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DESIGNING AND SIMULATING SMART HOME ENVIRONMENTS AND RELATED SERVICES

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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 [Bertoldi et al. 2012]; secondly a lot of research recently focuses on smart device connectivity issues and information management models [Kofler et al. 2012] as well as energy efficiency architectures and services for the smart home [Torunski et al. 2012]. 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 [Papetti et al. 2013]. Contrariwise, the majority of the existing systems are usually strongly technology-oriented and focused on the single sub-system potentialities [Chen et al. 2009]. 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 behaviour is neither investigated nor detailed in literature. Some companies use simulation tools to optimize they own products separately, but when they are composed to create 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 [Lasierra et al. 2013].

For this purpose, the presented research defines 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 behaviour. 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 (Modelling 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's behaviour for a certain life span (daily, monthly, yearly). Then, a second tool (Simulation tool) allows simulating the behaviours and performance of the modelled smart home environment to support designers and engineers. Such tools can be adopted in different design stages:

a) 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 behaviour, 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;
b) 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.

The paper describes the tools application on a real use case that considers a simple set of interoperable devices (washing machine, dishwasher, fridge, heat pump, and some auxiliary systems), which intelligently cooperate exploiting the home area network. It is used firstly to optimize energy efficiency performances of single devices and, than, to simulate the home environment and the effects of an energy-control service on the basis of the reduction of total energy consumption and global cost for final users. 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.

2. Research Background

2.1 Smart home design

The smart home is a special place where smart devices are interconnected and interoperate to provide advanced services. Services can be oriented to the execution of automatic tasks or directly support the users' activities. In both cases they aim at generating some benefits for the users: energy saving, cost reduction, safety improvement, and more comfortable life in general [Tiiu and Kaisa 2004]. This concept of smart home implies creating a distributed infrastructure that makes different devices or sub-systems working together and manages the interrelations between them (e.g. smart appliances, home automation system, digital entertainment system, healthcare devices, surveillance system). Furthermore, smart device development imposes the management of a huge quantity of data: as a consequence information flow has to be well coordinated both inside the smart home and outward [Li and Yu 2011]. This issue becomes particularly important with the introduction of household appliances (washing machine, dishwasher, etc.) due to their complexity (i.e. numerous programs, settable functions, interaction with external home conditions and events).

The resulting infrastructure has been called Smart Home System (SHS) [Aiello and Dustdar 2008]. Traditionally, a SHS adopts a central architecture where the sub-system interconnections can be guaranteed by a residential gateway, which guarantees integration between devices and sensors differing in terms of connections and communication protocols, and serves as a bridge between the Home Area Network (HAN) and the external networks (i.e. Internet) [Cheng et al. 2012]. The residential gateway allows interoperability inside the HAN and creates an integrated environment with a lot of devices cooperating and exchanging data. Numerous SHS architectures have been proposed, but they lack in interoperability and are strongly technology-oriented [Perumal et al. 2009]. Indeed, in most cases the information exchange takes place vertically, so data flow from the single device to the gateway without communicating with other devices, or to the manager of its sub-system [Perumal et al. 2010]. It is mainly due to the wrong design approach adopted: indeed, single devices or sub-systems are designed separately without considering the high-level system. It obstacles exchanging data among all devices, fully exploiting system capabilities and potentials and finally offering integrated services. As a conclusion, a real SHS integrated design is still missing.

In this context, SHS design can be realized by adopting a holistic approach that considers all devices and a wide range of smart home functionalities [Papetti et al. 2013]. Such an approach will start from

the analysis of the high-level system functions and consider both the technological requirements and the users' needs and skills [Nazmiye et al. 2013]. Some studies explored smart home user-centred design, but they have some limitations: they usually focus on some design features, in particular the user interface [Wu et al. 2009]; they evaluate design by assessing performances and services offered by a specific device without considering high-level system functionalities [Meguire et al. 2005].
Contrarily, system interoperability is fundamental to enable exploiting the information generated or elaborated by all the smart home devices and create advanced services to fulfil the users' needs. In this context, a study explored the smart home user experience and highlighted the main characteristics of smart home users [Haines et al. 2005], but it remains at a theoretical level and does not support the design of the suitable technological infrastructure.

