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Review

On the Energy Efficiency in the Next Generation of Smart Buildings—Supporting Technologies and Techniques

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Abstract: Energy efficiency is one of the most relevant issues that the scientific community, and society in general, must face in the next years. Furthermore, higher energy efficiencies will contribute to worldwide sustainability. Buildings are responsible for 40% of the overall consumed energy. Smart Grids and Smart Buildings are playing an essential role in the definition of the next generation of sustainable Smart Cities. The main goal is reducing the impact of energy consumption on the environment as much as possible. This paper focuses on information communication technologies (ICTs) and techniques, their key characteristics and contribution to obtain higher energy efficiencies in smart buildings. Given that electrical energy is the most used, the investigation mainly centres on this energy. This paper also pays attention to green energies and energy harvesting due to their contribution to energy efficiency by providing additional clean energy. The main contribution of this investigation is pointing out the most relevant existing and emerging ICT technologies and techniques which can be used to optimize the energy efficiency of Smart Buildings. The research puts special attention on available, novel and emerging sensors, communication technologies and standards, intelligence techniques and algorithms, green energies and energy harvesting. All of them enable high-performance intelligent systems to optimize energy consumption and occupants' comfort. Furthermore, it remarks on the most suitable technologies and techniques, their main features and their applications in Smart Buildings.

Keywords: smart building; energy supply; energy distribution; energy management; energy efficiency; energy savings; sustainability; green energy; energy storage

1. Introduction

Environmental sustainability requires the minimizing of the impact of human activities on the region where they take place. Energy demand is predicted to noticeably increase in the forthcoming years as a consequence of population growth, the economy increasing and the demand for more comfort. Energy consumption worldwide grew by 2.3% in 2018 (Global Energy & CO_2 Status Report. https://webstore.iea.org/global-energy-co2-status-report-2018). A large percentage of the energy demand corresponds to buildings. According to this fact, buildings' energy efficiency must be increased to face the world level sustainability challenge which should include appropriate construction materials, green energy sources, energy harvesting, energy-efficient storage and intelligent energy management considering both the provisioning and consumption of individual elements [1].

According to recent studies [2], 40% of the overall energy consumed corresponds to buildings. Even worse, buildings contribute to the overall CO_2 emissions in the same proportion [3]. Since buildings, whether they are aimed at houses, factories, business, governmental, shopping or hospitals, are responsible for 40% of the global energy use, the design and development of more energy-efficient buildings requires proper efforts and investment.

The term designing ideal facilities refers to guaranteeing the health of buildings, renovated and updated, throughout their life and, at the same time, meeting the sustainability goal through an appropriate management of the available resources including external energy supply, energy harvesting and green energies, as well as energy consumption to reduce both costs and CO_2 emissions. Countries are committed to achieving a sustainable growth and development, to analyse and track the progress so far and to address new and emerging challenges guaranteeing sustainability [4].

In this scenario, the initiatives for the optimization of the energy use mainly target its reduction, especially in public buildings, but it is also needed to face the increasing demand of quality by the present urban society. Efficiency is one of the factors that most impacts the energy pollution reduction goal. In this paper the main focus is electrical energy efficiency, especially how ICT (Information and Communication Technologies) can offer proper support to energy distribution and consumption. The term Smart Grids refers to the use of intelligence to integrate and manage the available energy resources including generation, distribution, storage and consumption.

There are several definitions of Smart Building. Among them, the following has been preferred for its simplicity—A Smart Building is a set of communication technologies enabling different objects, sensors and functions within a building to communicate and interact with each other and also to be managed, controlled and automated in a remote way [5]. Beyond this definition, we can state that a Smart Building consists of the smart use of sensors, actuators, information and communication technologies and intelligence techniques and technologies to control and optimize the use of the building resources (energy sources and infrastructures) and offering the best comfort to occupants.

Buildings need sensors to get information about the building ambient condition and the available resources. We can include, among others, temperature, humidity, light intensity, airflow, smart energy meters. Actuators are any item or device which can be controlled, like light switches, windows, lifts, doors, air conditioner, ventilation system, presence detectors, among others. ICT are essential to interconnect all these elements. They send the information collected by sensors to the control unit and delivers the commands from the control unit to the actuators to make an action. The Smart Building uses information technologies to appropriately process and store the information collected from all the building's sensors. The data are stored on databases for their use. We can consider ICT resources like cloud computing to manage and process the available data. Intelligence refers to the use of technologies and techniques to make decisions, that is, it uses the data provided by the sensors and stored in the database to analyse the data, the constraints and the goals and to make decisions to control the different actuators in the Smart Building.

Modern analytics techniques provide Smart Buildings with the ability to better understand the overall building's energy consumption, that is, peak/valley periods, more/less consuming equipment, environmental parameter evolution throughout the day, appliances usage, and so forth. All this information can be used to optimize the individual's comfort and energy use based on the current data, the history and evolution of power consumption and the prediction of its immediate evolution. Energy efficiency shows a rising distinction of competitive advantage of governmental/public services, business, industry and private activities. Energy efficiency improvement requires interacting with the occupants of the installations and the different elements, devices, energy sources, metering, and so forth, to collect relevant information of the environment including external data sources as weather sensing systems and energy supplier performance. Furthermore, by adding intelligent features to the Smart Building, by using artificial intelligence and machine learning techniques, it grants the Smart Building the ability to learn from the performance history (which could be featured in new analytics techniques) while making decisions in real-time to achieve the highest energy use efficiency [6].

Usually, buildings use different types of energy sources to energize the distinct facilities and equipment, for example, heating systems, HVAC, warm water, lighting, commodities, and so forth.

Electricity, gas and petrol are traditional sources of energy. In a wide sense, Smart Buildings include managing:

- Energy: including smart metering, demand responsive systems.
- Lighting and elevators: daylight meters, presence sensors, lift demand.
- Issues detectors: fire, smoke, watering, detectors.
- Smart metering: electricity water, gas.
- Monitoring: parking lot occupancy, security.
- Ambient comfort: lighting, HVAC, windows.

Since several years ago, the use and optimization of green energies to reduce emissions to the environment has attracted the attention of the scientific community and specifically ICT engineers and scientists. The term green building refers to a facility equipped with green energy and energy harvesting equipment, sensors for metering ambient and consumption parameters (temperature, light intensity, power consumption, etc.), data storing and processing intelligent systems and control and actuators equipment aimed at improving the efficient use of the available energy resources. Green building can save up to 40% of the total energy expenses and decrease the overall CO_2 emissions by up to 37% compared to a regular building.

