# Standards and Technologies from Building Sector, IoT, and Open-Source Trends

**Benoit Delinchant and Jérôme Ferrari**

## 1 From Home Automation to Smart Home

In the 2010s, everything had to be smart. This qualifier can be applied to systems capable of capturing, communicating, and acting. In particular, in 2009, with the explosion of the theme of smart grids (Fig. 1), linked to the decentralization of the electricity network, a direct consequence of the need to improve the penetration of renewable energies, such as solar photovoltaics, distributed on the territory. The same goes for Smart Home, the use of the term listed by Google [1] takes off again during this period and is followed by the smart city which integrates energy, transport but also security issues with especially facial recognition systems.

It all began in the twentieth century with the introduction into the house of motorized equipment to relieve tedious tasks within the house such as washing clothes (1904), cooking (oven, refrigerator, robot ...), washing dishes, clean (vacuum cleaner, etc.), etc. This equipment introduces the concept of home automation or "home automation" which appears as the contraction of the Latin word domus (home) and the word robotics. But beyond this individual equipment, automating previously manual activities, home automation introduces the concept of automated and centralized control. The very first protocol for controlling home appliance was the X10 developed in 1975 by Pico Electronics of Glenrothes, Scotland. Its objective was to remotely operate the power supply to light fixtures or electrical equipment plugged into an outlet. Its principle is based on the power line carrier (Powerline Carrier Systems (PCS)). X10 is a technology still existing, which is also able to use other media such as radio frequency, but which retains characteristics that can be called archaic, sending for instance the signal three times to increase the probability of being received.

B. Delinchant · J. Ferrari (✉)
G2Elab, CNRS, Grenoble INP, University of Grenoble Alpes, Grenoble, France



S. Ploix et al. (eds.), *Towards Energy Smart Homes*,
https://doi.org/10.1007/978-3-030-76477-7_3

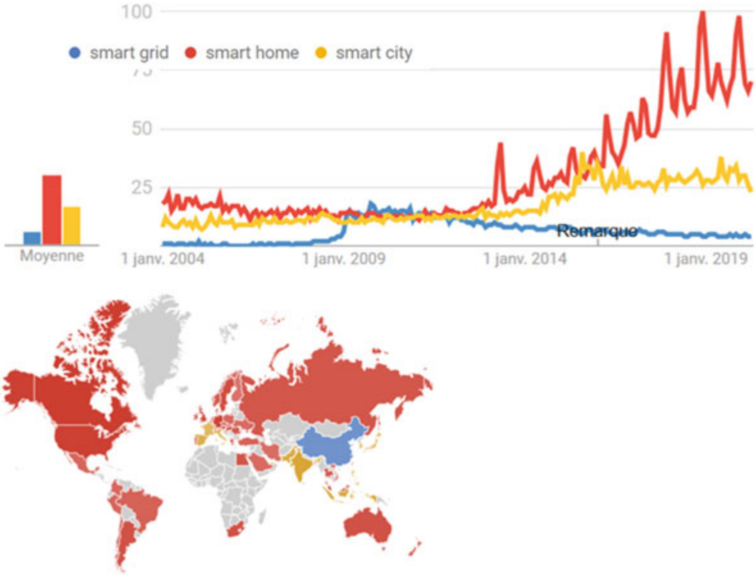



**Fig. 1** Google trends for smart grid, smart home, and smart city (https://trends.google.com/trends/explore?date=all&q=smart%20grid,smart%20home,smart%20city)

In the early 1990s, home automation had to overcome a large number of challenges such as high costs at all levels, from development to maintenance, including manufacturing and installation [2]. In addition, their use was reserved for interested people mastering the technologies and agreeing to spend time on GUIs that are not very ergonomic.

In a more recent study [3], the authors always indicate a high overall cost, a complexity linked to incompatible equipment, a lack of reliability, and always a great difficulty of handling by an average user.

Associated with Building Automation, the term Intelligent Building appeared in the 1980s. The vision, and therefore the definition, that we attribute to intelligent building is largely dependent on the authors and their point of view, but we can also consider that they evolve over time. In particular, Wigginton and Harris have listed 30 different definitions [4]. The first were purely technological, such as in 1983 when Cardin refers to Intelligent Buildings as "Buildings which have fully automated building service control systems." Others have a broader vision which is part of a compromise between the well-being of the occupant and the optimization of resources. "A building that creates an environment that maximizes the efficiency of the occupants of the building while at the same time allowing effective management of resources with minimum life-time costs" [Intelligent Buildings International (IBC) cited by Wigginton and Harris [4]]. The latter definition is also used in numerous scientific publications on the intelligent building.

According to Ghaffarianhoseini [5] "Current definitions of IBs have gradually considered the users' interactions and even the social values of users [ . . . ] raise the idea that intelligent living environments must be aware of and responsive to their occupants' demands and activities".

Wilson in [6] is dividing research topics on smart homes into three categories:

1. **Functional**: considers the smart home as a way of better managing the daily living demands.
2. **Instrumental**: focuses on managing and reducing energy demand in households towards a low-carbon future.
3. **Socio-technical**: considers smart homes as the next wave of development regarding daily life digitization.

Responding to the well-being of the occupant is therefore a first challenge, and this requires an environment capable of capturing and acting according to the needs of the occupants and their well-being. Generally speaking, it is the interaction with the occupants which makes it possible to achieve the objectives of the smart building, which can go beyond the well-being of the occupant. This is particularly the case for the current objectives linked to the energy transition, to which this work is addressed.

## 2 Standards and Performance Indicators from Building Sector

### *2.1 Standards to Deploy Energy-Efficient Technologies*

Directives and associated standards have been in place for several years aimed at massively deploying energy performance technologies in buildings. In 2018, the European Parliament updated directives 2010/31/EU on the energy performance of buildings and 2012/27/EU on energy efficiency. In particular, emissions from European buildings will have to be reduced by 80–95% by 2050, compared to 1990. This challenge can partly be met by the residential sector and monitoring, interaction, and piloting technologies.

The new 2018 directives on the energy performance of buildings (2010/31/EU) and energy efficiency (2012/27/EU) are translated into standards (see Fig. 2). Throughout this chapter, we will have the opportunity to cite a number of these standards and see how smart home technologies are adapted to them or not.

We can already evoke with Fig. 2 that a certified building (ISO 50001), that is to say having implemented an energy management system, is exempt from the obligation of energy audit (EN 16247). In France, for example, a company building with more than 250 people or a condominium with more than 50 dwellings must undergo an energy audit every 4 years. This is an exhaustive examination and analysis of the energy use and consumption of a site or a building, with the aim of identifying energy flows and potential for improving the energy efficiency and then report on it. Individual houses are subject to a much less restrictive Energy Performance Certificate (in French "DPE") at the time of sale. We could imagine that an equivalent system could be developed in smart home in order to lead to a continuous improvement in the energy performance of all housing.

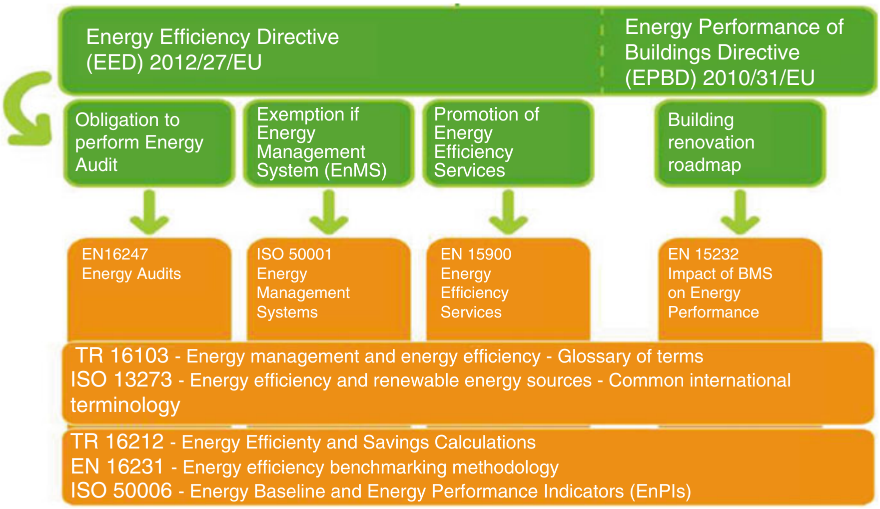



**Fig. 2** Consistency between regulations and standardization—European Level. (Source: Obara [7])

In Sect. 3.2.3, we will discuss the energy management methodology defined in the ISO **50001** standard as well as the associated services that can be offered by Energy Service Company (ESCO) in the framework of EN 15900: 2010—Energy efficiency services.

Finally, we will more particularly develop energy management systems (EMS) and their performance defined in standard EN 15232.

## 2.2 *The Benefits of Energy Monitoring*

### 2.2.1 Measure and Verification (M&V), from Design to Real Performances

A delivered building does not operate efficiently immediately. The building and its equipment must be regulated and its occupants informed and accompanied during the first year of operation according to the uses and seasons. This year of learning the building is very important to avoid consumption drifts and/or user discomfort. The commissioning and monitoring of technical installations must not be left to chance. Only energy and technical An effective building monitoring will be able to identify deviations, anomalies and give indications to reduce or even eliminate them in the best of cases. This monitoring is all the more essential since it still happens that, despite the drifts observed and reported, certain problems remain unsolved 2 years after their commissioning. Good practice requires that M&V is well integrated into the process of identifying, developing, procuring, installing, and operating energy conservation measures (ECM).

There is often a distortion between the consumption assumptions, studied in design, and the actual consumption of a building in operation. The causes of these distortions can be numerous: deviations in particular related to the choice of materials and their implementation, the climate, the conditions of occupation or management of equipment, the varied behavior of users, etc.

Post Occupancy Evaluations (POE) based on questionnaires and on-site physical measurements is used to improve the ways that buildings are used to support productivity and well-being. Specifically it is used to account for building construction quality. According to Leitner [8], the most used evaluation methods are questionnaires and on-site physical measurements. The most frequently evaluated criteria were lighting, internal temperature and thermal comfort, and acoustic comfort. In Di Giuda [9] authors are exploring the potential application of IoT sensors and Machine Learning techniques to POE.

An effective building monitoring will reduce the majority of overconsumption, dysfunctions, and therefore the satisfaction of the occupants, but also improve knowledge of the systems in use and their daily operation. The monthly invoice control is the first monitoring tool to be implemented. However, this control is not sufficient to identify precisely the causes of possible overconsumption. To maintain the level of performance and the loads linked to the building, only real follow-up after reception makes it possible to identify and understand the origin of these distortions in order to reduce them quickly.

### 2.2.2 Energy Performance Contracting

In order to ensure that the performance defined in the design for a new construction or renovation will be achieved, an energy performance contract (EPC) can be established between a project owner and an operator in order to set an energy efficiency objective.

An international standard call International Performance Measurement and Verification Protocol (IPMVP®) defines best practice for quantifying the results of energy efficiency investments and increase investment in energy, demand management and renewable energy projects.

Indeed, energy savings cannot be directly measured, because savings represent the absence of energy consumption. Instead, savings are determined by comparing measured consumption before and after implementation of a program, making suitable adjustments for changes in conditions. The comparison of before and after energy consumption should be made on a consistent basis, using the following general equation:

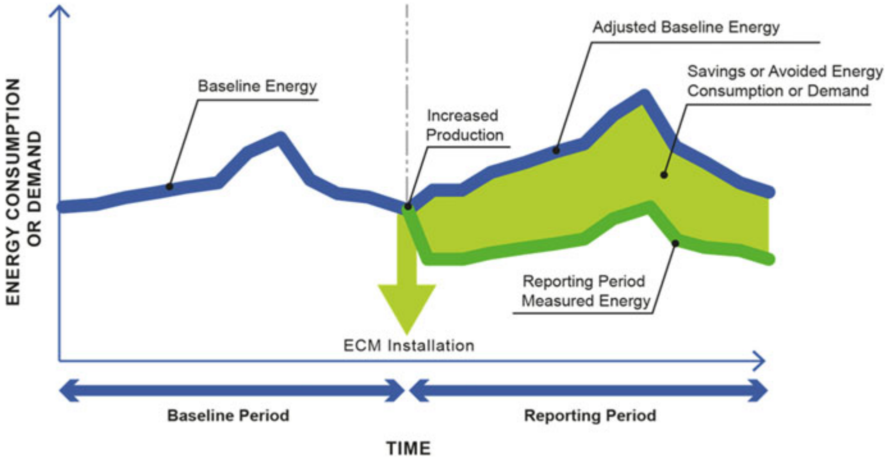



**Fig. 3** International performance measurement and verification protocol (IPMVP®). Source: Efficiency Valuation Organization (https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp)

$$\text{Savings} = (\text{Baseline Period Energy} - \text{Reporting Period Energy}) \pm \text{Adjustments}$$

IPMVP's framework requires certain activities to occur at key points in this process and describes other important activities that must be included as part of good M&V practice (Fig. 3).

Some researchers are looking for key factors like competence, integrity, communication, or reciprocity in generating trust and cooperation in energy performance contracting (EPC) [10]. Other are looking for Blockchain and smart contracts to provide a trading platform that enables the execution and enforcement of agreements between untrusted parties without involving a trusted third party [11]. This kind of new smart contract can be easier to extend to smart home.

### 2.2.3 Impact of End-User Energy Consumption Feedbacks

Numerous studies have analyzed the effects of providing feedback to the occupant on energy consumption. Ehrhardt-Martinez et al. [12] in particular identified 36 studies carried out between 1995 and 2010 and categorized the impact of the technology used on energy saving. The category called indirect feedback is characterized by global information such as the monthly invoice, provided with a consequent delay of several months. The energy savings linked to this feedback are relatively low, up to 8% with daily information. The other category corresponds to real-time feedback, that is to say directly related to the occupants' action. This instantaneousness is much more beneficial in improving occupant behavior, which can reach average savings of more than 10% (Fig. 4).

