ICT Technologies, Techniques and Applications to Improve Energy Efficiency in Smart Buildings

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Abstract: Currently, most of the human activities impact the environment. Worldwide sustainable development is required to preserve a good quality of life. Energy efficiency is one of the most relevant issues that the scientific community and society must face along the next decades. This paper focuses on reviewing and noting the main factors which impact the optimization of electrical energy efficiency in *Smart Buildings*, including distribution, consumption analysis, strategies and management. Smart grids and smart buildings are playing a key role in the definition of the following generations of cities where the impact of energy consumption on the environment must be reduced as much as possible. Notwithstanding, all the factors impacting the production and distribution must be also taken into consideration by energy production companies and distribution companies as well. Green energies are being introduced in smart cities and buildings, only slower than required, and in general, focusing on the consumption side asking for higher performance monitoring and control techniques, and encouraging to incorporate energy harvesting initiatives to improve the overall efficiency. In this paper, the major target is pointing out all the relevant factors influencing smart building energy efficiency, up to the consumer side and, at the same time, paying attention on distribution and generation issues and, specifically, available communication standards, technologies, techniques, algorithms, which enable high performance systems to optimize energy consumption and occupant comfort.

1 INTRODUCTION

Environmental sustainability requires minimizing the impact of human activities on the region where they take place. Energy efficiencyy is one of the factors which most impacts on the energy pollution reduction goal. In this paper the main focus is the electrical energy efficiency, especially how ICT (Information and Communication Technologies) can offer a proper support to energy distribution and consumption. When intelligence is introduced in the distribution part, the term Smart Grids is used. Its improvement requires the interaction with the occupants and the different elements, devices, energy sources, metering, etc., to collect relevant information of the environment including external data sources as weather sensing systems and energy supplier performance. Furthermore, the addition of intelligent features to the smart building, by using artificial intelligence and machine learning techniques and engineering skills, grants the smart building the capability to *learn* from the performance history (which could be featured by new analytic techniques) while making decisions in real-time to achieve the highest energy use efficiency (Karkare et al., 2014).

The use of new technologies as smart energy metering (electricity and gas), smart lighting as part of the smart grid, renewable energies, low power consumption equipment (printers, HVAC, appliances, etc.) combined with green energies will contribute to energies efficiency (Bhutta, 2017).

Figure 1 depicts the block diagram of the system architecture used to optimize energy consumption by using data analytics and high-performance algorithms. Heterogeneous raw data are collected at *Data collection* system which stores the data onto the *Data-*

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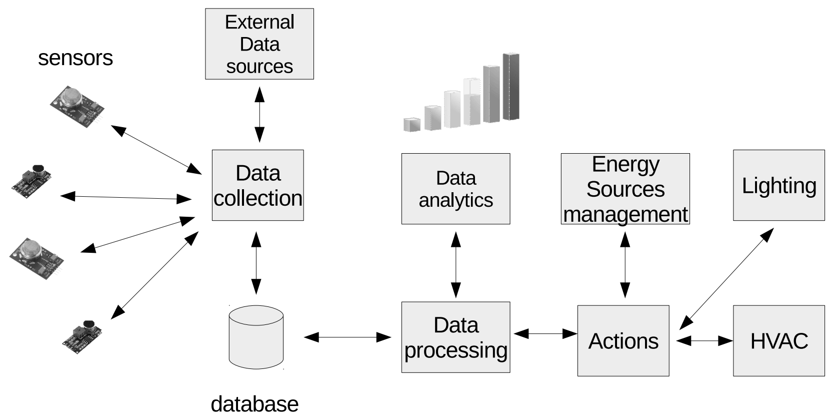

Figure 1: Example of the system architecture.

Base. The processing unit *Data processing* consists of a high-performance algorithm which processes the data and combines with the *Data Analytics* to make decisions, based on artificial intelligence and machine learning. Data analytics, management and production tool are used to identify trends and predict tendencies.

