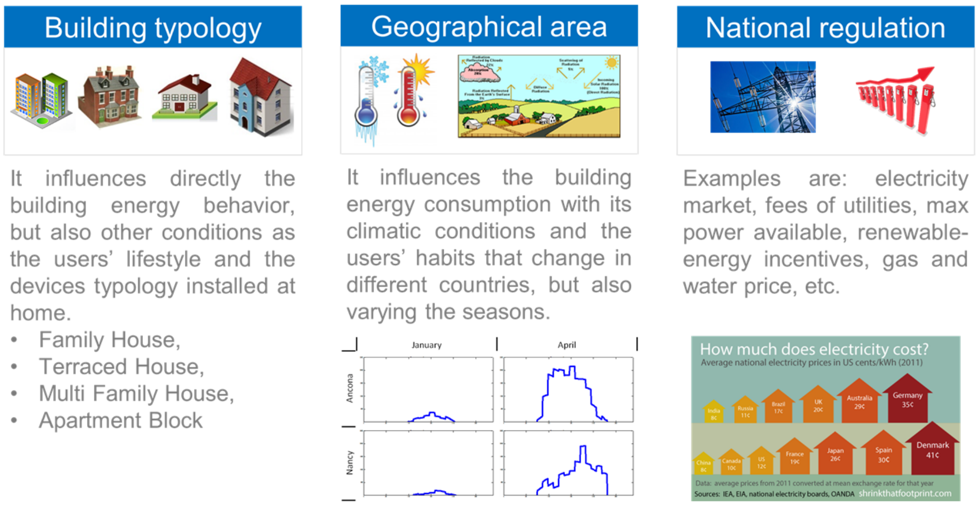


Figure 14: The main categories of external parameters.

4.5 Service Requirements for energy-related services

The service requirements for the energy-related services involves the search, classification and design at the logical level of the service. It starts with the investigation of data produced by the users' needs analysis and the data research and processing, which is explained in the previous paragraph. For first, this step helps to find and classify existing services that can be simulated, evaluated and eventually improved. Furthermore, it permits to create new services that can be useful not only for consumers, but also for other actors as companies, designers and utilities. At this step, the services are classified and designed from a high point of view, subsequently they will be imported in the Simulation tool and the logics developed will be translated in programming language. The test in the virtual home environments helps to improve the service quality identifying if it is useful, in which cases and for what user's typologies.

Up to now the tool considers a set of energy-related services belonging different smart home functionalities. Some of them are listed below:

- Statistics about total consumption or aggregate data for device category in a certain period of time;

- Analysis of historical consumption trends;
- Smart scheduling of household appliances;
- Energy recovery of hot drain water;
- Energy management of thermal systems.
- Energy habits monitoring with tips to how improve the behavior;
- Products test and comparisons.

A specified application will be developed to show to customer the most proper energy fee policy according to their energy use. Available data can be also used to forecast the future consumption and provide indications to users.

The smart device scheduling service is one of the most important services investigated, so that, it is presented and detailed hereafter. The Simulation workflow for smart energy management of household appliances is shown in Figure 15.

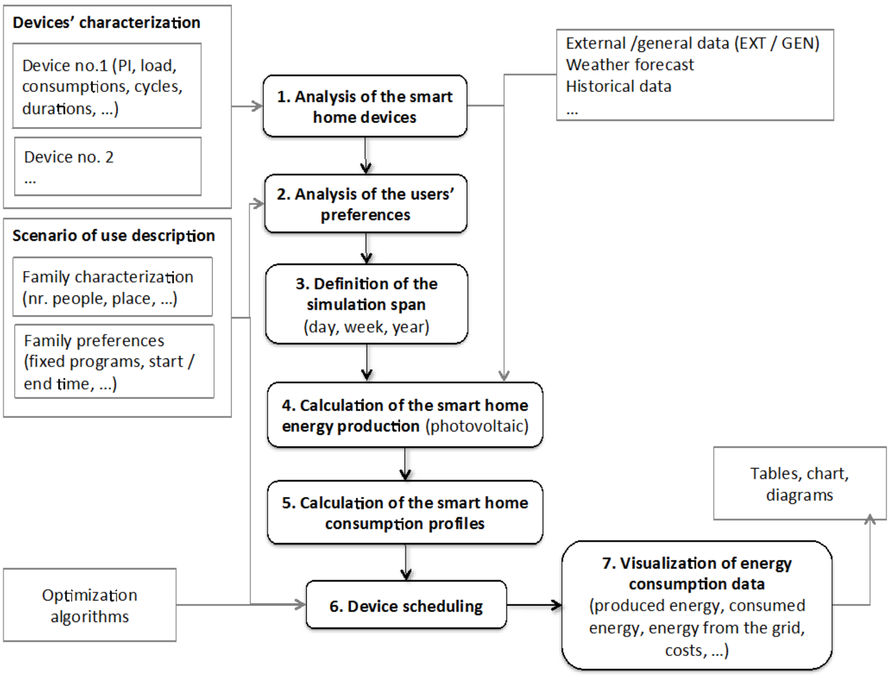


Figure 15: Workflow for the smart devices scheduling service.

Another important service developed and added to the Simulation tool is the smart management of thermal devices. This service is very important as thermal devices produce the highest energy consumption in the house. This service include the possibility to connect all thermal devices and some household appliances to the water tank that acts as a core of the system. The service involves the energy management of these complex systems that includes hot water fluxes and all devices. A scheme that represent the system architecture is presented below (Figure 16).

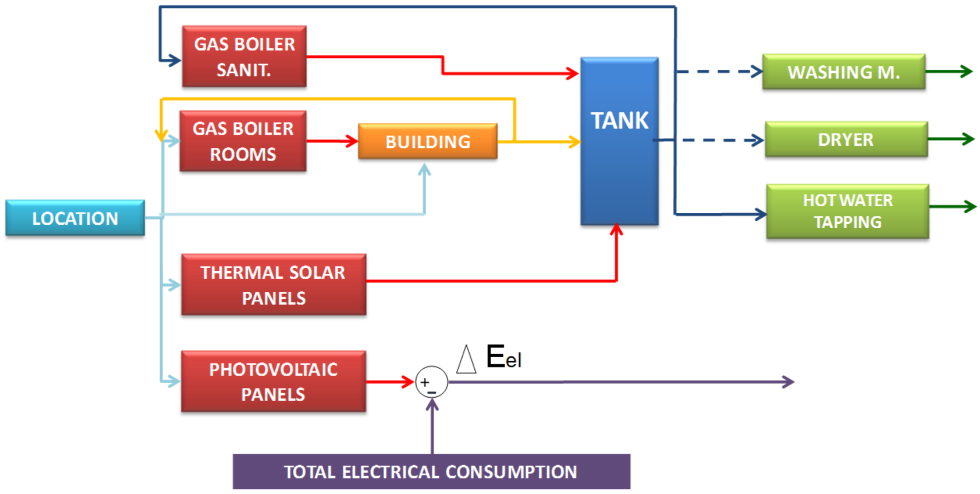


Figure 16: Example of the system architecture with the energy management of thermal devices.

In this research, it was investigated the energy lost through the hot drain water, e.g. during a shower. This problem is emerged during the analysis of all residential energy fluxes that highlighted that the energy related to the hot water is approximately the 12% of the total energy consumption. Part of this energy used in the bathroom is thrown away, while it could be recovered. Furthermore, from the analysis of the user's needs emerged that many consumers want to reduce the energy consumption, but they would not change their habits. This kind of service is a smart service, but does not involve the user's habits and leads only an initial cost. The service idea include a system to install in the bathroom able to save the energy wasted with the hot drain water; it includes a heat exchanger to recover thermal energy and a user interface that informs the user about their consumptions and savings. A scheme of the system is presented below (Figure 17).

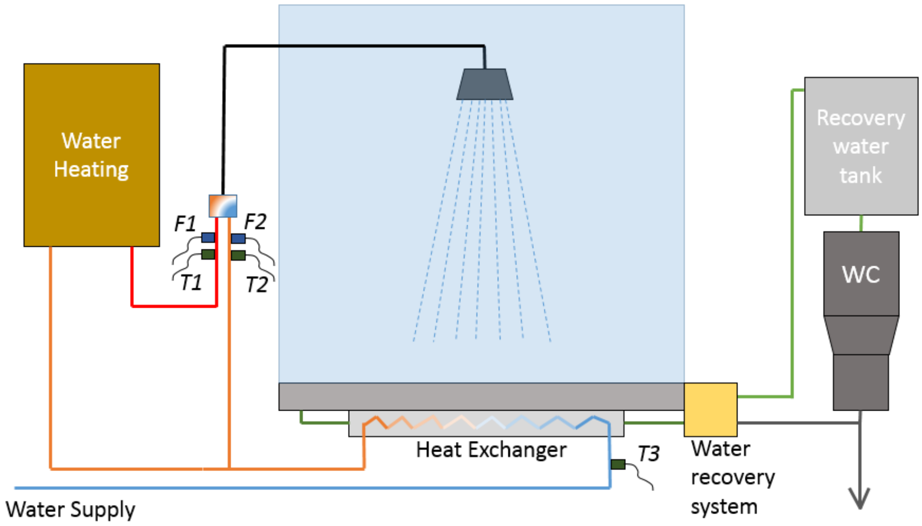


Figure 17: The system layout to provide the described service.

The three described services will be tested in cases study that will be presented in the Chapter 6.

4.6 The Modeling Tool

The Modeling tool is an instrument with an interactive interface able to generate the home configuration to simulate; furthermore, it permits to adapt the detail of the input data on the base of the user needs and skills. The use scenario includes devices, user habits, and relationship between them and with external entities. This section describes the operation of the Modeling tool that is the organization of its interface, how it interacts with the knowledge base and the use-case design process. The goal of this tool is to guide the user towards the modeling of the home scenario that he/she wants to simulate. It allows the devices selection and the boundary conditions definition to reproduce as faithfully as possible the real use case.

Currently, the Modeling tool considers the most common electrical and thermal home devices, renewable energy production systems, electrical and hot water storage systems, the shell of the house, data of the geographical area. The devices can be selected from appropriate menus that show data necessary to describe their technical characteristics and dwellers habits of use. The generated output is sent to the simulation tool and it allows the reconstruction of the building's energy behavior.

The principal characteristic of the Modeling tool is to facilitate and speed up the process of the scenario definition. In fact, all data could be directly managed in the Simulation tool, but this would require the knowledge of programming language and longer times for the data entry. For this purpose, in the Modeling tool, the user finds a user-friendly interface and he/she has the possibility to display the information at different levels of detail. Furthermore, the Modeling tool offers the opportunity to use innovative features that perform the auto filling of some data. They are very useful when a user does not know some parameters or for fast simulations that do not require a high results accuracy (e.g. simulation for statistical evaluation, simplified simulation for inexperienced users). The modeling tool is a knowledge-based tool and it is linked with the knowledge gained during the processes of data research and elaboration (paragraph 3.1) where there were defined the rules that identify the links between the considered parameters.

4.5.1 Overview of the Modeling Tool

The tool is built in Microsoft Excel environment and its interface is organized in four sections: Start page, Electrical devices, Thermal devices, Building envelope and Geographical area. The peculiarity of the Modeling tools is the generation of a usage scenario starting from some simple input data that even a non-expert user can understand (Figure 18).

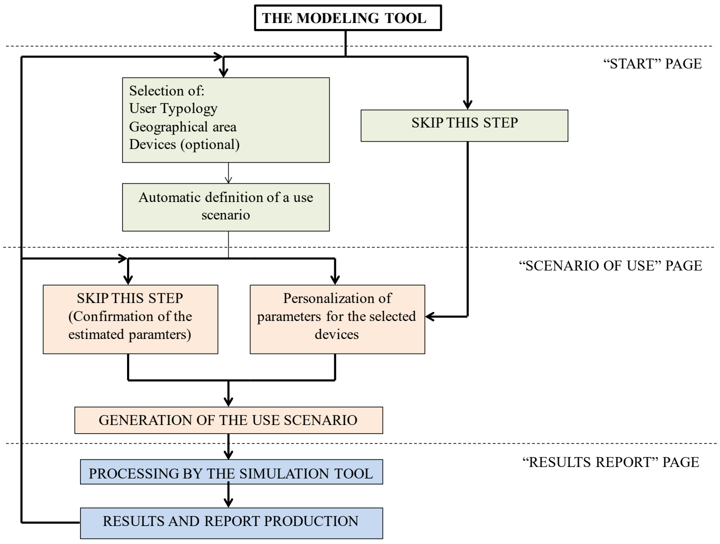


Figure 18: The Modeling tool's workflow.