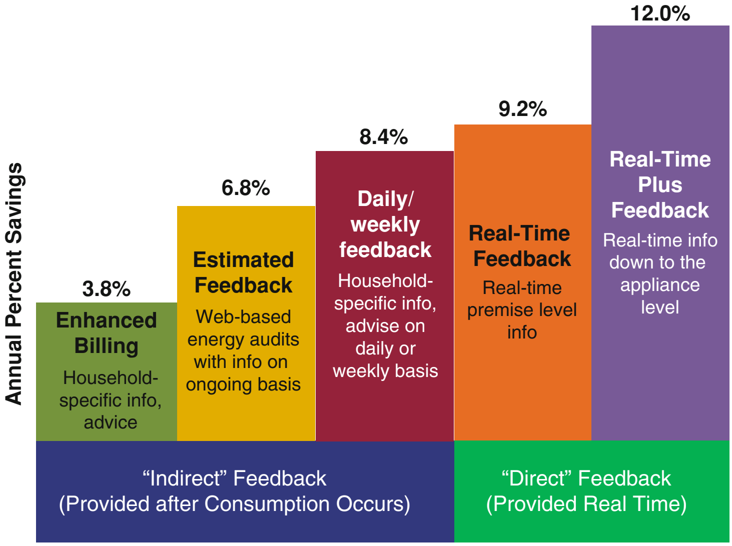



**Fig. 4** Average Household electricity savings (4–12%) by feedback type. (Source: Ehrhardt-Martinez et al. [12])

**Table 1** French RT2012 monitored usages

| | |
|---|---|
| Heating (except for individual wood systems) | For the individual systems, the consumptions of the auxiliaries can be taken into account in this item or in the "other" item. For collective systems, auxiliaries are not taken into account |
| Cooling | |
| Dwelling Hot Water | |
| Electrical outlets | These are devices connected to electrical outlets. The specialized circuits intended for the cooking department are counted in the "other" item |
| Other | These are real estate lighting, specialized circuits for the hob and nonelectric oven (gas) of the individual air conditioning or individual automations |

New French buildings are subject to thermal regulation (e.g., RT2012), which require them to have an energy consumption monitoring system that informs occupants, at least monthly, of their energy use, by energy type. However, sub-metering by usage or by dwelling is not required if a mathematical desegregation method is defined and indicated to the occupant. The usages considered are heating, cooling, and dwelling hot water (DWH), as well as electrical outlets and others (see Table 1).

The regulations do not impose a technical solution and give full freedom to go beyond. In particular, certain items are not considered (lighting for accommodation, thermal auxiliaries, parking lighting, exterior lighting, inverter, etc.) or for collective buildings, consumption linked to common areas (elevators, ventilation boxes, lighting of common areas, etc.). In addition, there is no obligation to install sensors for the system operation monitoring. Finally, the parameters of thermal comfort in all seasons are not controlled, while the installation of temperature sensors in several representative zones as well as outside would provide a lot of information for a more detailed analysis of consumption linked to heating and cooling.

This requirement of consumption display in the residential sector is an important advance for the involvement of the occupants in sobriety and energy performance. Supervision, via a set of communicating sensors and a data centralization system, is the first tool of a more complex system called the Building Management System (BMS) or Technical Building Management (TMB). These BMS were first developed in large buildings (tertiary and industrial) due to the high cost and their complexity. Although in a different situation, the residential sector must take advantage of existing developments, in particular existing standards.

### 2.2.4 Beyond the Building, Interaction with the Power Grid

The classical steps for building design from bioclimatic design to energy system design and renewable energy production on site can be extended to the district level. Step 4 in Fig. 5 includes Smart Building into the urban district/urban system. The goal is to address the overall system of district/city/region, including the interaction of the building with the infrastructure (building to grid). Then several optimizations can be done regarding load management, building as energy storage, building as energy consumer and producer (prosumer), and control engineering to facilitate interaction with the occupant and (energy) infrastructure (smart grids).

This is also the concept of *transactive energy networks* which could turn homes from passive energy consumers into intelligent, active energy storage and service providers for the future grid [14] as described in Fig. 6.

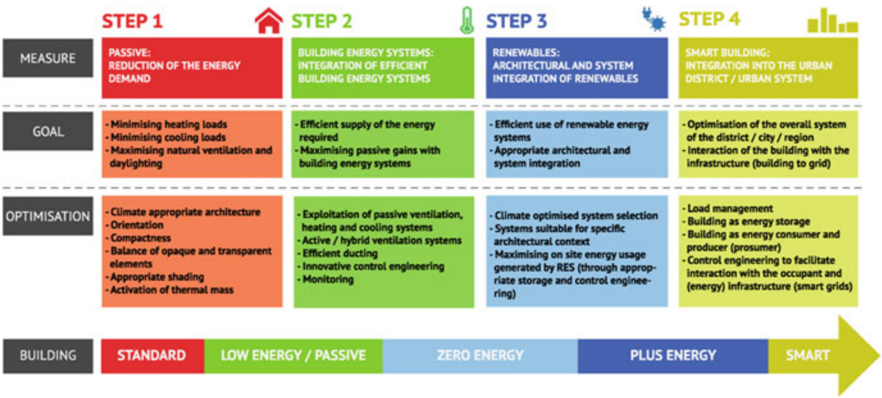



**Fig. 5** Methodology for efficient and sustainable building design including the integration into the urban district/urban system. (Source: Märzinger and Österreicher [13])

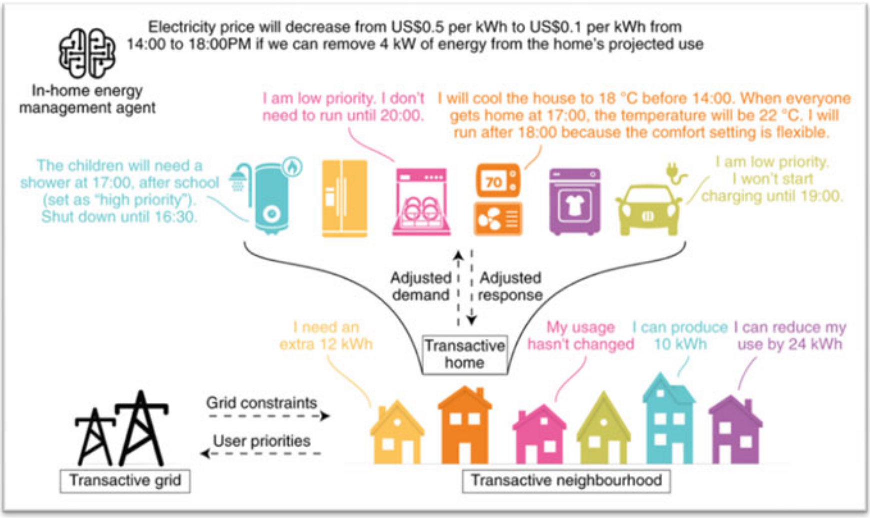



**Fig. 6** Illustration of transactive energy networks. (Source: Wang [14])

## *2.3 Standardized Performance Indicators*

Higher-level measures and indicators must be defined in order to quantify how far the building is to the targets and then to the objectives. An indicator used to set targets corresponds, for example, to the consumption in kWh per unit of use. The nature of the energy consumed, the duration considered, and the unit representative of the use are indicated. For example, this may be the electrical energy consumption for air conditioning in kWh/m$^2$/year of occupied room. These indicators can be corrected by climatic conditions, they can be corrected by the actual durations of use of the premises. Other indicators are used to monitor performance drifts in energy systems. These are, for example, the efficiency of fuel generators or the performance coefficients of thermodynamic equipment (COP, EER), or the consumption of ventilation which may indicate overconsumption probably linked to the fouling of filters. In the following we will draw a review on available indicators from smart home.

### 2.3.1 Disaggregation of Overall Consumption and Categorization

We saw previously that a real-time display by usage could be important. A building's energy use can be divided into heating, cooling, domestic hot water, air movement, lighting, household/office equipment, indoor transportation, auxiliary devices, and cooking, as shown in Fig. 7.

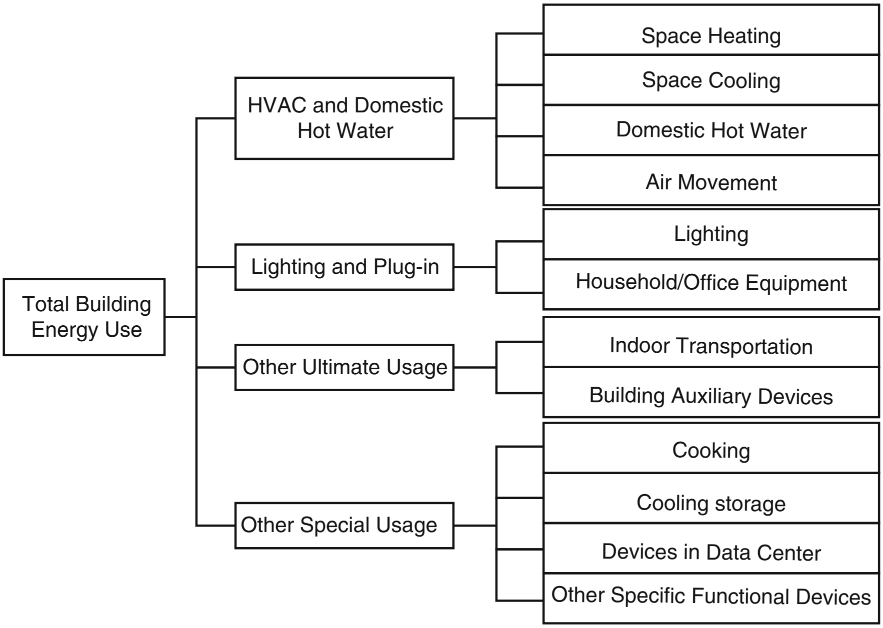
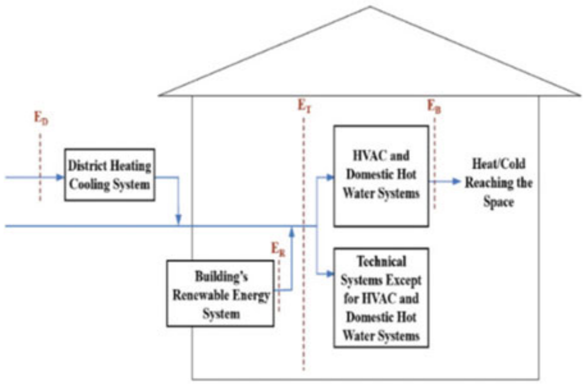



**Fig. 7** Classification of end-use energy consumption. (Source: Jin [15])

**Fig. 8** Energy consumption of a building by boundaries in ISO 12655:2013




International Standard ISO 12655:2013, about presentation of measured energy use of buildings, is considering boundaries described in Fig. 8, which is used to decompose the energy flows. This standard was last reviewed and confirmed in 2018 and remains current. But with the arrival of Zero Energy Buildings, other boundaries can be considered, especially to calculate indicators such as Load Matching indicators and Grid interaction Indicators [16] (see Fig. 8).

### 2.3.2 Standards on Performance Indicators

The European Committee for Standardization (CEN, French: Comité Européen de Normalisation) published in 2007 two standards on performance indicators. EN 15603 provides methods for measuring and calculating the energy use of buildings, and EN 15217 tells how to represent it on a scale or a label. These two standards led to two ISO standards:

– ISO 16346: Energy performance of buildings—Assessment of the overall energy performance (an improvement and generalization of EN 15603).
– ISO 16343: Energy performance of buildings—Methods for expressing energy performance and for energy certification of buildings, which succeeds to EN 15217.

They have been replaced recently by (EN) ISO 52003-1 and (CEN) ISO/TR 52003-2. ISO 52003 defines overall energy performance feature, such as total primary energy use, nonrenewable primary energy use, renewable primary energy use, renewable energy ratio, greenhouse gas emissions, and annual energy costs. It also defines numeric indicator such as total primary energy use per useful floor area [kWh/m$^2$], total primary energy use [kWh], and nonrenewable primary energy use per useful floor area [kWh/m$^2$].

In order to generalize indicators definition, IEA presents in IEA [17] a conceptual framework for the development of building energy performance metrics with examples for metric parameters (Fig. 9).

| | |
|---|---|
| **Inputs** | Final energy (total, electricity, gas, etc.)<br>Primary energy (total, electricity, gas, etc.)<br>Energy cost (total, electricity, gas, etc.) |
| | *Per* |
| **Outputs** | Persons served (total population, occupants, employees, etc.)<br>Floor area served (total, occupied, heated, cooled, enclosed)<br>Buildings served (total, grid-connected, etc.)<br>Service level provided (amount of heating, cooling, lighting, etc.)<br>Economic value (GDP, property value, etc.) |
| | *For* |
| **Scope** | Sector (all buildings, residential sub-sector, services sub-sector [commercial and public])<br>Building types (single-family, multi-family, office, healthcare, etc.)<br>End uses (heating, cooling, water heating, lighting, appliances, cooking, etc.)<br>Region (country, state, city, etc.) |
| | *Normalised by* |
| **Normalisation factors** | Climate (ground temperature, heating degree days, cooling degree days)<br>Economic indicators (purchasing power parity, currency, etc.)<br>Time (percent change from baseline date, lifecycle) |

**Fig. 9** Conceptual framework for the development of building energy performance metrics. (Source: IEA [17])

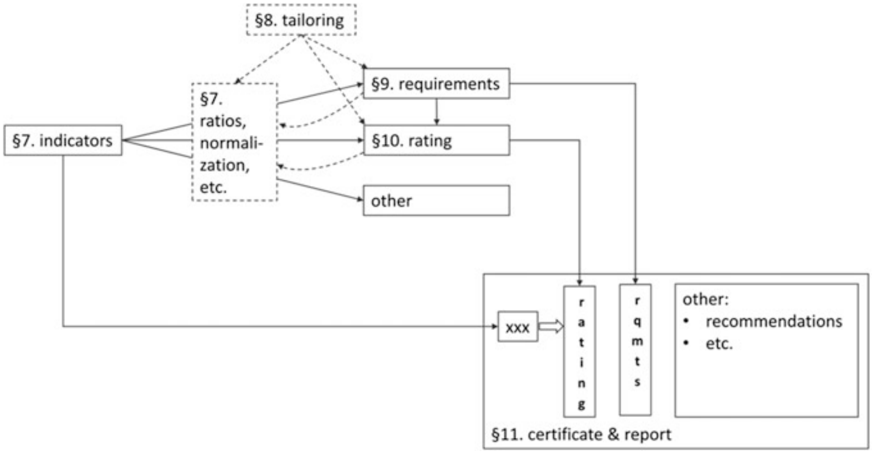



**Fig. 10** Schematic description of indicators usage from ISO 52003 [18]

The framework uses four basic metric parameters: input, output, scope, and normalization factors. The input is the amount or cost of the energy by fuel source; this could be expressed as final (also known as delivered or site) energy, or as primary energy, or as the cost of energy. It is also possible to express these input into environmental impact such as $CO_2$ emissions. The output reflects the service provided by the energy, and can include the building space (floor area) served, the number of people or number of buildings served, or the amount of cooling and heating provided. The scope is a classification of the metric, such as the portion of the buildings sector under consideration (e.g., the entire buildings sector, or certain building types, or energy end uses). Finally, the normalization factors are used to modify the basic input-per-output metric values, such as economic purchasing power differences among regions, climate differences that impact heating and cooling energy use, and change in time relative to a reference or base year.

And finally, Van Orshoven and van Dijk [18] provides a description of EN ISO 52003 to make intelligent use the Energy Performance Building (EPB) assessment outputs based on indicators (Fig. 10).