2 ENERGY SAVING ESTIMATION

Table 1 shows different technologies which are used in smart buildings to achieve higher energy efficiencies. The combination of ICT and intelligent materials increase the savings in energy, and it's the best strategy to improve the overall building efficiency (King and Perry, 2017).

In concrete, data analytics can process the data coming from several sources/sensors, event from surrounding smart buildings, in order to optimize the parameters regulating the different energy generating/consuming items in order to seek for the highest performance and energy savings. The larger the available data to be processed, the higher the accuracy of the action to take.

3 TECHNOLOGIES AND TECHNIQUES FOR IMPROVING ENERGY EFFICIENCY

The deployment of smart and energy-efficient buildings is sustained by the development of the appropriate technologies, techniques and devices with suitable features.

3.1 Green Energies

Green Energies energize buildings independently of external power sources. Currently, the most common situation is a hybrid configuration (Billanes et al., 2018). The term *Distributed generation* concerns the use of several energy harvesting on-site sources at each smart buildings to produce its energy (electricity). Figure 2 depicts the yearly electricity consumption in commercial buildings and the expected saving as well [1]. The largest savings are achieved in lighting (Bonneau et al., 2017).

In (Matiko et al., 2013) the authors introduce a study focussing on energy harvesting current state-of-the-art and application, so far. Additionally to the traditional energy harvesting technologies and techniques, as using solar panels, thermal exchanger, etc., highlighting those new technologies showing a relevant potential to be used as energy sources like: electromagnetic waves, kinetic, thermal, aire flow. The results for most common harvesting techniques:

- indoor solar cell (active area of 9 cm^2, volume of 2.88 cm^3): approx. 300 μW from a light intensity of 1000 lx;
- thermoelectric harvester (volume of 1.4 cm^3): 6 μW from a thermal gradient of 25^oC;
- periodic kinetic energy harvester (volume of 0.15 cm^3): 2 μW from a vibration acceleration of 0.25 ms^{-2} at 45 Hz;
- electromagnetic waves harvester (13 cm antenna length and energy conversion efficiency of 0.7): 1 μW with an RF source power of -25 dBm;
- airflow harvester (wind turbine blade of 6 cm diameter and generator efficiency of 0.41): 140 mW from an airflow of 8 $m \leq -1$.

[1] Source: Lutron.

Table 1: Smart technologies and materials energy savings in buildings.

System	Technology	Energy savings
HVAC	Variable speed control	15-50 % of pump or motor energy
HVAC	Smart ambient sensing	5-10 %
Plug load	Smart plug	50-60 %
Plug load	Advanced power strip	25-50 %
Lighting	Sensors, actuators smart control	45%
Lighting	Web-based management	20-30% above controls savings
Window shading	Automated shade system	21-38%
Windows hading	Switchable film	32-43%
Windows hading	Smart glass	20-30%
Building automation	Building automation system	10-25% whole building
Analytics	Cloud information-based	5-10% whole building

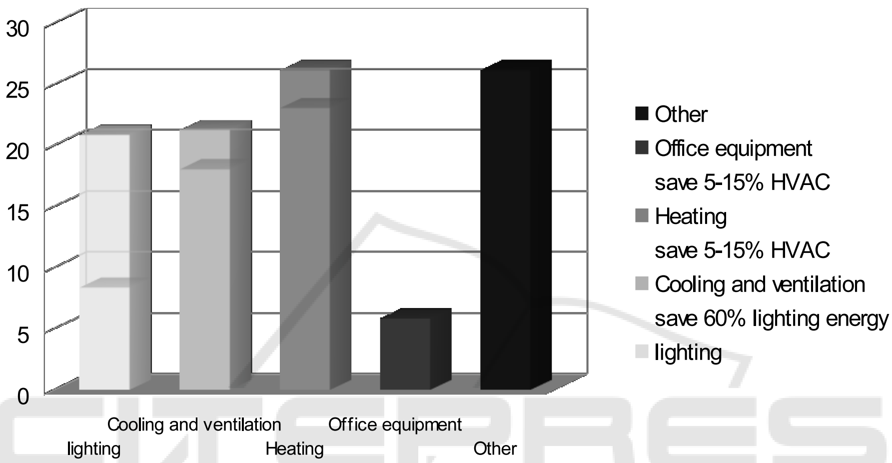

Figure 2: Commercial buildings energy use breakdown and predicted savings.

