# Latest trends in Integrating Building Automation and Smart Grids

Survey Paper

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*Abstract*—**Previously mostly independently considered topics grow more and more together to form the building blocks of the future smart city. The building itself needs to be built as a zero average energy consuming building, posing requirements mainly on thermal and electrical parameters. Those parameters need to be known and controlled, requiring intelligent control techniques and cross-layer optimized sensor networks. Finally, very differently used buildings together participate in the infrastructure of the city, which gives them freedom to passively burden the grids, or actively help stabilizing them, while benefitting from different tariffs in the smart grids. This paper summarizes the state of the art of those topics with respect to industrial electronics.**

***Survey, industrial electronics, smart grid, sensor networks, building automation, system integration***

## I. Introduction

Building automation is the key to sustainable, safe and comfortable buildings. By for instance accessing internal facilities like heating, ventilation and air conditioning and linking it to enhancing information like room bookings or weather forecasts, building automation can substantially contribute to the efficient operation of the building. Building automation is also the key to the integration of buildings into smart grids [1] and with other external applications such as cloud computing. In a typical scenario for instance, various household appliances of multiple residential users such as refrigerators, TVs, washing machines, and plug-in hybrid electric vehicles are interconnected via a Home Area Network. They are further connected to the local power distribution network via smart meters [2], where also renewables communicate [3].

Still methods are needed to design and integrate sensor and actuator networks with hundred thousands of nodes. They have to be maintained in a cost-efficient way. Current research covers themes like energy harvesting [4] and saving on all aspects of the system [5], and applications like ambient assisted living [6], geriatric health care, facility management, efficiency improvement in hospitals, and many others. The key to providing improved services in building automation is to process complex scenarios [7], which are compiled of diverse sensory information and the corresponding technical intelligence [8, 9] that is able to react in an adequate way. Furthermore, building automation systems must be seen as dependable systems covering both safety [10] and security aspects of various applications and under differing in the degree of rigor. Finally, to convince customers to make their houses more grid-friendly, tariff models or other kind of feedback mechanisms are needed to generated reasonable revenues for them. Several studies are carried out to prove their effectiveness, e.g. [11].

The main objective of this paper is to review latest results of the research community of industrial electronics, whose society within the IEEE, the IES, acts as the organizer of this conference. At the conference, latest advances and developments in design, modeling, simulating and implementing tools for, or systems of, sensor and/or actuator networks with advances towards user orientation, wireless connectivity, dependability, energy efficiency, context awareness and ubiquitous computing will be presented.

## II. Building Control

The buildings sector is on the edge of an innovation rupture: a broad spectrum of requirements needs to be fulfilled: providing comfort, assistance, safety and security to users; energy efficient operation; and flexibility in operation and maintenance. Building automation systems play a central role in achieving these goals, since they are today intelligent systems capable of complex communication and control tasks [12, 13]. Novel research is required that includes the whole life cycle of a building, for example, automated design and commissioning. During operation novel sensors and actuators are needed together with the necessary intelligence on all levels of building automation to successfully process the information. Communication is partly becoming wireless, especially in the area of refurbishment. The increasing system complexity in buildings requires advanced data models, better building controls and approaches to complex system modeling inspired by other disciplines.

Structured descriptions and data models are the next practical step in the development of building automation. Data, which is today available from many data sources, has to be

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made accessible for machine to machine communication in order to benefit from existing information by reusing it in different domains. The Building Information Model (BIM) is the collection of data that origins from the process of creating a building and its systems. It represents the physical and the functional properties of a building and is therefore an excellent starting point for building automation systems that need structured information about a building (see also [14, 6]). Furthermore, the building moves more into the context of its infrastructure, i.e. electric and thermal grids. The possibilities for exploiting existing degrees of freedom in load shifting are manifold and are supported by the developments in the electric smart grid, which is becoming intelligent itself with improved means of communication [3, 15].