2.2 Information management for energy efficiency in the smart home

The introduction of the smart appliances within a home network pushed towards the definition of a proper information management system, able to mange their energy consumption and performances. Indeed, modelling the energetic behaviours of devices when integrated into a smart home is particularly interesting due to the high impact of the residential sector on energy consumption globally [Bertoldi et al. 2012]. It means understanding which functions a certain device is able to perform when connected to the network, what information can be sent, which commands can be received, and which functions can be enabled for energy efficiency.
In this context a first step is represented by the CHAIN project by CECED (European Committee of Domestic Equipment Manufacturers) [CECED], which faced device interoperability issues and established a preliminary application profile for connected home, and promoted the standard CENELEC (European Committee for Electro-technical Standardization) in 2007 (i.e. EN 50523-1 e EN 50523-2). After that, numerous projects all around the world focused on energy efficiency [Alam et al. 2012]. Most of them focus on energy management through data exchange within the home network and the smart grids, whereas other projects introduced standard rules for the information exchange between the users and the utilities. Furthermore, since smart home systems are usually finalized to provide services for final users, several energy efficiency services are analysed: e.g. energy monitoring, energy consumption estimation [Shin and Hwang 2012]. Some studies describe house occupant characterization, model the typical consumption profiles and adopt a rule-based management system for reducing consumptions [Bonino et al. 2012]. Other projects highlight the characteristics of the residential electric consumption by country, providing a database of average energy performance and behaviours for a set of device classes, which also comprehend use profiles and potential savings [MICENE], [REMODECE].
However, all energy-oriented projects usually focus only on the analysis, simulation and optimization of a specific function and do not consider interoperable tasks between all the devices connected to the home network nor exploiting the entire technological infrastructure. Also when energy-control services into an interoperable network have been proposed, there are some open issues regarding their effective implementation [Bansal et al. 2011].
As a conclusion, having a proper smart home architecture and defining standards for energy efficiency for networked devices are fundamental aspects to realize high-level energy-control services and exploit smart home capabilities. However, these aspects are studied separately so far.

3. Research approach for smart home modelling and simulation

The present research responds to the main challenge emerged from the analysis of the state of art: supporting design and simulation of smart home environments and related user-centred services. In particular the research adopts a joint approach to model the smart home and the behaviour of its interoperable devices, and simulate services by exploiting the device interoperability.
The proposed approach starts from the definition of high-level system architecture and the specific users' requirements, which are the underpinning concepts to create user-centred smart home products as well as services. After that, it models the interoperable environment by introducing an information management system able to manage the available data collected from all devices. Finally, it simulates the smart home behaviours in specific use cases (i.e. definition of the information flow, analysis of the

devices' interconnections, analysis of the home events or users' interaction, definition of the objectives, selection of the most proper management rules), and analyses the benefits by comparing the results obtained in different conditions, to find out the optimal solution and the relative management strategy. This approach has been adopted for energy efficiency but can be replicated similarly also for other objectives and functions (assisted living, comfort, etc.).

The process can be summarized into 5 steps:

- **Step 1.** Definition of the smart home environments, that consists of mapping all the devices connected with their characteristics and behaviours (e.g. washing machine with 7kg loading in A+ energetic class and touch display + mobile application);
- **Step 2.** Definition of the service objective (e.g. energy-efficiency and cost reduction);
- **Step 3.** Analysis of the user's needs in relation with a specific use scenario (e.g. elderly people living alone in France, young married couple with an active lifestyle in German, a young family with two little babies in Spain, etc.);
- **Step 4.** Modelling approach to create a reliable model of the smart home environment and the use scenarios;
- **Step 5.** Simulation and analysis of the benefits and costs by the proposed tools.