The main focus of the paper is introducing ICT technologies and techniques, their key characteristics and contribution to achieve higher energy efficiencies in Smart Buildings. Given that electrical energy is the most used, this investigation mainly centres on this energy. Also, green energies and energy harnessing are included as technologies and techniques that contribute to energy efficiency.

The remaining part of this paper is organized as follows. Section 2 justifies the need for the investigation and development of Smart Buildings. Section 3 introduces the supporting technologies, the main features and their role in the Smart Building. Afterwards, Section 4 describes the most relevant techniques which are being developed to improve energy efficiency, including Artificial Intelligence and Big Data. Section 5 describes the need for being connected to the Internet, to the cloud, its advantages and issues with special emphasis on security and introducing the Cloud of Smart Buildings. Section 6 discusses the outcomes in the framework of this work, while Section 7 remarks on the trends and challenges of Smart Buildings development in the next years. Finally, Section 8 summarizes and draws the main conclusions and future trends of this work.

2. Energy Saving Estimation

This section performs a brief insight of the savings which Smart Buildings are obtaining. It justify the need for further investigation and development of technologies and techniques.

Energy savings estimation tools are required to balance the investment in infrastructures and equipment to increase the energy efficiency and the reduction in energy consumption and the timeline to know when the cumulative savings are higher than the investment.

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 is the best strategy to improve overall building efficiency [7].

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

Different strategies are used in Smart Buildings to increase energy-saving and the installation of sensing devices, automating controls and optimizing systems have demonstrated to be the most impacting way, Renovation and update of single devices/equipment by using new technologies can provide energy savings about 5–15%. Considering the sets of intelligent sensors and actuators to monitor, control, activate/deactivate which can be found in a Smart Building, the energy efficiency increases noticeably and energy savings result in 30–50%.

Table 2 shows how the use of smart technologies in public buildings (schools, offices, hospitals, etc.) can impact remarkably on the energy consumption resulting in savings up to 40% [7].

Table 2. Impact of smart technologies in buildings: Commercial sub-sector energy savings.

Building Use	Average Surface m^2	Average Savings (%)
Education	10,000	11
Office	5000	23
Hotel	20,000	6
Laboratory	7000	40
Hospital	12,000	18

Figure 1 depicts the yearly electricity consumption in shopping buildings and the expected savings, as well. Lighting management is the technique which provides the largest energy savings [5].

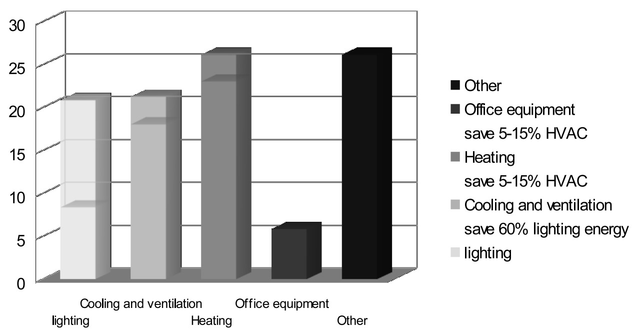

Figure 1. Commercial buildings energy use breakdown and predicted savings [5].

3. Supporting Technologies

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

In this section, a brief overview of the most relevant technologies are introduced. Since the introduction of simple devices, like mechanical thermostats, the evolution addressed the increasingly integration of intelligence capabilities supported by devices with higher performance, like programmable thermostats which work in a much more flexible and accurate way than the mechanical ones, leading to remarkable energy savings.

3.1. Green Energies and Energy Harvesting

The increasing use of renewable energies sources in new buildings (either private or public) into the growing smart grids will be the most significant and effective means of decreasing CO_2 emissions to the atmosphere. So far, the renewable energies that are being used for electricity generation include [8]:

- wind generators,
- solar panels,
- biomass,
- hydropower.

Figure 2 depicts the worldwide Photovoltaic (PV) cumulative power in 2017. PV energy is the most contributing green energy in sustainability, so far. The figure shows that China is leading this contribution.

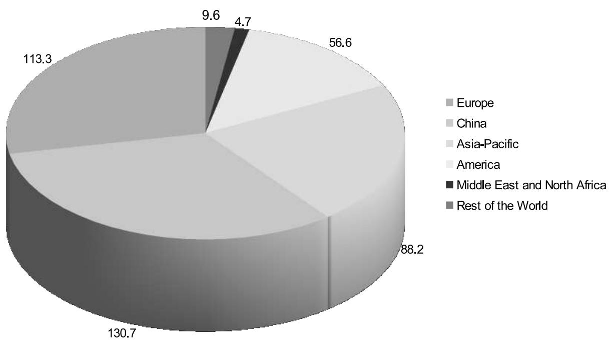

Figure 2. Photovoltaic (PV) world cumulative power in 2017 (GW). (Source: International Energy Agency.)

Green energies are key elements in the definition of future Smart Buildings and their sustainability. They would energize buildings independently of external sources. Currently, the most common situation is a hybrid configuration where the main power supply comes through the energy provider and a complementary green energy source. Research in energy harvesting is an active field where new approaches are continuously assessed to get green energy. Local laws can be, in some cases, an obstacle for its deployment, as well as the installation costs, although they are decreasing day to day [9–12]. The convergence of cheaper renewable technologies, digital applications and the growing role of electricity is a crucial aspect of change, and is the key to prospects for achieving many of the global sustainable development goals [13,14].

The term *Distributed generation* concerns the use of several energy harvesting on-site sources at each Smart Building to produce its energy (electricity). Green or renewable energies are considered sources of clean, inexhaustible and increasingly competitive and efficient energy. The main difference from the traditional fossil fuels concerns their diversity, availability and potential to be used worldwide [15]. The major weakness of green energies for Smart Buildings regards the current cost, but the trend is a continuous drop at a sustained rate. On the opposite end, the cost of fossil fuels increases every day [16].

In Reference [17], the authors introduce a study focusing on energy harvesting current state-of-the-art and application, so far. The study addresses buildings used either for commercial activities (malls, shopping centres, etc.) or those allocated for residential. Additional to the traditional energy harvesting technologies and techniques, such as using solar panels, thermal exchangers, and so forth, the review highlights those new technologies that show potential to be used as energy sources such as:

- electromagnetic waves;
- kinetic, electrokinetic;
- thermal;
- airflow.

Electromagnetic (optical and radiofrequency), kinetic, thermal and airflow-based energy sources are emerging harvesting techniques within buildings [18,19]. Most common state-of-the-art energy harvesters can provide the following energy (based on real measurement) [17]:

- 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 °C;
- periodic kinetic energy harvester (volume of 0.15 cm^3): 2 µW from a vibration acceleration of 0.25 m s^{-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 $m \leq -1$.

