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Internet of things for Energy efficiency of buildings

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***Abstract*— Among the strategies for improving the energy performance of buildings, in addition to the building envelope characteristics and the integration of renewable energy sources, particularly important are those which focus on the efficient management of electrical systems and air conditioning systems, especially for existing buildings. In this scenario, the ongoing revolution of everyday objects wirelessly connected to the network, called the "Internet of Things" (IoT), is creating interesting and unexpected opportunities in reducing energy consumption and improving environmental comfort in buildings.**

The article offers an analysis of the state of the art of the Internet of Things applied to the management of buildings, highlighting the functions that can be monitored and controlled and the benefits that can be achieved in terms of comfort and energy savings in the various categories of equipment (mechanical, electrical, plumbing, lighting, etc.).

Keywords – Internet of things, Smart building, Home automation, Smart appliances, Energy efficiency of buildings, Sustainable architecture

I. INTRODUCTION

The important targets for energy consumption reduction in the building sector fixed by the European Union in 2020 and the achievement of Zero Energy Buildings (ZEB) also pass through an intelligent management of equipment, able to provide the best environmental comfort and safety conditions while maximizing resources efficiency, thanks to the ability to link environmental conditions and actual needs.

In this framework, Building Automation Systems (BAS) are proving particularly effective: their demand is continuously and steadily growing, thanks to the debut on the market of several devices applicable to individual components of the domestic technological system. Based on Wi-Fi data transmission, these allow to have the home literally at hand, with no need for wiring or retrofitting existing equipment. Called "Internet of things"(IoT), the revolution of the large network of web connected, smartphone controlled everyday objects is an ever expanding sector, intended to grow to 26 billion units installed in 2020 representing an almost 30-fold increase from 0.9 billion in 2009, most of which in residential dwellings [1]. IoT devices can be integrated in all energy consuming equipment (air conditioning systems, electrical switches and sockets, lamps, appliances, plumbing, etc.) or in building envelope elements such as doors and windows, offering users the possibility to optimize energy efficiency, micro-climatic conditions and safety.

II. BUILDING AUTOMATION SYSTEMS

Comfort, safety, energy consumption reduction, flexibility and ease of use are increasing needs for building users and the demand for intelligent "Building Automation Systems" to satisfy them is ever growing, with a global expense in this sector destined to reach 21,9 billion dollars in 2018, from 7,3 in 2014 representing a 28.4% compound annual growth rate [2].

Thanks to "Building Automation Systems", all individual building subsystems (electrical distribution, air conditioning, water system, lighting, data network, access control, elevator control, fire and security systems, renewable energy and energy storage, electric mobility) can become part of a single central system, also able to learn users' needs and behavior, to anticipate solutions or provide recommendations. These systems make use of forecasting, optimization and evaluation algorithms that acquire real-time data from smart sensors and meters, placed in strategic points of the building, capable of detecting internal microclimate parameters, space and ICT infrastructure use, attendance, weather data and energy quality. Based on the input data analysis, the system suggests actions to support building management optimizing energy consumption; users, on the other hand, as an active part of the system can monitor consumption instant by instant, by tablet or smartphone, and improve their behavior accordingly, becoming agents of saving themselves.

Depending on the type of system used, smart home appliances are able to perform partially autonomous (following fixed and predetermined responses to environmental parameters) or fully autonomous programmed functions, based on responses to environmental parameters directed by dynamic programs that can be generated or improved by self-learning.

The Digital Operating Building Solution (Di-BOSS), jointly developed by Finmeccanica, Columbia University and the real estate firm Rudin Management Company ranks among the most innovative intelligent integrated platforms. It is already operating in 4 skyscrapers in New York (3 Times Square, 345 Park Avenue, 355 Lexington, 415 Madison Avenue) and by 2015 it will be installed on 12 other buildings; in just 6 months after its activation it has achieved about $ 500,000 in savings, or approximately 10% of total energy expense.

III. INTERNET OF THINGS REVOLUTION FOR ENERGY EFFICIENCY IN BUILDINGS

In addition to Building Integrated Automation Systems, a new generation of low-cost sensors connected to the Internet is now available to reduce the energy consumption of buildings.