The "Start page" section is a simplified user interface that contains the parameters related to the user typology, the building envelope, the geographical area and the devices to simulate (Figure 19). In an easy way, the user can define basic parameters that already allow defining an average scenario of use. From these simple input data, the Modeling tool generates an automatic compiling of the other sections in which all devices and related data involved in the use scenario are presented in details. Despite this function, before the simulation the user can decide to modify personally each single parameters created or to leave those inserted automatically, but also to activate devices that were not selected.

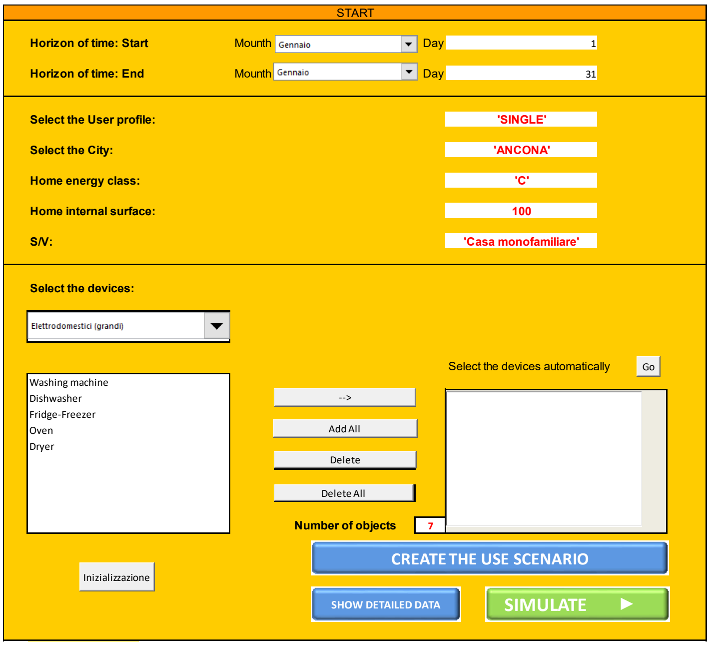


Figure 19: The start page of the Modeling tool.

The use of the Start page is not indispensable and the user can directly start working in the other sections. Key parameters are the user typology (e.g. family) and the city of residence, which already allow to define an average scenario of use, i.e. which devices are statistically present in a house for that area and how the selected consumer uses them. The device section is not necessary, in fact, it is also possible to insert the devices in an automatic way based on the user profile and the geographical area (the town is associated with a country, and then it is considered the diffusion of the selected devices in that country). After the compilation of the fields is completed, it is possible to press the button "CREATE THE USE SCENARIO". The command triggers an internal process of the tool that retrieve from the database the information necessary to define the parameters of the devices in relation to the use case considered. Such data can be viewed accessing the other sections of the tool through the "SHOW DETAILED DATA" button. For each device, technical data related to its characteristics and those related to the user habits are shown. At this step, it is possible to customize them or to leave those eventually inserted automatically. It is worth to notice that when the user wants to define the use scenario in manual mode, he/she can access directly to the other sections of the tool, which of course, it will be empty.

The “Electrical device” section contains devices that for their operation involve mainly the electric energy. In this section, it is possible to select the small and major household appliances, the photovoltaic plant, the electrochemical storage, all consumer electronics devices and the electricity contract typology. For the household appliances, a weekly usage profile can be defined (Figure 20).

WASHING MACHINE - FAMILY 4 PEOPLE

Week profile: Energy label class: A

	Time of use: -1 = NO USE		Load:		Temperature:		Schedule start-end:			
Sunday	10,00	[h]	5	[kg]	60	[°C]	10,00	-	18,00	[h]
Monday	8,00	[h]	5	[kg]	40	[°C]	8,00	-	18,00	[h]
Tuesday	8,00	[h]	5	[kg]	40	[°C]	8,00	-	18,00	[h]
Wednesday	19,00	[h]	5	[kg]	40	[°C]	-	-	-	[h]
Thursday	20,00	[h]	5	[kg]	60	[°C]	-	-	-	[h]
Friday	20,00	[h]	5	[kg]	40	[°C]	8,00	-	18,00	[h]
Saturday	-1,00	[h]		[kg]		[°C]		-		[h]

WASHING MACHINE - ELDERLY COUPLE

Week profile: Energy label class: A

	Time of use: -1 = NO USE		Load:		Temperature:		Schedule start-end:			
Sunday	8,00	[h]	5	[kg]	60	[°C]	8,00	-	15,00	[h]
Monday	-1,00	[h]		[kg]		[°C]		-		[h]
Tuesday	8,00	[h]	4	[kg]	40	[°C]	8,00	-	15,00	[h]
Wednesday	-1,00	[h]		[kg]		[°C]		-		[h]
Thursday	11,00	[h]	4	[kg]	60	[°C]	11,00	-	15,00	[h]
Friday	-1,00	[h]		[kg]		[°C]		-		[h]
Saturday	15,00	[h]	4	[kg]	40	[°C]	-	-	-	[h]

Figure 20: Example of a weekly usage profile for a family with 4 people and an elderly couple. The section “Schedule start-end” is a configuration of a Smart Home service.

The previous image shows the weekly usage profile auto-filled for two different users’ typology related to a washing machine. As can be seen from the figures, the parameters differ mainly in time slots of use and frequency of use weekly. In fact, the elderly couple starts more cycles during the middle of the day, compared to the family who often uses the washing machine mainly during the evening. The “Schedule start-end” section refers to the service of Energy Management that allows programming the start of the device when the energy produced from renewable sources is available. The fields allow defining the time horizon in which the user wants to start the service.

As the washing machine, other devices have a cyclic and schedulable operation and for these product can be generated a weekly profile of use. Also electronics devices with a typical constant energy consumption are included in this section; the tables for the data input are slightly different. In fact, they require setting the days of use, the time to start, the time to stop and the power consumption.

At the bottom of the page there are tables related to renewable-energy production (photovoltaic panel) and storage (electrochemical battery). These systems can be set and managed to find the optimal solution for habits and necessities of a particular user in terms of costs and comfort. Obviously, it is necessary to set the energy tariff to make a correct evaluation, for this purpose the table related to the power contract is located below the just described tables.

The electrical devices currently present in the tool are: washing machine, dishwasher, dryer, oven, fridge-freezer, auxiliary devices (pumps), lightings, small household appliances, consumer electronics devices (console, PC, etc.), Photovoltaic plant and storage battery.

The “Thermal devices” section include the devices involved in the production and storage of the thermal energy. In this section, the user can set the HVACR and DHW devices, the thermal solar system, the user habits for the rooms and hot water temperatures settings. These devices have a continuous operation and they are strongly influenced by external parameters and by habits of the user (Hot water tapping, Set-point internal temperature, etc.); for this category of devices is not possible to define a clear scheduling. Regardless of the typology, all devices identified as “loads” are linked with storage devices (if included in the scenario) that act as a bridge between the loads and the renewable-energy production devices. The figure below (Figure 21) shows an example of input data required for a hot water tank.

WATER TANK					
Tank volume:	200	[l]	**Tset-point daylight hours:**	45	[°C] 7:00 to 23:00
Hysteresis from Tset-point:	5	[°C] (Tset-hysteresis)	**Tset-point night hours::**	45	[°C] 23:00 to 7:00
Tank thickness:	0,05	[m]	**Thermal conductivity:**	0,023	[W/(mK)]

Figure 21: Main setting of the water tank (other parameters are not shown in this table).

The table shows the principal data displayed in the Modeling tool for the water tank, further technical details concerning the geometry of the tank and the coils inside it can be edited in a separate section. In fact, for those devices that have a complex operating condition, it is created another section usable by users interested in a very detailed modeling. However, default data can be left in most cases.

For the renewable-energy production system, input data are mainly of a technical nature, in fact they refer to the plant size and its physical characteristics. An example is shown below for the solar panel; the image (Figure 22) shows the parameters that the user can set.

THERMAL SOLAR PANEL		
Panel surface:	2	[m^2]
Number of collectors:	1	
Max efficiency ETA_0:	0,74	
Panel dispersion coefficient K1:	4	[W/(m^{2}K)]
Panel dispersion coefficient K2:	0,012	[W/(m^{2}K^2)]
Absorption efficiency IAM:	0,929	
Orientation (from south):	0	[deg] sud->ovest positive direction
Tilt angle (from horizontal plane):	30	[deg]

Figure 22: Thermal solar panel main settings (other parameters are not shown in this table).

The solar thermal panel is linked to the hot water tank, in fact it transfers the heat produced through a coil, which are located inside the tank. The geometry of the coil is an example of parameter that are not visible in the “standard” input page of the Modeling tool, but that can be customized in an outdoor section.

The thermal devices currently considered are: hot water tank, gas boiler, heat pump (for rooms, hot water and air conditioning), solar thermal panel.

The “Building envelope and Geographical area” section involve the characteristics of the building envelope and the definition of the city in which it is located. It includes three different ways to define the building envelope that differ for the detail of the input data. The simplest way requires only two input data: the building year of construction and the building’s typology (Figure 23). Based on these two information, the tool recovers data in the database and produces a typical configuration of the building for type and year indicated. A second method, currently usable only for Italy, requires the energy efficiency class, the type of building and the floor area of the building. The third method permits to design the envelope in details and requires the following data: the surface of the elements, the thermal transmittance, the direction of the external element, the adjacent environment to any surface, the degree of infiltration air and the effect of thermal bridges. The tool inserts other parameters automatically.

CHOOSE THE METHOD OF CALCULATION	
Select the method:	**'TYPOLOGY AND YEAR'**
TYPE OF BUILDING - YEAR OF CONSTRUCTION	
Select the type of building	**'Apartment building'**
Select the year of construction:	**'1976-1990'**

Figure 23: Envelope data entry with the method “Typology and Year”.

Once the modeling phase is completed, it is possible to generate the use scenario through an output file readable by the Simulation tool. The list of information contained in the output file is summarized below:

- The selected devices and their technical specifications;
- The user habits and characteristics (e.g. how he/she uses such devices);
- The links between the selected devices (e.g. connection water tank-washing machine, water tank-gas boiler, etc.);
- The external parameters;
- The simulation’s horizon of time;
- The Energy management service.

Once the simulation is completed, the Modeling tool imports the output results produced by the Simulation tool and shows all data to the users. The visualization includes table and graphs understandable for the user that can, furthermore, makes comparison between different scenarios simulated. On overview of the output interface of the modeling tool will be shown in the paragraph 4.7.

4.5.2 The Modeling Tool's Architecture

VBA and database

The modeling tool is designed in Microsoft Excel. The tool uses the basic functions of the application Office and the programming language Visual Basic for Applications (VBA) through the "macro" of Excel, whose functions and concepts are the same as the standard Visual Basic application. The logical calculations have been created using some classic programming structures such as *If ... then ... Else*, *For cycles*, *While Loop cycles*, *Select Case strictures*, etc. Furthermore, other macros define the formatting of the Excel sheets.

The large amount of data that characterize the home environment must be well organized in databases from which the macros of the tool get the necessary information. The preliminary work was focused mainly in the construction of tables with the data described in section 4.4 including the relationship between users, devices, and external parameters. In fact, the first version of the Modeling tool was able to generate the scenario of use, but it was a static program without versatility for the user. It means that the tool required all data of all the considered devices, so the non-expert user was not able to perform a simulation without knowing technical data of products and information about the home envelope. Furthermore, it required many time to insert manually the data related in all fields, so it was not easy to make fast simulations. Obviously, if the user want to produce a very accurate simulation defining all aspects of all devices, it will be necessary to spend time in the data input phase. For this purpose, it was decided to develop functions able to help the user in the creation of the use scenario that is the data input. Subsequently, tables for the management of all the devices were built (Figure 24) and, finally, specific functions have been developed to add new devices in the database. That function has been inserted with aim to have a scalable and always updated program since, as already described in Chapter 2, home automation and more generally technology are always evolving. In this part, there are not described the VBA code for reasons of space and because the detailed description of the work done for the creation of functions and databases are present in the work linked to the note [134].

Elenco dei vari dispositivi Aggiungi...