The results shown above reveal how the energy harvesting technologies applied to buildings show great potential and the need for the use of various harvest technologies. The harvested power could either be used to replace batteries or to prolong the life of rechargeable batteries for low-power (approx. 1 mW) electronic devices.

Figure 3 shows a diagram of the great potential of energy sources management in a Smart Building when several sources are available. The figure depicts how the current development trends are facing energy harvesting against external green energies and traditional fossil energies.

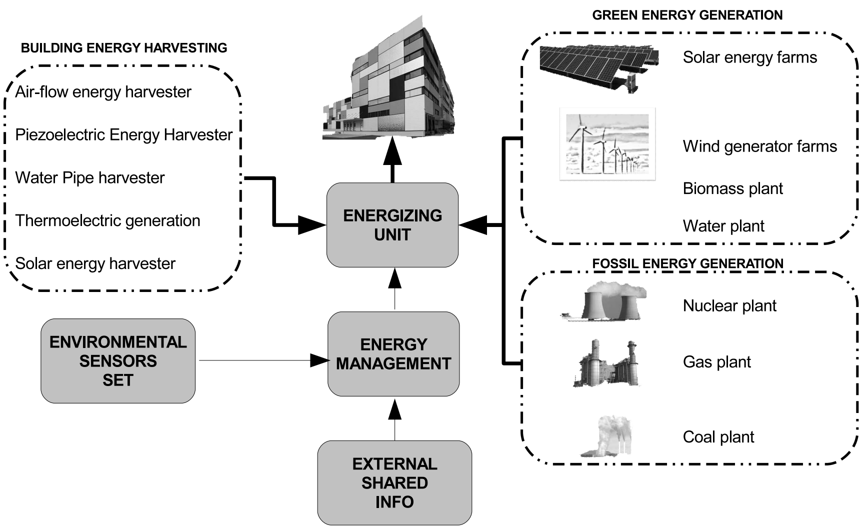

Figure 3. Energy sources management in a Smart Building: energy harvesting vs. external green energies and traditional fossil energies.

3.2. Wireless Technologies for Smart Buildings

The main decision for interconnecting devices and equipment is choosing the most appropriate technology. The first decision is choosing between wired or wireless solutions. Each technology has its advantages and drawbacks. The problem specifications impose constraints, which lead to the most appropriate technology.

When using wired technologies, the main issue is the lack of flexibility, since any change in the distribution of the network requires putting in new wiring, resulting in a high maintenance cost. However, they can be very robust against interferences produced by other systems.

Due to the advances in ICT technologies and techniques, it is possible to deploy networks of connected devices working with different standards and protocols, with distinct physical connexions (wired, wireless, optical). This option requires additional network equipment (like middleware, routers, etc.) to enable the interoperation. This kind of equipment is already available in the market. These possibilities open high expectations on energy efficiency, cost savings and pollution reduction as well [20].

Like any emerging market, the lack of regulations and the wide variety of standards, it is difficult to guarantee the interoperability between most extended standards. Furthermore, despite well-known most used standards, for example, Wi-Fi, Bluetooth, Zigbee, EnOcean, Thread or KNX (KNX is an open standard (see EN 50090, ISO/IEC 14543) for commercial and domestic building automation), there are some protocols which are aimed at dedicated tasks in Smart Buildings. For example, DALI and Mobus protocols are aimed at setting on/off the lighting system. Another example is Opentherm, which is specifically developed for heating/cooling systems control. Another example is the MBus protocol, which is used in smart metering devices. Smart Buildings need the convergence of protocols to improve their ecosystems by guaranteeing the interoperability and information exchange to address the energy efficiency goal.

So far, several communication protocols and standards have been identified, which are the outcome of traditional development based on the specific end application (ad-hoc) to achieve the highest efficiency and performance. However, the Smart Buildings need for sharing, collecting and processing data, pushes engineers to develop new services which are inter-operating in data networks [21–25].

Table 3 compares different transport layer standards, where the most relevant features, such as security and quality of services (QoS), are considered. Currently, security is one of the main concerns in Smart Buildings given that they will connect to the internet to exchange data to improve the overall system performance and optimize energy efficiency.

Table 3. Internet of Things (IoT) Transport Layer Standards Comparison.

Protocols	UDP/TCP	Architecture	Security and QoS	Header Size (Bytes)	Max Length (.tes)
MQTT	TCP	Pub/Sub	Both	2	5
AMQP	TCP	Pub/Sub	Both	8	-
CoAP	UDP	Req/Res	Both	4	20 (typical)
XMPP	TCP	Both	Security	-	-
DDSv	TCP/UDP	Pub/Sub	QoS	-	-

Table 4 shows some features of the most commonly used Internet of Things (IoT) technology standards [25]. Due to the different characteristics each standard offers, each one is appropriate for concrete constraints—power consumption, range, data rate, robustness, security.

Table 4. 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

Table 5 draws the most relevant standards for IoT, featured in terms of radio range. Some standards, as NFC (Near Field Communications), operate in a range up to just centimetres. These technologies are appropriate for Smart Buildings applications where the distance between devices to be connected is short, that is, indoor communications. There is no strict line dividing long from short-range communications. However, it is commonly accepted the following division based on distance units—short-range is given in metres and long-range in kilometres.

Short-range communications enable indoor links and they can be used for different purposes—sensing, control, signalling, monitoring, data exchange, given the range is up to a few metres (like in NFC and RFID standards). Besides, there are other short-range technologies which operate in a range up to hundreds of metres (like WiFi, Bluetooth, Zigbee and LoRa standards). These standards can be used for indoor/outdoor communications (around the building), that is, without connecting to other buildings, external networks or resources. Long-range technologies and standards are appropriate to interconnect buildings, that is, building-to-building communications. These standards are appropriate to exchange information with surrounding buildings or smart systems (e.g., smart grids and smart cities infrastructures).

Table 5. Range of the various technologies used in IoT systems.