These systems are applicable to any type of building and are able to intelligently monitor environmental parameters of interiors or energy consumption of individual appliances or electrical outlets, providing users with real time information on their smartphone, anywhere in the world they may be. The service also includes sending email or SMS notifications, along with eventual alarm or equipment failure warnings.

In addition to data reading, some of these systems allow real time operations, always via smartphone, on household equipment and appliances by programming their on-off schedule or adjusting activity levels as needed. Objects become self-recognizable and acquire intelligence due to the ability to communicate information about themselves and gain access to aggregate information from any other devices. Alarm clocks anticipate themselves in the event of traffic, plants tell the watering system when it is time to be watered, smart thermostats track the comings and goings of occupants to adjust the temperature when necessary, smart lighting self-switches on after a prolonged absence for security purposes. All objects can take a proactive role by connecting to the Net. The goal of the Internet of things is to make the electronic world draw a map of the real world, giving an electronic identity to things and places from the physical environment. Objects and places equipped with Radio Frequency Identification (RFID) labels or QR codes already communicate information to the network or to mobile devices such as smartphones.

This growing phenomenon has also led two American giants Apple and Google to develop Internet of Things solutions for buildings.

After several years of work Apple has filed the patent for his first official iHome Intelligent "System and method of determining location of wireless communication devices / persons for controlling / adjusting operation of devices based on the location", which uses home automation and the multimedia capability of Apple products to transform the house into a thinking organism.

Intelligent iHome is indeed an organism capable of detecting occupants presence and movements, anticipating usual behaviors and changing its structure depending on the needs. Taking advantage of position sensors, GPS and remote control technology, the "smart home" can notice the arrival of the car in the garage or, through your mobile phone, the crossing of the entry threshold, operating the oven for dinner rather than the coffee machine or even opening the door on your approach.

Even Google has debuted in the home automation and smart home sector, with the purchase of a company specialized in the production of smart thermostats and indoor detection systems. The goal is to achieve a "conscious House," which through Digital Life and the Internet of Things, opens to the digital and multimedia world, to help users in house management and in energy consumption reduction.

IV. IOT ENVIRONMENT MONITORING SYSTEMS

As regards monitoring systems, remote information devices are available on the market, that provide real-time data on temperature, air humidity and quality, CO_2 concentration, illumination and noise levels, even suggesting the user which action to take in case of non-optimal conditions.

By installing one of these devices in a house or office room, it is possible to obtain accurate and timely information on the internal microclimate, linking the subjective state of an individual with the objective conditions of the environment. For example, you can understand why and when you start to feel a sense of sleepiness during a meeting, evaluate the effects of temperature and air quality on sleep, measure the levels of noise that cause ailment or decrease productivity, know when and where to ventilate environments or adjust the temperature. Some controllers, as well as gathering input from various temperature, lighting, location, and contact sensors, are also able to inform the user in real time on any event to happen at home, from a flooding in the cellar to the opening of a door or the start of any appliance.

V. IOT APPLIANCES MONITORING AND CONTROL SYSTEMS

With regard to the systems that allow, in addition to monitoring, to operate appliances and electrical equipment, these can manage air-conditioning (heating in winter and cooling in summer), lighting, or manual or scheduled start and stop of appliances by controlling individual power outlets. You can also extend remote control devices to doors, by installing smartphone controlled locks accessories, and monitor licenses and electronic keys distribution with dedicated systems, or to windows with remote controlled actuators, with programmable, solar powered opening.

A. AIR CONDITIONING CONTROL SYSTEMS

For air conditioning monitoring and control, available systems are accessible via web and capable of self-learning and foresee system programming by automatically reducing air temperature when the house is unoccupied. In those situations, sensors pick up the lack of movement and select the 'auto-away' setting, reducing the temperature to the lowest level programmed. These systems are also able to study users' behavior: they record temperatures set during the day and, after a week of training, are able to repeat them themselves during the following days. If your preferences change, the system will update its behavior without needing to be reprogrammed. The thermostat also shows the setting of the energetically optimal temperature, indicating the potential saving and registering it on the application. Some systems also monitor the costs for air conditioning, sending an alert to the user when he is going to exceed his set budget.