### 2.3.3 Smart Readiness Indicator (SRI)

The 2018 revision of the European Energy Performance of Buildings Directive (EPBD) aims to further promote smart building technologies, in particular through the establishment of a Smart Readiness Indicator[1] (SRI) for buildings. As part of indictors, SRI aims at providing simple and understandable criteria to rank smart

[1] https://smartreadinessindicator.eu

buildings regarding several criteria in order to reach a better energy performance. As described in Fig. 11, the expected advantages of smart technologies in buildings are:

- Optimized energy use as a function of (local) production
- Optimized local (green) energy storage
- Automatic diagnosis and maintenance prediction
- Improved comfort for residents via automation

The three functionalities of smart readiness in buildings are:

- Readiness to adapt in response to the needs of the occupant
- Readiness to facilitate maintenance and efficient operation
- Readiness to adapt in response to the situation of the energy grid. As described in Fig. 12, Verbeke et al. [19] outlines a quantitative approach based on the load shifting potential using BMS and energy storages, and then a subsequent


**Fig. 11** Expected advantages of smart technologies in buildings. (Source: Verbeke et al. [19])

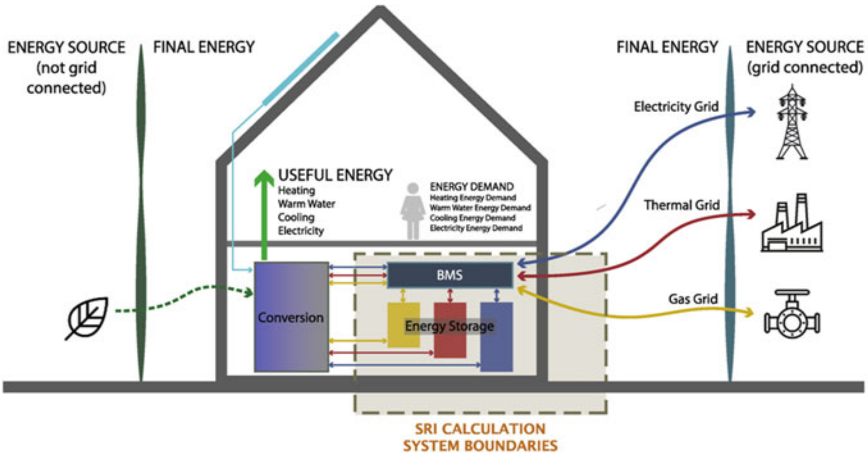



**Fig. 12** System boundaries of SRI calculation. (Source: Verbeke et al. [19])

active interaction of the building (energy use and production) with energy grids, including electrical, thermal, and gas.

Most of smart services are related to the automation of the control of technical building systems, as defined in the technical standard EN 15232 already introduced in part *Standards to deploy energy-efficient technologies*.

According to Hogeling [20] SRI will characterize the ability of a building:

- To manage itself
- To interact with its occupants
- To take part in demand response and contribute to smooth, safe, and optimal operation of connected energy assets

Other initiatives, such as the one of Smart Building Alliance[2] (SBA), a French association, is also addressing SRI questions since several years, defining certification schemes for smart buildings such as *Ready2Services* for commercial buildings and *Ready2Grids*.

## 3 Building Automation and Control System

### *3.1 Introduction to BACS*

The global and integrated vision of Building Automation and Control Systems (BACS) is essential and goes beyond the simple regulation implemented on isolated equipment. Indeed, multiple interactions take place in a building and the centralized vision of the BACS makes it possible to obtain control aimed at optimizing all the criteria at the same time. For example, if you consider HVAC (Heating Ventilation and Air Conditioning) systems that deal with both heating/cooling and ventilation, you could say that opening a window disrupts its operation. Likewise lighting or obscuring solar gain also disturbs thermal regulation. The lighting is also subject to the windows shutter. We therefore see that all these devices interact and a global centralized vision is necessary (Fig. 13).

Building Automation and Control Systems (BACS) or simply Building Automation System (BAS) aim at providing smart functionalities. BACS is generalized with Building Management System (BMS), and when considering energy explicitly, it is called Building Energy Management System (BEMS) [21].

According to Research and Markets [22], the major factors that drive the market for BMS are significant cost benefits to industrial, commercial, and residential users, simplified building operations and maintenance, increasing demand for energy-efficient and eco-friendly buildings, and growing integration of IoT. It places energy and IoT as a central key words of building management systems.

Regarding standards, the ISO 16484-1:2010 defines the operational implementation of BACS during the different phases of a project:

[2] https://www.smartbuildingsalliance.org/

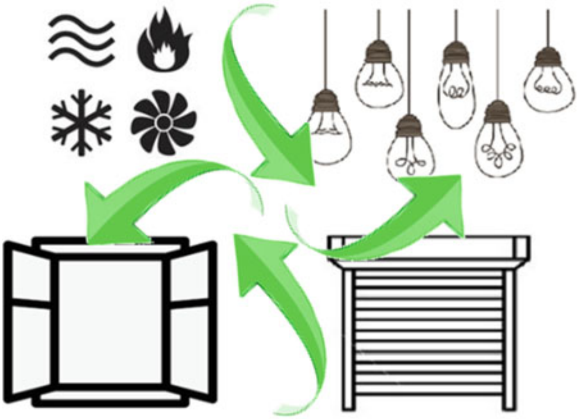


**Fig. 13** Integrated global control is required in order to cope with physical interactions

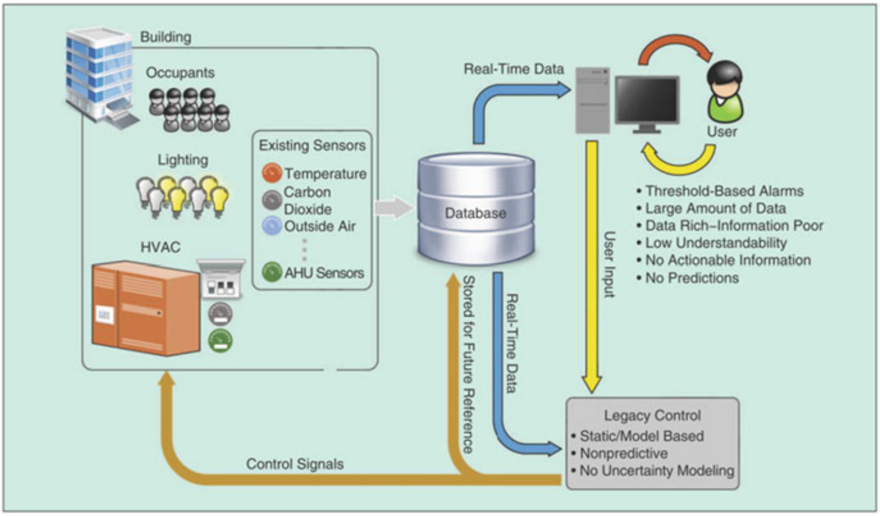



**Fig. 14** Typical building automation system. (Source: Manic [23])

- Design (determination of project requirements and production of design documents including technical specifications)
- Engineering (detailed function and hardware design)
- Installation (installing and commissioning of the BACS)
- Completion (handover, acceptance, and project finalization)

It is addressing the various aspects relating to project specification and implementation, hardware, functions, data communication protocol, and data communication conformance testing.

The following figure (Fig. 14) illustrates the operation of a classic BACS offering standard functionalities that will be detailed in the next section.

## *3.2 Building Management System Functions*

The functions of the BMS can be categorized as follows:

- **Monitoring**: Functions which facilitate the tasks of technicians who maintain the functionality of the equipment, with the aim of minimizing downtime.
- **Supervision**: Functions that allow technical managers to know, record and manage operations. The objective is to control the installations as close as possible to occupations and uses, to know the operations, the consumption of the equipment, the interventions to be carried out and those that have been carried out.
- **Energy efficiency continuous improvement**: Functions that measure efficiency and thus provide elements to maintain and improve it. The objective is to establish consumption indicators, adapt supplies as closely as possible, implement energy improvements, minimize expenses, measure the savings made.

### 3.2.1 Monitoring

Monitoring makes it possible to maintain the availability of operations by informing the technical managers and the interveners who ensure the maintenance of the equipment of significant events and of the alarms which call for an intervention.

The functions for monitoring are based on binary input state, coming from state detectors, or created when exceeding the limits assigned to the measurements or counting. Procedures for the transmission and presentation of information are defined with priority levels, acknowledgment procedures, and logging.

### 3.2.2 Supervision

Supervision allows you to know the status of the equipment and to control its operation:

- Inform in real time the stakeholders who perform technical management and operational tasks. For this, the measurements, counts, operating states, and events are centralized, transmitted remotely, and presented in dashboards.
- Adapt the management of the equipment to the uses by easy means of action to: control, remotely adjust, configure the operating conditions, and derogate from the automated systems.
- Record technical data for technical management, operating tasks and allow monitoring for energy efficiency to be carried out.

The supervised equipment can be, among other things, the power supply (electrical board); emergency power (generators, batteries), lighting, heating, ventilation and air conditioning (HVAC), plumbing (lift pumps, tanks, etc.), access control, fire devices (alarms, extinction).

We generally categorize physical data according to their discrete or continuous type:

- States (operation modes of equipment, position, command return, etc.);
- Measurements (temperature, operating time, number of failures, etc.).

We can extract from these physical points other information such as alarms (failure, abnormal stop, measurement exceeding a threshold, etc.) or additional quantities such as the thermal power calculated from flow rate and supply/return temperatures.

A dashboard is presenting the dynamic states of points on images corresponding to their location: plans of the premises, photos of the equipment, or block diagrams of the installations. The displayed points: operating states, commands, settings, measurements, or counts are selected according to their interest for the supervisors. Meters can be grouped according to their nature (electrical energy, thermal energy, water) and their location (general and on each zone) (Fig. 15).

The means of action can be manual commands such as starting, stopping, and/or operating an appliance at partial load. It can also be a programming of the intermittences of the equipment. Several pieces of appliances are controlled by recorded periodic programs (day, week, or year) such as thermal equipment, lighting, domestic hot water, fans, elevators, load shedding of power stations ...[3]

It can also involve the offloading of electricity consuming stations to reduce costs by adapting their operations to tariff signals, or by a forecast algorithm (chilled water generators with hourly or daily storage, kitchen equipment ...), while retaining the possibility of temporarily derogating from this automation.

Advanced management strategies can also be implemented, such as night ventilation for cooling the structures; natural cooling by introducing outside air; free cooling by outdoor air-water exchange; integrated control of solar protection,

**Fig. 15** Examples of smart home dashboards. (Source: Manic [23]) (https://www.pinterest.com/pin/302726406202699573/)

[3] https://dribbble.com/shots/4612989-Smart-home-dashboard-concept

lighting and air conditioning terminals. The parameters of these automations are adjusted to adapt them to weather conditions or to the particularities of use.

Finally, regulation algorithms are implemented to maintain set points such as ambient temperatures. Rising and lowering of temperatures can be optimized, that is to say, anticipated or delayed, taking into account ambient and/or outdoor temperature measurements.

All of the time-stamped data can be recorded in a trend log. The conservation period is to be configured according to the needs and capacities of the available equipment. These time series can be consulted a posteriori to analyze and optimize monitoring.

### 3.2.3 Energy Efficiency Continuous Improvement

A continuous improvment process allows a more efficient use a continuous improvement process for more efficient use of energy through an energy monitoring plan as well as energy analyses based on the monitoring and supervision data described above. This approach directly linked to the ISO 50001 energy management standard, is based on the PDCA (Plan-Do-Check-Act) methodologies. PDCA is an iterative four-step management method used in business for the control and continuous improvement of processes and products (Fig. 16).

**Plan**: An energy plan is the determination of the initial energy baseline, the energy performance indicators, the strategic and operative energy objectives, and the action plans. These data and evaluations form the basis of the following improvement processes. They also make it possible to identify potential for improvement of energy efficiency.

**Do**: In this phase, planning and action takes place, improvements are aimed for and implemented. Indicators and objectives for energy performance are defined on

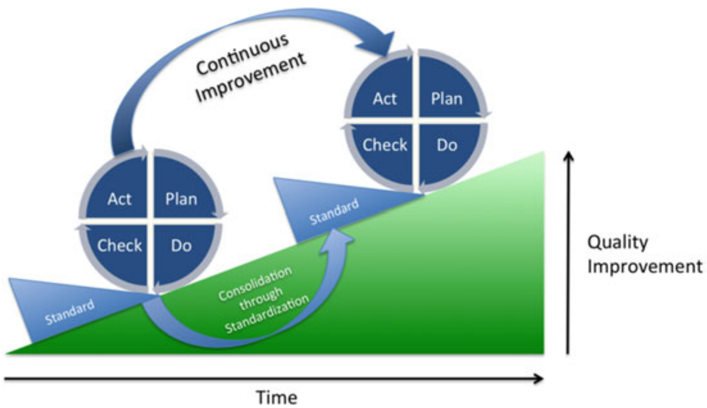



**Fig. 16** Continuous quality improvement with PDCA. (Source: Johannes Vietze, CC BY-SA 3.0)

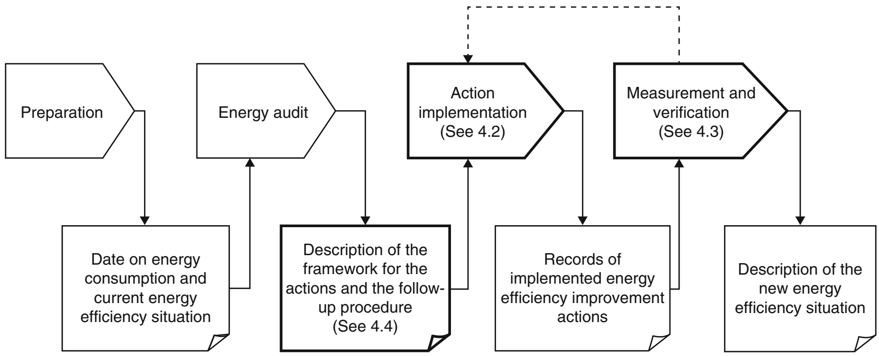



**Fig. 17** Typical process of providing energy efficiency services (EN 15900:2010)

the basis of the results of the energy assessment. In doing so, action plans are also created, with which the objectives for the improvement of energy performance can be achieved.

**Check**: The plans executed in the "Do" phase must continually be checked to ensure that they are effective. To do this, core processes that are significant to the energy-related performance are monitored and measured in this phase. The results are compared to the previously established objectives.

**Act**: The constant measurements are broken down in reports. These form the basis for further studies, in order to improve the energy-related performance and the BEMS.

The data must be kept in order to conduct comparative analyses over different periods (annual in general). It is important to regularly update the use of the building, in order to adapt the targets depending on some changes like space allocation, energy contracting prices, etc. Finally, it is important to communicate these analyses, in particular with occupants. Whether it is information concerning the energy consumption observed but also the actions that make it possible to reduce it.

Figure 17 presents a typical process of providing energy efficiency services (EN 15900:2010).

## *3.3 Energy Management Algorithms*

### 3.3.1 Overall Energy Performance Assessment

Since 2017, the ISO 52000 series aims to reorganize all the standards relating to the energy performance of buildings. ISO 52000 contains a comprehensive method of assessing energy performance as the total primary energy used for heating, cooling, lighting, ventilation, and domestic hot water of buildings. According to Elizabeth Gasiorowski-Denis [24], it will help accelerate progress in building energy efficiency utilizing new technologies and approaches to building design, construction, and management.