Group	Technology	Range
Short range	RFID (passive)	<3–5 m
	WiFi (active)	<100 m
	Bluetooth/BLE	<100 m
	WiFi	<250 m
	WirelessHart	<100 m
	Zigbee	<100 m
	Z-Wave	<100 m
	NFC	< 10 cm
Long range	LoRa	10–15 km
	(E-) GPRS	<15 km
	LTE	<11 km
	NB-IoT	<11 km
	SigFox	<50 km
	Weightless	<13 km
	LPWAN	10–15 km
	WiMax	<50 km

IoT technologies are versatile and can be used for different goals. This characteristic is an advantage which enables connecting various systems in a wise way when they are using the same communication standard or protocols. Table 6 shows the main areas where IoT technologies enable applications to connect different devices to exchange data collected from many sources. Collected data are processed and fed to the intelligent unit to make the appropriate decisions. Collaborative-IoT is the pathway to improve energy efficiency and comfort in Smart Buildings and any other system as well. Hence, standards usage convergence in different applications would smooth the step to set real joint-operation. The further the information collected, the higher the accuracy and performance of the system.

Table 6. IoT major applications.

Sector	Application
Telematics & Transport	Automotive OEM (original equipment manufacturer) Vehicle Tracking Container Tracking Ship Tracking Fleet Management OBD (on-board diagnostics) DVR (digital video recording) Insurance Box.
Energy & Smart Grid	Electricity Meter Gas Meter Water Meter Heat Meter Smart Grid Wind energy generation Solar Panel Charging Pile.
Smart City & Smart Buildings	Building & Street Lighting HVAC Lighting, Traffic Light Lifts monitoring Digital Signalling Advertisement led panels LED illumination Garbage Bin Monitoring Smart Parking lots.
Security	Video surveillance: borders, buildings, streets. Building security, monitoring and controls, Occupancy detection.
Industry	Industrial PDA, Rugged Tablet PC Pipeline Management UAV (unmanned aerial vehicle), Robotics Flow Meter, Refrigerator monitoring Industrial Control and Monitoring
Healthcare and Social System	Personal Tracker, Pet Tracker Wearables Elderly Monitoring Remote Medical Equipment Glucometer, Blood Pressure Monitor
Agriculture	Trail Camera Farm Machinery, Irrigation Meteorological Station Wildlife Tracking Environment Monitoring

Another relevant feature when selecting the most appropriate technology and standard for the implementation of the communications is the payload, that is, the amount of data each packet is carrying. The payload size impacts the throughput of the link. Furthermore, the larger the number of packets to transmit the whole data, the higher the power consumption. Hence, when selecting the communications standards, energy consumption and throughput are key parameters. Table 7 shows the maximum data payload for the most relevant standards.

Table 7. Maximum available data payload comparison for various protocols.

Protocol	Max. Data Payload (Bytes)
ZigBee	102
6LoWPAN	102
Low Power Wi-Fi	2312
LoRaWAN	64
BLE	33
SigFox	29
NB-IoT	1600
Z-Wave	4 to 6

Table 8 shows the comparison of main wireless communications standards most relevant features including the frequency band of operation, the maximum transmitting data rate, the maximum range to establish a reliable connection, the energy efficiency and cost. Energy efficiency is relevant because, in many applications, the device is powered by batteries and they must guarantee a long operating life, to reduce maintenance cost. Even when they are powered from the wall-plug electricity, it must be energy efficient to contribute to the overall Smart Building efficiency [26].

Table 8. Comparison of the most relevant features of the main wireless communications standard.

Standard	Frequency	Data Rate	Range	Energy Efficiency	Cost
2G/3G	Cellular bands	10 Mbps	11 km	low	high
LTE Cat 01	Cellular bands	1–10 Mbps	11 km	high	low
6LoWPAN	subGHz and 2.4 GHz	20–250 kbps	10–100 m	medium	low
Low Power Wi-Fi	subGHz, 2.4, 5 GHz	0.1–54 Mbps	100 m	high	low
LoRaWAN	subGHz	50 Kbps	10–15 km	high	medium
Bluetooth/BLE	2.4 GHz	1, 2, 3 Mbps	100 m	high	low
SigFox	subGHz	<1 kbps	50 km	high	medium
NB-IoT	Cellular bands	0.1–1 Mbps	11 km	medium	high
Z-Wave	subGHz	40 kbps	100 m	high	medium
Weightless	subGHz	0.1–24 Mbps	13 km	high	low
802.15.4	subGHz	40, 259 Kbps	15 km	high	low
ZigBee	2.4 GHz	25 Kbps	100 m	high	medium
WirelessHART	2.4 GHz	25 Kbps	100 m	high	low
Thread	2.4 GHz	1, 2 Mbps	10–30 m	high	medium

3.3. Smart Energy Management

In the last decades, environment sustainability challenges have attracted immense research activity aimed at designing management systems for energy efficiency and Smart Buildings improvement. To face this purpose, engineers and scientists focus their investigation on using sets of sensors to monitor, for example, how energy is consumed in every facility and equipment of the building. Afterwards, a smart system which collects and processes the available data to make the appropriate decision. The final goal is to achieve the highest energy efficiency. In this context, artificial intelligence is a helpful tool. In Reference [1], the authors propose using a linear regression-based system model to analyse the collected data. These data contain information about the energy consumption measured in two actual smart homes. Data from both homes are exchanged to allow the machine learning algorithm to improve its performance.

Smart metering devices also contribute to energy efficiency. They provide real-time energy consumption information which is used to improve energy efficiency given their key features—improved real-time energy consumption visualization, instantaneous energy management monitoring and control. As an example, if one knows the prime-time history (peak power consumption time-slots) cost the staff in charge can decide when (in which time slot) to use those appliances consuming more power to save energy (money), that is, during valley time [20].

4. Techniques for Energy Efficiency Improvement

This section introduces the main techniques which are being used and in continuous evolution to contribute to the development high-performance energy efficient Smart Buildings.

4.1. Predictive Circuits Ratings

There exist several valuable techniques aimed at the efficient management of the available resources [27]. Among those techniques, we identify calculating the thermally permissible load of the transportation circuits. Traditionally, it was computed by using either a standardized computation method, which is based on very simple electrical and thermal models of circuits or by a collection of empirically obtained assumptions under normal operating conditions which, given they depend on environmental conditions (humidity, temperature, etc.), are usually determined for the various seasons along the year.

In practice, the application of such simplistic models avoids an exhaustive analysis but, in general, it leads to very conservative results with safety margins for the rating higher than expected to optimize the energy management efficiency. The advantage is the freedom degree that the network management operator holds to achieve the system constraint costs, which leads to the conclusion that the limits on power flows are relatively modest.

In Reference [28], the author identifies some key challenges (among others) which must be faced to achieve the expected performance:

- Better and more accurate weather forecast methods and techniques at a local level, using novel technologies.
- Development of algorithms capable to manage data more efficiently, based on artificial intelligence and machine learning techniques.
- Improvement of thermal modelling techniques, more accurate and at a lower cost.