Other systems also incorporate a geolocation feature called "geofencing", which according to the position of the smartphone, communicates to the thermostat when the user

leaves the room or is approaching in order to adjust the operation of the plant accordingly.

Others can integrate with one's car, in order to coordinate air heating or cooling with the navigator estimated time of arrival.

For upgrading and improving the efficiency of existing individual devices, wall mounted Wi-Fi-enabled smart thermostats with infrared emitting diodes are finally available, permitting to replace the standard remote with the user's smartphone.

B. LIGHTING CONTROL SYSTEMS

To control lighting, smart systems are available that allow to manage house lighting using a smartphone or tablet. With simple and intuitive applications, these systems allow to remotely control the lighting system with custom settings and a timer for every need. They can recreate any color and can brighten up a room in a million different ways. You can use an application to capture the colors of a photo, and then re-create them in the house environment. Just snap a picture or choose one from your smartphone, then drag the pointer to the desired color and the light hue will change immediately. You can also use the timer to modulate the intensity of light, such during awakening. Better yet, you can recreate the image of a rising sun according to the desired hue. These systems can also help you focus, giving a boost of energy and promote relaxation: just choose one of different recipes – like Relax, Focus, Food or Reading – from the application. With a personal account you can log in from anywhere in the world via a web browser or from your smartphone and conveniently manage house lighting.

Some systems also provide the connection with motion sensors that can automatically turn off the lights when you leave the house and turn them on again when you return. Programs like 'Night Mode' switch the light on when the system detects motion in the middle of the night, and if no one has been home for more than two days, a Smart Security feature is able to simulate human presence inside the house.

C. CONTROL OF ELECTRICAL EQUIPMENT

Concerning the control of electrical appliances, market available systems can be connected to individual power outlets providing real-time information on energy consumption and costs and offering the ability to turn appliances on and off remotely whenever you want, via Bluetooth or Wi-Fi. For example, with a single click you can turn off all appliances on standby, or obtain information on the energy performance of a single device in order to determine its incidence in overall consumption, optimize its use or replace it with a more efficient one.

It is estimated that the installation of electrical appliances monitoring and control systems at home can lead to 300 € savings per year on your electricity bill, with an 850 kg / year reduction of carbon dioxide levels emitted into the atmosphere.

D. APPLIANCES

Several manufacturers have recently launched new models of smart appliances that allow users to send messages to monitor and manage their appliances, such as refrigerators, washing machines or ovens.

A Smart refrigerator has an internal wide-angle camera that takes a picture every time the door is opened. Users can view the image on a mobile device to control the food you have at home. The Smart Refrigerator also allows users to keep track of expiration dates and can recommend recipes based on available food.

The Smart Washing Machine allows users to send text messages to monitor and manage the appliance. You can write messages like "what are you doing?" to find out at what point of the wash cycle the machine is going through or select the appropriate washing program.

Finally, with Smart Oven, users can communicate which meal they intend to cook and the system will pre-heat the oven accordingly at the right temperature.

E. WATER CONSUMPTION

Internet of things can help to achieve significant benefits also in terms of tap water consumption for indoor use and irrigation. Furthermore, reducing water consumption allows to save not only drinking water but also the fuel to heat it, resulting in energy and economic savings, as well as reduction of air pollution and greenhouse effect.

Regarding indoor uses, available systems are able to monitor both the flow and the temperature of water in real time and can be easily installed directly at the points of use. Stored on a remote server, data about water consumption can be read by a smartphone or tablet and can be configured to trigger an alarm in case of exceeding the consumption targets set by the user. For their operation, these systems collect energy directly from water flowing inside the pipe.

Concerning irrigation systems on the other hand, new smart systems collect data on weather conditions and soil condition to water the land according to the actual needs.

In particular, the sensors are able to detect the lighting, humidity, temperature, humidity and soil nutrition conditions. The system can in fact detect even small variations in the electrical properties of the soil, normally associated with changes in humidity, acidity and fertility.

All data collected is used by the system to manage the automated irrigation of vegetation (also allowing to save water when it rains and to avoid plants drowning) and can be viewed in real time via an app, which can also send alerts when the soil is too dry and offer suggestions to maximize plant health. The application can also recommend the most suitable plants species for a given type of soil and amount of exposure to solar radiation. For their operation these systems are equipped with a solar panel with an integrated battery.