Here we are focusing on building management parts of ISO 52000. For instance:

ISO/DIS 52120-1 helps on building automation and controls and building management:

- A structured list of control, building automation and technical building management functions which contribute to the energy performance of buildings.
- A method to define minimum requirements or any specification regarding the control, building automation and technical building management functions, contributing to energy efficiency of a building, to be implemented in building of different complexities.
- A factor-based method to get a first estimation of the effect of these functions on typical buildings types and use profiles.
- Detailed methods to assess the effect of these functions on a given building.

ISO/DIS 52127-1 "Building management system" is relative to operational activities, overall alarming, fault detection and diagnostics, reporting, monitoring, energy management functions, functional interlocks, and optimizations to set and maintain energy performance of buildings (equivalent to standard EN 16947).

In Fig. 18, Hogeling [20] presents the set of standards supporting the implementation of the Energy Performance of Building Directive in Europe and specifically

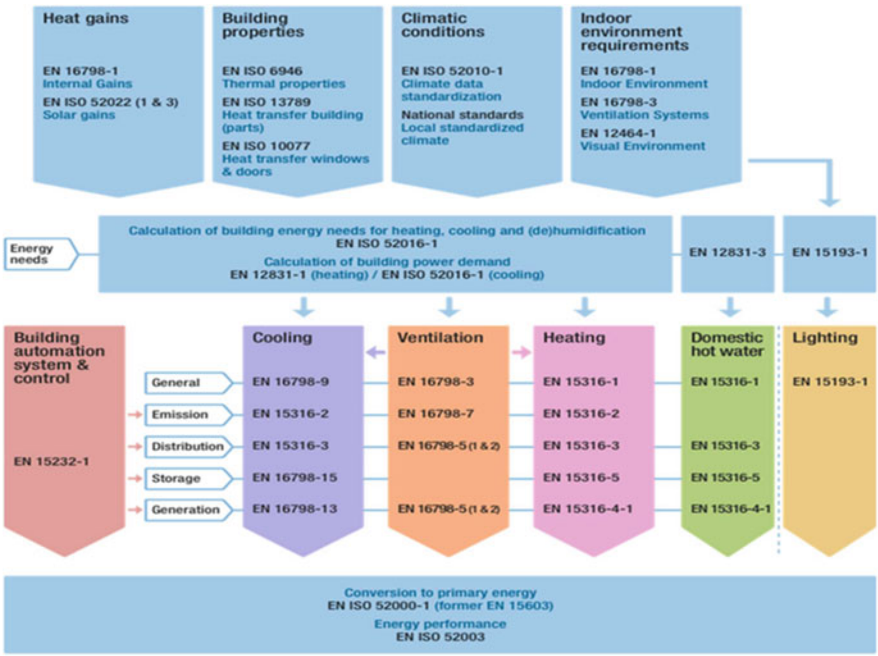



**Fig. 18** The set of standards supporting the implementation of the Energy Performance of Building Directive in Europe

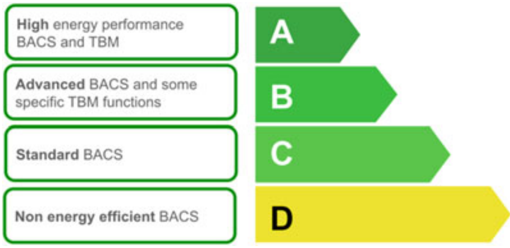



**Fig. 19** Four energy-efficient BACS and TBM according to EN-15232

addressing the relation between ISO52000 and other standards. One can notice that standard EN-15232 on Building Automation & Control Systems is contributing transversally to most of energy domains. This standard is detailed in the next section.

### 3.3.2 Impact of Building Automation

EN 15232-1: 2017 is on Impact of Building Automation, Controls and Building Management. It lists the regulation functions, with a residential/nonresidential distinction, and realizes a distribution in efficiency classes (A, B, C, and D) (see Fig. 19). It also defines methods (detailed or simplified estimation) for calculating the impact of BACS and Technical Building Management (TBM) functions on energy performance.

### 3.3.3 Control of Energy Systems

Among the systems that have an impact on consumption, HVAC is certainly the most important. The current control systems must make it possible to modulate ventilation, heating, and cooling as required. Conventionally based on a calendar, the control of HVAC systems is increasingly becoming a function of sensors which allow real needs to be achieved. This has, for example, been the case with thermostats for heating systems, with temperature set point avoiding to control directly the power, which must adapt automatically by a regulation loop including a temperature sensor which activates or modulates the power.

Similarly, we are now looking to be as close as possible to the needs of the occupants, with radiant heating with presence detector which is activated only in occupied rooms. It is the same idea with the lighting, first we modulate according to the needs (close to the bay windows or rather in the dark corners), then we activate only if there is occupation, more or less fine (at room level, or on each lamp).

Occupancy detection capacity is therefore increasingly important for integrating energy systems into a control loop. This function can be performed by various devices such as infrared sensors (PIR motion sensor) or even measurements of the $CO_2$ concentration in the air. Even more sophisticated systems of Indoor Positioning

Systems (IPS) appear based on radar technologies or indoor geolocation using radiofrequency technologies (bluetooth).

Electric motors are used at all levels in the energy systems of buildings, whether they are compressors for cooling units, fans, circulators, or pumping. According to GIMELEC [25], the average load rate for engines under 500 kW is around 55–60%. At 80% of the load, the energy consumption is 95% of the nominal on/off operation, 50% with continuous variation systems. Thus, it is possible to optimize the operating point on ventilation systems (resp. Pumping) up to 50% of energy savings generated (resp. 30%), and a payback time of less than 2 years (resp. 3 years).

However, these conventional methods of regulation are not optimal because of the systems' dynamics, in particular those related to heating due to thermal inertia. Indeed, this can range from a few minutes for radiant systems to several hours for a heated floor for example. It is therefore necessary to anticipate to better control.

### 3.3.4 Adaptive Behavior, Predictive Automation, Control, and Maintenance

The regulatory functions presented above offer significant efficiency gains and can be implemented without the need to deploy complex and smart technologies. Intelligence in buildings are features such as anomaly detection, predictive modeling, optimization, and perhaps one of the most important premises of artificial intelligence, learning on their own. With the increasing amounts of diverse and dynamically changing data, extracting relevant and actionable information through legacy BEMS is difficult. This leads to a flood of data and decreased situational awareness, which may result in suboptimal building behavior.

Furthermore, the control strategies employed are often static and non-predictive; hence, they fail to adapt to changing environments and deteriorating building states. According to Manic [23], BEMS needs to be adaptive in order to cope with constant changes inside and outside the building such as occupancy patterns, aging of materials and equipment, floor plan changes, etc. As described in Fig. 20, BEMS functionalities are going further than simple regulation, they may use adaptability, predictive modeling, multisensor fusion, dynamic optimization, state-awareness, providing actionable information, etc.

Thus, techniques based on Model Predictive Control (MPC) (Artiges, [26]) are developing more and more. Commercial connected thermostat solutions (Netatmo, Qivivo, Nest, etc.) anticipate, for example, the heating restart in order to reach the set point taking into account the building's thermal inertia. The models being, for these thermostats, obtained by machine learning methods on the basis of the history of the data collected.

Finally, it should be noted that the challenges linked to the introduction of renewable energies go far beyond the regulation and control functions which we

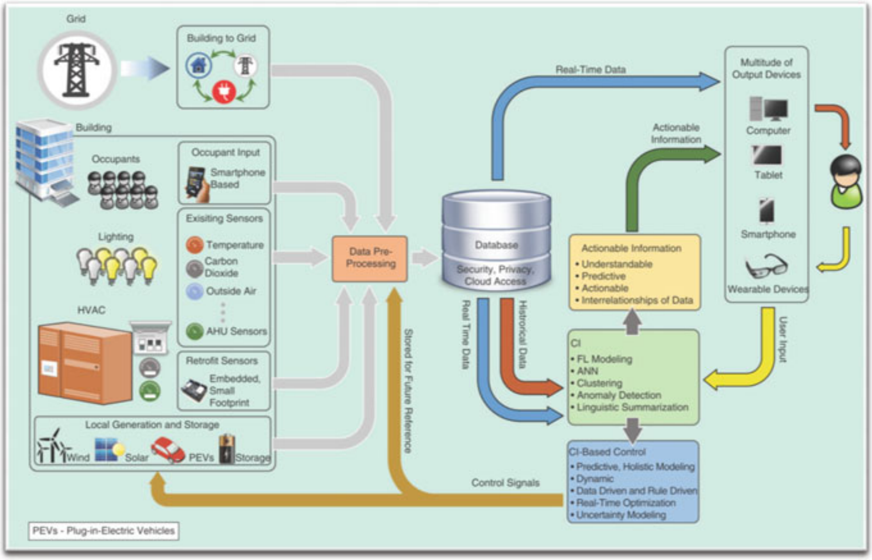



**Fig. 20** Smart BEMS architecture. (Source: Manic [23])

have just discussed. Measures to reduce consumption can also be combined with intelligent management of costs depending on the energy sources available. In particular, the photovoltaic production during the day to operate, for example, a washing machine.

Energy systems such as HVAC are intended to be regularly maintained and controlled. In a house with dual-flow ventilation, it is, for example, recommended to change the filters every 6 months. Malfunction or degradation of HVAC system components causes reduced comfort on the one hand, and approximately 15–30% waste of energy on the other hand (Katipamula, 2005).

In the same way that a gas boiler is annually checked by a technical agent, it becomes necessary to generalize these scheduled preventive maintenance operations to all equipment. On the other hand, these visits can be costly; moreover, it is possible that a defect appears between two visits, or even that a defect is not detected by a visual examination.

Based on real-time monitoring of energy systems, it is possible to perform Fault Detection and Diagnostics (FDD) but also predictive maintenance. It is indeed possible by artificial intelligence algorithms to detect drifts and intervene before it is too late. Numerous research studies still make it possible to develop these techniques to make them truly operational, in particular to adapt easily to changes in piloting mode and to different configurations of the building (Verbert, [27]).

## *3.4 Technical Building Management*

### 3.4.1 Architecture

Industrial control system theory traditionally describes Building Automation & Control System (BCAS) using three levels (see Fig. 21):

- Management System level: a subsystem for user interactive interface
- Automation level: a data processing software for processing sensory data and performing energy-saving strategies
- Field level:
  - A sensory infrastructure for monitoring energy consumption and environmental features
  - An actuation infrastructure for modifying the environmental state

Each level are able to communicate using many communication protocols and are physically linked with specific equipment such as device controllers and gateway.

H. Michael Newman, who was the father of BACNet[4] (Building Automation and Control Networks), defines these three levels:

*The management level* is where the majority of operator interface functions reside. Additional functions include communication with controllers, monitoring,

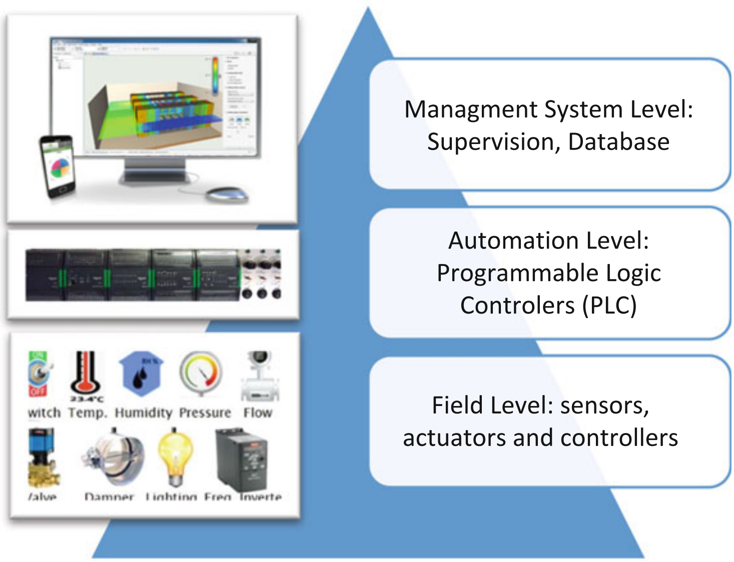



**Fig. 21** Architecture of a building automation and control system

[4]https://www.big-eu.org/en/news/news-press-releases/news/mike-newman-the-father-of-bacnet-has-passed-away

alarm, trend logging and statistical analysis, centralized energy management functions, and communication with, or coordination of, dedicated non-HVAC systems such as fire alarm and security control. As a practical matter, most of the devices at this level are personal computer workstations.

*The automation level* is where the majority of real-time control functions are carried out. The devices tend to be general-purpose, programmable controllers.

*The field-level* contains the devices that connect to sensors and actuators. We would tend to think of field-level devices as unitary or application-specific controllers.

Through years, supervisory control and data acquisition (SCADA) has been more and more connected[5]:

- First generation: "monolithic/standalone"
- Second generation: "distributed" across multiple stations, which were connected through a LAN
- Third generation: "networked" with standardized communication protocols
- Fourth generation: "web-based" through Internet and without dedicated software.

As illustrated in Fig. 22, in such a fourth generation, energy systems such as chiller, Air Handling Unit (AHU), Uninterruptible Power Supply (UPS), and Diesel Generators (DG sets) are still connected to BMS but also to Cloud platform in order to access data and alert from everywhere. It allows also nonfunctional services such as data safety and security that do not have to be addressed by the building itself.