3.2 Communications in Smart Buildings

The advances in ICT technologies and techniques open high expectations about energy efficiency goals (Telekom, 2015). Wired technologies have no flexibility: Any change in the network distribution involves new wiring, causing a high maintenance cost. However, they can be very robust in the case of receiving interferences of other systems. Despite well-known most used wireless standards, e.g., Wi-Fi, Bluetooth, Zigbee, EnOcean, Thread or KNX [2], some protocols are aimed at dedicated tasks in smart buildings, e.g., DALI and Mobus protocols are protocols aimed at setting on/off lighting system; Opentherm was specifically developed for heating/cooling systems control. And MBus is used in smart metering devices (Saritha and Sarasvathi, 2017), (Sethi and Sarangi, 2017).

Table 2 shows some features of the most commonly used IoT technology standards (Dr.R and Velumani, 2014). Some standards, as NFC (Near Field Communications) are appropriate for indoor facilities data exchange, given the range is up to a few metres. Others, operate up to hundreds of metres (WiFi, Bluetooth, Zigbee, etc.). These standards can be used for indoor/outdoor communication at a building level, i.e., without connecting-to external networks or resources. Long-range standards are appropriate to connect to other buildings.

3.3 Artificial Intelligence and Big Data

Artificial intelligence and machine learning techniques allow Smart Buildings adapting to occupants needs. Using high-performance algorithms for intelligent energy management buildings will increase the comfort, efficiency, resilience and safety (Siemens, 2018). To optimize energy consumption and efficiency, Smart Buildings must manage: Energy (smart metering, demand responsive systems); Lighting and elevators (daylight meters, presence sensors, lift demand); Issues detectors (sensors to detect fire, smoke, watering); Smart metering (electricity water, gas); Monitoring (parking lot occupancy, security); Am-

[2] KNX is an open standard (see EN 50090, ISO/IEC 14543) for commercial and domestic building automation.

Table 2: IoT Technology Standards.

	RFID	NFC	WiFi	ZigBee	Blue-tooth	WSN
Network	PAN	PAN	LAN	LAN	PAN	LAN
Topology	P2P	P2P	star	Mesh,star,tree	star	Mesh, star
Power	Very low	Very low	Low-high	Very low	low	Very low
speed	400 kbs	400 kbs	11-10 Mbs	250 kbs	700 kbs	250 kbs
Range (meters)	< 3	< 0.1	4-20 m	10-300 m	< 30 m	200 m

bient comfort (lighting, HVAC). Continuous energy consumption metering devices can improve energy efficiency based on: improved real-time energy consume visualization, instantaneous energy management monitoring and control.

Advanced analytics tools can help to discover hidden insights from your raw data coming from different sources in the smart building, e.g., sensors, metering devices. Given a database where raw data is stored, the Analytics tools process and transform huge amounts of raw data into remarking reports and dashboards. These tools allow tracking the key defined or identified energy efficiency metrics, providing feedback regarding long-term trends, highlight outliers, and uncover hidden insights. Based on this set of information, the algorithms based on artificial intelligence and machine learning will interact with the different components of the smart building to increase energy efficiency and improve comfort.

Modelling energy building profile enables developing ad-hoc strategies. Key parameters are identified, and algorithms are developed to process the collected data and make decisions based of the history and the result of predictive models (Ahrens et al., 2016), which are useful to design the proper strategies for higher energy efficiency..