Elettrodomestici (grandi)	Elettrodomestici (piccoli)	Termico	Energia rinnovabile	Elettronica di consumo	Controllo ambientale
Elenco dispositivi	Elenco dispositivi	Elenco dispositivi	Elenco dispositivi	Elenco dispositivi	Elenco dispositivi
Lavatrice	Piano cottura	Caldaia	Fotovoltaico	Tv	Illuminazione
Lavastoviglie	Cappa cucina	Pompa di calore (ACS + Riscaldamento)	Solare termico	Console	
Frigo	Macchinetta del caffè	Climatizzazione estiva	Batteria di accumulo	PC	
Forno	Ferro da stiro			Hi-Fi	
Ascugatrice	Phon				
	Tostapane				
	Stampante				

Figure 24: Table containing the devices in the database.

Currently, the language of this section of the program is Italian. The button "Aggiungi" or “Add” is the module control button and opens an Excel Userform that allows inserting a new device by typing the name and choosing the device category between those listed.

Figure 25: Flow chart of the macro to insert a new device. It starts from the Userform and then the device is displayed in the “CLASSES DATA” sheet.

Once the device is inserted in the database, it is automatically displayed in the excel sheet called "CLASSES DATA" where there are the devices’ tables containing data related to devices operation and their statistical habits of use by the consumers. In the database, the devices are grouped in devices’ classes, so when a new device is added, it has to be plugged into the correct category. For this purpose, it was written a control condition to avoid incorrect entries of devices. All data of the inserted devices are upgradeable and their type of use changeable. All devices can be replaced with others if no longer needed.

The interface's functions and the design strategy

The interface is one of the most important elements of any program. The programmer must be proficient in building it according to the complexity of the tools and the experience of users who will use it. Much time has been devoted to these aspects to make the interface intuitive and easy to manage, as well as to ensure a good simulation for the user. The aim was to build a user interface adaptable to the user typology, experts and non-experts.

With the aim to have an interface usable by all people, it is designed the "Start page" described in paragraph 4.5.1. It is designed to perform a fast and easy simulation, because with a small number of data input, it permits to simulate a home configuration of use. The peculiarity of the tool is the possibility to execute an auto-filling of the data required to produce the configuration of use, which is the output of the Modeling tool and the input of the Simulation tool. Thanks to a restricted number of basic parameters that the user has to provide, the tool is able to automatically generate the home scenario.

It is possible to identify three main sections in the interface of the "Start page":

- Time section, it defines the simulation time horizon;
- User and home typology, containing information about the user class his/her home;
- Devices section, where can be selected the various devices of the home environment.

Before to start a new simulation, it is useful click on "Initialize" button: it will erase all traces of the data generated by previous simulations.

The energy required and many other variables are strongly influenced by the climate, hence the simulation's horizon of time is a parameter of primary importance. This part of the interface allows defining such information by choosing the month and the day of start/end of the simulation by a specific Excel combobox. Thanks to proper functions, the tool recognize the month and its number of days (February is composed by 28 days, in fact leap years are not considered). A special validation function ensures that the inserted time horizon is correct.

The selection of the home typology permits to reconstruct the envelope of the home. This section define the home envelope with a simple data input, such as: the available home surface, the energy class and the type of home (terraced house, single house, etc.). This section does not involve particular function, but it permits to presents the information in an easy way understandable by the novice user and then converts automatically the data in the format required by the Modeling tool.

The definition of the user typology is one of the most important parts, because it is linked with the devices as it defines their profile of use. Thanks to specific functions, the tool takes in the database the devices' data according to the user profile provided.

The selection of the city is another important parameter as it is linked with the weather data. In fact, the variable "city" permits to access in the database and load the weather data related to the selected city.

The "Device selection" area is dedicated to the selection of devices that the user wants to involve in the simulation (Figure 26). This part is very easy to use for the user, but it hides many complex functions that permit to generate an accurate scenario of use. In the interface it is possible to distinguish different elements (Figure 26): a "combo box" for the device category selection (A), the devices in the database for the selected category (B), the commands to add/delete devices (C), a "list box" to show the chosen devices for the simulation (D) and, finally, a command for the automatic insertion of the devices (E).

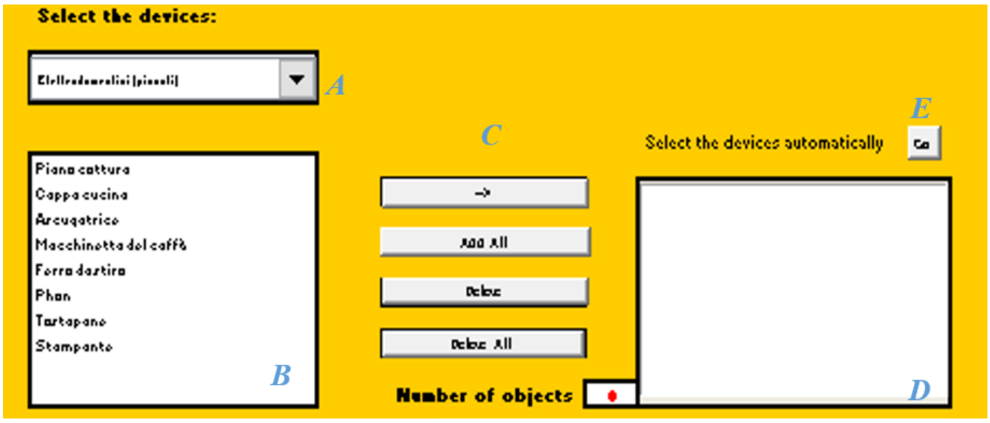


Figure 26: The "Device selection" area.

The first operation to perform is the selection of the devices category, after the selection of the category in section B it will appear all the devices present in it. For this function, the tool operates in dynamic modes and it permits to the user to add new devices in the database or to delete the existing ones without problems of visualization. Furthermore, when the user add a device, it will disappear from the list box on the left (B) and it will appear in the list box on the right (D). The commands for the devices management are: insert a single device, insert all devices, delete a single device and delete all devices. An Excel "Msgbox" will appear in case of wrong selection by the user (e.g. the selection of an empty line). A counter shows the number of selected devices.

With the button "Select the devices automatically", the Modeling tool will choose the devices based on their average diffusion for the selected "User typology". In this case, the tool queries the database to provide the devices' list to add in the simulation. In fact, in the database there is a special table that collects the list of devices commonly found in the home for each user typology; it may be changed according to the future developments.

Once the input phase of the "Start page" is completed, the Modeling tool will perform an auto-filling of the input data for all the sections included in the defined scenario (Figure 27). A dedicated function was developed for this operation.

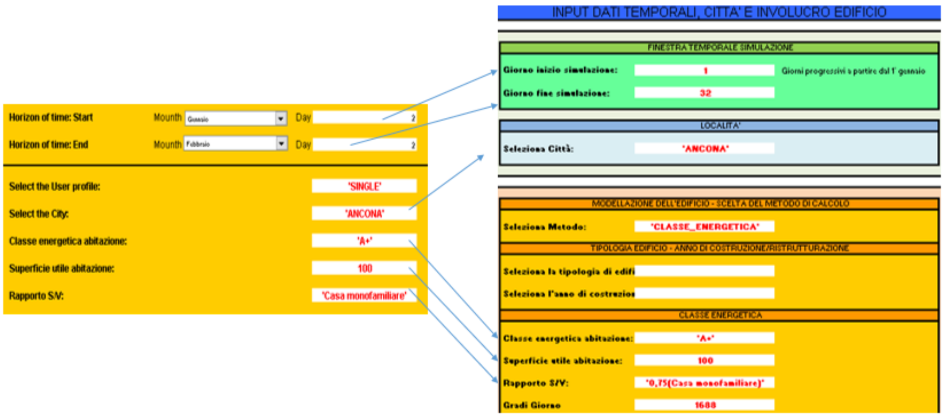


Figure 27: Link between the "Start page" and the other sheets of the tool.

The sheet "Electrical device" is described in the previous pages and includes all devices that have an operation strictly linked with an electric consumption. This section permit to configure al the "electric devices"; they are configurable manually, automatically (in the "Start page") or using both method, that is, the first input is performed by the auto-filling function and then details are adjusted manually. The affected features include the auto-filling of devices' data according to the selected user class and other information received in the scenario configuration step of the “Start page". To do this, it has designed a structure that initially activates a search of the selected devices in the “list box” (D) present in the "Start Page." Subsequently, with a "top-down" approach, the system starts from the main parameter (user class) and according to the chosen option it will recall the various related functions (one per category) for entering the data of the selected devices that are withdrawn from “classes-device tables” in "CLASSES DATA” sheet. The Electric devices have a different operating mode, so they are grouped in devices’ categories and the auto-filling is done using different methods. In fact, each major household appliances have a dedicated macro that manages their data, i.e. the parameters of a washing machine are different from the parameters of an oven. In particular, the fridge-freezer has a continuous operation while the other household appliances have a defined cycle that is strictly linked with the habits of the users. Consumer electronics devices and other small household appliances with a constant power consumption are managed by a macro that include functions suitable by all these products. Furthermore, the user can add and set manually new devices to simulate, in particular non-popular devices.

The thermal devices treatment is crucial since they have a high-energy consumption. As for envelope and for electrical devices, it has been created a separate sheet that collects the information of these systems. The considered devices are gas boiler, heat pump (for domestic hot water and rooms heating/cooling), solar thermal panel and hot water tank. The thermal system configurations are fully customizable by the user, consistently with technological feasibility. If the user use the simplified interface, also the thermal system can be automatically designed. In this case, the user can select the devices that want/have at home and based on the product selected the tool generate the commonly used configuration with those devices. The function that manages the auto-filling of thermal devices include the following system configurations:

- Gas boiler, it is the simplest residential solution; the system is not equipped with a tank for hot water storage, so rooms and domestic hot water are heated instantaneously by the gas boiler. The system can have radiators or underfloor heating.

- Gas boiler + Heat pump, the system includes the hot water tank within which are laid two coils, one on the upper part connected to the gas boiler and another in the bottom connected to the heat pump. Normally, both hot water heater and rooms heating are primarily operated by the heat pump and only in case of necessity the gas boiler is activated. In case of unfavorable weather conditions runs before the boiler and in extreme climatic conditions, the heat pumps remain turned off (Figure 28).

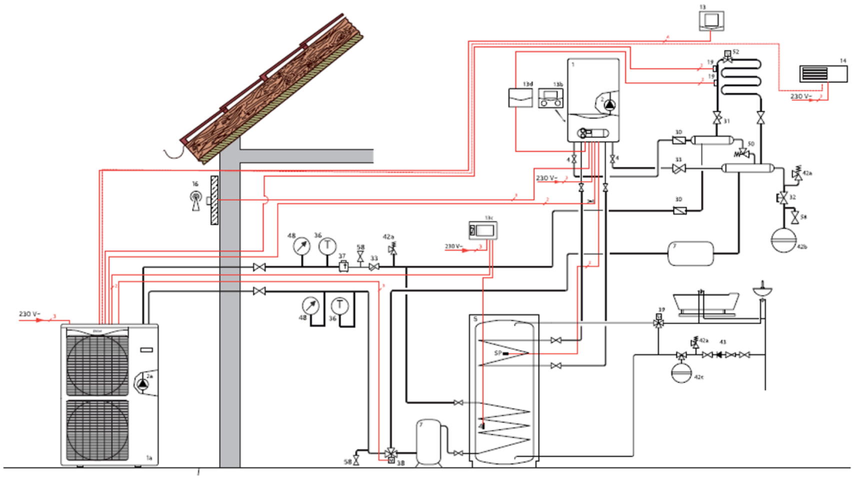


Figure 28: Example of system configuration with gas boiler and heat pump.

- Gas boiler + Solar thermal panel, also in this case the system includes the hot water tank with two internal coils, but now at the bottom there is connected the solar panel. The rooms heating is operated by the gas boiler.
- Heat pumps, there is the hot water tank with one coil at the bottom (its height can always be changed manually) connected to the heat pump and at the top it is placed an auxiliary electric resistance. The rooms heating is operated by the heat pump.
- Heat pumps + Solar thermal panel: there is the hot water tank with two coils; the heat pump is connected at the top while the solar thermal panel is connected at the bottom. An auxiliary electric resistance is situated at the top. The heat pumps performs the rooms heating.

- Solar thermal panel, this particular use case could be present in warm regions (e.g. summer holiday houses). It includes a hot water tank with a coil connected to the solar panel. The room heating system is not present.