TABLE I. INTERNET OF THINGS DEVICES FOR SMART HOUSING

Controllable functions	Leading IoT products on the market
Monitoring of environmental parameters (indoor/outdoor) Remote information on air quality, lighting, air temperature, humidity, noise levels	Cube sensors, NetAtmo, Twine, Spotter
Electric Monitoring of energy consumption and on/off control for individual appliances/outlets	Meterplug, Belkin WEMO, Wattio, Pivot Power Genius, Parce Smart Plugs
HVAC Monitoring of environmental parameters and energy consumption along with remote control Auto-programming and self-optimization based on learning of users' habits Automatic operation based on the presence/absence of people (geolocation services) Automatic operation based on the weather conditions and fixed budget	NEST, NetAtmo, Lyric smart thermostat, Vivint Sky
Lighting Remote information and control of lighting equipment Multiple, automatic switch on of lights according to specific scenarios (guests, party, home theater, etc.). Self- switch on after a prolonged absence for security purposes following patterns copied from the automatic recognition of reality Centralized lighting power off when the system recognizes the absence of users Completely autonomous and automatic lighting management	Philips HUE, Spark, Insteon, LIFX Labs, Lumen Smart Bulbs, GE Link, Goldee, GreenWave Reality, iLumi
Appliances Ability to send messages to monitor and manage home appliances such as refrigerators, washing machines or ovens	LG HomeChat, Samsung SmartHome
Waterworks Monitoring of consumption of hot and cold water for indoor uses Monitoring of environmental conditions (air temperature, humidity and lighting) and of soil humidity and nutrition and automatic or remote control of irrigation water	Driblet, Edyn
Home security Ability to geofence home boundaries, check in on live video and audio feed, monitor ambient conditions, view trends and statistics, set up alerts for "irregularities" at home, control other smart devices Remote locks control, access and permissions remote control	Piper, Vivint Sky, Sentri, Lockitron, Key2share

VI. CONCLUSIONS

We have now entered the era of the Internet of Things (IoT), characterized by a multitude of "intelligent" objects capable of communicating and interfacing with each other.

With this capability, and the interaction between objects and needs of individuals (interaction design) we can reduce the energy consumption of buildings while improving environmental well-being.

The Internet of Things could also prove particularly useful during energy demand peak times, with the ability to manage power consumption in a more rational way. Inside the building, all devices can talk to each other, interact with the network and generate information on the amount of energy they are consuming. Once information is gathered, the data could be used to take some decisions to better manage the overall system. Smart appliances, for example, could independently make decisions on when to start their cycle based on when the network is freer and more energy is available, or when the cost is lower. Thus, for example, even energy production from renewable sources monitoring can synchronize with supply and consumption expected by users, such as charge/discharge cycles of electric vehicles connected to the building. From this point of view, the "Vehicle-To-Building" technology is particularly interesting in the prospects of electric mobility development, allowing energy exchange between buildings and vehicles aimed at reducing energy consumption and managing emergencies. The building can take advantage of energy contained in vehicles batteries at times when electricity is most expensive, to recharge them when energy costs less.

However, to turn this scenario into a proven reality, substantial problems still need to be addressed, starting from the "dialogue" between various applications and devices manufactured by different companies, to reach the definition of a common standard at an international level.

For this purpose, recently three different non-profit consortia have been established: All Seen Alliance (Microsoft, Qualcomm, LG, Sharp, Panasonic), Industrial Consortium Internet - IIC (AT & T, Cisco, GE, IBM) and the Open Interconnect Consortium - OIC (Atmel, Dell, Broadcom, Intel, Samsung and Wind River). These consortia aim to define wireless connectivity requirements of Internet of Things devices, and thus ensure interoperability between systems, regardless of form factor, operating system or supplier. Open source platforms will allow all products from different manufacturers to communicate independently with each other regardless of brand, on any type of platform (Wi-Fi, Bluetooth, Wi-Fi Direct, Zigbee, ZWave and Ant+) and without need for further ad hoc software.

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