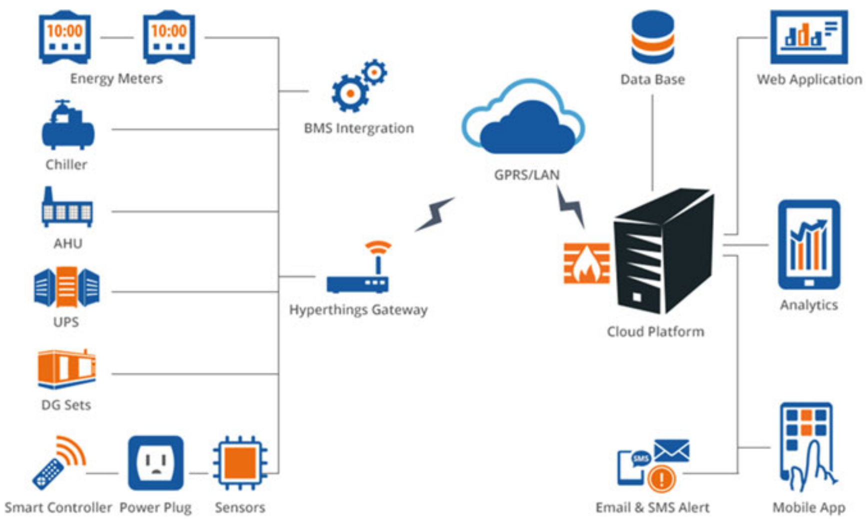



**Fig. 22** Web-based SCADA. (Source: Calvert Controls [28])

[5] https://en.wikipedia.org/wiki/SCADA

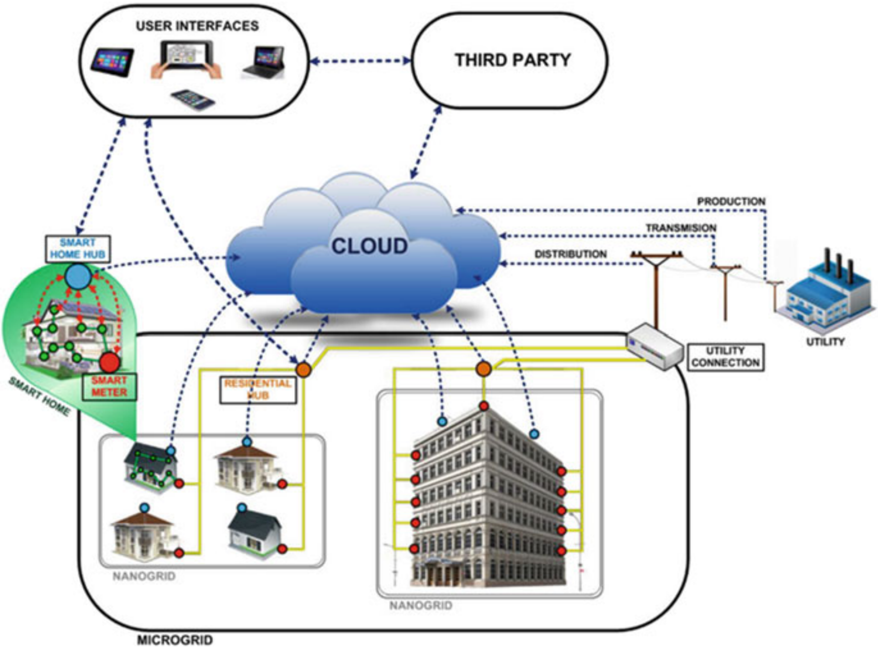



**Fig. 23** Third-party services on top of web based. (Source Totonchi [29])

Then, third parties can benefit from this architecture in order to provide services in a more scalable manner as described in Fig. 23.

### 3.4.2 Communication Technologies

Building Automation count a lot of communication technologies that can be categorized depending on several criteria such as the openness, centralization, or versatility [30]:

- *Openness* describes dependency of a system on a manufacturer. Open protocols are BACnet, KNX, LonWorks, DALI, OpenTherm, EnOcean... Nowadays most of protocols tends to be open. Proprietary protocols are developed by one or a consortium but does not open specifications such as Universal Powerline Bus (UPB).
- *Centralization* describes the degree of independency of each component of the communication network. Centralized systems are based on PLC using protocols such as Modbus, while decentralized or distributed systems allow peer-to-peer (P2P) communication such as KNX.
- *Versatility* represents the ability of a system to cover one or more control tasks in building and home automation. KNX or LON are able to control HVAC, lights,

shutters/blinds . . . While DALI bus is specialized on light control or OpenTherm focused on heating control.

Home networks can use either wired or wireless technologies to connect endpoints. But classical building automation is using mainly wired technologies:

– Twisted pair of copper cables is mostly common wired physical support. This medium provides for instance the physical connectivity between the Ethernet interfaces present on a large number of building IP-aware devices, but also RS845 widely used for field buses.
– Fiber optics offer much higher bandwidth and/or lower latency characteristics associated with end-to-end optical signaling.
– Power lines are also used to communicate over existing power wiring, using devices also known as HomePlug.

Protocols can address field, automation, or management levels as shown in Fig. 24 for some protocols. There can be high-level versatile protocols such as BACNet (Building Automation and Control Networks) or WEB-Service oBIX (open Building Information Exchange) which are designed for applications such as HVAC, lighting control, access control, and fire detection and provides mechanisms for building automation devices to exchange information, regardless of the particular building service they perform.

There can be field-level protocols as shown in Fig. 25 that can also be versatile protocols such as Modbus or specific ones like M-Bus for Automatic meter reading or DALI for light control.


**Fig. 24** Communication protocols can cover different level of BMS. (Source Siemens Building Technologies [31])

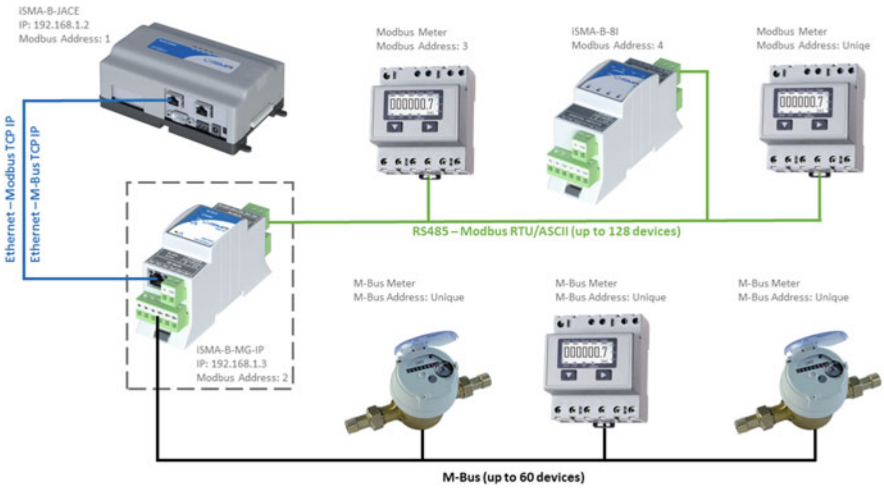



**Fig. 25** Automatic meter reading using Filed bus (M-Bus & Modbus) connected to the automation level using Ethernet physical support and TCP/IP protocols. (Source: http://energycare.dk/portfolio-item/meter-gateway/)

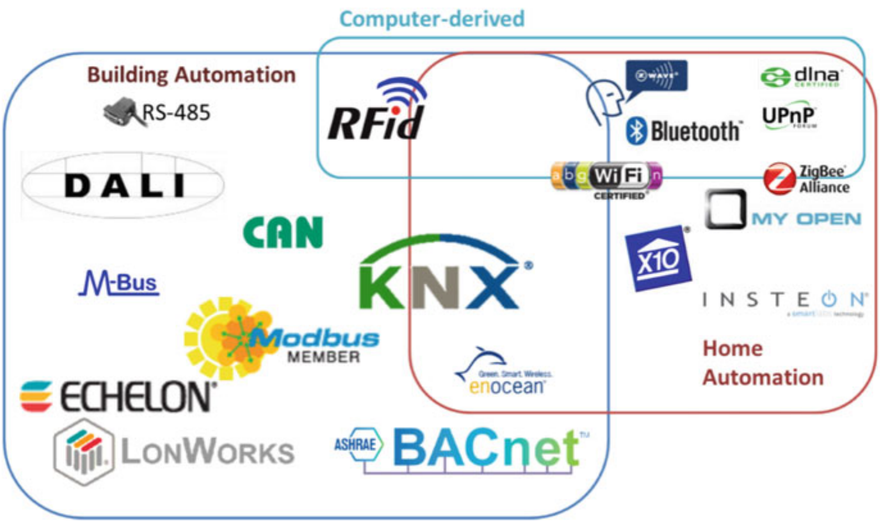



**Fig. 26** From building automation to home automation. (Source: Bonino [32])

Building Automation protocols and technologies are not covering exactly the same requirement than Home Automation, that is why other protocols are more dedicated to Home Automation, and some of them are coming from Internet technologies or Computer technologies. Wireless technology are especially more developed for Home Automation than in Building Automation as described in Fig. 26.

# 4 Home Automation Technologies

## *4.1 Home Automation Market*

### 4.1.1 Home-Specific Constraints

The principles of energy efficiency in buildings are based on technological solutions that we have just reviewed, but these are expensive and complex to deploy and therefore mainly reserved for the tertiary sector, hotels or high residential standing. With lower resources, the installation costs of smart home technologies must be drastically reduced, hence the emergence of free/open-source solutions, Do It Yourself (DIY) solutions. The market is less structured and the standards presented before are not really used. Smart home solutions are built as occupants need them, exacerbating the need for interoperability and adaptable wireless technologies. The generalization to all housing and the advent of the smart-home can only be done through a technological revolution, a paradigm shift such as that of the wireless Internet of things (IoT), Cloud services, and open-source/open-hardware as it can be represented in the following figure (Fig. 27).

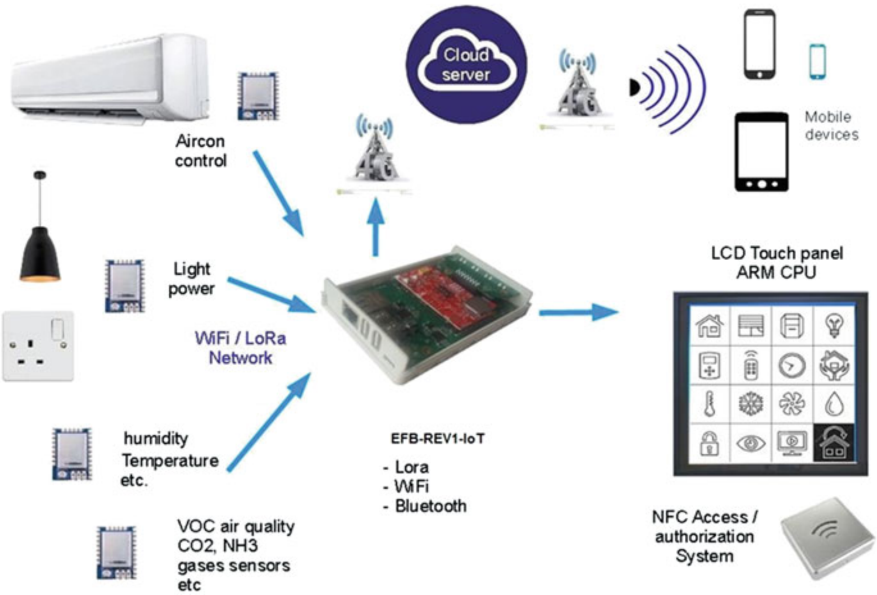



**Fig. 27** Example of home automation architecture. (Source: Hackaday, https://hackaday.io/project/166414-home-automation-architecture-based-on-lora)

### 4.1.2 Smart Home Key Technologies and Market

The Hype cycle for emerging technologies (Fig. 28) shows that “Connected Home” and “IoT Platform” have already reached the Peak of Inflated Expectations and are now going to the stable position (Plateau) between 2023 and 2028. “Virtual assistants” also reached the peak but is going faster to mature products (before 2023). This technology can advise end-user, and interact with natural language processing (NLP) such as chat-based solutions that uses text or audio commands, to monitor and control the home appliances [34]. But the next revolution with artificial intelligence will be in the capacity of virtual assistant to really advice end-users and not only to control home appliance.

According to the Gartner report [33], the increasing number of IoT and related services is leading to a growth of 700 million smart homes in 2020. According to Research and Markets [35], the smart home technology market is expected to reach an estimated $112.8 billion by 2024 with a consumer need for simplicity and personalized experience, and the growing adoption of cloud-based technologies. According to another source [36], using Statista[6] data, the size of the world smart home market is about 33.4 billion US dollars in 2017 and is expected to rapidly increase to 78.2 billion US dollars by 2022.

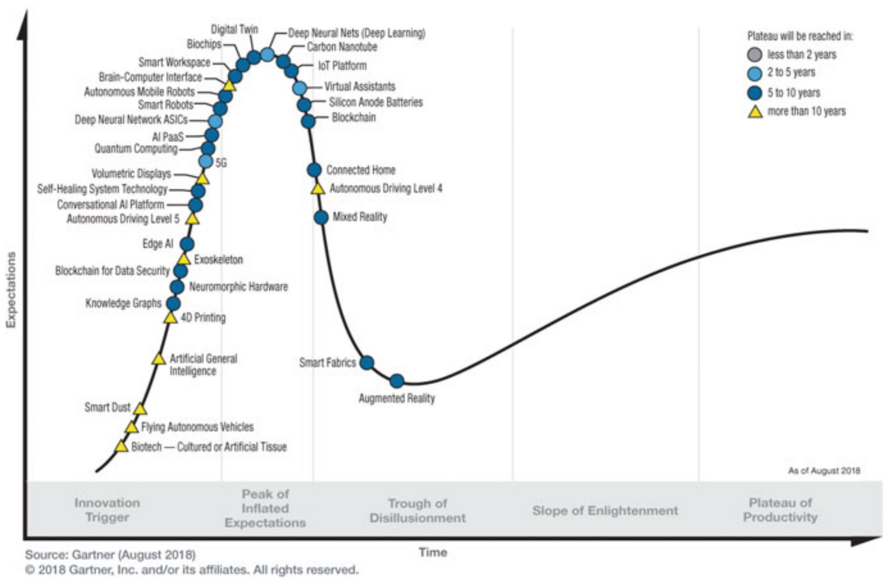



**Fig. 28** Hype cycle for emerging technologies—Gartner [33] (https://blogs.gartner.com/smarterwithgartner/files/2018/08/PR_490866_5_Trends_in_the_Emerging_Tech_Hype_Cycle_2018_Hype_Cycle.png)

[6]https://www.statista.com/

Emerging trends, which have a direct impact on the dynamics of the smart home industry, include development of voice assistant technology for high-end automated households or emergence of air quality sensor devices that measure volatile organic compounds (VOCs).

According to Qolomany [37], 33% of IoT smart building market will be supplied by artificial intelligent technologies by 2023, and automation systems of smart building will grow up to 48.3% CAGR (Compound Annual Growth Rate) from 2018 to 2023. By 2025, the growth of connected home living will reach 3.7 billion smartphones, 700 million tablets, 520 million wearable health-related devices, and 410 million smart appliances in the connected person world.

According to Lobaccaro [38], IoTs are becoming increasingly embedded in the society by allowing faster and more efficient interaction between users and both public and private environments. IoT development has been recognized as having significant potential to create an interactive energy management system for homes.

## *4.2 Internet of Things (IoT) Technology*

### 4.2.1 IoT Definition and Characteristics

The Smart Sustainable Cities group (SSC) of the International Telecommunication Union (ITU) defines Internet of things in ITU-T SSCIoT 2 [39] as a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies. Through the exploitation of identification, data capture, processing, and communication capabilities, the IoT makes full use of things to offer services to all kinds of applications, while ensuring that security and privacy requirements are fulfilled. From a broader perspective, the IoT can be perceived as a vision with technological and societal implications.

According to the Cluster of European Research Projects on the Internet of Things [CERP-IoT] [40], an autonomous home network has to be intelligent and capable of sensing and adapting to environment changes while performing self-capabilities (e.g., configuration, healing, optimization, protection). Autonomy will make home network architecture highly dynamic and distributed enabling the interworking of several devices and systems. Interworking of home networking systems and devices with other systems and devices external to the intranet will be achieved via Personal Virtual Private Networks (VPN). Any device or thing that has human input controls can be used to securely interface with the building's services to monitor status and change its settings. Using home automation devices with wireless communication technologies, all of building's "things" can have two-way communication with each other. For example, the thermostat can be controlled from the console of the refrigerator, or the detection of a mobile phone entering a room allows to configure automatically the light atmosphere. The washing machine can stop if the oven is switched on in order to respect the electric subscription limit, etc.