In most of the cases, the problem is technically already solved. Furthermore, it is not a regulatory issue given the proposed improvements do not imply regulation changes. But it is a business problem, its current practice is the main obstacle for proposed deployment of improvements, the required investment and staff update for new data usage. Anyway, these new techniques, materials and technologies will slowly penetrate the different regions and distinct speed.

4.2. Artificial Intelligence and Data Analytics

Artificial intelligence and machine learning techniques allow Smart Buildings to adapt to changing conditions. Thus, by using high-performance algorithms for intelligent energy management will increase comfort, efficiency, resilience and safety [29]. Artificial intelligence develops algorithms to make decisions based on previous experience (training) and the current data input. Machine learning algorithms are included in artificial intelligence. These techniques learn from past and current experiences in order to optimize their performance. This behaviour is quite appropriate in the energy efficiency optimization of Smart Buildings.

Deep Learning is a major technological innovation in artificial intelligence which supports the development of future Smart Buildings. It tries to mimic the brain hierarchical understanding of objects and environments. Based on this technique, computers learn to recognize patterns from people in the facilities, room temperatures and daylight intensity, and so forth. The deep learning high performance and efficient algorithm correlates with existing records to optimize the energy usage in HVAC, lighting, and so forth.

Data analytics, management and production tools are used to identify trends and predict tendencies. Advanced analytics tools can help to discover hidden insights from the raw data coming from different sources in the Smart Building, for example, sensors, metering devices. Analytics tools process and transform huge amounts of raw data into meaningful information. These tools allow for the tracking of 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 infrastructures to increase energy efficiency and improve comfort [30]. The estimations of savings in yearly powering cost in Smart Buildings could be noticeable [31–36].

Figure 4 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 by the *Data collection* system which stores the data onto the *Database*. 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. Afterwards, the *Actions* unit determines which elements or devices are required to actuate on the available elements (energy sources, HVAC, lighting, windows, curtains, etc.) to improve the overall energy efficiency. The benefits come from various directions:

- energy costs reduction;
- comfort increase;
- equipment failure prevention;
- management cost reduction;
- maintenance cost savings;
- lower environmental impact.

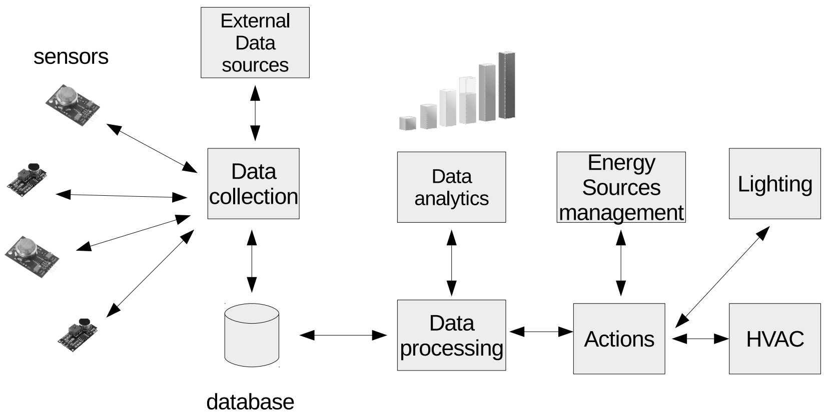

Figure 4. Example of the system architecture used for optimize energy consumption by using data analytics and high performance algorithms.

4.3. Big Data for Energy Efficiency Optimization in Smart Buildings

Emerging techniques based on Big Data [37,38] collect and manage huge amounts of data to extract patterns and to infer or predict behaviours. Several applications, ranging from business, health, defence, communications, control prediction, forecast, and so forth, benefit from Big Data. These techniques introduce a new approach to improve building energy efficiency [39]. To accomplish the optimization of energy efficiency, the first step is identifying the key parameters involved in the problem and, afterwards, suitable algorithms are developed to process the collected data and make decisions based of the history and the result of predictive models of how energy is consumed in Smart Buildings [40]. Those models are useful for designing the proper strategies leading to higher energy savings, that is, to improve energy efficiency.

An individual resources management system, capable of making a decision and performing actions to save energy, can be developed by figuring out the particular energy building profile [41]. To verify the feasibility of this proposal, the authors apply their approach to a reference building (contextual data from a complete year of monitoring). First, they characterize the building in terms of its contextual features and energy consumption and then they select appropriate techniques to generate the most accurate model of the reference building, which estimates the energy consumption, given a set of inputs.

The energy demand from ICT equipment and networks represents a relevant percentage of the overall demand. The information society lives around networks of distinct types and it is fundamental for current social development, the economy and private usage. As a consequence, society needs telecommunications networks and infrastructures with superior energetic features and high energy efficiency to fit global sustainability and environmental goals.

To achieve the expected result, considering that capacity is adapted to traffic demand fluctuations with time, an accurate and robust estimation of the traffic energy demand is needed. Among other possibilities, using Wiener filtering techniques has demonstrated to be a suitable method for achieving a reliable traffic demand prediction tool. The results showed in Reference [40] remarks that network capacity dimensioning based on the proposed Wiener filtering traffic estimation method results in promising and reliable results which enables the design and implementation of a high performance sustainable and efficient network.

Furthermore, smart buildings can identify system and equipment faults, and inefficient performance, in real-time through modern data analytics techniques. This feature leads to additional savings by predicting the overall system performance and preventing stopping the systems due to failures. Figure 5 shows an estimation of the savings due to fault early identification.

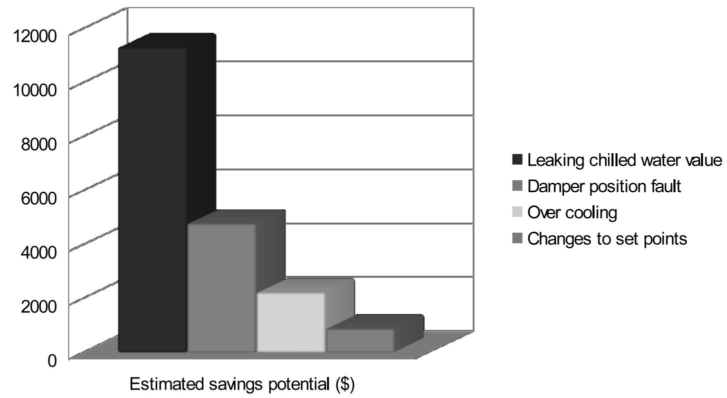

Figure 5. Example of fault detection and diagnosis output.