In [16] the authors show an approach of structuring information through the life cycle of the building, that is, design, planning, commissioning and operation with a special focus on monitoring. It employs a BIM by means of Industry Foundation Classes (IFC); the two main use cases are simplified self-commissioning and monitoring, where the actual monitoring data are augmented with metadata from the BIM. [17] provides a classification of sensors, actuators, controllers and other infrastructure necessary in building automation with regard to their feasibility for supporting building automation functions. This addresses the necessity of integrating sensor sources from different industries and different communication media into one consistent view of the building and its inhabitants' activities. A next step is shown in [7], where sensor networks are used to create a surveillance system capable of detecting scenarios (e. g. lost luggage on an airport) that can be predefined or learned during observation. Digging deeper into the topic of buildings as complex systems [8] give a comprehensive overview on the field of cognitive automation, which goes beyond classification of equipment and information and examines methods and algorithms for advanced processing of information: situation recognition, human-like system behavior and modeling the mechanisms of human cognitive abilities. The area of autonomous perception is covered in [18], where the lower layers of perception are modeled and used to classify scenarios.

A different approach on integrating data in building automation systems is shown in [19]. The authors describe a middleware that shall overcome the discrepancies in data semantics and syntax between different building automation network systems. An application of extending the use of sensors to other domains is shown in [20], in which the authors use the CO2 concentration to estimate occupancy in a small room, thus saving the user from manually controlling ventilation.

On the technological side of building automation networks wireless communication has established itself in building automation. One of the issues in wireless networks, namely ZigBee, is tackled in [21], which looks at the limitations and possibilities of ZigBee networks with regard to the network size, yielding results on the recommendable network structure.

A clear benefit of automated building is the ability to influence the internal processes during operation. Buildings have intrinsic storage capabilities in the energy systems (e.g. thermal storages for hot water and heating) and in the building structure itself (i.e. walls and ceiling as well as air). These storages can be used to exploit available degrees of freedom without affecting user comfort – an important aspect when looking at the building in the context of the connected infrastructure. The electrical grid has the need to modify the electrical demand in order to follow production ([22], see also section III); therefore building automation is an interesting possibility. [23] builds this bridge between local building automation and the electric smart grid, focusing on the classification of electric plug-in loads. This step is required when considering controlling these loads for the sake of energy management. In a similar fashion [24] identifies electric loads using a combination of supervised self-organizing maps and support vector machines.

Looking at electric power consumption of a building as a whole the authors of [25] propose an active power filtering scheme for power-factor correction in order to support the smart grid. The approach introduces a controller additional to a smart meter to reduce the reactive power part.

## III. ULTRA-LOW POWER WIRELESS SENSOR NETWORKS

Another important research subject in the field of building automation is the communication between different inhabitant-controlled devices like lighting, heating and cooling (with temperature sensors), elevators, windows, data displays, and even household appliances like dish washers and refrigerators. All of these devices can be controlled in a centralized manner if the required environment data (e.g. room temperature, number of present persons in a room, open-state of windows, doors, and refrigerator doors, …) is available.

A similarly bustling area of research is in the automotive communication. Many systems are changed from cable-based to wireless to save cables and thereby weight and in the end fuel. Examples are many comfortability systems like distance sensors or safety related systems like tire pressure monitoring [26, 27].

The data needed for central control is collected by numerous specialized sensors and transferred to the central unit or distributed local central units.

Nowadays, mainly two channels are used in building automation, namely power-line-communication (PLC) [28, 29] and wireless communication. The former is easily applicable for devices which have to be connected by cable to the power grid, anyway. However, a large number of connected PLC devices lead to diverse problems from channel congestion to security issues [30]. More commonly, wireless communication is used. Wireless sensor networks (WSN) don't need physical cable infrastructure and can even connect ad hoc to devices currently in reach.