- Gas boiler + Heat pump + Solar thermal panel, this configuration include the hot water tank with two coils. The coils at the bottom is connected with the solar panel. The coil on the top is connected both with the gas boiler and with the heat pump, the system automatically switch between the two according to the external and internal temperature. The same situation happens for the rooms heating that can be performed by the gas boiler and the heat pump alternatively (Figure 29).

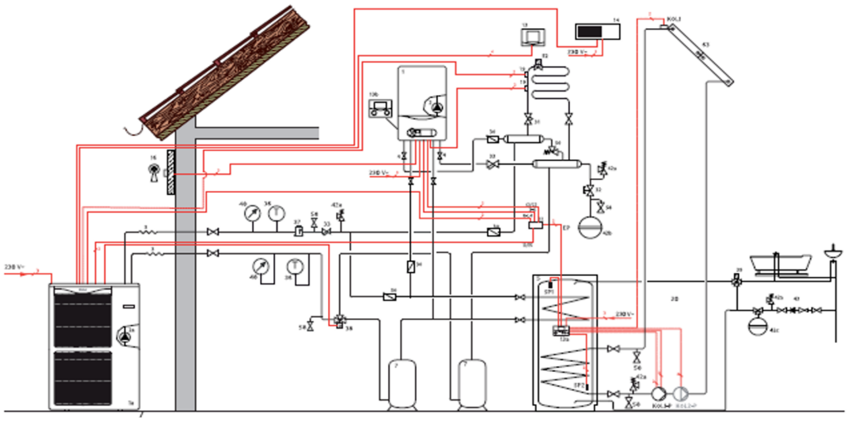


Figure 29: Example of system configuration with gas boiler, heat pump and solar thermal panel.

The function that manage the configuration of the thermal system include some Boolean logics, in fact the user in the "Start page" can select the devices just described and the tool, according to those devices, will create the configuration. In particular, the macro translates the selected devices in a variable composed by the concatenation of three numeric characters, each of which is "0" or "1" depending on the presence or not of the associated thermal device. For example, the first configuration with only the gas boiler is represented by vector "100" while the vector "111" represents the last configuration with all the devices selected. The string "000" means that no thermal devices are chosen; for this situation, a communication to the user is sent with the information of the absence of thermal devices.

The communication is written in an Excel Msgbox and then the routine is closed without executing instructions.

Some inputs parameters included in the sheets of the Modeling tool are constant and they are not directly linked with the parameters of the “Start page”, so they are preliminary set and they are not modified in the auto-filling. Furthermore, a separated user interface contains detailed data of some devices that can be useful by experienced users to perform an accurate simulation. Also this data are not involved in the auto-filling and they are preliminary set to default parameters.

4.7 The Simulation tool

The simulation tool allows running the use scenario defined in the Modeling tool. It contains the virtual models of real devices and it is able to reproduce their operation based on input parameters set in the previous phase. Its structure is designed to reproduce the conditions of the environment in which residential devices are located, so it considers the relationships that exist between devices and how they operation is affected by the external environment and user preferences. The simulation tool is able to reproduce the electric model, heat model and the water fluxes of the home environment. The simulation process involves an initial data import and recognition of products and systems that the user has selected in the Modeling tool. Then, an iterative process begins performing the calculation in dynamic regime of the values relative to the selected scenario within the chosen horizon of time. After this procedure, the tool produces results report including energy consumptions, operating costs, environmental impacts and the relative graphs. The results are transferred in an output file that the Modeling tool is able to load and to translate in table and graphs. Therefore, the user does not see the programming language, but work in the user-friendly interface of the Modeling tool.

In the following part, a description of the simulation tool structure is provided. The tool perform a dynamic building energy simulation with a fixed time step, which can be set before the start of the simulation. Currently, the tool was validated for a time-step from 5 minutes to 1 hour. The horizon of time can be set from one day to one years.

The considered devices are the same present in the Modeling tool; the equations that represents the considered devices are presented in the following paragraphs.
In the last part of this work, the Simulation tool has been linked with a multi-objective optimization tool with the aim to automatically find the best solution and improving the tool's potentialities. This is a work in progress and it requires more time to make it easily usable as, currently, it requires many manual settings that needs experience in the field of optimization problems.

4.7.1 Building envelope

The simulation tool includes equations to model the building thermal behavior; it uses the resistance-capacitance model with 1 resistance and 1 capacitance (1R1C) that is a simply dynamic lumped-parameter model able to provide a good description of thermal inertia caused by the envelope and internal mass effects [135]. The considered resistance is an equivalent resistance (R_{eq}) that derives from the calculation of each building element resistances. The heat flows considered in the capacitance (C_{build}) are the solar heat gains through the windows ($\dot{Q}_{sol}$), the heating and cooling load ($\dot{Q}_{hcl}$), heat lost/gained for air exchanges ($\dot{Q}_{air}$) and other sources ($\dot{Q}_{int}$) such as occupants' heat production and internal heat gains [136]. The solar heat gains through windows considers the solar irradiation during the daylight hours, the direction of the window exposure and the window solar factor (g_{gl}). The building is considered as a single zone temperature and the temperature calculation is performed by the following differential equation:

$$\frac{1}{R_{eq}}\,[T_{int}(t) - T_{amb}(t)] + \dot{Q}_{total}(t) = C_{build}\,\frac{dT(t)}{dt}$$

In the equation T_{int} is the internal temperature, T_{amb} is the external temperature, $\dot{Q}_{total}$ is the building net heating load and it is composed by the described heat flows:

$$\dot{Q}_{total}(t) = \dot{Q}_{sol}(t) + \dot{Q}_{hcl}(t) + \dot{Q}_{air}(t) + \dot{Q}_{int}(t)$$

4.7.2 Thermal storage

The simulation tool include the model of a stratified fluid storage tank with optional immersed heat exchangers and internal heaters. This component reproduces a cylindrical tank with a vertical configuration through 1-D transient heat balance equations. The fluid in the storage tank interacts with the fluid in the heat exchangers (through heat transfer with the immersed heat exchangers), with the environment (through thermal losses from the top, bottom and edges) and with up to two flow streams that pass into and out of the storage tank. The tank is divided into isothermal temperature nodes (vertical stratification) and it is possible to control the degree of stratification specifying of the number of "nodes". Each constant volume node is assumed to be isothermal and interacts thermally with the nodes above and below through several mechanisms: fluid conduction between nodes and through fluid movement (either forced movement from inlet flow streams or natural stratification mixing due to temperature inversions in the tank). Auxiliary heat may be provided to each isothermal node. Other options are the temperature set on heater thermostats and the overall heat transfer coefficient for heat losses, and the dimensional parameters for the storage and HX.

The model used for the simulation of the water tank behavior is based on equations that derives from the TRNSYS Type 60 mathematical reference [106], [137], [138] The 1-D model is used, since it has proved to produce good results in the temperature profiles calculation of vertical storage tank [139], [140].

In this type of storage tank, heat can be transferred into and out of the storage tank through 3 unique fluid flow streams. Two of the fluid streams mix with the storage fluid while the third flow stream transfers heat to/from the storage tank through an immersed heat exchanger (the HX fluid does not mix with the storage fluid). The natural convection from the heat exchanger to the fluid in the storage tank can be a difficult problem to solve. Compounding this problem is the fact that the effects of the heat exchanger fluid mass must be considered for these types of systems. The problem breaks down into the required solution of two coupled differential equations:

$$dT_{Tank}/dt = (Q_{in,Tank} - Q_{out,Tank})/C_{Tank}$$

$dT_{HX}/dt = (Q_{in,HX} - Q_{out,HX})/C_{HX}$

where $Q_{in,Tank}$ and $Q_{out,Tank}$ are functions of the ambient temperature, the inlet fluid conditions and flow rates, and the heat exchanger temperature, and $Q_{in,HX}$ and $Q_{out,HX}$ are functions of the inlet fluid temperature and flow rate to the heat exchanger and the tank temperatures. The detailed description of the method to solve the previous differential equation is shown in [106], [137], [138].

4.7.3 Electrical storage

The electrical storage is modeled with a linear formulation that can reproduce the operation of a Li-ion or Lead-acid batteries. The proposed formulation it was well described in [141]. The considered parameters are the battery state-of-charge (SOC), the battery capacity (C_{stor}), the internal loss (α), the input energy flow (E_{in}), the output energy flow (E_{out}), the efficiency in charging (η_{in}) and discharging (η_{out}).

$$SOC(t) = SOC(t-1)\,\alpha + E_{in}(t)\,\eta_{in} - \frac{E_{out}(t)}{\eta_{out}}$$

$$SOC(t) \leq C_{stor}$$

The SOC has not to drop below a minimum threshold (SOC_{min}) in order to limit premature battery deterioration from deep discharges. This value, however, can be modified in the modeling phase to represent different battery's typologies; e.g. Lead-acid batteries have a higher minimum SOC (about 40%) than LI-ion batteries (about 20%).

$$SOC \geq SOC_{min}$$

The maximum input/output energy flow ($E_{in,max}$, $E_{out,max}$) depends on the battery capacity and on the battery typology. These variables can be set in the modeling phase with the battery capacity.

$$E_{in} \leq E_{in,max}$$

$$E_{out} \leq E_{out,max}$$

4.7.4 Solar thermal panel

This component represents the thermal performance of different collector types using the theory shown below. The global thermal performance is determined by the number of modules and the characteristics of each module. The global incident radiation on the solar collectors is composed by the direct, diffuse and albedo contributions.

$$I_{global} = I_{direct} + I_{diffuse} + I_{albedo}$$

From the values of solar irradiation, azimuth angle, zenith angle (in the considered city in the time step) and collectors orientation (user data), it is possible to determine the overall radiation incident on solar panels through the appropriate trigonometric formulas. The model of the solar panel is based on the equation for proposed by Duffie and Beckman [142] for the calculation of the thermal collector efficiency. The efficiency (η_{sp}) is defined by its characteristic parameters η_0, a_1 and a_2. The first represents the performance of the panel when the average temperature of the liquid in the collector is equal to the ambient temperature. The other two are coefficients of thermal dispersion and responsible of efficiency decreases.

$$\dot{Q}_{sp}(t) = \dot{m}(t)\ c_p\ (T_{out}(t) - T_{in}(t))$$

$$\dot{m}(t)\ c_p\ (T_{out}(t) - T_{in}(t)) = \eta_{sp}\ I_{global}(t)\ S_c$$

where $\dot{Q}_{sp}(t)$ is the heat produced by the solar panel in the time step, $\dot{m}(t)$ is the mass flow rate, c_p is the water specific heat at the operating pressure, $T_{out}(t)$ and $T_{in}(t)$ are the outlet and inlet temperatures and S_c is the total panel surface. The parameter that characterize the solar collector is its efficiency that is defined as follow:

$$\eta_{sp} = \eta_0 - a_1 \frac{\left(\frac{(T_{in} + T_{out})}{2} - T_{amb}\right)}{I_{global}} - a_2 \frac{\left(\frac{(T_{in} + T_{out})}{2} - T_{amb}\right)^2}{I_{global}}$$

In the last equation the parameters T_{amb} represents the external temperature. The irradiance incidents on the solar panel could be affected by the angle of the sun's rays, so it is possible to define a parameter called IAM (Incident Angle Modifier) to take into account of the real collector behavior η_{sp}.

4.7.5 Photovoltaic panel

The considered parameters for the solar photovoltaic panel (PV) are the number of panels, the module surface, the orientation of the modules compared to south (azimuth, positive direction from south to west), the inclination of the modules to the horizontal (tilt), the efficiency of the system that include the cell's efficiency and the balance of system (BOS). The global solar irradiation is calculated as described in equation below.

$$I_{global} = I_{direct} + I_{diffuse} + I_{albedo}$$

The total electrical power produced by the array of PV modules will be:

$$\dot{Q}_{pv}(t) = \eta_{pv}\, I_{global}(t)\; n\; S_m\; BOS$$

where $\dot{Q}_{pv}(t)$ is the electrical energy produced in the time step, η_{pv} is the efficiency of the cell (it depends of the cell typology), n is the number of modules, S_m is the absorbing area of the single PV module. The calculation of the global incident radiation is shown in the description of the solar thermal panel.

4.7.6 Heat pump

The analytical model evaluates the heating performance of a small size system of air/water type in terms of COP in heating mode, while for cooling mode the identification parameter is the EER. The equation of COP is the following:

$$COP = COP_{fl} \times PLF \times DOF$$

The COP_{fl} represents the system's full load performances. The first factor (PLF) takes into account the effect that the partial loads have on the efficiency of the machine while the second coefficient (DOF) expresses the performance degradation that is observed when the liquidation of the frost formed on the outdoor heat exchanger occurs.