5. Connectivity Concerns

This section introduces the *Cloud of Smart Buildings* as a paradigm for achieving higher energy efficiency, among other potential benefits. Besides, due to the connection of Smart Buildings to the Internet, there are security issues and cyber-risks, which must be considered and fixed to avoid cyberattacks.

5.1. Cloud of Smart Buildings

The main trend is the rapid evolution of interoperability and interconnection between previously isolated components, communication protocols and subsystems, but computer security and privacy are also paramount.

Connectivity has demonstrated to be useful for achieving higher energy efficiencies in Smart Buildings. A Cloud of Smart Buildings (CoSB) allows the sharing of information among the connected facilities. Even cloud computing can be included to process the bulk data provided by the CoSB members and to deliver to each one the customized data which influence the particular building energy efficiency. The main benefits are:

- Data aggregation and sharing from different sources provide additional information to the analytics tool achieving higher performance.
- Due to the number of items installed at each building, the CoSB concept will help to define a scalable architecture which is easier to manage.
- Smart Building sensing capabilities both indoor and outdoor, 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. The number of used sensors can be scaleable.
- Smart Building solution includes automation and real-time analytics which provides reach information, higher accuracy and energy saving, and efficiency optimization. Complex algorithms can be used to improve the performance and prediction of energy demand and weather.
- A major feature is the possibility of easy integration with, e.g., other buildings to create the cloud of Smart Buildings, the smart grid, smart city, etc.

5.2. Security Issues and Trends in Smart Buildings

Currently, Smart Buildings are more than a set of rooms where many sensors have been installed as well as some actuators which, based on the decisions of an algorithm, regulate some elements (air conditioner, heating system, windows, curtains, etc.) to achieve energy efficiency, saving some money. So far, Smart Buildings operate as an energy-consuming island, sometimes combining sensing and actuating with some green energy sources, like solar panels.

Smart Buildings integrate into the *buildings society* like a *social network*, that is, buildings could connect each other, they could share information and integrate into higher structures such as smart grids and smart cities. Smart Buildings are becoming part of the Internet of Things, the Internet of Clouds, or even larger structures. Hence, they are connected and can be accessed from anywhere around the world. These features make Smart Buildings much more vulnerable than non-connected buildings.

The need for connection is clear, given that sharing information about the environment can improve energy management, that is, energy efficiency. As an example, environmental (weather) information can be shared to have a more accurate map of temperatures in an area given that appropriate artificial intelligence and machine learning algorithms can be developed to efficiently manage the distinct elements (lighting, heating, etc.) according to current, and even future, situations based on the prediction determined by the algorithms.

So, modern Smart Buildings are ready to interconnect with other systems through communication networks and the Internet. Smart Buildings must guarantee they are not controlled by unauthorized devices (people) and they must guarantee the comfortability of the occupants. Hence, for such mission access security and restrictions must be implemented to avoid destructive intrusions and non-repairable consequences. Malware can be the starting point of terrible consequences.

The drawback of being connected systems is the high possibility of creating vulnerabilities in the security system. Due to the critical consequences an intrusion would provoke, design engineers must face the security challenges for Smart Buildings by implementing security features, for example, including mutual authentication, identification and confidentiality in smart-building deployments.

In general, as a connected system like any other IoT system (independently of the size), deploying an effective end-to-end security strategy should, at least, include the following key features [42]:

- Smart Buildings mutual authentication: every equipment holds its own true and unique identifier (TUI) as the ID-card which proves its identity to others;
- message integrity guarantee mechanism: which prevents an interfering party from hacking or altering a message;

- confidentiality of data transfers: which involves coding messages so only authorized parties can read them.

The protection of collected data will be a key element in the development of smart technologies. Privacy concerns could slow down the sale of connected devices, whether used to monitor babies or automate homes. Data must be protected from potential hackers and encryption software on connected devices must safeguard information appropriately. Protection against cyberthreats should be ensured to ensure the security of users.

Smart Buildings are the target of cyber-attacks generating security issues of companies and organisations. This is due to the well-known existence of weak points through which attacks can access to the building network and compromising the whole company security, including personal private data [43]. Smart Buildings' security is attracting the attention of researchers due to the complex scenario composed by the different protocols which are used to interconnect distinct devices, equipment and systems—sensors, actuators, processing unit, database, and so forth.

The IEC has designed and published more than 200 cybersecurity standards that help to increase the resilience and robustness of critical infrastructure and IT systems in the face of a rapidly-evolving cyber threat.

There are some communication protocols used for buildings automation which do not provide the required security level. For example, Modbus communications are not protected by any cryptographic primitive. Also in KNX nodes by simply sniffing the data traffic it is possible to compromise authentication commands as a text password is delivered over the link.

6. Discussion

The construction industry is already using smart technology to face the problem of energy efficiency. Buildings, whether homes, offices, factories, hospitals or other public and private spaces, are responsible for more than 40% of global energy use and one-third of global greenhouse gas emissions.

Most sectors of economic activity, including construction, entertainment, health, education, shopping, transportation and retail, are using ICT to build real Smart Buildings. We connect devices and systems to the cloud to exchange information as part of the Internet of Things. They collect, monitor, exchange and analyse data to improve the user experience.

Smart technologies help cities and buildings to improve security, as well as managing their transportation, health services, water and energy resources. An example is intelligent grids, which help to achieve the integration of intermittent renewable energy sources and save energy by managing supply and demand and storing energy. The integrated sensors provide real-time information to automatically detect and respond to system problems. They can also be used to manage lighting, HVAC and to monitor traffic conditions and infrastructure amortization.

The increasing penetration of Smart Buildings and their integration with the smart infrastructures as smart grids and smart cities will generate benefits in different facts. Specifically, this new collaborative framework contributes to enhancing energy efficiency and the comfort of occupants.

At a higher level, new technologies and materials and intelligent metering and monitoring systems, are increasing the efficiency in production, transportation and distribution. Advanced algorithms and analytics tools are being used to analyse and predict the energy demand and, hence, the distribution process can be much more efficient.

Smart Buildings' highest accuracy is achieved when the appropriate resources are used to achieve the lowest energy consumption and the best comfort for individuals. The main features that 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 guarantee the flow of data among the different elements that compose Smart Buildings.

Figure 6 shows a possible block diagram of a Smart Building which includes the most commonly used devices and equipment. A database could be used to store the history of the collected data which would be used for different purposes—failure prediction, identification of facilities showing over-the-average power consumption, energy demand trends, and so forth. Sensing, metering and actuators are connected to a gateway to guarantee interoperation in those cases where the building uses numerous communication standards. The firewall is aimed to provide the appropriate cybersecurity level to all the facilities located in the Smart Building.