One of the most important scientific questions is the energy consumption of wireless sensors, as many of them are implemented in the form of battery-powered embedded systems. Obviously, it is important to design cheap, small devices with a long battery life. This can be achieved by a clever chip design or by power management in the running system itself [31], the use of smart compression schemes [5] for communications, or even network-topology-based optimizations [32]. In some approaches, the extension of battery life is achieved by means of energy harvesting. This means that energy is taken from the environment to partly or fully fuel the device in question. In buildings, e.g. ambient light can be harvested [4]; in the automotive area, e.g. vibrations of the tire on the street can be exploited [33]. Other approaches try to compare different possible designs and choose the most energy-saving approach (design space exploration); this is mostly done by energy consumption estimation in simulations [34]. In some cases, only single chips are simulated and optimized, other approaches simulate and monitor the energy consumption of specific messages throughout the whole sensor network [35].

Another field of research is the analysis of the data sent throughout the network. There are many available wireless protocols like ZigBee, OneNet, EnOcean, 6LoWPAN, etc., so the designer of a wireless sensor has to decide which protocol to use [36]. In many cases, a specific routing is proposed to enable real-time operation [37].

All these optimizations make sensor networks in buildings useful and help enhance safety and security.

## IV. THE SMART GRID

The smart grid, i.e. the IT-enabled energy infrastructure is a domain-integrating system. It connects physical processes like generation, distribution and consumption of energy with business, economic, and social processes. Beside the data-intensive and data-driven integration of these processes via energy analytics [38] and business processes it is mainly the systems' behavior and its control that is of interest for this article.

### *A. Modeling and simulation of smart grids*

[39] describe two fundamentally different ways of looking onto the problem of modeling and simulating an intelligent energy system.

The first option stems from classical physical modeling. The dynamics of the individual elements is modeled via physical equations, i.e. differential equations in all their different forms, and integrated to one physical system model. The modeling and simulation problem arises when the IT parts are integrated. Discrete and asynchronous in their nature, they cause much trouble to the traditional solvers of physical system models. Mainly busy with finding zero-crossings, these solvers scale very badly, when faced with such hybrid models.

The alternative path starts from the opposite edge. A community of autonomous and potentially discrete entities (a.k.a. agents) is created to represent the hybrid energy system. While this method is very efficient and shows good scalability in simple systems, it becomes cumbersome when more complicated physics need to be represented. It is clear that there is a substantial need for research in hybrid models and their respective methods and tools.

One of the main expectations towards the smart grid is the increased capacity for renewable energy sources. While being ideally emission free and cheap, these energy sources cause management and demand-supply matching problems due to their intermittent nature. One way to overcome this is to integrate battery (or other) storage into the grid and have this managed by the smart grid. An alternative is to leverage flexible loads [40] and have them balance the fluctuating supply side. [41] simulates and proposes and integrated solution that eases the investment costs of expensive batteries.

Intelligent air conditioning devices shall support the load balancing feature of storage batteries. A hardware-in-the-loop system is used in a comparative study. It is shown that a holistic approach of taking the battery state and the process variables (i.e. human comfort via the air conditioning) into consideration outperforms other strategies in terms of minimizing the capacity of the battery and thus reducing the cost of this system.

A fuzzy logic controller is used in two different ways, either evaluating the battery charger or the air conditioner with priority. The two control strategies lead to a potential battery downsizing of 25 or 35 kWh respectively, which is an encouraging result.

### *B. Smart grid management algorithms*

Any technical system can potentially benefit from additional and/or better information about its state. [42] gives an example in this direction: Smart meters are used for diagnostics and model based control. One central part of this work is to take the overall consumption of a facility and derive device-specific consumption out of this via signal analysis. Various power signal properties like real/reactive power or transients are used to detect individual devices like a washer or an electric furnace.

Based on this additional operations knowledge, a thermal black-box model of the building is derived, which is in turn the basis for diagnostics (refrigerant leakage) and control (model based predictive control) of residential facilities.

Leaving the demand side, the rest of the smart grid still offers a large area of applying intelligent algorithms. [43] compares two classical algorithms, used for optimal power flow: particle swarm optimization and genetic algorithms.

