Enabling the smart grid via building automation

The continuously increasing trend of internet of things, ubiquitous computing and communication is redefining our everyday experiences: objects like smartphones and smart devices create an aaa pervasive interaction between human, physical and computational elements. This interaction is particularly relevant in the smart energy sector, where not only single buildings can be equipped with smart appliances, but these smart appliances (including energy generation, conversion and storage devices) can communicate and interact with each other at the level of blocks of buildings or eventually districts. This ecosystem of smart buildings would finally interact with the power grid, envisioning the so-called smart grid framework.

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It is well known that the building sector in EU accounts for around 40% of the total energy consumption and 40% of emissions [1]. The current setting is far from being smart: buildings and users act as passive consumers, absorbing energy from the grid on a disconnected and disorganized basis. As a consequence, all the physical energy (thermal and electric) processes that are necessary to sustain the building operational structure, including heating, ventilation, air conditioning, charge of plugin electric vehicles, local energy generation and energy storage, operate at far from optimal regimes. The situation appears particularly inefficient if we consider not only the building level, but also the district-scale operational structure. While the US are slowly moving toward a smart-grid scenario, the status of the smart grid in the EU is still in its infancy [2]. A complete paradigms shift is necessary in the way energy is generated, stored and consumed: many scientists, researchers and industrial stakeholders are striving to enable this paradigms shift by focusing on the following questions:

How can the interaction between human, physical and computational elements be exploited to create districts of smart buildings with enhanced efficiency in energy generation and consumption?

Can blocks of smart buildings not only reduce their energy footprint, but also self-sustain themselves and possibly generate an excess of energy (positive footprint) to be used for extra services?

The goal of these researchers is to optimize the operation of blocks of smart buildings by developing information and communication technologies embedded with the intelligence to transform districts into energy-aware self-optimizing environments [3]. The European Union is certainly supporting such research efforts by open several research and innovation calls with the Horizon 2020 framework (the EU Funding Programme for Research and Innovation): recent examples are the calls in the Energy Efficient Buildings and Energy Efficiency topics: “New tools and methodologies to reduce the gap between predicted and actual energy performances at the level of buildings and blocks of buildings (EeB-07-2015)”, “Demand response in blocks of buildings (EE-06-2015)”, or the upcoming Low Carbon Energy topics “Next generation innovative technologies enabling smart grids, storage and energy system integration with increasing share of renewables: distribution network (LCE-01-2016-2017)”, “Demonstration of smart grid, storage and system integration technologies with increasing share of renewables: distribution system (LCE-02-2016)” [4].

THE ROLE OF INFORMATION AND COMMUNICATIONS TECHNOLOGY AND DEMAND RESPONSE

Those readers thinking that the smart grid is essentially a matter of having more efficient solar panels, better wind turbines and energy storage might be surprised in discovering that this is only a small portion of the whole picture. The European Union has been heavily investing in research, development and innovation aiming at enabling the smart grid via real-time optimization of energy demand, storage, and supply at the level of a block of buildings, in a word, ICT (Information and Communications Technology). In fact, many energy suppliers have raised serious concerns about the widespread utilization of renewable energy sources in the power grid. The reason is essentially technical: the intermittent and stochastic nature or renewable energy. The presence of intermittency and stochasticity in the power generation put at stake the stability of the current grid: frequency and voltage cannot be guaranteed, and this might lead in some catastrophic cases, to failures and power outages. In a nutshell: increasing the number of solar panels and wind turbines is necessary, but not sufficient in a smart grid scenario. Then, how to fully exploit the benefits of renewable energy without endangering the safe and reliable availability of power? The answer sought by research and industrial stakeholders seems to purse the enhancement of (residential and non-residential) buildings with ICT, i.e. pursuing improved building automation. What if buildings were equipped with intelligent energy management systems with the objective of (autonomously) reducing the difference between peak power demand and minimum night time demand? This would certainly reduce the need for expensive and polluting peaking power plants, thus improving both energy efficiency and emissions. Not only: if the building demand were intelligently shaped depending on the availability of renewable energy sources, it would potentially be possible to fully exploit renewable energy, eventually store and/or convert it for later use, and eventually even have an excess of energy. Researcher and industrial experts have almost unanimously denoted the capability of buildings to automatically shape their demand in response to events in the grid with the term demand response. Demand response is the intentional modification of normal consumption patterns by end-use customers in response to incentives/rewards from grid operators. It is designed to lower electricity use at times of high wholesale market prices or when system reliability is threatened. Demand response requires consumers to either actively respond to signals from the operator or, in what may be a more appealing option, to make use of automated solutions to enter into contracts with service providers, thus resulting in an *automated demand response* (ADR). Automated demand response enables end users to participate actively in energy markets and profit from optimal price conditions, making the grid (heat, cold, electricity) more efficient and contributing to the integration of renewable energy sources. These are extremely relevant objectives in view of the European 2020 energy targets. At the district-scale level, increasing use of building automation technologies for intelligent energy management (both thermal and electric loads) could act as an enabler for the deployment of automated demand response in both residential and non-residential (commercial and office) buildings.