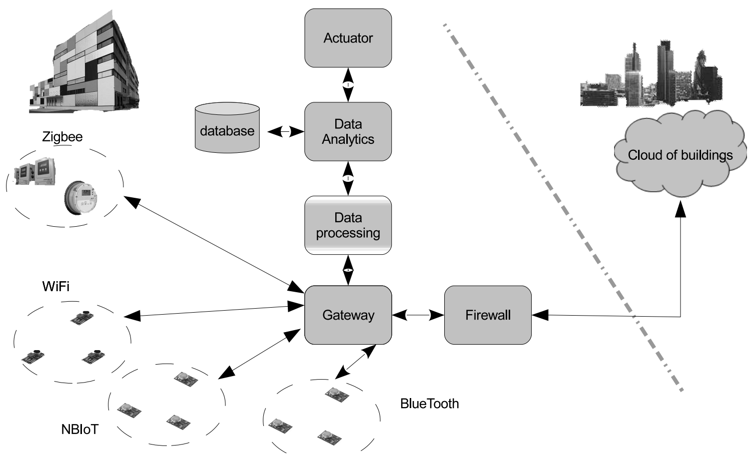

Figure 6. Overall view of the Smart Building connectivity both at building and cloud level.

The terms reliability and resilience are related and when describing the definition of one of them the other arises [44,45]. The deployment of energy redundancy by managing different sources is an option for improving the reliability of the smart grid. Furthermore, this approach also has an additional advantage—it increases system resilience. On the other hand, redundancy also increases the deployment cost.

The regulations and policy are a major impacting factor in the deployment of Smart Buildings. In Europe, energy efficiency is addressed by several research and development programs. Two directives of the European Commission in 2010 and 2020 focus on energy consumption reduction in buildings, and the *Directive on Energy Performance of Buildings* was updated in 2016, which mainly focuses on HVAC energy efficiency. According to this directive, "all new buildings must be nearly zero-energy buildings by 31 December 2020 and by 31 December 2018 for public buildings" (Recommendation EU 2016/1318 Guidelines for the promotion of nearly zero-energy buildings (NZEBs)).

Regarding the US, the *Department of Energy* is directing its attention to the development of standards aimed at improving HVAC energy efficiency. This ambitious goal will achieve an efficiency of about 15% in new devices by 2023 [5].

Many technologies can support Smart Buildings to achieve the highest energy efficiency. Data collection, processing, exchange and decision making enable the enhancement of the overall building comfort and resources optimization (more accurately and reliably). The interconnection among the different subsystems (sensors, actuators, metering devices, databases, intelligent data processing systems) must be guaranteed. For such a purpose, there are several possibilities as shown in Table 9, where the advantages and disadvantages of commonly used technologies are remarked. For each concrete scenario, a particular set of technologies (ICT) will be the most appropriate and the overall solution would be a combination of them, that is, a heterogeneous communications system.

Table 9. Advantages and drawbacks of widely used and well established technologies.

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

Energy efficiency can be implemented by very simple electronics. For example, reporting people's motion and occupancy of facilities can be obtained by simple sensor devices which can be easily used, for example, to control in real-time the air conditioning system, ventilation and lighting. The control unit, which includes intelligence abilities, analysis of the data and regulation of equipment and devices to improve ambient feeling and comfort, and productivity of the individuals who are occupying the facilities and, at the same time, optimizing the energy consumption level, reducing energy costs. Likewise, using new technologies and a smartphone to manage a lift would lead to an energy consumption reduction of about 3–10% of the overall power consumption of the building and increased the users' comfort [46].

To achieve further savings, additional intelligence in the system is required. 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, for example, considering hysteresis cycles and the historical information records, which is held by the system to be processed by data analytics techniques and, afterwards, to make the appropriate decisions, based on artificial intelligence and machine learning high-performance algorithms.

The constraints usually imposed on the supporting (intelligent) system include being low-cost, high performance, secure, reliable and accurate. The expected result is a smart-energy-efficient-building guaranteeing the comfort of occupants as individually as possible, and machine learning seems to be an appropriate tool. The low-cost constraint limits the capabilities of the support technologies and techniques and, as a consequence, the achievement of the best result.

Figure 7 depicts the main equipment in a Smart Building which can be supervised by the intelligent monitoring and control system based on artificial intelligence techniques and algorithms, most of them impacting on energy efficiency.

Figure 7. Major equipment in a Smart Building.

7. Future Smart Building Challenges

This section summarizes and remarks on the challenges which must be faced to achieve the benefits of future Smart Buildings. The main potential improvements are identified, new technologies and techniques, new parameters which can influence on the energy efficiency optimization, and social facts which impact their deployment, for example, regulations.

Overall building energy consumption has a remarkable worldwide impact on the environment, due to the CO_2 emissions during the production process. Currently, new technologies and techniques are used to reduce the environmental impact by using the so-called green energies (solar panels, wind generators, etc.), as well as energy harvesting, that is, systems installed in the building to get energy independently of sellers. The systematic design and construction of Smart Buildings is a must to achieve the environmental compromises and sustainability objectives.

Regarding the trends in Smart Buildings, the following are very active fields in the context of connectivity, interoperability, cybersecurity and data privacy. As buildings and homes become smarter, they require the storage of more information and the use of communication technologies (ICT), audio, video and multimedia systems, and diverse hardware. International IEC standards cover many aspects of these components to ensure their quality, as well as to guarantee security. Many devices and systems are manufactured in parts. Furthermore, standards also consider the need for interoperability to ensure that buildings incorporating these technologies can operate safely.

The following terms which have appeared throughout this paper refer to facts which should be on the agenda of the agents impacting Smart Building development for improving Smart Buildings' energy efficiency and sustainability:

- air pollution control;
- energy conservation;
- energy management systems;
- energy Internet, energy security;
- renewable energy sources, emission reduction;
- smart grids, smart power grids;
- renewable energy synergy, wind power generation, energy harvesting;
- energy utilization, energy-saving, coordinated scheduling, energy storage.

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 worth mentioning:

- gateways which interconnect buildings to the grid;
- cyber-risk of connected devices;
- detecting and preventing particular types of attacks;
- ensure secure interoperability between protocols;
- use of artificial intelligence and machine learning to improve security;
- privacy;
- confidentiality;
- data integrity;
- cryptography;
- availability;
- non-repudiation.