4 FUTURE SMART BUILDING CHALLENGES

Connectivity contrbutes to achieve higher energy efficiencies. A *cloud of smart buildings* (CoSB) allows sharing information among the connected facilities. The main benefits are:

- Data aggregation from different sources provide additional information to the analytics tool achieving higher performance.
- The CoSB concept will help to define a scalable architecture easier to manage.
- Smart building sensing capabilities, and sharing the collected data could be especially suitable for handicapped citizens.
- Provided smart buildings are equipped with a variety of sensors, electronics, actuators, etc., an immense volume of data (big data) is continuously generated.
- Smart building solution includes automation and real-time analytics which provides reach information, higher accuracy and energy saving, and efficiency optimization.
- Easy integration with, e.g., other buildings to create the CoSB, the smart grid, smart city, etc.

Due to connectivity needs, the following are very active fields: *Interoperability, cybersecurity and data privacy*.

In (Pilgrim, 2019), the author identifies some key challenges (among others) which must be faced to achieve the expected performance:

- Better and more accurate weather prediction methods and techniques at local level.
- Development of algorithms capable to manage data more efficiently based on AI and ML.
- Improvement of thermal modelling techniques, more accurate and at a lower cost.

Regarding the security of smart buildings, there are key issues where more efforts are required to guarantee the appropriate level of security. Among them, it is worthy to remark:

- gateways which interconnect buildings to the grid,
- cyber-risk of connected devices,
- detecting and preventing particular attacks,
- ensure secure interoperability between protocols,
- use of AI and ML to improve security,
- privacy, confidentiality, availability, non-repudiation.
- data integrity, cryptography.

5 DISCUSSION

Smart buildings highest accuracy is achieved when the appropriate resources are used to achieve the highest energy efficiency. The main features which characterize the current state-of-the-art of smart buildings rely on the following key elements:

- High-performance Computer. It is the hardware which hosts the required algorithms and processes the collected data to make decisions.
- Data Analysis and Decision Making Software Tools. It is the main core of the intelligence system which can receive the data collected by different sensors and measuring elements, and other relevant data from other sources of information such as networks from information nearby buildings sensors.
- Among other functions, this intelligent system must be able to analyse data from different sources, whether internal or external to the building, to make a more precise decision.
- Advanced Analytics Tools. These techniques are currently used to obtain multiple information from among all the data collected, they can even determine trends to be able to anticipate certain events, for example, a sudden change in temperature outside the smart building. This task will be carried out with greater success the more data from the environment are obtained, for example, the data collected by nearby buildings.
- Sensors Network. that allows us to obtain the maximum possible information from the environment. For this, different types of environmental sensors should be available, focusing on the energy management of ventilation, cooling and heating systems. In other cases, it will be important to have the possibility of measuring lighting levels, i.e., light intensity.
- Measuring Devices. It is important to know the instantaneous energy consumption. However, to have two systems that are more precise and, above all, capable of managing the available energy resources in the most efficient way possible, it is necessary to have a consumption history to allow data analysis tools to make decisions in historical consumption function, current consumption and consumption forecast. Moreover, similar actions could be performed for every single device, being able to reach the maximum possible granularity in the energy management and comfort provided by occupants of the building, at the cost of an increase in the deployment price.
- Communication Infrastructure. This is the backbone of the system. This system has a capital role in the smart building. It is responsible to provide the appropriate infrastructure to warranty the flow of data among the different elements which compose smart buildings.

Figure 3 shows a possible block diagram where are all the elements in the smart building are depicted. A database could be available to keep the history of the collected data which could be used for different purposes: failure prediction, identification of facilities consuming more power, energy demand trends, etc. Sensing, metering and actuator devices are connected to a gateway given various communication standards are being used. The firewall must provide the appropriate security.