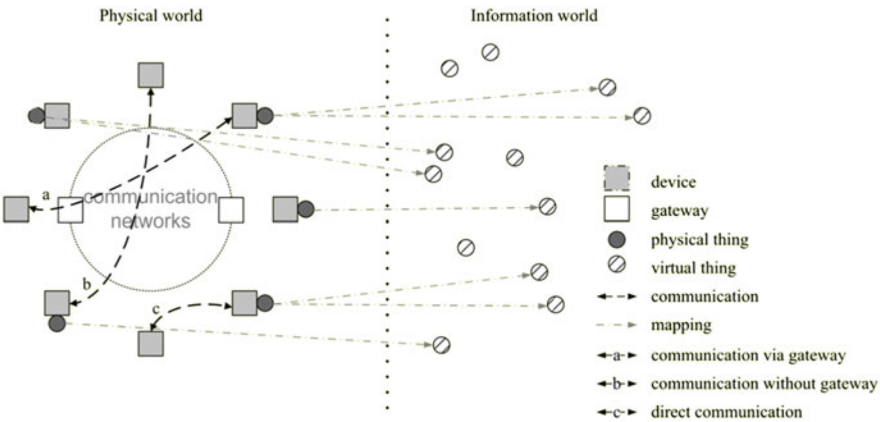



**Fig. 29** Technical overview of the IoT and interactions between physical devices [39]

The IoT is expected to greatly integrate leading technologies, such as technologies related to advanced machine-to-machine communication, autonomic networking, data mining and decision-making, security and privacy protection and cloud computing, with technologies for advanced sensing and actuation.

As represented in Fig. 29, a physical thing may have a mapping with one or more virtual things in the information world. Virtual thing can also exist without any associated physical thing. A device has the mandatory capabilities of communication and optional capabilities of sensing, actuation, data capture, data storage, and data processing. Devices communicate with other devices through the communication network, with (case a) or without (case b) a gateway, or directly (case c).

The **fundamental characteristics** of the IoT are defined by [39] as follows:

– **Interconnectivity**: With regard to the IoT, anything can be interconnected with the global information and communication infrastructure.
– **Things-related services**: Such as privacy protection and semantic consistency between physical things and their associated virtual things.
– **Heterogeneity**: The devices in the IoT can be heterogeneous, based on different hardware platforms and networks.
– **Dynamic changes**: The number of devices, their own state and their context change dynamically (e.g., sleeping/waking up, connected/disconnected, location, speed, etc.)
– **Enormous scale**: number of connected devices, communication triggered, data generated and processed can be huge.

Associated to the previous fundamental characteristics, IoT may provide **high-level requirements such as context-awareness, interoperability, security, or privacy** that can be detailed here.

### 4.2.2 Context-Aware IoT

Ubiquitous or context-aware computing has proven to be successful in understanding sensor data. Collection, modeling, reasoning, and distribution of context in relation to sensor data plays critical role in adding value to raw data and to help understanding it.

According to Perera [41], a system is **context-aware** if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task. Where **context** is any information that can be used to characterize the situation of an entity. Where an **entity** is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves.

Figure 30 presents contextual information **who** (identity), **where** (location), **when** (time), **what** (activity), in two different columns, depending on how they are obtained. First column is about information retrieved directly from sensors (e.g., GPS sensor readings as location information), while second column corresponds to virtual sensors, where information are computed using primary context, using sensor data fusion operations or data retrieval operations such as web service calls.

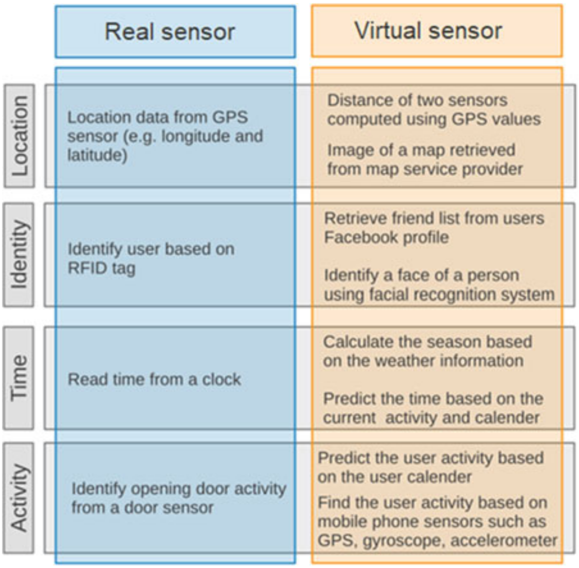



**Fig. 30** Context information collected by real sensor or calculated by virtual sensor. (Adapted from Perera [41])

### 4.2.3 IoT Interoperability

Interoperability needs to be ensured among heterogeneous and distributed systems for provision and consumption of a variety of information and services. Interoperability can be first achieved using standards defined by organizations such as IP Smart Objects (IPSO) alliance, European Telecommunications Standard Institute (ETSI), AllSeen alliance with AllJoyn open-source software framework, Open Interconnect Consortium (OIC) with IoTvity open-source software framework or IoT-A forum with OpenIoT open-source platform for connecting physical and virtual sensors to the Cloud. Interoperability has also been attempted to be solved by using Semantic Ontologies which provide deeper understanding of the raw sensor data enabling machines to take decisions based on simple rules [42]. Semantics provide a different dimension to the data interoperability at a higher level than what just raw data gives; Sensor Semantic Network (SSN) provides a comprehensive set of ontologies for interpreting the sensor data. SenML (Sensor Markup Language) has proposed to provide a common media-type for sensor data exchange.

Tayur and Suchithra [42] defines the application layer interoperability requirements:

- Protocol: defines preferred language of communication such as HTTP, CoAP, or MQTT
- Message: specifies the encoding and structure of the data based on JSON, XML, or Binary
- Semantics: allow interpretation of the meaning and context via established ontologies which work on the raw sensor data converted into web data interchange format RDF (Resource Description Framework)
- Behaviors: indicate the list of operations either configuration or management that are available and it must be context specific.
- Properties: define the list of attributes and properties of the device that can be used for configuration and operations (example can be vendor name, light on/off status).

OFFIS—Institute for Information Technology represent in Fig. 31 the distance to bridge between two systems interface that need to communicate. These systems can be natively interoperable, of some adaptation have to be done more or less easily depending on this distance if they are sharing common semantic model (CIM: Common Information Model), common syntax, or nothing [43].

### 4.2.4 IoT Security

In the IoT, everything is connected which results in significant security threats, such as threats towards confidentiality, authenticity, and integrity of both data and services. A critical example of security requirements is the need to integrate different security policies and techniques related to the variety of devices and user networks in the IoT.

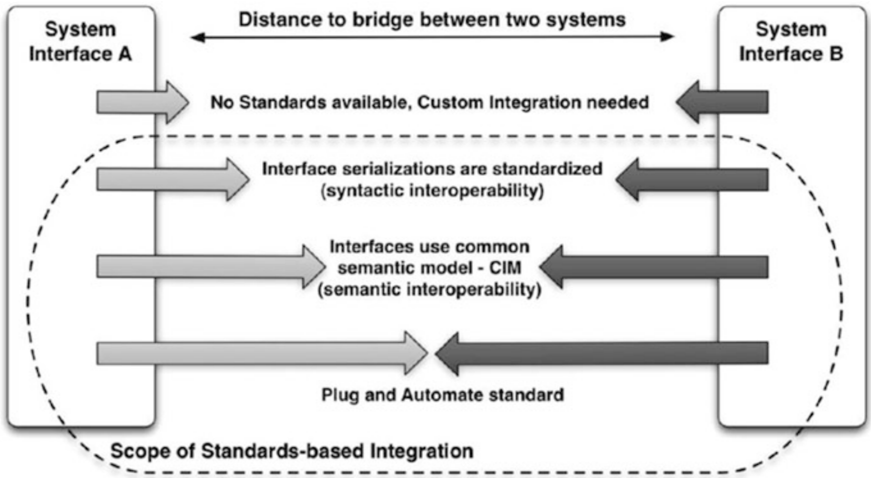



**Fig. 31** Semantic integration distance for interoperability. (Source: OFFIS)

The 2017 attack by the Triton malware, which targeted critical systems of petrochemical plant in Saudi Arabia through the Triconex safety controller (Schneider Electric), showed the potential destruction that these types of threats can bring. With the convergence of operations technology (OT) and internet technology (IT), as well as the robust adoption of the Industrial Internet of Things (IIoT) by ICS operators, risks have grown. IoT that provides external access of home network are a gateway for criminals who can attack personal data such as bank access codes, or demand ransom for intimate data.

Based on the literature survey [44], a few threats to the SCADA systems in IoT-cloud environments are defined below:

– Advanced Persistent Threats: An unauthorized person attempts to gain access to the system using zero-day attacks (unknown attack) with the intention of stealing data rather than causing damage to it.
– Lack of Data Integrity: Data integrity is lost when the original data are destroyed, and this could happen through any means such as physical tampering or interception.
– Man-in-the-Middle (MITM) Attacks (spoofing and sniffing attacks): In a spoofing attack, a program or person masquerades as another program or person to gain illegitimate access to the system or the network. In a sniffing attack, the intruder monitors all the messages being passed and all the activities performed by the system.
– Replay Attacks: A valid message containing some valid data is repeated again and again; in some cases, the message may repeat itself. These attacks affect the performance of SCADA systems and can be serious threats when a replay attack delays messages sent to physical devices.

– Denial of Service (DoS) Attacks: It makes a service unavailable for the intended user, for instance by overloading computer resources.

In Alrawi et al. [45], author has developed a methodology to analyze security properties for home-based IoT devices defining scores[7] depending on the device, mobile application, cloud endpoint, and network.

– Device: Vulnerabilities in IoT systems manifest themselves in hardware, software, and side-channels and they are exacerbated when combined. Mitigating vulnerabilities relies on vendors, adopting mature technologies.
– Mobile Application: Trusted by IoT devices, mobile applications are attack points and still suffer from over-privileged permissions, programming errors, and hard-coded sensitive data. Vendors should make conservative assumptions about the trust relationship and limit the interactions with core services.
– Cloud endpoint: Are suffering from misconfiguration and vulnerable services that can be properly secured using industry standards. Third-party cloud providers play an important role by offering securely managed IoT platforms, which vendors are adapting.
– Communication: IoT devices may still rely on insecure protocols that do not offer confidentiality or integrity but mitigate them by using TLS/SSL protocols. Many devices lack encryption on the LAN, which leave them susceptible to MITM attacks.

For instance, to assess and analyze the old but still used Modbus communication protocol's vulnerability and risks, Byres [46] used an attack tree model, revealing that the Modbus protocol is weak and lacks basic security requirements such as integrity, confidentiality, and authentication. They recommended using firewalls, Intrusion Detection Systems (IDSs), and encryption techniques for secure communications.

More recently, Fouladi and Ghanoun [47] performed MITM Attacks on a Z-Wave door lock, causing a lot of turmoil in the security and home automation world. They were able to intercept the unencrypted packets being sent between devices and the controller, and easily retrieve the home and node IDs. They could easily dissect packets for timestamps, home IDs, sources, and targets, as none of this information is encrypted. Using this information, the team was able to spoof the controller, sending raw packets to devices that appeared to come from the real controller. This attack relies greatly on the lack of encryption in the first generation of Z-Wave. Therefore, in the later generations, Z-Wave radio chips support encryption to increase security.

Protocols are more and more secured, but some attacks are not related to technology issues but user lack of awareness. For instance weak password or manufacturer default password can be used to easily access home network.

[7] https://yourthings.info

### 4.2.5 IoT Privacy

Identification and access control technologies provide link between data and user's devices. Sensed data of things may contain private information concerning their owners or users. Profiling methods based on linked records can reveal unexpected details about users' identity and private life. The IoT needs to support privacy protection during data transmission, aggregation, storage, mining, and processing.

Privacy is more than security; for instance, it has been proved in Caputo [48] that cloud traffic analysis allows to detect the presence of a person in a house equipped with a Google Home device, even if the same person does not interact with the smart device.

Moreover, vendor or third parties have grant access to your data; that is why the EU General Data Protection Regulation (GDPR) provides an essential guidance to achieve a fair balance between the interests of IoT providers and users. But many challenges are still to be met, such as those detailed in Wachter [49] about:

- Profiling, inference, and discrimination
- Control and context-sensitive sharing of identity
- Consent and uncertainty
- Honesty, trust, and transparency

## *4.3 IoT Architecture*

### 4.3.1 Four Layers Architecture

It is usual to represent communication system in the classical seven level OSI model. Here IoT is simplified to four layers levels (Fig. 32):

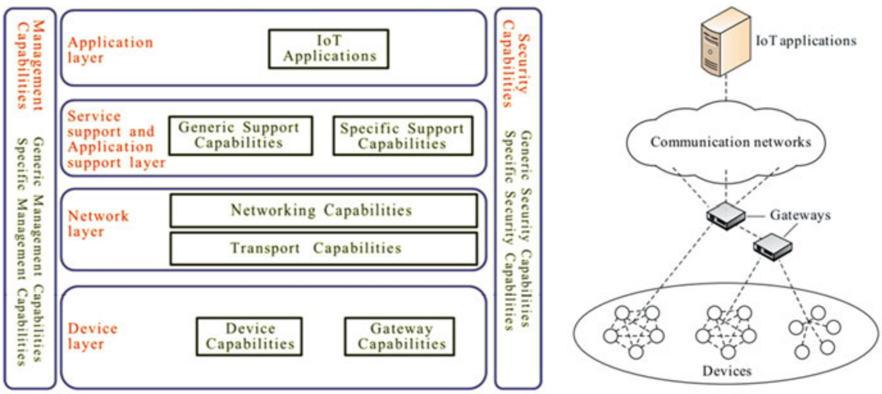



**Fig. 32** Four level layers of IoT reference model [39]

- Application layer contains IoT application.
- Service support and application support layer contains generic support capabilities such as data processing or data storage and specific ones.
- Network layer contains networking and transport capabilities, providing relevant control functions of network connectivity, such as access and transport resource control functions, mobility management or authentication, authorization and accounting (AAA), and transport capability for data information, IoT-related control and management information.
- The device layer contains device capabilities such as direct and indirect interaction with the communication network to gather and upload information with or without gateway, Ad-hoc networking construction (to increased scalability and quick deployment), Sleeping and waking-up . . . The device layer contains also gateway capabilities such as multiple interfaces support (e.g., USB, ZigBee, Bluetooth, or Wi-Fi), and protocol conversion at device level (e.g., ZigBee and Bluetooth) or at both device and network layer (e.g., ZigBee and 4G)

In a similar way to traditional communication networks, IoT **management capabilities** cover the traditional fault, configuration, accounting, performance, and security (FCAPS) classes, i.e., fault management, configuration management, accounting management, performance management, and security management.