Right now, there is a wide-open research area with several opportunities for most of the technologies concerning Smart Buildings and which require appropriate attention:

- presence-based flexibility;
- facilities, and buildings control;
- tenants attraction and retain;
- workers efficiency and productivity;
- comfort feeling;
- maximize daylight;
- information technologies;
- communications technologies;
- cybersecurity;
- interoperability.

Information and communications technologies are paramount for succeeding in this challenge. Information collection and exchange and interoperability require the development of appropriate communications standards that are more efficient and reliable. Artificial intelligence development will allow the design of algorithms which increase the accuracy of processing and actions. This includes machine learning, big data and deep learning techniques.

Table 10 summarizes, for different kinds of equipment or infrastructure, the resources which should be used in a Smart Building to optimize, among other things, its energy efficiency.

Table 10. Equipment management vs. technologies and techniques.

	Sensors	Actuators	Communications	Intelligence	Security
HVAC	temperature humidity Air-flow Smart thermostat	Speed control Working cycle Heating control Cooling control	Sensors-to-intelligent system Intelligent system-to-element to control External data sources	Data processing Data Analytics Big Data Artificial intelligence	Firewall Robust protocols
Lighting	Light intensity	Switch Light regulator	Sensors-to-intelligent system Intelligent system-to-element to control External data sources	simple command	Firewall Robust protocols
Windows	Open/close	Motor	Sensors-to-intelligent system Intelligent system-to-element to control External data sources	simple command	Firewall Robust protocol
Lift	Occupancy Stop demand/level # Potential occupants Weight	Motor control	Sensors-to-intelligent system Intelligent system-to-element to control	Data processing Data Analytics Artificial intelligence	Firewall Robust protocols
Door	Proximty	Motor Switch	Sensors-to-intelligent system Intelligent system-to-element to control	simple command	Firewall Robust protocols
Energy management	Smart metering Energy resources status	Switch	Metering-to-intelligent system	Data processing Data Analytics Big Data Artificial intelligence	Firewall Robust protocols Cryptography
Acess security	Cameras Wireless ID fingerprint	Motor	Sensors-to-intelligent system	Artificial intelligence	Firewall Robust protocols Cryptography
Fire, wateing ...	Smoke Temperature	Switch	Sensors-to-intelligent system intelligent system-to-element to control	Data processing Artificial intelligence	Firewall Robust protocols Cryptography
Failure prediction	temperature humidity Air-flow Smart thermostat Smart metering	Stop	Sensors-to-intelligent system intelligent system-to-equipment to control	Data processing Data Analytics Big Data Artificial intelligence	Firewall Robust protocols

8. Conclusions

This paper focuses on energy efficiency in Smart Buildings, identifying the energy resources most used in buildings and the elements that can be managed to enhance energy savings. More specifically, the factors that influence energy efficiency and the technologies that make it possible to increase this improvement in energy efficiency, energy savings and the reduction of CO_2 emissions to the atmosphere have been analysed.

In this context, information and communications technologies play a relevant role. So far, smart devices such as thermostats, temperature sensors, light intensity meters, presence detectors, and so forth, have been employed to provide energy savings by switching on/off lights or managing HVAC in simple ways.

However, scientists and engineers working on the design and development of Smart Buildings have realized that a large amount of information about the overall state of the buildings as well as each of their facilities, allows more accurate decisions to be made to more efficiently manage energy and building resources (including energy harvesting) that impact energy consumption.

Connectivity is, therefore, a critical feature in Smart Buildings, where all the elements that are installed—that is, sensors, actuators, electromechanical elements, databases, information processing system, and so forth—must be well interconnected. For this purpose, wireless technologies are the most suitable as they provide greater flexibility and a lower deployment cost. Besides, they include a certain degree of security.

Within wireless technologies, all those related to the Internet of Things are identified as the most suitable. This fact is due to their extensive use in many common systems and devices, such as smartphones, allowing easy integration of devices and systems.

However, there are still a wide variety of standards applicable to IoT. This is because each specific application within a Smart Building requires choosing the most appropriate technology according to the necessary range, power consumption restrictions and the volume of data to transmit/receive.

This fact makes necessary, in most cases, the interoperation between wireless standards and therefore the need for 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 cyber attacks is one of the issues that is being addressed in recent years to provide the appropriate means to avoid cyber risks and while not compromising either the safety of people, installations, or personal data.

To conclude, it is worth noting the following remarks:

- Intelligent applications in the building sector, supported by ICT, result in an intelligent building which can save energy by increasing its efficiency, and, additionally offer handicapped people additional support.
- Identify smart technologies and applications which most optimize energy efficiency (the highest energy savings) and are most cost-effective and provide higher comfort.
- Smart Buildings are ready to interconnect and integrate into Smart Grids and Smart Cities.
- They contribute to sustainability.
- Improves people's 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 for the optimization of energy consumption and billing.
- Energy consumption control by setting on/off appliances—lighting, HVAC, etc.
- Data collection for processing and making 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 to monitor and track people and things (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, which was involved in this project, was directed by César Benavente-Peces).

Finally, it is worth making 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 meets, capable of collecting, transmitting/receiving and sometimes processing and sharing 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-effectiveness.
- In many applications, e.g., Smart Buildings, the use of heterogeneous wireless technologies is 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 to achieve a more accurate analysis of the building and providing a more precise response, resulting in the best comfort for all the occupants and higher energy efficiency.
- A simple smartphone can interact with IoT based systems, including Smart Buildings.

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Abbreviations

The following abbreviations are used in this manuscript:

AMQP	Advanced message Queuing Protocol
CoAP	Constrained Application Protocol
CoSB	Cloud of Smart Buildings
DC	Direct Current
DDSv	Data distribution service for real-time systems
EPGap	Energy Performance Gap
FTP	File Transfer Protocol
GW	Giga-Watt
HVAC	Heating, Ventilation, Air conditioning
HVDC	High voltage direct current
ICT	Information and Communication Technologies
IoT	Internet of Things

IP	Internet Protocol
LTE-A	Long-Term Evolution Advanced
LTE	Long-Term Evolution
LoRaWAN	Long Range Wide Area Network
MQTT	Message Queue Telemetry Transport
Mtep	Million tons equivalent petrol
NFC	Near Field Communication
PV	Photo-Voltaic
QoS	Quality of Service
RFID	Radio-frequency identification
RTU	Remote Terminal Unit
SEEB	smart-energy-efficient-building
TCP	Transmission Control Protocol
TUI	True and unique identifier
UDP	User Datagram Protocol
WirelessHART	Wireless Highway Addressable Remote Transducer Protocol
XMPP	Extensible Messaging and Presence Protocol
6LoWPAN	IPv6 over Low Power Wireless Personal Area Networks

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