Step 1 is carried out on the basis of the technical sheets provided by the smart devices' manufacturers and / or in collaboration with the manufacturers themselves; the final scope is to extract all necessary information to properly model the smart home devices and appliances.

Step 2 usually depends on the context of use; this research focus on energy-efficiency.

Step 3 involves sample users to investigate their habits and behaviours by different techniques (e.g. interviews, questionnaires, and brainstorming sessions) and applies market survey when available. At the end, a list of users' needs is defined: it provides information about useful services supporting people in the specific context of use are defined.

Step 4 models a specific smart environment with the final aim to identify those functionalities able to satisfy the identified user's needs for the specific context of use in order to provide a certain service or properly manage the devices' functioning. For this aim, smart devices are identified and displaced in homogenous classes according to the typology, treated data, and home interaction modalities (i.e. Household appliances, Environmental control devices, Domestic Hot Water devices and Heating-Ventilation and Air Conditioning devices, Consumer electronics, General-purpose meters). Device classification for smart home has been described in a previous research work [Peruzzini et al. 2013]. Then, available data are grouped in different categories in order to elicit the relations between the information generated by the smart home devices and their functions. Information categories adopted in the research are:

- Product Identity number (PI), that refers to all information provided by the manufacturing company able to identify a certain device and its care or maintenance actions (e.g. datasheets, standard consumptions, etc.);
- Continuous Monitoring data (CM), that includes information characterizing the continuous monitoring of the device when it is turned on (e.g. energy consumption, water consumption, etc.);
- Control Parameters (CP), which refers to functional parameters characterizing the specific device, which are continuously analysed and compare with a set of target parameters (e.g. speed, rates, temperatures, etc.);
- State Parameters (SP), that regards data about the status of home devices and are used to monitor a particular scenario or to carry out device remote control;
- General data (GEN), that comprehends data generated by external entities and define the use scenario (e.g. building typology, home dwellings, fees of utilities, climatic conditions);
- Derived data (DER), that concerns data derived from post-processing elaboration and statistics analysis carried out by auxiliary systems (e.g. average time of use, average expenditure over the time, use frequency);
- Graphical User Interface data (GUI), which comprehends data generated by users as direct or remote setting (e.g. on/off, close/open, show details, set parameters, etc.).

In this way Step 4 creates a logical reference model where information categories are matched with devices' classes and rules able to manage all the relations between devices, information and events in order to realize the desired service functions by executing a set of tasks.
Step 5 proceeds with the simulation by using a tool that traduces the model into behaviours and defines the sequence of events to emulate a certain condition as well as the smart home response. It considers also the interaction between the smart devices and home dwellings, but also with energy utility and technical staff.
Such an approach is general as it can model and simulate different smart home environments as well as services for different purposes.

4. The smart home simulation tool

When the smart environment reference model is completely designed, as described in the previous sections, it can be executed by the simulation tool. The result is a simulated environment able to reproduce the device behaviours for a certain service and evaluate the outputs for different scenarios of use. It allows comparing different functioning by applying either manual or automatic modalities, and effectively validating the information exchange and the achieved benefits in the simulated smart home. The simulated scenarios consider the selected devices and execute the defined rules according to the designed model to simulate the expected behaviours and benefits or costs. The simulation tool has been realized as a Matlab application and it is controlled by Visual Basic macros. It consists of two main tool: the first one guides the expert to insert all data describing the smart home devices, the use scenarios, and the service to be simulated (**Modelling tool**); the second one executes the designed scenario and shows the achieved outputs by tables, diagrams and graphs (**Simulation tool**).