In the full load performances, the proposed model imposes a linear relationship, but adds the condition that the actual COP (at full load) is always greater than 1, as it happens for the ideal one [143].

$$COP_{fl} = 1 + \alpha_h \times (COP_{Carnot} - 1)$$

$$COP_{Carnot} = \frac{T_{hot}}{T_{hot} - T_{cold}} \approx \frac{T_{w,out}}{T_{w,out} - T_{out}}$$

COP_{fl} is the actual COP at full load, COP_{Carnot} is the COP of the reverse Carnot cycle, α_h is a parameter that takes into account all the irreversibility contained in the real cycle. The temperatures of the heat zone (T_{hot}) and the cold zone (T_{cold}) are approximate, respectively, with the water outlet temperature of the air conditioning circuit (Tw, out) and with the outside air temperature (Tout). Temperatures are expressed in Kelvin. For simplicity, the parameter α_h can be assumed equal to 0.31.

The performance at partial loads of heat pumps depend on the temperatures of the work cycle and on the heat demand of the building. The part load factor (PLF) considers the effect of the load on the performance, which is related to the load factor (PLR), i.e. the ratio between the power output and the power at full load [144], [145].

$$PLF = \frac{PLR}{\beta_h \times PLR + 1 - \beta_h}$$

β_h is a parameter related to the ratio between the power absorbed during periods of off and the power consumption during periods of on. For simplicity, the parameter β_h can be assumed equal to 0.73.

Regarding the defrosting cycles, the proposed model expresses the degradation in performance due to the defrosting operations as proportional to a climatic severity factor (CSF), which in turn depends on the temperature and outdoor air humidity.

$$DOF = 1 - \gamma_h \times CSF$$

$$CSF(T, rh) = CSF(T) \times CSF(rh)$$

$$CSF(T) = \begin{cases} 1 & if \quad T_{out} \le T_1 \\ \dfrac{T_0 - T_{out}}{T_0 - T_1} & if \quad T_1 > T_{out} > T_0 \\ 0 & if \quad T_{out} \ge T_0 \end{cases}$$

$$CSF(rh) = \begin{cases} 0 & if \quad rh_{out} \le rh_0 \\ \dfrac{rh_{out} - rh_0}{100 - rh_0} & if \quad rh_{out} > rh_0 \end{cases}$$

γ_h, T_0, T_1 and rh_0 are parameters that depend on the particular heat pump model. For simplicity, these arbitrary values can be used: $\gamma_h = 0.22$, $T_0 = 2.8$ °C, $T_1 = -0.5$ °C and $rh_0 = 72\%$.

4.7.7 Household appliances

Each household appliance has a different operation mode, consequently in the Simulation tool they are modeled with different equations and logics. The design of household appliances models started from two different points.

In the first case, the producer give us the device's operation logics that were transferred through the programming language in the Simulation tool. In this case, the devices is represented by equations and functions that simulate the device cycles.

In the second case, we started from a measurement campaign with the scope to find the cycle power profile. From the results obtained, the device's operating mode is reproduced.

For each household appliance, the Simulation tool include several devices typologies (e.g. different energy label class, different size, etc.), therefore the user is able to select a representative model of the product that he/her has at home or who would like to buy. In the market, there are many producers and each of them have several devices with different management logics, but it is worth to notice that the power profile is very similar for same products typologies. For this purpose, the design methodology for each household appliances started from a general product model that have been adapted to the different product variants present in the Simulation tool.

In this document, there will not provided neither the operation logics nor the cycle power profile as in many cases we do not have the authorization to their dissemination. Despite this, some general appliances power profile can be found in this report [126].

Chapter 5. Simulation Tool's Validation

This chapter shows the validation process of the Simulation tool. In particular, the model of each considered devices was first designed, than implemented in the tool and finally verified in cases study. In some cases, the validation process was made comparing the results produced by the Simulation tool with data obtained in measurement campaigns. In other cases, the Simulation tool results was compared with data produced by other simulation products that had previously been validated.

<u>Validation of thermal devices and external parameters</u>

The first validation report considers the thermal devices and it presents the simulation of a particular devices configuration made by the Simulation tool and another already validated software. The system configuration includes a building envelope, a boiler, a hot water tank, solar thermal panels, photovoltaic panels and requests of hot water. The hot water tank is connected with the heat users (hot water withdrawals) and with the heat generators (gas boiler and solar thermal panel). The photovoltaic panel produces electricity for the home and enters the surplus in the network. The rooms heating is made by the gas boiler. The load losses and the loss of heat along the connecting pipes are not modeled in detail and are considered with a constant parameter.

The validation procedure was performed in the following steps:

- The same time horizon have been set in the two tools;
- The following parameters have been set identically between the two models: the shape of the hot water tank, the geometry of solar and gas boiler coils in the tank, the heating system and the characteristics of the solar and photovoltaic panels. The properties of materials and fluids that constitute the system have been defined in a congruent manner.
- The characteristics of a simplified building model (in terms of overall transmittance) have been defined in a similar way;
- The control parameters in terms of set points are the same.

TEST 1:

The main common input parameters for both the simulations are listed below:

- Volume of the tank [L]: 200
- Set point temperature of the tank [°C]: 65
- Temperature of hysteresis of the tank [°C]: 2
- Hot water tapping profile: M
- Gas boiler standard power [kW]: 26,40
- Set point temperature of the rooms - daytime [°C]: 20
- Set point temperature of the rooms - nighttime [°C]: 18
- Temperature of hysteresis of the rooms [°C]: 0,4
- Solar thermal panel area [m2]: 2
- Effective photovoltaic panel area [m2]: 14
- Building effective area [m2]: 75
- Building energy class: G
- Building form factor (S/V): 0,43
- City: Ancona (Italy)

The following table shows the results obtained by the two software in a horizon of time of one year.

	Simulation tool	Dymola model
Total energy consumption [kWh]	15211	15251
Energy consumption for rooms heating [kWh]	13284	13304
Energy consumption for DHW [kWh]	1927	1947
Solar energy irradiation on solar panels [kWh]	2560	2390
Energy produced by solar thermal panels [kWh]	1478	1560
Energy loss from the tank [kWh]	480	483
Energy produced by photovoltaic panel [kWh]	3625	3906
Total electrical consumption [kWh]	298	294

Table 8: Output results compared between the two tools.

The percentage deviation in the first simulation is proved to be:

Ep $_{\text{Total energy consumption}}$ = 0.26%

Ep $_{\text{Energy consumption for rooms heating}}$ = 0.15%

Ep $_{\text{Energy consumption for DHW}}$ = 1.03%

Ep $_{\text{Solar energy irradiation on solar panels}}$ = 6.87%

Ep $_{\text{Energy produced by solar thermal panels}}$ = 5.40%

Ep $_{\text{Energy loss from the tank}}$ = 0.62%

Ep $_{\text{Energy produced by photovoltaic panel}}$ = 7.46%

Ep $_{\text{Total electrical consumption}}$ = 1.35%

The tools produce also graphs and, for example, it is possible to compare temperature profiles of the water inside the storage tank. The two profiles are very similar and this is reflected in the low error rate of dissipation of the tank.

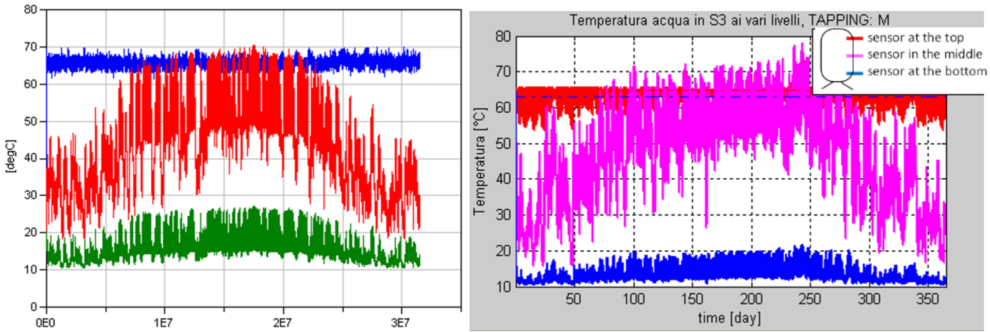


Figure 30: Water temperature in the hot water tank. Dymola model (left) vs Simulation tool (right).

TEST 2

The main common input parameters for both the simulations are listed below:

- Volume of the tank [L]: 200
- Set point temperature of the tank [°C]: 65
- Temperature of hysteresis of the tank [°C]: 2
- Hot water tapping profile: M

- Gas boiler standard power [kW]: 26,40
- Set point temperature of the rooms - daytime [°C]: 20
- Set point temperature of the rooms - nighttime [°C]: 18
- Temperature of hysteresis of the rooms [°C]: 0,4
- Solar thermal panel area [m2]: 2
- Effective photovoltaic panel area [m2]: 14
- Building effective area [m2]: 75
- Building energy class: C
- Building form factor (S/V): 0,43
- City: Nancy (France)

The following table shows the results obtained by the two software in a horizon of time of one year.

	Simulation tool	Dymola model
Total energy consumption [kWh]	6118	6319
Energy consumption for rooms heating [kWh]	3849	4001
Energy consumption for DHW [kWh]	2269	2318
Solar energy irradiation on solar panels [kWh]	2119	2059
Energy produced by solar thermal panels [kWh]	1208	1281
Energy loss from the tank [kWh]	429	395
Energy produced by photovoltaic panel [kWh]	3221	3462
Total electrical consumption [kWh]	191	171

Table 9: Output results compared between the two tools.

The percentage deviation in the first simulation is proved to be:

$Ep_{\text{Total energy consumption}} = 3.23\%$

$Ep_{\text{Energy consumption for rooms heating}} = 3.87\%$

$Ep_{\text{Energy consumption for DHW}} = 2.14\%$

$Ep_{\text{Solar energy irradiation on solar panels}} = 2.87\%$

$Ep_{\text{Energy produced by solar thermal panels}} = 5.86\%$

$Ep_{\text{Energy loss from the tank}} = 8.25\%$

$Ep_{\text{Energy produced by photovoltaic panel}} = 7.21\%$

$Ep_{\text{Total electrical consumption}} = 11.05\%$

In conclusion, from this analysis can be extracted these consideration:

- The Simulation tool is efficient under the simplifying assumptions with which it was built. It is able to consider a considerable amount of devices and variables; therefore, it would be impossible to achieve precision of an ad hoc system developed for specific functions. In particular, the instrument is suitable to perform energy balances;
- It is an optimal solution in the analysis of specific case studies and in particular in the assessment of the most suitable home setup. In fact, it is able to reproduce the real home configuration of the particular user in terms of user's habits and devices and envelope characteristics.

<u>Validation of the heat pump model</u>

In the last years, RSE [146] made numerous monitoring of different types of heat pumps to understand what are the current real performances of their installations. The validation activities described in this report takes data from one of these monitoring campaigns which covered a small system with an air/water heat pump [147], [148]. The validated model uses the same equations and logics included in the Simulation tools (the heat pump model is described in paragraph 4.7). In the equations of the simulated model, there are introduced three terms related to the full-load performance, performance at part load and the effect of the defrost cycles. The heat pump is characterized by the nominal power and three parameters: αh, βh and γh. In the validation, the values αh, βh and γh are, respectively, 0.31, 0.73 and 0.22.

In Table 10 and in Figure 31 comparisons between results of the virtual model and the experimental data are provided.

		COP/EER	
		Experimental data	Simulated data
1° measurement session	January	2,81	2,80
	February	2,99	3,01
	March	3,03	3,05
	April	3,49	3,44
	Total	**2,98**	**2,99**
2° measurement session	June	2,58	2,63
	July	2,68	2,68
	August	2,92	2,86
	September	2,62	2,93
	Total	**2,73**	**2,74**
3° measurement session	October	3,22	3,29
	November	3,26	3,31
	December	2,71	2,69
	January	2,87	2,86
	Total	**2,90**	**2,90**

Table 10: Comparison between the simulated and measured performances.