**Security capabilities** are present at each layers. It can be authorization, authentication, data confidentiality and integrity protection, privacy protection, security audit and anti-virus, and integrity protection and validation, access control . . .

### 4.3.2 Cloud-Based Architecture

Smart Home solutions architecture (Fig. 33) is mostly based on a gateway with an intelligent part to manage local automation and a cloud part to manage user interaction and database.

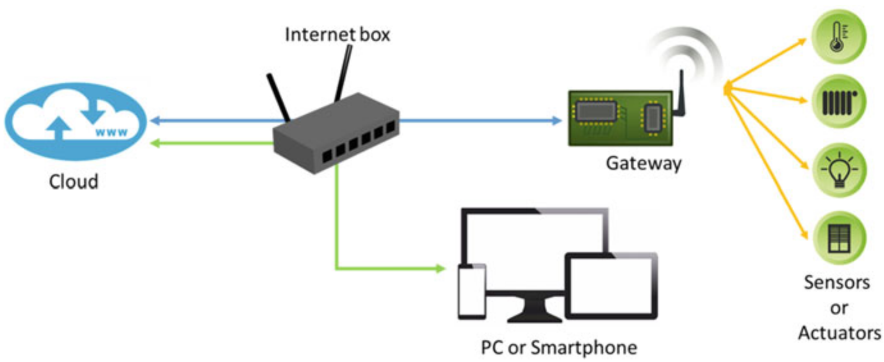



**Fig. 33** Classical architecture of Smart Home solutions

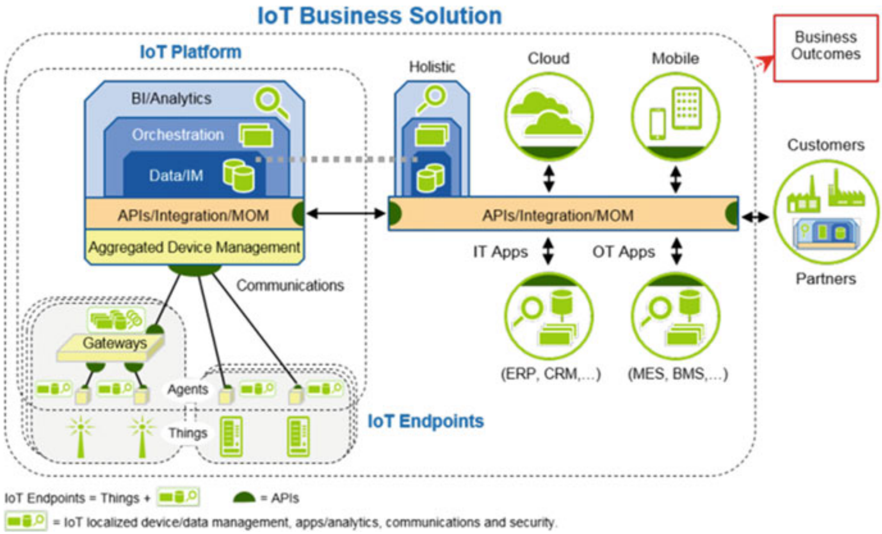
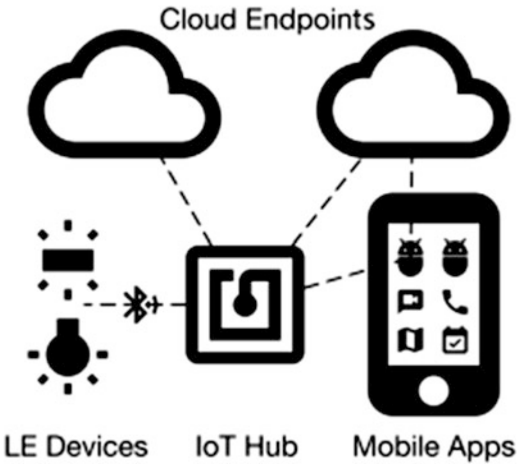



**Fig. 34** IoT business solution. (Source: Gartner [50])

**Fig. 35** IoT deployment in a cloud-based architecture. (Source: Alrawi et al. [45])




Moreover, third parties' access grant is part of the new architectural model of IoT (Fig. 34).

Installation of such a device follows a classical scheme (Fig. 35), where low-energy (LE) devices are connected (e.g., Bluetooth) to an IoT hub or directly to the vendor mobile application in order to configure network connection, then able to access cloud platform.

Let us consider Netatmo, a French company that offers a connected thermostat, a weather station, and a face recognition security system. The data can be consulted by

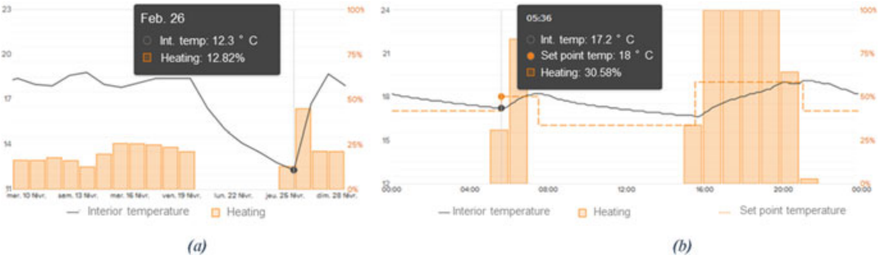



**Fig. 36** Netatmo thermostat data viewed on the cloud application. (**a**) During 1 month, with manual remote heating restart before the come back from holidays. (**b**) During 1 day with heating restart by machine learning

smartphone application, and by website. Figure 36 illustrates the Thermostat's web interface with manual remote heating restart and automatic learning-based morning restart:

(a) **Manual remote heating restart**: has been used here to reactivate heating system before coming back to home at the end of holidays. The graph shows a temperature decrease from 19 °C to 12.3 °C in one week, and a rise back to 19 °C during 2 days. It leads to no heating consumption during a week, and double consumption during 1 day to retrieve the initial temperature.

(b) **Learning-based morning heating restart**: While user set point has been defined to have 18 °C when occupants wake-up (7 am), the controller has learnt the thermal behavior and anticipate the heating at 05:36 in order to reach temperature at the desired time. It is the same for the evening, starting heating from 3:30 am taking temperature rise into account.

We have just seen that Netatmo data is accessible from a remote server. The data is automatically uploaded from the IoT device and is accessible as long as the company maintains the service. But the data is also available through API (Application Programing Interface[8]) so that anyone can develop applications using these sensors. The owner of the IoT can then grant access to his data for a third-party application and benefit from new services.

As discussed in IoT privacy part above, it is important to know about the data access possibilities of connected systems that appear on the market. The first precaution concerns the property of the data which must remain with the owner rights, including the data remove. Then, the security of the data, if those data are available on a server, they must be accessible by secured manner, and if accesses are authorized, to know the treatments and objectives of these treatments.

In Table 2 below are summarized some manufacturers that can be currently met on the home automation market in terms of monitoring and control.

[8] https://dev.netatmo.com/

**Table 2** Some example of home-automation device manufacturers and prices

| Providers | Protocols | Approximated prices |
|---|---|---|
| Xiaomi Home | Zigbee<br>Wifi | Gateway: 20 €. Device price is varying from 10 € the temperature/humidity sensor up to 300 € the robot vacuum cleaner |
| Fibaro | Zwave | Gateway: 40 €. Device price between 50€ and 100€ |
| IKEA | Zigbee | Gateway: 30 €. Device price from 15 € for a socket plug, up to 150 € for connected blinds |
| Somfy | 433mhz | Very varied price |
| DeltaDore | X3D | Gateway: 100€. Device 50€ |
| Smappee | Wifi, bluetooth, Modbus, MQTT | Gateway: 300€. Device 50€ |

### 4.3.3 Typical IoT for Home Energy Monitoring

The following figures illustrate typical monitoring for three specific flux, namely electrical, gas, and water fluxes.

Figure 37 is relative to typical IoT for home electrical consumption monitoring. They can be placed on the electrical distribution board or directly on appliances. It can also use existing measurements such as the main electricity meter such as Linky smart meter or pulse-based electrical counter (Table 3).

Figure 38 is focusing on electricity monitoring for PV system generation. A storage can be added and energy flux can be monitored with different control strategies such as self-consumption (Table 4).

Figure 39 is relative to typical IoT for gas-based heating and hot water consumption monitoring (Table 5).

Figure 40 is relative to typical IoT for water consumption monitoring (Table 6).

## *4.4 Wireless Communication Energy Consumption*

### 4.4.1 Wireless Characteristics

As described in Fig. 41, wireless protocols have to be chosen depending on data rate and range required by application domain. For instance, home automation range is from 10 to 100 m, then technologies such as Z-Wave or EnOcean are widely used, associated with a mesh network which uses nearby devices to piggyback communication to devices in all buildings rooms. Depending on the range, the network is called a Wireless Local Area Network (WLAN, e.g., Wifi) or a Wireless Personal Area Network (WPAN, e.g., bluetooth). Multimedia communication requires high-rate protocol such as wifi, but for home automation, low-rate (about 100 kb/s) is still enough. The target is then to reach as close as possible the targeted application.

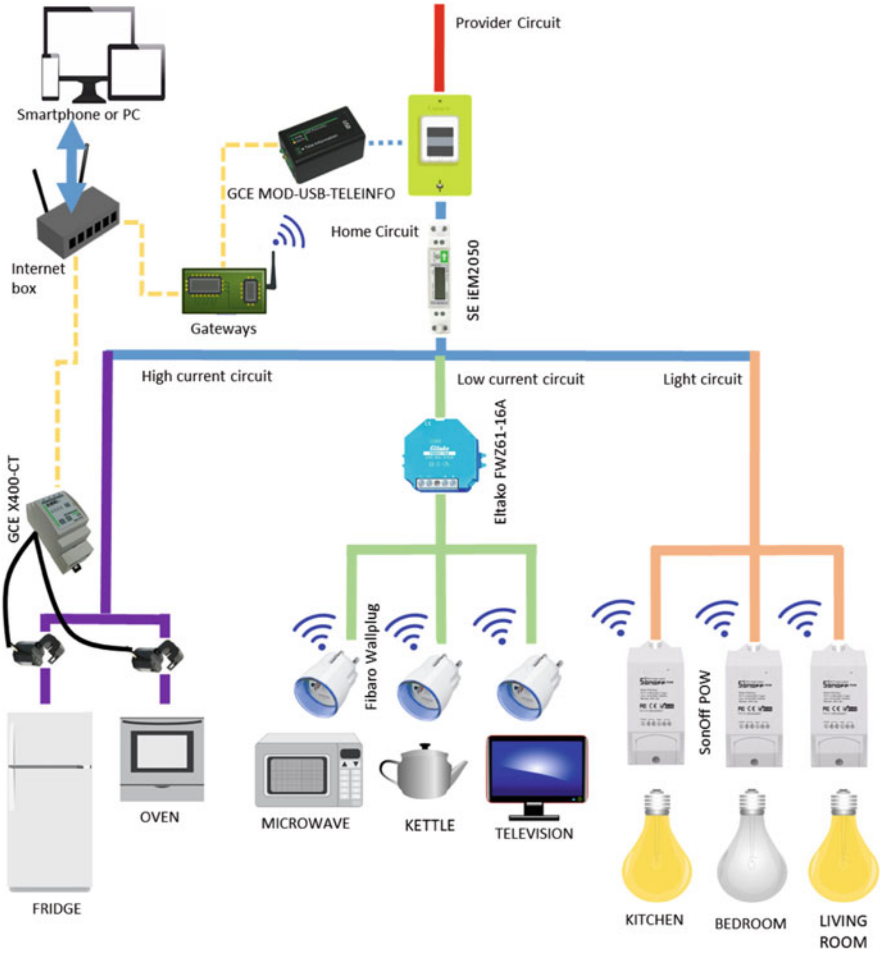



**Fig. 37** Typical IoT for home electrical consumption monitoring

Indeed, if one increases the range or data rate, the consumption is increasing too. That is why we are focusing on Low-Rate Wireless Personal Area Network (LR-WPAN). Other protocols are available for LR-WPAN such as 6LoWPAN, BLE (Bluetooth low energy), Thread, UWB (Ultra WideBand), ZigBee, and ANT+.

IEEE 802.15.4 is a technical standard which defines the operation of LR-WPAN. It specifies the physical layer and media access control for LR-WPAN, and is maintained by the IEEE 802.15 working group, which defined the standard in 2003. It is the basis for the Zigbee, ISA100.11a, WirelessHART, MiWi, 6LoWPAN, Thread, and SNAP specifications.

**Table 3** References and properties of electrical meters

| Meter | Reference | Measurements | communication |
|---|---|---|---|
| Main electricity meter | GCE electronics TELEINFO | – All data provided by main counter (Linky) such as index, power, high/low period . . . | USB |
| Main electrical circuit meter (distribution board) | Schneider electric iEM2050 | – Active and reactive energy<br>– Active and reactive power<br>– Power factor<br>– Current<br>– Voltage<br>– Frequency | Modbus |
| Sub circuit meter (distribution board) | GCE electronics X400-CT | – Current (hot plug using tore) | Ethernet |
| sub circuit meter | Eltako FWZ61-16A | – Active energy<br>– Active power | Enocean |
| sub circuit meter & switch | SonOff POW R2 | – Active energy<br>– Active and reactive power<br>– Power factor<br>– Current<br>– Voltage | Wifi |
| socket meter & switch | Fibaro FGWPE-102-ZW5 | – Active energy and power<br>– Remote switch | Zwave |

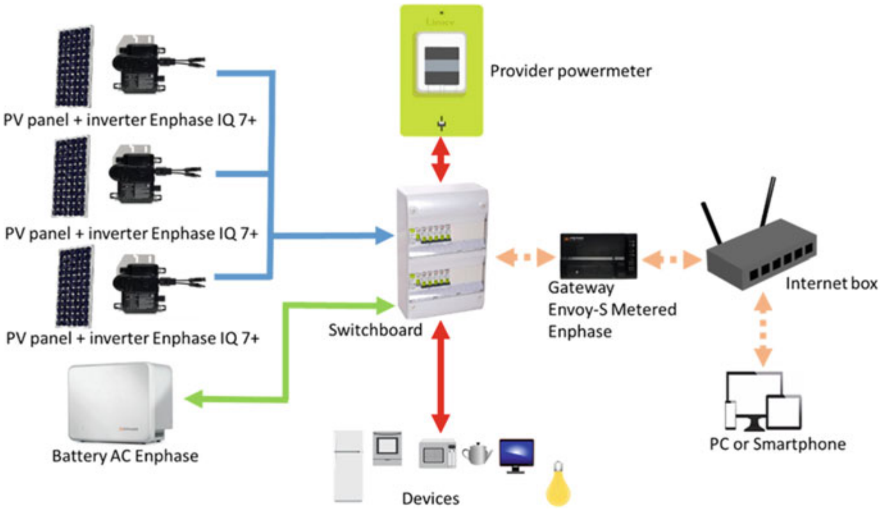



**Fig. 38** Autoconsumption system monitoring composed of PV production based on micro-inverters and energy storage system