Figure 1. Modelling tool interface: definition of the smart home environment

4.1 Modelling tool

The Modelling tool actually considers the most common home devices (i.e. washing machine, dish washer, dryer, fridge, oven, heater, photovoltaic panel, solar thermal panel, general consumer electronics, general meters): they can be selected by drop-down menus to create the simulated environment and each of them is specified indicating manually its characteristics (e.g. for washing machine average loading, energetic class, etc.). Indeed, the system has databases containing known data (i.e. home features, the weather conditions, the tapping profile of the hot water, etc.), which are taken from literature and from field tests. However equations are completely defined by the specific data inserted by the expert. Figure 1 shows the main Modelling tool interface.
Similarly also the scenario is defined: the user can model the "family" and its characteristics by a dedicated macro (i.e. place, number of people, age of people, professions, hobbies, etc.) and define the use cases by mapping the "family" habits on a hypothetical weekly plan. Habits go from number of washing cycle per week or use of the oven for instance, to the definition of the setting times and family's preferences. With the term "family" we refer also to one member or a group of friends, in a broad sense. It is worth to notice that if the expert has a precise mapping of the use case, he/she can design it properly; if not, the tool offers the most common solutions based on market analysis and socio-demographic surveys country by country. Such models have been created in collaboration with manufacturing companies and some players in this sector. In this context renewable energy systems are included as meters as the information provided by the dedicated smart plug, neglecting the specific system parameters.

4.2 Simulation tool

The Simulation tool allows executing the designed smart home environment and use scenario by following a precise sequence of actions. Obviously it depends on the service to be simulated. Up to now the tool considers a set of services, belonging to different macro-functionality (Energy efficiency, Comfort, Product care): smart scheduling and hysterical data analysis about Energy efficiency, Heating automatic regulation and Lighting automatic regulation about Comfort, remote maintenance about Product care. Other services referring also to other functionalities will be introduced soon (e.g. People tracking and fall detection about Ambient Assisted Living).
This research focused on energy efficiency, so that the smart device scheduling service is investigated and detailed hereafter. The Simulation workflow for smart energy management is shown in Figure 2.

5. The use case: simulation of the smart home energy management service

The use case considers a pre-defined smart home system, composed of a set of common devices, and three different use scenarios ("families") to simulate the smart home energy management service in different context. 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, that 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 maximize reduce the global energy consumption as well as cost. Simulation consists of the application and execution of the workflow depicted in Figure 2. 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.