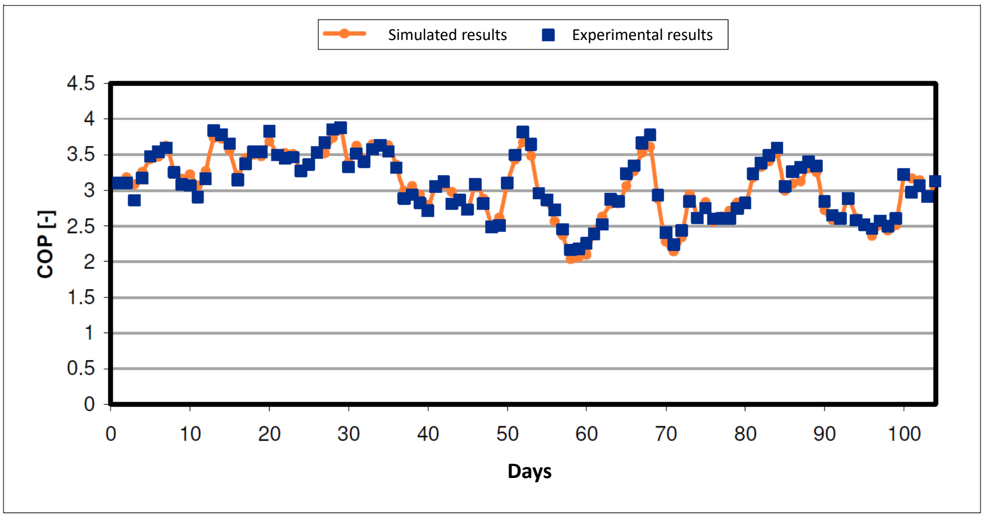


Figure 31: Comparison of COP between the analytical model and the experimental data (third monitoring session).

During the cooling season the coefficient of defrost operations is not considered and only two αc and βc parameters are present. The model calibration was performed with data from the second monitoring session. The resulting values for αc and βc are, respectively, 0.83 and 0.23. In Figure 9 and Table 6 is shown a comparison between model and monitoring data.

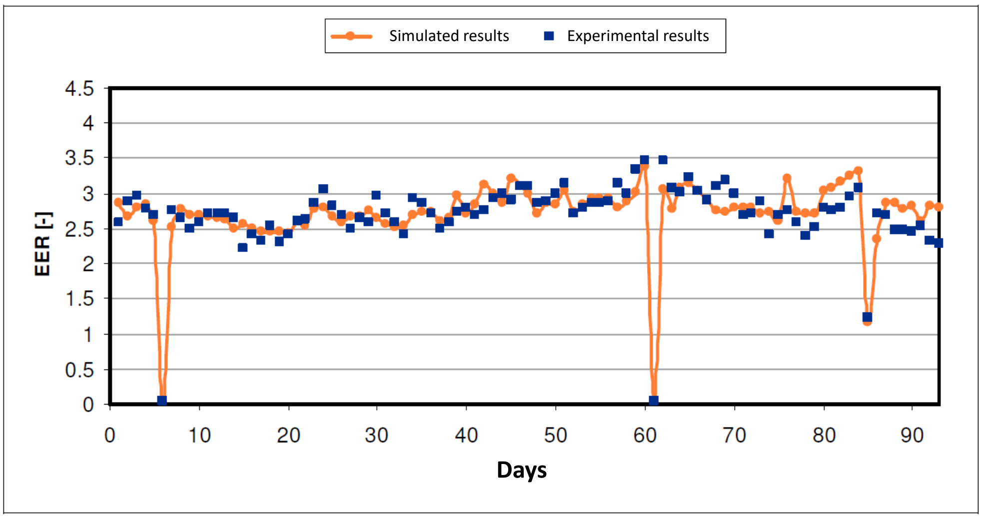


Figure 32: Comparison of EER between the analytical model and the experimental data (second monitoring session).

Electrical devices

The majority of this devices group are household appliances, but it includes also auxiliary devices (e.g. pumps for rooms heating and hot water) and other electronic devices with wider functions typologies. In the market, there are many companies that produces different models of the same product and each of them introduces different management logics. This means that each single product has a different cycle power profile and it is impossible to create a model for each of them, since the following methodology it was used.

- Design of a general device's model with variables that can be regulated to modify/adapt its behavior;

- Comparison between the simulated and the measured (real) power profile of the selected appliance. In this phase, it is crucial that the trend of the curves and the cycle duration are the same.
- Creation of the virtual product variants starting from the data sheets provided by the companies. Important parameters are the cycle duration, the maximum power and the cycle energy consumption.
- Final assessment of all modeled products that includes comparison between simulated data and data declared by companies or, when available, the comparison with the real measured consumption.

Many of residential electrical devices have a constant power consumption; some of them are used discontinuously (e.g. hairdryer, hood, etc.) while the other part have a continuous operation (modem router, printer, etc.). For these kind of appliances, a validation was not made as they are represented only through a constant that represent their power consumption.

Chapter 6. Cases Study

This chapter presents three cases study of energy-related services developed with the presented methodology. The cases study demonstrate the effectiveness of the services in terms of energy efficiency, reduced costs and reduced environmental impact. Different use scenarios are tested to show how different uses' habits are modelled and how the same smart environment brings different benefits for different use cases.

6.1 Case study 1: The Smart device scheduling

The use case considers a pre-defined smart home system, composed of a set of common devices, and three different use scenarios (user typologies) to simulate the smart home scheduling service in different contexts. The use case demonstrates how to use the proposed method and tool for validating a specific design product-service solution (the smart energy management service realized in the defined smart home system) for different users. Such service combines two functionalities: smart device scheduling and energy saving optimization, which are realized by managing the users' preferences and the adoption of photovoltaic panels and its interaction with the smart grid in different ways. In particular, the smart device scheduling service adopts the users' perspective and assigns high relevance to both the users' preferences and cost reduction; while the energy saving optimization applies optimization algorithms to reduce the global energy consumption as well as cost without taking into account user preferences. Simulation consists of the application and execution of the workflow depicted in Chapter 4. In both cases, the final scope is properly designing such service and concretizing the real benefits, mainly by finding out the economic benefits due to its adoption on different scenarios.

The modeling phase

The use scenarios consist of a common smart home infrastructure in three different cities and three types of "families" analyzed.

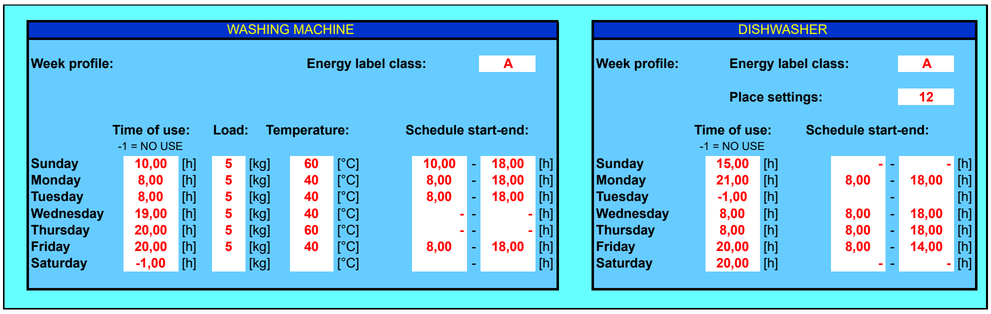
The smart home set of devices (smart home) is composed of:

- Washing machine: Front-loading, Energy rating A, Max load 6 Kg;
- Dishwasher (Family with 4 people): Energy rating A+, 12 place-settings;
  Alternatively a dishwasher for low loadings (Single and Couple): Energy rating A+, 10 place-settings;
- Boiler circulation pump: standard pump with 100 Watt power;
- Fridge-freezer: capacity: 290 L total net, Energy rating A+;
- Stand-by level of consumption: average data for the use scenarios (472 kWh per year);
- Photovoltaic panel for electricity production: no. 13 standard modules of 1.5 square meters (global area of 20 square meters) with 14% efficiency.

Three commonest use cases in Europe represents the modeled user's typologies:

- A middle-aged family composed of 4 people (a mother, a father, a son and a daughter), where parents' age ranges from 30 to 50 years old;
- An elderly couple, where both of them has over 65 years old;
- A young single, which age ranges from 24 to 40 years.

Each scenario has been represented by its habits in using the home devices. Figure 3 shows how use data are inserted into the modelling tool for the first scenario (middle-aged family) about washing machines and dishwasher. All cases are analyzed into three different cities of European countries: Ancona in Italy, Nancy in France, and Stockholm in Sweden. For each location, the commonest energy contract is considered by an average energy cost (euro per KWh), and the daily photovoltaic panel generation profiles are produced by the Simulation tool that uses data od solar irradiation taken from European databases. Figure 4 shows the daily performances of PV panels (profiles) in different months and the quantity of energy typically produced per week in different seasons.



WASHING MACHINE

Week profile: Energy label class: A

	Time of use: (-1 = NO USE)		Load:		Temperature:		Schedule start-end:			
Sunday	10,00	[h]	5	[kg]	60	[°C]	10,00	-	18,00	[h]
Monday	8,00	[h]	5	[kg]	40	[°C]	8,00	-	18,00	[h]
Tuesday	8,00	[h]	5	[kg]	40	[°C]	8,00	-	18,00	[h]
Wednesday	19,00	[h]	5	[kg]	40	[°C]	-	-	-	[h]
Thursday	20,00	[h]	5	[kg]	60	[°C]	-	-	-	[h]
Friday	20,00	[h]	5	[kg]	40	[°C]	8,00	-	18,00	[h]
Saturday	-1,00	[h]		[kg]		[°C]		-		[h]

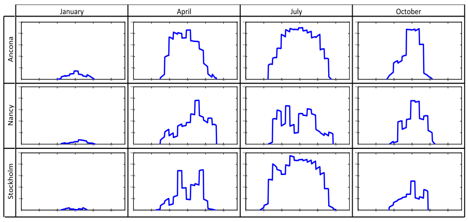
DISHWASHER

Week profile: Energy label class: A

Place settings: 12

	Time of use: (-1 = NO USE)		Schedule start-end:			
Sunday	15,00	[h]	-	-	-	[h]
Monday	21,00	[h]	8,00	-	18,00	[h]
Tuesday	-1,00	[h]		-		[h]
Wednesday	8,00	[h]	8,00	-	18,00	[h]
Thursday	8,00	[h]	8,00	-	18,00	[h]
Friday	20,00	[h]	8,00	-	14,00	[h]
Saturday	20,00	[h]	-	-	-	[h]

Figure 33: Use scenarios for the simulation (e.g. middle-aged family).



SEASON	ANCONA PV energy produced [kWh/week]	NANCY PV energy produced [kWh/week]	STOCKHOLM PV energy produced [kWh/week]
Winter (January)	30,92	19,12	14,14
Spring (April)	109,42	72,61	86,5
Summer (July)	151,86	99,19	152,37
Autumn (October)	54,77	37,32	38,42

	ITALY	FRANCE	SWEDEN
Electricity price [€/kWh]	0,23	0,15	0,21

Figure 34: PV panel performance for the three locations analyzed in the use case.

It is worth to notice that the living place not only influences the energetic performance of the photovoltaic panels, but also determines the living style and the users' habits in using the home devices (average washing cycles per week, devices connected to the network as stand-by, etc.). From the economic viewpoint, all scenarios do not consider any energy efficiency incentive, because incentives differ from different countries and change from year to year. In this way, results are more objective and comparable, and are also conservative as real benefits for final users will be greater at least, never smaller.

The service simulation: results and discussions

The Simulation tool allows investigating the effect of the smart home energy management service on the three users' typologies (middle-aged family, elderly couple and young single) in the considered locations (Ancona, Nancy and Stockholm). For the present use case, simulation is executed in three different conditions:

- AS-IS condition: it represent the actual condition (so people living in a smart home properly arranged, but they do not exploit the energy management service);
- Scheduled condition: users exploit the smart home energy management functionalities, and in particular they apply the smart device scheduling;
- Optimized condition: users fully use the smart home energy management service also by using its optimizations tools, which proceed with iterative analysis for optimizing the energy consumption by scheduling the devices' functionalities according to the system algorithms. This condition brings the greatest benefits but users cannot freely act on device settings.

Analyses are carried out on daily, weekly and yearly lifespan. Hereafter, the weekly results are presented because they better highlight the benefits for final users in different seasons Figure 36. Figure 35 shows how the device scheduling function acts. It compares the energy consumption profile in the three analyzed conditions for the use scenario "elderly couple living in Ancona on Monday in October". The diagrams show the energy profile produced by the PV panel (blue line), the washing machine consumption profile (red line), the dishwasher consumption profile (green line), and the other systems (light blue line below).