Flexibly designed, the two options were tested on standard power buses. While both algorithms converge and optimize by their very nature, it is interesting to see how they are applied to real-world smart grid problems. The paper gives quantitative results for minimizing fuel usage. Both algorithms find similar optima, while differing in their computational complexity.

### *C. Communication technology in smart grids*

The "smart" part of the smart grid often relies on communication [1]. Distributed algorithms and cooperating energy resources need interaction. Depending on the electric grid level, various topologies and technologies are used [17].

One of the most modern ways of integrating processes (of business or technical nature) is the service oriented architecture (SOA). It offers the most sophisticated level of interoperability and support compared to alternative architectures, although it comes with costs like communication overhead, caused by

XML and other things. [44] describes a building energy management platform for smart communities, based on XML and standard IP communication. SOA proves to be the right paradigm to integrate such a system. Quantitative results about the communication system and even the achieved CO2 reduction are given.

Another massive player in the smart grid is the approaching electric mobility. Various types of (semi) electric cars will require smart charging in order to fit into a modern electricity system. [45] analyzes the necessary communication interfaces of a smart charging infrastructure. By means of use cases, various transactions and situations are analyzed.

## V. SMART CITY BUILDING BLOCKS

Smart grids are a central part of what smart cities. The coordinated and sustainable use, transport, and generation of electric and thermal energy require a flexible and dependable infrastructure. Beside the technological aspects, it is mainly its integrating role in this “system of systems” that makes the smart grid prominent. It has to dynamically interface for instance with mobility systems like traffic control, economic systems, policy makers and the garbage collection, since all these systems are interlinked. Smart buildings are the building blocks that have to be able to communicate and adapt their requirements with a certain degree of flexibility in electric and thermal energy. The electric grid is the first beneficiary of this flexibility, since the increase in consumption as well as photovoltaic production will put increased pressure on the grid.

Renewable energy sources are a crucial component of the smart city. Aside of ensuring the deployment of a sufficient amount of technologies in and around the city, the mismatch between consumption and production of renewables has to be solved. Aside of pump storage plants the existing storages within the city are a key to improving deployment of renewables. Again the thermal storages within a building can be exploited for this purpose, in combination with a building management system the intelligent building supports the smart city in this regard.

## VI. CONCLUSION AND OUTLOOK

The research about building automation, smart grids, sensor networks, and their integration is well established within the Industrial Electronics Society of IEEE. This conference, being the flagship event of the society, annually brings together researchers from all over the planet, which fosters exchange and communication, topics that cannot be overestimated in interdisciplinary research, which arises when previously mature stand-alone fields grow together.

Recent advances in building controls can be found in the area of energy efficiency and flexibility of operation: available data are better structured so that existing information is accessible in an integrated fashion, which is a vital requirement for an integral topic like energy efficiency. Building controls and management advance with regard to exploiting flexibilities for the sake of demand side management, paving the way for integrating renewable energy sources. Methods to provide this flexibility are taken from basic information theory like ontologies, simulation and optimization, as well as artificial intelligence to handle the resulting system complexities. In a first step the building supports the smart grid, solving the energy supply issues without the need to increase grid capacities. On another level the smart city is the upcoming concept of integration: buildings, infrastructure and communication cooperate to achieve an overall optimum in the city with regards to energy efficiency, mobility and comfort.

On the other hand, mainly with respect to the electrical grid, the management of the grid, given the parameters of the new players like renewables, reached world-wide attention in research and politics. It is the interplay of new and optimized components with a new systems perspective that leads us to better efficiency and an optimized energy system. The enabling factor is information technology.

However, it can be anticipated that similar mechanisms and structures as for the electric grid will be introduced to other kind of infrastructures. A trend to distribution of services can be observed, which is the driving factor behind. From the perspective of the smart city, smart grids however also tackle individual problems, thus, they too can be considered the bottom-up approach towards the smart city.

In the future, top-down approaches, which optimize between technological, economic, legal, social, cultural, political, and structural aspects of the city will be necessary. Only as such, the vision of the smart city will become built reality.

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