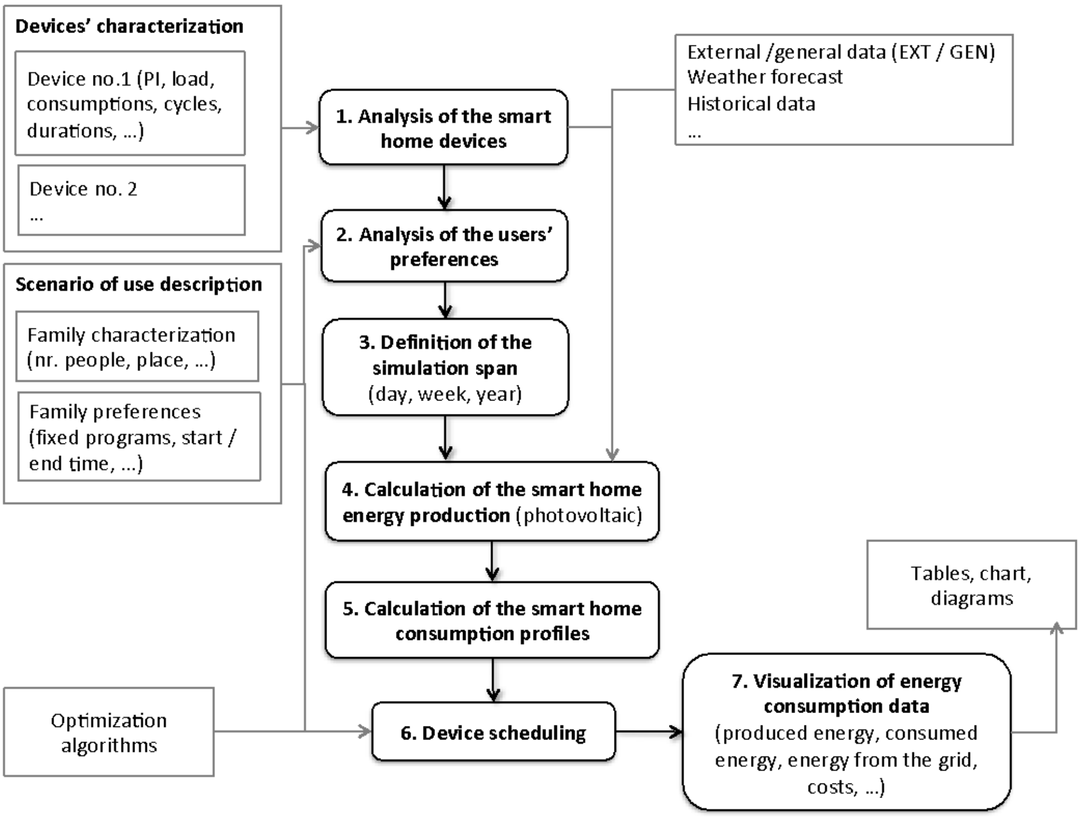


Figure 2. Workflow for the simulation of the smart energy management service

5.1 Smart home modelling

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

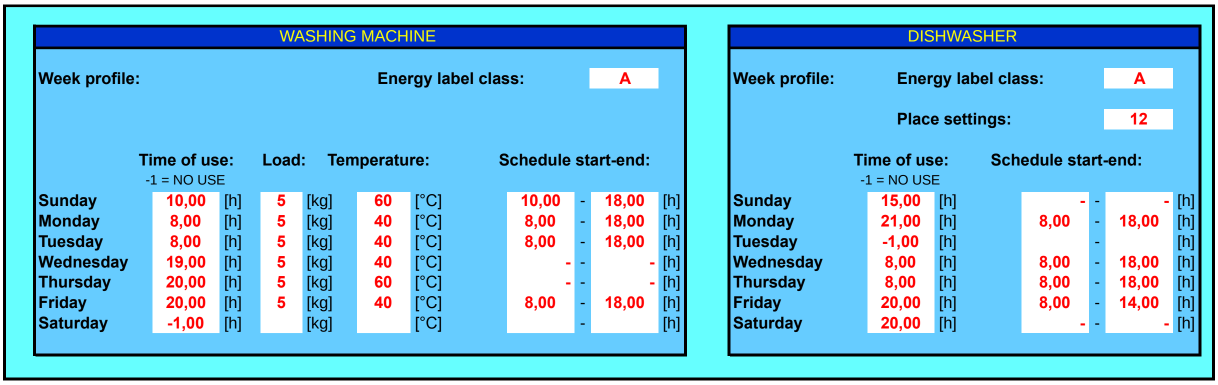
The smart home set of devices (smart home) is composed of:

- a washing machine: INDESIT IWC6083, Front-loading, Energy rating A, Max load 6 Kg;
- a dishwasher for families: Siemens SN64D000EU, Energy rating A+, 12 place-settings;
- alternatively a dishwasher for low loadings: INDESIT DIS361A, Energy rating A+, 10 place-settings;
- a boiler circulation pump: standard pump with 100 Watt power;
- a fridge-freezer: SAMSUNG RB29FSRNDSA, capacity: 290 L total net, Energy rating A+;
- a stand-by level of consumption: average data for the use scenarios (472 kWh per year);
- a photovoltaic panel for electricity production: no. 13 standard modules of 1.5 squared meters (global area of 20 square meters) with 14 % efficiency.