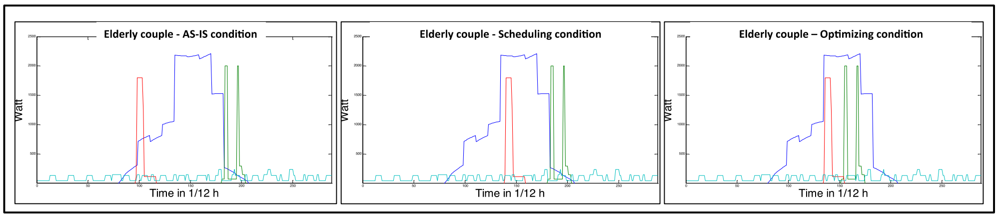


Figure 35: Devices daily scheduling in the scenario "Elderly couple in Ancona in October".

WINTER WEEK

	Condition	Electricity from the grid [kWh]	Electricity from PV panel [kWh]	Expenditure [€]	Saving [€]	User choice
FAMILY	AS-IS	21,70	6,29	4,99	-	***
FAMILY	After Sched.	18,18	9,81	4,18	0,81	*
FAMILY	Max	16,32	11,67	3,75	1,24	[illegible]
COUPLE	AS-IS	15,83	6,10	3,64	-	***
COUPLE	After Sched.	13,81	8,12	3,18	0,46	*
COUPLE	Max	13,00	8,93	2,99	0,65	[illegible]
SINGLE	AS-IS	14,30	5,38	3,29	-	***
SINGLE	After Sched.	12,48	7,20	2,87	0,42	*
SINGLE	Max	11,68	8,00	2,69	0,60	[illegible]

SUMMER WEEK

	Condition	Electricity from the grid [kWh]	Electricity from PV panel [kWh]	Expenditure [€]	Saving [€]	User choice
FAMILY	AS-IS	12,22	15,77	2,81	-	***
FAMILY	After Sched.	9,10	18,89	2,09	0,72	*
FAMILY	Max	6,16	21,83	1,42	1,39	[illegible]
COUPLE	AS-IS	6,82	15,11	1,57	-	***
COUPLE	After Sched.	5,66	16,27	1,30	0,27	*
COUPLE	Max	5,14	16,79	1,18	0,39	[illegible]
SINGLE	AS-IS	7,56	12,12	1,74	-	***
SINGLE	After Sched.	6,47	13,21	1,49	0,25	*
SINGLE	Max	5,16	14,52	1,19	0,55	[illegible]

SPRING WEEK

	Condition	Electricity from the grid [kWh]	Electricity from PV panel [kWh]	Expenditure [€]	Saving [€]	User choice
FAMILY	AS-IS	15,33	12,66	3,53	-	***
FAMILY	After Sched.	11,68	16,31	2,69	0,84	*
FAMILY	Max	8,90	19,09	2,05	1,48	[illegible]
COUPLE	AS-IS	9,40	12,53	2,16	-	***
COUPLE	After Sched.	7,53	14,40	1,73	0,43	*
COUPLE	Max	7,03	14,90	1,62	0,55	[illegible]
SINGLE	AS-IS	9,35	10,33	2,15	-	***
SINGLE	After Sched.	7,93	11,75	1,82	0,33	*
SINGLE	Max	6,88	12,80	1,58	0,57	[illegible]

AUTUMN WEEK

	Condition	Electricity from the grid [kWh]	Electricity from PV panel [kWh]	Expenditure [€]	Saving [€]	User choice
FAMILY	AS-IS	19,04	8,95	4,38	-	***
FAMILY	After Sched.	15,43	12,56	3,55	0,83	*
FAMILY	Max	13,55	14,44	3,12	1,26	[illegible]
COUPLE	AS-IS	13,55	8,38	3,12	-	***
COUPLE	After Sched.	11,62	10,31	2,67	0,44	*
COUPLE	Max	10,39	11,54	2,39	0,73	[illegible]
SINGLE	AS-IS	11,92	7,76	2,74	-	***
SINGLE	After Sched.	10,83	8,85	2,49	0,25	*
SINGLE	Max	9,28	10,40	2,13	0,61	[illegible]

Figure 36: Benefits comparison between users' typologies in the four seasons in Ancona.

The AS-IS condition in Figure 35 represents the current situation; the scheduling condition is obtained by adopting the smart device scheduling and taking into account the user preferences; the optimizing condition maximizes the environmental and cost benefits by exploiting specific programming algorithms (they allow maximizing both sustainability and money saving). Figure 36 shows the detailed results for the three users' typologies in different scenarios located in Ancona in four weeks during the year representing different seasons. Benefits are expressed by considering the money saved. Figure 37 summarizes the most significant results and compares the benefits for the use scenario "middle-aged family". Analyses consider a lifespan of one week. Table on left compares savings obtained in different countries and in three simulation conditions in autumn; table on right shows the same results in winter.

The simulation results highlight the benefits for final users for the selected use case. They demonstrate the use of the proposed tool for the first objective: quantify the effectiveness of a certain service realized into a smart home thanks to the simulation on different scenarios. The tool can be also used to compare different smart home design alternatives for a specific scenario or target markets (e.g. young people living alone, elderly people, etc.) by service tailoring and optimization according to their habits and the impact of environmental conditions (e.g. solar irradiation, typical users' behaviors, etc.).

Finally, the use case highlights the features of the proposed tool: flexibility, thanks to the ability to model both smart home environments and use scenarios; modularity, as the smart home reference model can be improved by adding new tools; personalization, due to the high level of customization of service functionalities and the wide range of users that can be created and simulated.

It is worth to notice the proposed case study is a starting point to validate the approach, but the analysis can be extended also to more complex systems, where the benefits of having scheduled and optimized scenarios can be bigger and more significant.

MIDDLE-AGED FAMILY in AUTUMN (weekly results)						
Conditions		Electricity from the grid [kWh]	Electricity from PV panel [kWh]	Expenditure [€]	Saving [€]	User choice
ANCONA	AS-IS	19,04	8,95	4,38	-	***
	Sched.	15,43	12,56	3,55	0,83	*
	Optimiz.	13,55	14,44	3,12	1,26	[illegible]
NANCY	AS-IS	19,63	8,36	2,94	-	***
	Sched.	16,77	11,22	2,52	0,43	*
	Optimiz.	14,17	13,82	2,13	0,82	[illegible]
STOCKHOLM	AS-IS	21,05	6,94	4,42	-	-
	Sched.	18,26	9,73	3,83	0,59	*
	Optimiz.	15,37	12,62	3,23	1,19	***

MIDDLE-AGED FAMILY in WINTER (weekly results)						
Conditions		Electricity from the grid [kWh]	Electricity from PV panel [kWh]	Expenditure [€]	Saving [€]	User choice
ANCONA	AS-IS	21,70	6,29	4,99	-	***
	Sched.	18,18	9,81	4,18	0,81	*
	Optimiz.	16,32	11,67	3,75	1,24	[illegible]
NANCY	AS-IS	23,52	4,47	3,53	-	***
	Sched.	20,65	7,64	3,10	0,43	*
	Optimiz.	20,52	7,47	3,08	0,45	[illegible]
STOCKHOLM	AS-IS	24,35	3,64	5,11	-	-
	Sched.	22,39	5,60	4,70	0,41	*
	Optimiz.	21,12	6,87	4,44	0,68	***

Figure 37: Comparison between benefits for “middle-aged family” in three countries.

6.2 Case study 2: A Complete Use Scenario

In this section, a complete real use scenario is reproduced and simulated, starting from the "START" page until the presentation of the results. The selected user profile is a Young couple living near the city of Ancona (Italy). The devices are selected manually on the "START" page and all the parameters entered by the automatic filling are confirmed without making changes. The aim of this case study is to show the benefits of the smart management on thermal devices. For this purpose, two different devices configurations for the same user profile (Young couple) are modeled, simulated and the results analyzed. For both simulation, the horizon of time runs from January 1 to January 31 (1 month).

Configuration 1

The following list shows the selected devices:

- Major household appliances: Washing machine, Oven, Fridge-Freezer, Hood;
- Small household appliances: Coffee Maker, Hair Dryer, iron;

- Consumer electronics: Notebook, TV LCD, Printer, Router WI-FI, game console;
- Environmental control: Lighting, Gas Boiler circulation pump;
- DHV and HVAC: Gas boiler;
- Renewable-energy production: None;
- Building: Single home with a surface of 180 m2 and energy class “C”.

The first configuration includes common residential devices and it represents the use scenario in the majority of residential use cases. In particular, the gas boiler is the unique thermal device that manages the rooms heating and the hot water production. There are not renewable-energy production devices. The buildings and the electrical appliances are the same in both configurations.

Configuration 2

The following list shows the selected devices:

- Major household appliances: Washing machine, Oven, Fridge-Freezer, Hood;
- Small household appliances: Coffee Maker, Hair Dryer, iron;
- Consumer electronics: Notebook, TV LCD, Printer, Router WI-FI, game console;
- Environmental control: Lighting, Gas Boiler circulation pump;
- DHV and HVAC: Gas boiler, Heat pump, Hot water tank;
- Renewable-energy production: Thermal solar panel;
- Building: Single home with a surface of 180 m2 and energy class “C”.

This configuration can also be seen through the scheme on the Figure 38. It reproduces the system architecture and the links between the interoperable devices that the Modeling tool creates in the design phase.

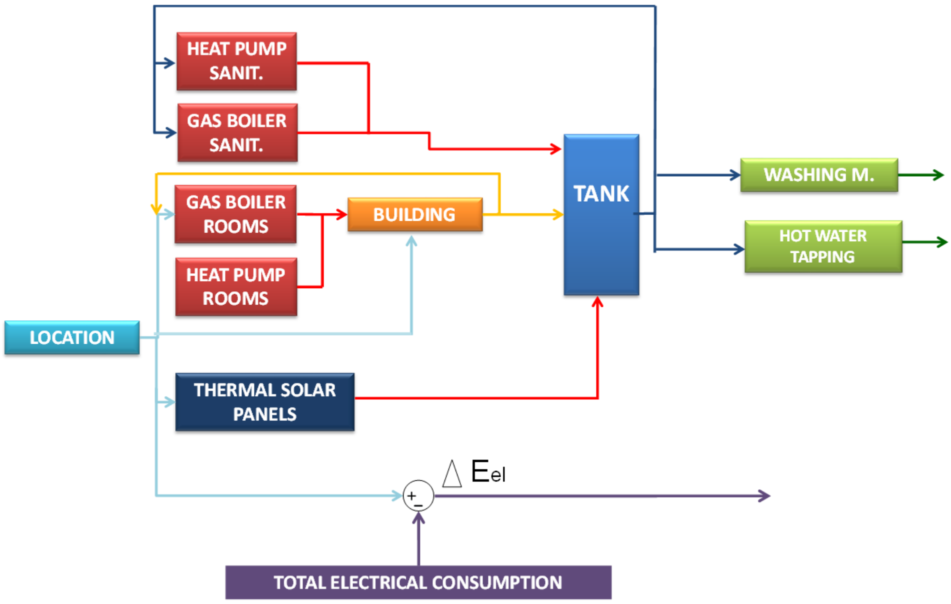


Figure 38: Scheme of the system architecture.

In this configuration, the hot water tank is the core of the system. Heat loads are connected to it as outputs (washing machine, dryer and hot water tapping) and heat generators are the inputs (gas boiler and solar thermal panel). The gas boiler is unique, but in the scheme is represented by two separate blocks, because the circuit for rooms heating is separated from the circuit for water heating. The pressure drops and the loss of heat along the connecting pipes are not modeled.

Comparison between results of the two configurations

The following table show the results of the two simulated scenarios. The results of the configuration 1 are shown in the Table 11 and the results of the configuration 2 are shown in the Table 12.

RESULTS OF THE CONFIGURATION 1	
Total energy consumption [kWh]	1798,67
Total electric consumption [kWh]	154,95
Total gas consumption [kWh]	1643,71
Total costs [Euro]	171,35
Electricity cost [Euro]	23,47
Natural gas cost [Euro]	147,88
Total CO2 eq. Emissions [kg]	449,61
CO2 eq. Emissions for electricity [kg]	74,84
CO2 eq. Emissions for natural gas [kg]	374,77

Table 11: Results produced by the Simulation tool for the first devices configuration.