The terms *reliability* and *resilience* are related and when describing the definition of one of them the other arises (Albasrawi et al., 2014), (Haught and Paladino, 2012). An option to improve the reliability of the smart grid is deploying redundancy by managing different sources. Furthermore, this approach also has an additional advantage, it increases system resilience. On the other hand, redundancy also increases the deployment cost.

Data collection, processing and sharing are required to enhance the overall building facilities and resources more accurately and reliably. Connectivity among the different sensors, actuators, metering devices, processing and storing units, intelligent data processing systems must be interconnected. For such purpose there are several possibilities, as shown in table 3 where the advantages and disadvantages of commonly used technologies are remarked. For each concrete scenario, a concrete set of technologies will be the most appropriate and the overall solution would be a heterogeneous communications system.

Energy efficiency can be Implement by very simple electronics. For example, the data regarding people motion and occupancy or facilities obtained by appropriate sensor devices can be easily used to regulate the air conditioning system, ventilation and lighting levels in real-time. as consequence, The ventilation flow, air conditioner temperature, and light intensity can be regulated with the basic intelligence improving the environment for comfort and productivity of the individuals who are occupying the facilities and, at the same time the energy consumption level reduces the cost of the energisation.

To achieve further savings it is required including additional intelligence in the system. For example, the system can continuously measure the temperature of a facility and based on the information provided by the sensors it can take a more accurate action considering hysteresis cycles and the information corresponding to the history on their records taking along a given period of time, stored by the system to be processed by the processing unit to carry out a data analytics to make the appropriate decisions based on artificial intelligence and machine learning high performance algorithms.

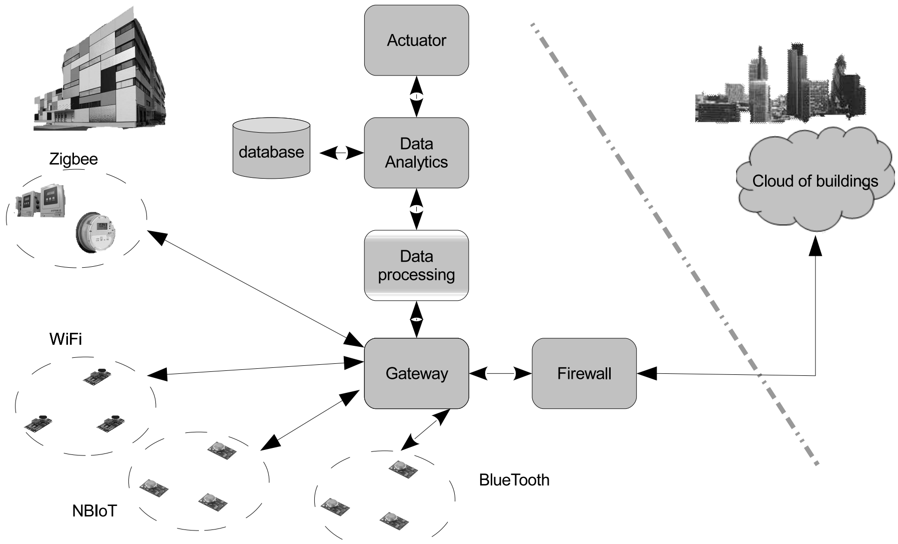

Figure 3: Overall view of the smart building connectivity both at building and cloud level.

Table 3: Advantages and drawbacks of widely used and well established technologies.

	Bluetooth	WiFi	ZigBee	THREAD
Pros	Low energy	Well established standards	Low energy	Low energy
	Available on mobile devices	Available on mobile devices	Well established standards	Low energy
	IPv6 based	Good range	Mesh network	Good range
		IPv6 based	Good range	IPv6 based
Cons	Star network	Star network	Not IP based	Not well established compared to ZigBee
	Short range		Not available on mobile phones	Not available on mobile phones
	Not mature			

6 CONCLUSIONS

Information and communications technologies are playing a relevant role in energy efficiency. So far, smart devices such as thermostats, temperature sensors, light intensity meters, presence detectors, etc., have been employed to provide energy savings by switching on/off lights or managing HVAC in simple ways.