The "families" modelled are represented by three of the commonest cases in Europe:

- 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 smart 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 analysed 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 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

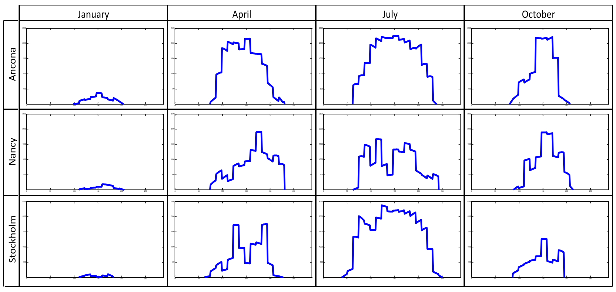
	Time of use: (-1 = NO USE)		Load:		Temperature:		Schedule start-end:			
Sunday	10,00	[h]	5	[kg]	60	[°C]	10,00	-	18,00	[h]
Monday	8,00	[h]	5	[kg]	40	[°C]	8,00	-	18,00	[h]
Tuesday	8,00	[h]	5	[kg]	40	[°C]	8,00	-	18,00	[h]
Wednesday	19,00	[h]	5	[kg]	40	[°C]	-	-	-	[h]
Thursday	20,00	[h]	5	[kg]	60	[°C]	-	-	-	[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 3. 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 4. PV panel performance for the three locations analysed in the use case

It is worth to notice that the living place not only influences the energetic performance of the solar 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 also 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.

5.2 Service simulation: results and discussions

The Simulation tool allows investigating the effect of the smart home energy management service on the three "families" (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 applied 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. Figure 5 shows how the device scheduling function acts. It compares the energy consumption profile in the three analysed 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).

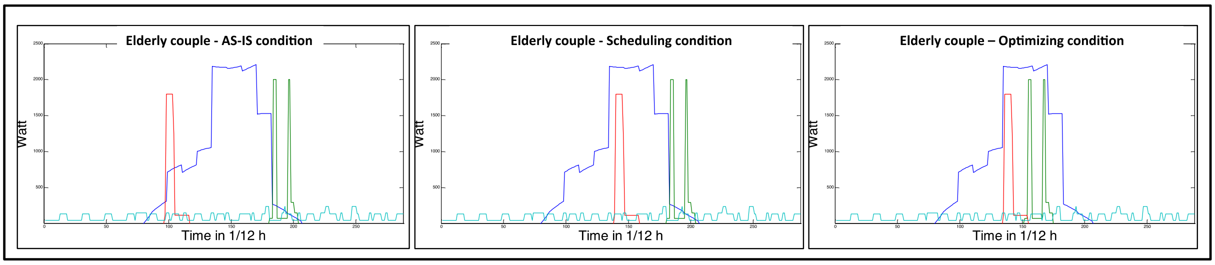


Figure 5. Device consumption profiling - scenario “Elderly couple in Ancona in October”

The AS-IS condition in Figure 5 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 6 shows the detailed results for the three “families” in different scenarios located in Ancona in four weeks during the year representing different seasons. Benefits are expressed by considering the money saved. Figure 7 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.

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	⍰⍰
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	⍰⍰
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	⍰⍰

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	⍰⍰
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	⍰⍰
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	⍰⍰

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	⍰⍰
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	⍰⍰
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	⍰⍰

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	⍰⍰
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	⍰⍰
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	⍰⍰

Figure 6. Benefits comparison of the 3 “families” in the four seasons in Ancona

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’ behaviours, 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 to be extended also to more complex systems, where the benefits of having scheduled and optimized scenarios can be bigger and more significant. Furthermore, it includes only traditional electrical generation and PV panels.

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 7. Comparison between benefits for "middle-aged family" in three countries

6. Conclusions

This paper presents an approach to model smart home environments and support service design by estimating the benefits for final users in terms of energy and money savings. 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 behaviours as well as the use scenario considering location, user's lifestyle, and habits. The proposed tool is tested by a use case simulating a smart home energy management service. The use case focuses on modelling a set of common devices and executing some energy management functions (i.e. device scheduling and energy saving optimization) for different scenarios where different family models and locations in Europe are analysed. Simulation allows supporting smart home design and service functions' configuration for distinctive family models in different European countries and quantifying the money saved for final users.

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