A POSSIBLE ADR ARCHITECTURE

Building automation promises innovative technologies to redesign our current inefficient energy paradigm. Optimization of the operation of districts of smart buildings via communication and control mechanisms can drive and “symphonically” harmonize all the thermal and electric physical processes at the district-scale. The developed intelligent energy management systems can exploit the connectivity guaranteed by smart embedded devices to establish optimal decisions/behaviors that can improve the efficiency of the interconnected system at the district scale. Automated demand response can be enabled by designing a comprehensive architecture encompassing the following functions:

a. *Connection and sensing*: provide a common platform through which a variety of devices, like smart electric appliances, sensor networks, plug-in electric vehicles, smartphones, can be connected with the network of building management systems and exchange data among themselves, with the users and with the grid;
b. *Data-to-information conversion*: elaboration of data collected from the devices (settings of the appliances, state-of-charge of storages, environmental variables, user preferences, etc.) and from the grid (available renewable sources, weather forecasts, energy prices, etc.) to extract district-scale information key energy performance indicators;
c. *Optimization of controls*: real-time solution of optimal control problems involving both continuous and discrete decisions - activate/deactivate appliances, shift loads, charge/discharge batteries, regulate settings of electric appliances and HVAC units - to optimize the energy flows that animate the ecosystem of buildings (e.g. to minimize energy consumption and energy cost, guarantee thermal comfort, etc.);
d. *Learning and adaptation*: cognition, assessment of the effect of possible decisions on key energy performance indicators; resilience to addition/removal of connected devices and to variation in user preferences and environmental conditions; correct operation of the system in front of large uncertainties and variability without human intervention to recalibrate and retune the system.

The resulting building automation system is supposed to create new synergies between building facilities and users, guaranteeing a balanced use of the energy resources via automated optimal demand response programs (energy management), and allowing occupants to be connected active energy players and make informed choices about energy consumption (ensure consumers’ engagement).

THE CHALLENGES

Are the envisaged ADR solutions already available? Simply speaking, no. Currently, energy demand in blocks of buildings is handled via heavy investments in the network infrastructure. Large energy storage devices are entrusted with dealing with intermittent energy generation, while new loads and demands are accommodated via the construction of peaking power plants running when there is a high demand for electricity. As energy storage devices are expensive and have a short lifespan, while peaking power plants supply energy at a much higher price per kilowatt hour and with higher greenhouse gas emissions, alternative solutions must be investigated. On the other side, ADR solutions, by managing in an optimal way demand and supply side, could optimize the existing grid without the need for heavy investments in the network infrastructure [5]. This vision does not come without challenges:

Future research will definitely have to focus on both theoretical in technological aspects required to solve the proposed challenges, among which:

- *Theoretical tools*: control of large-scale and distributed systems, adaptive and learning control, stochastic and embedded optimization, energy awareness through online social networking, big data signal processing, distributed sensing and estimation, …
- *Technological tools*: system services, electricity market, smart home, heating, ventilation and air conditioning (HVAC), building security, wireless communications

and networking, wireless home automation and monitoring, energy analytics, Internet of Things, …

Once full maturity both in theoretical and technological tools has been achieved, the smart grid scenario will be reality. The resilience achieved via the widespread availability of optimized districts that intelligently shape their energy demand will eliminate the need for larger peaking power plants and storage devices.

THE PRESENT

Researchers and industrial partners are addressing little by little the theoretical and technological challenges and coming up with innovative ADR solutions. At least two directions are being investigated to implement ADR: (1) intelligent interfaces between the users and the grid equipped with optimal energy management strategies; (2) distributed metering solutions with reliable communication between the users, the grid operator and among the buildings of the district.

- *Intelligent energy management*: most commercial buildings (such as offices, hotels or stores) do have an energy management system which monitors and distributes energy flows in the building to meet the thermal, visual and air quality specifications. However, isolated control of individual energy sub-systems without consideration of downstream sub-systems and occupied zones makes these energy management systems not yet designed with ADR actions in mind. While some types of loads that cannot be curtailed (industrial machines, PCs, etc.), heating, ventilating and air conditioning (HVAC) operation can be regulated and used for ADR. Several studies have been carried out to predict the effect of changing the HVAC control strategy on indoor comfort and energy consumption [6]; investigation of the influence of control of intelligent glazed facades and optimization of A/C unit set points based on a simplified comfort zone [7]; operation of a variable air volume air conditioning with respect to comfort and indoor air quality [8]. All these approaches show that relevant energy savings can be achieved without compromising thermal comfort [9,10]. Some outcomes from EU projects dealing with Intelligent energy management are shown in Figures 1 and 2.
- *Consumer engagement*: gamification techniques and ICT social applications have proved to be powerful in engaging users in energy-saving initiatives towards energy awareness and savings, including demand-side management programs [11]. CiteGreen [12] is a Web application inspiring people to perform actions for protecting the environment, giving credits to them for every sustainable action they commit. StepGreen leverages social networking sites to promote energy-saving behaviors of users [13]. Other applications leverage normative social influence and comparative feedback to affect citizens, such as EnergyWiz [14], Social Electricity [15] and Wattsup [16], applications that enables users to displays live data and/or to compare domestic consumption with Facebook friends. Moreover, OPOWER social application enables users to compare their consumption with houses sharing similar characteristics (e.g. square meters, no. of tenants) [17]. Some outcomes from EU projects dealing with consumer engagement are shown in Figure 3.