A large amount of information about buildings state allows making more accurate decisions to more efficiently manage the energy and building resources (including energy harvesting).

Connectivity is a critical feature in smart buildings, where sensors, actuators, electromechanical elements, databases, information processing system, etc., must be interconnected. For this purpose, wireless technologies are the most suitable as they provide greater flexibility and a lower deployment cost. IoT are identified as the most suitable due to their extensive use in many common systems and devices, such as smartphones, allowing easy integration of devices and systems.

Interoperation between wireless standards is often required and, therefore, a gateway that allows interoperability. Moreover, since smart buildings can receive information from the environment and other nearby smart buildings, Cloud of Buildings, it may even be necessary to use cellular technologies. The security of smart buildings against cyberattacks is one of the aspects that is being faced in recent years to provide the appropriate means to avoid cyber-risks and do not compromise either the safety of people, or the installations, or of the personal data.

The overall goal of this paper is showing the capabilities of ICT supporting technologies to optimize the energy consumption in buildings. Currently, these possibilities are not being systematically exploited although the appropriate tools are available, as claimed in this work.

To conclude, it is worthy to note the following remarks:

- Intelligent applications in the building sector, and supported by ICT, resulting in an intelligent building which can save energy by increasing their efficiency, and, additionally, offering handicapped people additional support.
- Identify smart technologies and applications which most optimize energy efficiency (highest energy savings) and are most cost-effective, and provide higher comfortability.
- Smart buildings are ready to interconnect and integrate into Smart Grids and Smart Cities.
- They contribute to sustainability.
- Improves people comfort and well.being.

On the other hand, the main smart buildings benefits regarding energy efficiency are:

- Energy management by using novel ICT technologies allows optimizing energy consumption and billing.
- Energy consumption control by setting on/off appliances: lighting, HVAC, etc.
- Data collection for processing and make decisions to control smart windows, occupancy detectors, temperature, etc.
- Efficient use of facilities to optimize energy consumption.
- Safety and security efficiency are a key motivation in deploying smart buildings.
- Individuals access control is needed and can be improved by using intelligent systems by monitoring and track people and things [3].

Finally, it is worthy to make some remarks about IoT in smart buildings applications:

- IoT is not a concrete technology or device aimed at a specific application, but a set of tools with different capabilities (standards) which include connectivity capabilities according to the standard each one meet, capable to collect, transmit/receive, sometimes process, and share data (using sensors and actuators).
- Relevant features of IoT devices are energy efficiency and wireless connectivity (sometimes energy harvesting).
- For each specific application/environment developers must point out the smart technologies which most optimize energy efficiency, providing the most reliable link and cost-effective.
- In many applications, e.g. smart buildings, using heterogeneous wireless technologies are needed to meet the various requirements for specific tasks (sensing, tracking, etc.) in distinct environments.
- Standards aimed at low power consumption, low data-rate and short-range (personal area network) technologies are specifically useful in sensors deployment.
- Long-range standards as cellular (2G/3G/4G/5G/LTE), WiFi, LoRa and low-power, long-range wide-area communication technologies could play a main role in smart buildings connectivity by collecting and delivering the data to the cloud.
- By using novel approaches based on artificial intelligence and machine learning, and analytics techniques, it is feasible achieving the higher accurate analysis of the building and providing more precise response, resulting in the best comfort to all the occupants and higher energy efficiency.

The next step will be the extension of the CoSB concept as a reality to achieve the efficient energy consumption goal.

[3] INVISUM (INtelligent VIdeoSUveillance SysteM): It was a project aimed at monitoring facilities for security purposes funded by the Spanish government. Partners: Moviquity, NVISION, Universidad Politécnica de a Madrid, Universidad Rey Juan Carlos. UPM's research group involved in this project was directed by César Benavente-Peces.

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