RESULTS OF THE CONFIGURATION 2	
Total energy consumption [kWh]	603,83
Total electric consumption [kWh]	496,55
Total gas consumption [kWh]	107,28
Total costs [Euro]	108,90
Electricity cost [Euro]	99,25
Natural gas cost [Euro]	9,65
Total CO2 eq. Emissions [kg]	264,29
CO2 eq. Emissions for electricity [kg]	239,83
CO2 eq. Emissions for natural gas [kg]	24,46

Table 12: Results produced by the Simulation tool for the second devices configuration.

The results analysis of the case study focuses the attention towards the thermal parameters of the simulated scenarios. The analysis of the energy consumption showed a decrease of 1194.84 kWh of energy consumption between the first and the second configuration. In fact, in the configuration 2 there is an increase of electricity consumption and a sharp decrease of natural gas consumption. This is due to the introduction of the heat pump and thermal solar panels that use electric energy and have improved the efficiency of the heating. Of course, the introduction of these two systems joined to the hot water tank involve higher purchase costs. In this case study, it was decided to not consider these costs as the global investment assessment of the system must still be introduced in the tool. The total costs pass from € 171.35 of the first configuration to € 108.90 of the second configuration; the saving is € 62.45. The total saving of CO2 eq. is 185.32 kg as the scenario change from 449.61 kg CO2 eq. of the first configuration to 264.29 kg CO2 eq. of the second configuration. In particular, the results find a strong improvement of efficiency in the production of hot water; in fact, its energy consumption is reduced by 275.07 kWh (first configuration 332.19 kWh to second configuration 57.12 kWh) with a cost savings of EUR 19.03 and CO2 eq. savings of 50.14 kg.

6.3 Case study 3: A System to Save Energy from Shower Drain Eater

In order to simulate the behavior of a shower in various conditions of use, in a quickly and economic way, it was decided to implement the model of this system in the Simulation tool. The system is composed of a particular heat exchanger that can be put behind the shower to recover the energy of the drain water that is still warm when it is wasted. At the base of the model, there is an algorithm that allows obtaining in an easy way the energy contribution that is supplied from the heat exchanger, and then, it is translated into economic savings. It allows evaluating the contribution provided by the heat exchanger through the comparison between the condition 1 "shower with heat exchanger" and the condition 2 "classic shower". This model contains “blocks” that simulate the heating system, the supply pipes, the thermostatic regulator of the shower and the heat exchanger.

The simulation results

The following assessments are helpful in evaluating the effectiveness of the system performances under various conditions of installation and use. It is a useful adjunct to the user that before the purchase of the shower system can quantify benefits relating to his particular use case. The use scenarios consist in five different cities and five users' typologies analyzed.

The selected cities are Palermo (ITA), Ancona (ITA), Torino (ITA), Nancy (FRA), and Stockholm (SWE). These European cities were chosen at different latitudes, since with different climatic conditions that affect the performance of the annual feed water temperature. Among them, there are three Italian cities showing that even within the same country the operating conditions of the system can change. The following graph Figure 39 shows the annual trend of the feed water temperature in all the cities listed above.

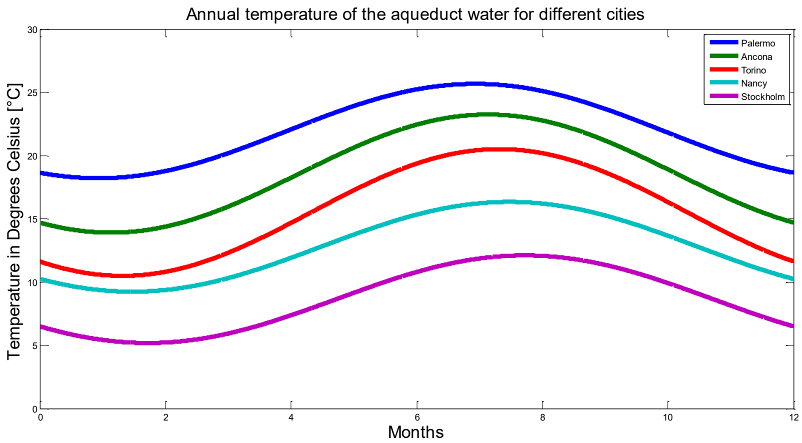


Figure 39: Annual trend of the feed water temperature in five European cities.

The considered typologies of users differ in the number of people present in the house and in their lifestyle, consequently they have different tapping profiles. The following data are based on information extracted from studies at European level, EU eco-design regulations for water heaters and questionnaires submitted to users. The parameter that mainly varies according to the type of user is the frequency of the showers, which leads to a greater or lesser consumption of water and energy. The weekly profile of use of the shower for each type of user is presented in the table below Table 13:

USERS TYPOLOGY			
User typology	**Weekly showers**	**Water flow [l/min]**	**Duration of a shower [min]**
Young Single	4	7,5	10
Elderly Couple	6	7,5	10
Young Couple	8	7,5	10
Family 4 people	14	7,5	10
Family 6 people	22	7,5	10

Table 13: Parameters related of the five user typologies.

Other parameters were considered fixed for all simulations. The table below Table 14 shows the assumptions made for these parameters.

OTHER PARAMETERS	
Efficiency (η)	0,7
Transient (tr)	40-50 s
Geometry	Parallel and counterflow
Heat transfer area (A)	0,05 m2
Position	Horizontal
Hot water set-point temperature (Thot)	60°C
Shower head water set-point temperature (Th)	40°C
Bathroom air temperature (Tbath)	23°C

Table 14: Values of the parameters considered in the use cases.

A first analysis considers the defined shower system installed in five different cities and in a selected use scenarios "Family with 4 people" to simulate the operation of the system in different context. This analysis shows what are the benefits for the same typology of user that lives in different European areas. For this purpose, the differences are highlighted in the Table 15 that demonstrates how the operation of the heat exchanger is dependent from the geographical area. The main factor that causes differences between the results is the external temperature and the solar irradiation that consequently affect the temperature of the feed water, in fact moving northward this temperature is lower as represented in the Figure 39.

Energy Saved in different cities for a Family with 4 people [kWh]						
Month	Weeks	Palermo	Ancona	Torino	Nancy	Stockholm
January	5	58,4	68,8	76,8	79,9	89,4
February	4	46,6	55,4	62,2	64,7	72,8
March	4	44,7	53,3	60,5	63,9	72,4
April	5	51,8	61,8	70,9	76,8	87,9
May	4	37,6	44,7	51,7	58,0	67,1
June	4	34,4	40,4	46,9	54,5	63,6
July	5	40,8	47,2	54,6	64,9	76,0
August	4	32,7	37,3	42,8	51,0	59,5
September	4	34,6	39,3	44,3	51,8	59,8
October	5	47,2	53,8	60,1	67,8	77,3
November	4	41,6	47,8	53,1	57,7	65,1
December	4	44,8	52,1	57,9	61,2	68,5
TOTAL		515,1	602,1	681,8	752,2	859,5

Table 15: Energy savings in five European cities at different latitudes.

The results demonstrate that, a lower temperature of the feed water leads to the recovery of greater energy in the heat exchanger, which is more efficient when there is a bigger temperature difference between the drain water temperature and the temperature of the feed water. It is worth to notice that the energy saved by the heat exchanger is more than the net energy recovered of a factor that is the efficiency of the heating system.

A second analysis considers the five selected categories of users and the city of Torino (IT) with the aim to show the differences in the operation of the shower system varying the habits of users (Table 16).

Energy Saved for different categories of users in Torino [kWh]						
Month	Weeks	Young Single	Elderly Couple	Young Couple	Family 4 people	Family 6 people
January	5	13,1	19,6	26,1	45,7	71,8
February	4	10,6	15,9	21,2	37,1	58,3
March	4	10,3	15,4	20,5	35,9	56,4
April	5	11,9	17,8	23,7	41,5	65,2
May	4	8,5	12,7	16,9	29,6	46,6
June	4	7,5	11,2	15,0	26,2	41,2
July	5	8,5	12,8	17,1	29,9	46,9
August	4	6,7	10,0	13,3	23,3	36,6
September	4	7,0	10,5	13,9	24,4	38,4
October	5	9,7	14,5	19,4	33,9	53,3
November	4	8,8	13,1	17,5	30,7	48,2
December	4	9,7	14,6	19,5	34,1	53,5
TOTAL		112,1	168,1	224,2	392,3	616,4

Table 16: Energy savings in the five considered categories of users in the city of Torino.

An economic assessment is useful to define the real benefits achievable for each typology of users. The analysis considers the net present value (NPV) during the ten years after the shower system installation with an initial price of 200 Euro (Figure 40):

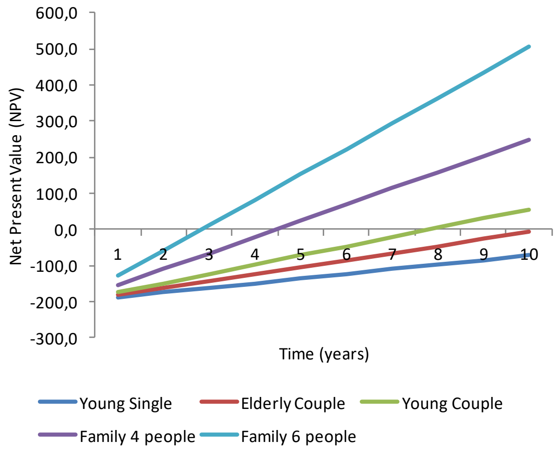


Figure 40: Net Present Value (NPV) calculated for the five categories of users.

The graph is based on data shown in the Table 16 of the city of Torino (IT) and evidences that the investment, at this initial price, is highly convenient for a family and on the contrary not profitable for a single. The result is a photography of the five extracted use cases in a selected city, but there are a huge quantity of data that influence the operating condition of the system and that are related to the particular use case. In fact, the tool is a useful help both for developer and consumers and the two previous analysis demonstrate how to use it for validating a specific design product-service solution for different typologies of users.

Chapter 7. Concluding Remarks

This paper presents an approach to model smart home environments and support service design by estimating the benefits for final users. It starts from the idea that the design of a smart home environment requires a holistic approach focusing on the users' needs by the use of an intelligence-based information management tools. For this purpose, the research proposes a structured approach to model the smart home complexity, and a simulation tool to model the smart devices' functionalities and behaviors as well as the use scenario considering location, user's lifestyle, and habits.

For first, it introduces a methodology to support smart home system design and improve information management in order to provide user-centred services. It adopts a user-centred design approach and promotes the creation of new services exploiting the smart devices interoperability. The method allows classifying smart home devices and data originated by different appliances and correlation them in order to define an information management model. Finally, such a model is adopted to drive system design and technologies benchmarking, and to define the intelligence-based services by a proper set of rules and algorithms. Thanks to the proposed model, smart home information can be easier extract, elaborated and exploited according to the users' needs and the service requirements identified. For each device class, the basic information to be managed are identified and associated to a system category.

Furthermore, the work focuses on the energy-related services and, in particular, it introduces knowledge base tools (the Modeling tool and the Simulation tool) able to simulate the energy flows of the buildings considering all the actors and their interaction rules. The developed tools can be used in different types of buildings, with or without renewable-energy production and storage systems, and in different use scenarios. Through the implementation of a knowledge base, both the novice users and professionals can produce an assessment of the energy flow inside the home. In fact, with a knowledge-based architecture, it is possible to adapt the analysis to the user needs and experience.

The Modeling tool is able to generate a use scenario in an easy way defining only few basic parameters, but also a detailed and complex analysis personalizing parameters of each single device. The Simulation tool allows simulating the use scenario defined in the Modeling tool reproducing the devices and system operation, their relationship and the influences of the external entities. It generates clear results reports with tables and diagrams with the possibility to make comparisons and the evaluation of the best solutions. With the proposed approach, it is possible to generate a residential building simulation quickly and without the knowledge of all complex required parameters.

The proposed tool is tested in three use cases simulating Smart Home energy management services. The use cases focus on modelling a set of common devices and executing some energy management functions for different scenarios. Simulation allows supporting smart home design and service functions' configuration for distinctive users' typologies in different European countries and quantifying benefits for final users.

Future works will consider a more detailed information asset for each device class and a wider classification by considering new devices that will be developed in the future, as well as will implement a smart home system prototype to test the planned functionalities and evaluate the service performances by usability and sustainability analyses.

Furthermore, other simulation tools will be developed to simulate and evaluate other Smart Home services.

Finally, in the final part of this work, the Simulation tool has been linked with a multi-objective optimization tool, but it requires improvements that will be done to make it easily usable and improve the tool's potentialities.

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