Unique ID: A_C_954

Link Established

Building: Chania

Sensors: 10

Time Step: 9

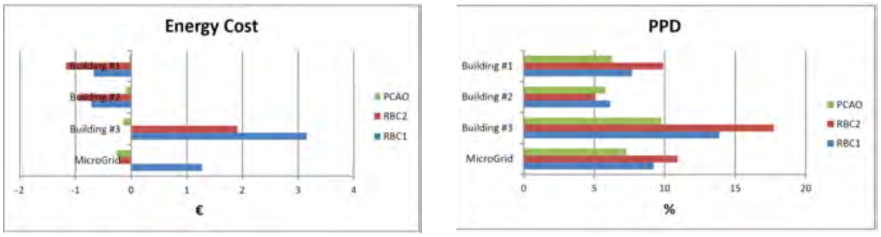
Temperature: 0

Humidity: 0

Show: Temperature

New File is Generated

-Figure 1- The Service Interface to the AGILE Intelligent Energy Management System (result of the project "Rapidly-deployable, self-tuning, self-reconfigurable nearly-optimal control design for large-scale nonlinear systems (AGILE), EU FP7-ICT-5-3.5")



-Figure 2- On a block of buildings of three office buildings, an intelligent energy management manages to have negative energy costs (i.e. revenues for the owners), while reducing the Predicted Percentage of Dissatisfied persons (PPD), i.e. improving comfort. This positive energy footprint is obtained by optimal energy management achieved via smart control mechanisms harmonizing all the HVAC operation: the HVAC energy demand has been shaped so as to fully exploit photovoltaic energy (result of the project "Systems-of-systems that act locally for optimizing globally (LOCAL4GLOBAL), EU FP7-ICT-2013.3.4")

Installation of local grids equipped distributed energy sources and loads will increase considerably in the future, driven by both theoretical and technological developments. Thus, sustainability of the future energy scenario is inherently linked to the development of intelligent building automation systems that fully integrates renewable energies, plug-in electric vehicles and energy demand, by optimizing production and consumption (heat, gas and electricity) at the block of buildings and district level. Consequently, the future energy grids will have significantly different characteristics from our current conventional energy grids. It is straightforward to envision a future where the emphasis will shift from smart districts to smart cities, regions, nations, etc [18]. This will surely bring extra opportunities, together with extra challenges. A few examples of challenges that future energy grids will have to face are:

- guaranteeing the energy demands of an increasing number of plug-in electric vehicles;
- ensuring large penetration of renewable energy sources with intermittent nature;
- satisfying the energy demands, both electric and thermal, of future large urbanized communities.

Enabling end users to participate actively in energy markets as a societal challenge whose solution is of uttermost importance. The interest of key stakeholders and the crucial role of energy make ADR timely and relevant. In the future we expect several cost-effective and interoperable ADR solutions to be demonstrated in blocks of buildings and under real-life operating conditions. Solutions will have to be compatible with smart grids and with the distribution network infrastructure.

-*Figure 3- Snapshots of Social Electricity: Main menu (top-left); Setting goals for energy savings (top-right); Detailed breakdown of overall consumption per electrical appliance (bottom-left); Comparison of production/consumption with similar users (bottom-right). (result of the project "Social Electricity Online Platform (SEOP), EU FP7-LLP-1-2013")*

THE FUTURE

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SHORT BIO OF THE AUTHOR

Simone Baldi was born in Florence, in 1983. He received the B.Sc. degree in Electronics Engineering, the M.Sc. degree in Automatic Systems Control Engineering and the Ph.D. degree in Automatic Systems Control and Computer Science Engineering, from Università degli Studi di Firenze, in 2005, 2007, 2010 respectively. He is assistant professor at the Delft Center for Systems and Control (DCSC) of the Delft University of Technology. Prior to this he has help postdoctoral positions at the Centre for Research and Technology, Hellas and at the University of Cyprus, Department of Computer Science.

His research interests include control of complex systems in the presence of uncertainty, with applications in building automation, energy management, demand response in buildings and block of buildings. He has been collaborating in several EU and national projects on these topics, including "Rapidly-deployable, self-tuning, self-reconfigurable nearly-optimal control design for large-scale nonlinear systems (AGILE)" (EU FP7-ICT-5-3.5), "Systems-of-systems that act locally for optimizing globally (LOCAL4GLOBAL)"(EU FP7-ICT-2013.3.4), "Advanced Methods for Building Diagnostics and Maintenance (AMBI)" (EU FP7-PEOPLE-2012-IAPP). More recently, he is collaborating with the Dutch Central Government Real Estate Agency and the Swedish Energy Agency on projects involving energy management and demand response (Innovatie-Rijswijk and Agile-Energy projects respectively).

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