**Table 4** References and properties of photovoltaic production and storage system

| Meter | Reference | Measurements | Communication |
|---|---|---|---|
| Electrical production and storage | Enphase Envoy-S Metered | – Transmit PV production for each micro-inverter and Battery storage | Wifi |
| PV panel + Inverter | Enphase IQ7 | – Monitoring of production | Power-line communication (PLC) |
| Battery | Enphase AC Battery | – Control strategies:<br>• Self-consumption<br>• Dynamic tariff adaptation<br>• Limitation of energy injection | Power-line communication (PLC) and TCP/IP |

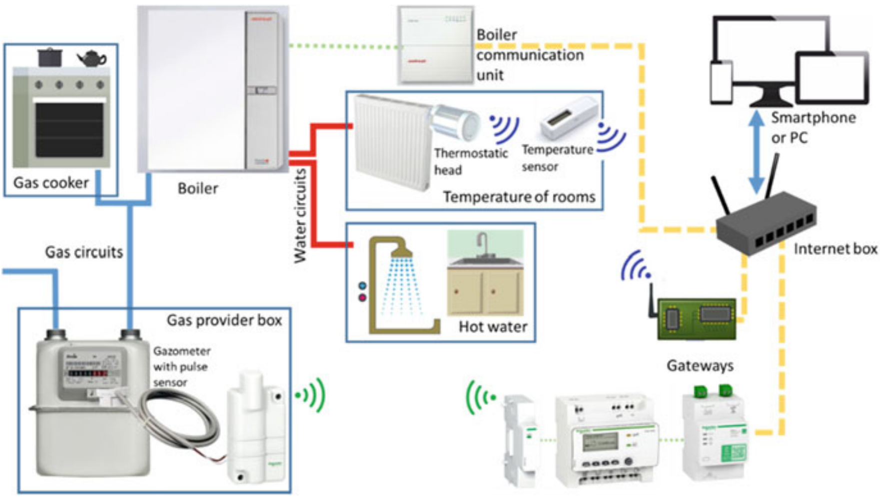



**Fig. 39** Typical IoT for gas-based heating and hot water consumption monitoring

**Table 5** References and properties of gas-based heating and hot water meters

| Meter | Reference | Measurements | communication |
|---|---|---|---|
| Main gas meter | Schneider electric Wiser Link | – Pulse-based gas consumption ($m^3$) | Radio + Ethernet |
| Boiler proprietary meter | Weishaupt WCM-COM | – All data provided by boiler | Ethernet |
| Heater regulator | Danfoss Living connect Z LC13 POPP | – Heater temperature | Radio (ZWave) |
| Ambiance sensor | NODON NOD_STP-2-1-05 | – Temperature<br>– Humidity | Radio (EnOcean) |

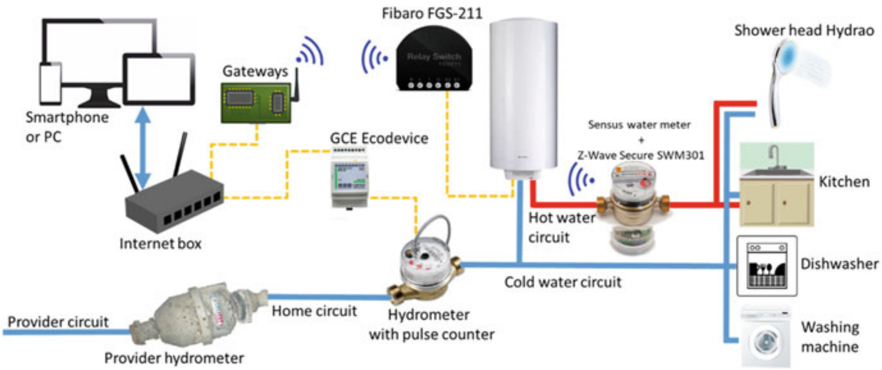



**Fig. 40** Typical IoT for water consumption monitoring

**Table 6** References and properties of water meters

| Name | Provider | Measurements | Communication |
|---|---|---|---|
| Main water meter | GCE electronics ecodevice | – Pulse meter | Ethernet |
| Domestic hot water meter | Sensus SWM301 | – Pulse meter | Z-Wave |
| Shower meter | Hydrao shower head | – Consumption | Bluetooth |
| Hot water switch | Fibaro FGS-211 | – Smart switch | Z-Wave |

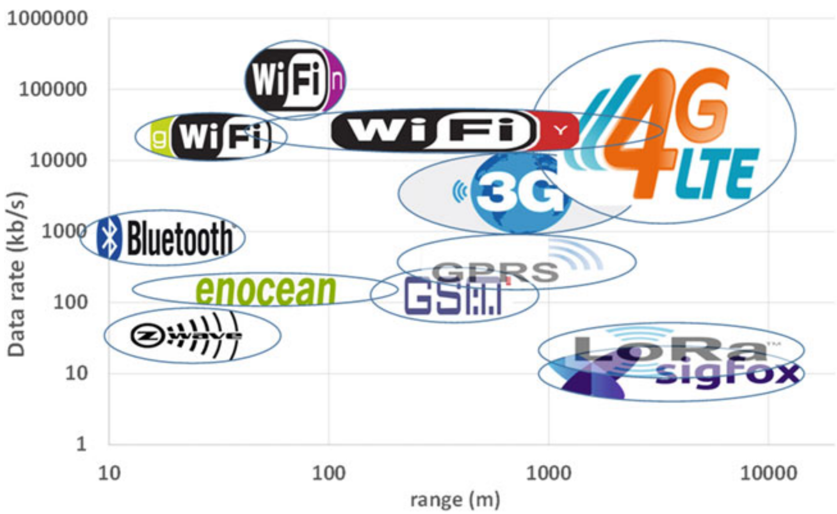



**Fig. 41** Range/data rate of the main wireless protocols

### 4.4.2 Will There Be Only One Standard?

Manufacturer are using different standards for wireless communication protocols. A non-exhaustive list with some properties is given in Table 7.

**Table 7** Some communication protocols with their properties

| Protocols | Frequencies | Range | Type of protocol | Number of nodes | Advantages |
|---|---|---|---|---|---|
| X3D | 434/868 MHz | 200/300 m | Proprietary protocol | 16 nodes for each gateway | Dual-band technology. High resilience to interference |
| Zigbee | 868mhz/**2.4 Ghz** | 100 m in mesh network | OpenSource | 65,000 nodes | Anyone can easily make nodes |
| Zwave | 868 MHz in Europe | 100 m in mesh network | Proprietary protocol | 232 nodes for each gateway | meshed network |
| Enocean | 868 MHz in Europe | 200 m with max 2 jumps | Open and interoperable | unlimited | Energy-efficient technology |
| Bluetooth Low Energy | 2.4 GHz | 100 m | Open | unlimited | low latency |
| Wifi | 2.4Ghz/5 GHz | 250 m | Open | 256 | Technology found in almost all buildings |

In the past few years, there has been a battle for the short-range, low-power protocol for smart home IoT applications between ZigBee and Thread. ZigBee started in 2005 and has millions of devices on the market. Thread is from Google Nest Labs and started in 2015. Thread/Weave was a Google/Nest play but now joins forces with the other two: Amazon and Apple. The new standard will be managed under Zigbee[9].

ZigBee (3.0/pro) and Thread are both open standard builds on the same physical and link layer protocol stacks (IEEE 802.15.4). Whereas their biggest competition in this space, Z-Wave, is using a proprietary Z-Wave standard.

Zigbee operates primarily in the 2.4 GHz radio band; however, some devices operate in the higher end of the MHz range (e.g., 868 MHz in EU, 915 MHz in the US).

Z-Wave is another mesh network; however, it operates at a lower frequency band of 918/860 MHz. This allows for a better device-to-device signal range at the cost of reduced data rates.

In contrast to the above technologies, Thread is a much younger and less established mesh networking standard. It is also built on IEEE 802.15.4 using 2.4 GHz radiofrequency. It is defined up until the Application Layer, which means that other application layer protocols such as MQTT can be used [51].

[9] Hui Fu, The IoT Smarthome Battlefield: A Jointly Endorsed IoT Standard for the Home Area Network (HAN), IoT for all, February 12, 2020. Ref: https://www.iotforall.com/connected-home-over-ip/

The question of one unique protocol is still open, but the history shows that it is better to invest on open and interoperable standards instead of waiting for the Holy Grail.

### 4.4.3 Energy Harvesting

The EnOcean solution has particularly benefited from the fact that it integrates energy recovery solutions to power its sensors making them autonomous and without intervention. This is, for example, the EnOcean PTM210 switch with an ECO 200 harvester (Fig. 42) which by mechanical-magnetic conversion will generate a pulse of electrical energy sufficient to supply the transmission and reception of a radio signal frequency.

For the EnOcean heater thermostat, the Seebeck effect (inverse of the Peltier effect) is used to transform a temperature gradient into electrical voltage. A very low voltage conversion module (ECT 310) is then necessary to exploit this energy to transmit the RF signal.

A more common energy recovery is that coming from light radiation by the use of photovoltaic cells integrated into the sensor. These include the EnOcean temperature and humidity measurements (Fig. 43a) or the Z-Wave anemometer (Fig. 43b).

In this area, the French company Enerbee[10] has developed an innovative solution for generating energy from all types and speeds of movement, for comfort and air quality applications based on HVAC control. Energy peaks are converted to useable energy delivering energy in the 100 μW to 10 mW range, which can be stored in a supercapacitor and managed using ultra-low leakage power management (Fig. 44).

These battery-less power solutions still pose some difficulties. Regarding the temperature sensor, it is necessary for the O2Line model (Fig. 43a) to have an average brightness greater than 100Lux (i.e., > 300 Lux, 8 h per day). However, certain areas of the buildings are particularly dark like some corridors. Thus, data

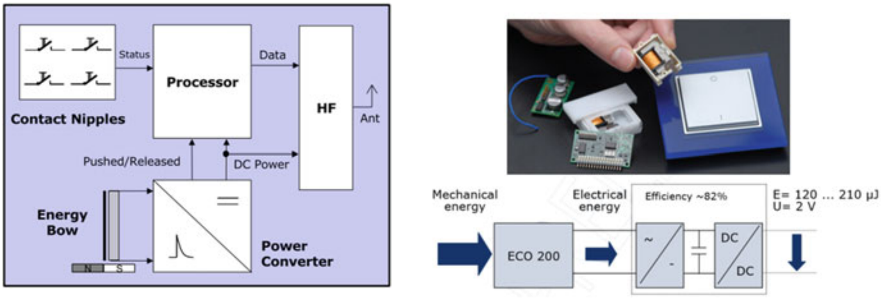



**Fig. 42** EnOcean, Energy harvesting. (Source: EnOcean)

[10] www.enerbee.fr

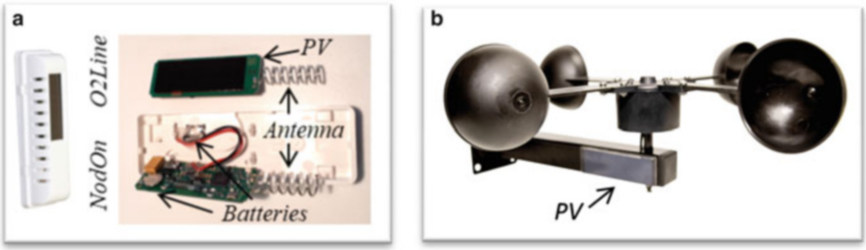



**Fig. 43** Photovoltaic (PV) energy harvesting. (**a**) EnOcean temperature and humidity sensor (NodOn and O2Line). (**b**) Z-Wave anemometer (POPP Z-Weather)

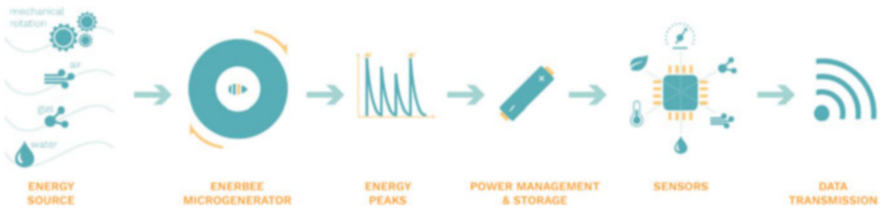



**Fig. 44** Mechanical rotation energy recovery. (Source: Enerbee)

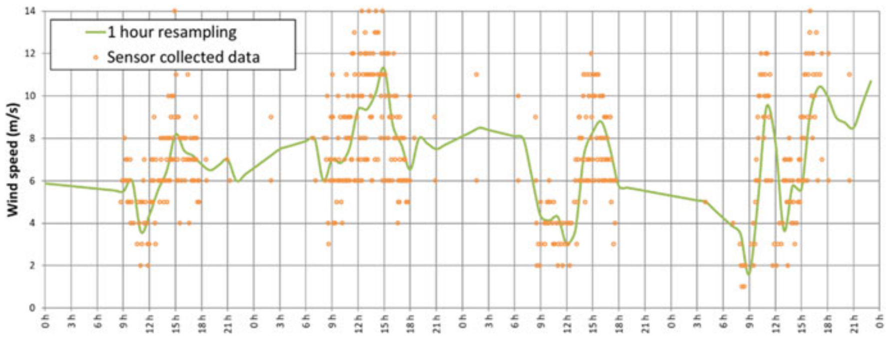



**Fig. 45** Anemometer measurements (POPP Z-Weather) and reconstruction of missing data

gaps are appearing during the night. This is why it is actually recommended to use versions including batteries, as is the case with the NodOn model (Fig. 43a).

Intelligent energy management can be implemented as in the case of the POPP Z-Weather module (Fig. 43b), with a much reduced data emission at night (Fig. 45). In addition, to limit the amount of data sent, the wind speed is coded on very few bits with a poor resolution of 1 m/s. In reality, it would have been better to size the PV cell and a storage allowing the transmission of the measurements more frequently because the reconstruction of the missing data is of very poor quality (Fig. 45).

# 5 Open-Source Home Automation

## 5.1 Open-Source Projects

### 5.1.1 Home Automation Software

We have seen in the previous section that commercial home automation proprietary solutions are available (Table 2), based on IoT with wireless communication and a cloud architecture. But free and Open-Source Software (OSS) home automation platform are numerous today as it is possible to find many[11] like: **openHAB** which can integrate with over 1500 devices and which has one of the biggest community with 33,000 members; **Home Assistant**, similar to openHAB, very flexible from the developer side; **Jeedom**, well known mostly for French community; **Domoticz**, with many step-by-step guidance on their web site.

These software have become more and more popular thanks to cheap nano-computers such as the well-known Raspberry Pi where these solution can be installed easily by end-users. The classical architecture presented in Fig. 33 is becoming the following one (Fig. 46) with an internal structure based on a main Core System using different plugins or add-on and a local database.

Compared to a fully cloud-based platform, these solutions are keeping data locally with the possibility or not to expose them on the Internet. Some solutions are easy to administer, others require more skills in network configuration and time on community forums. The IoT can then be connected to this home automation server,

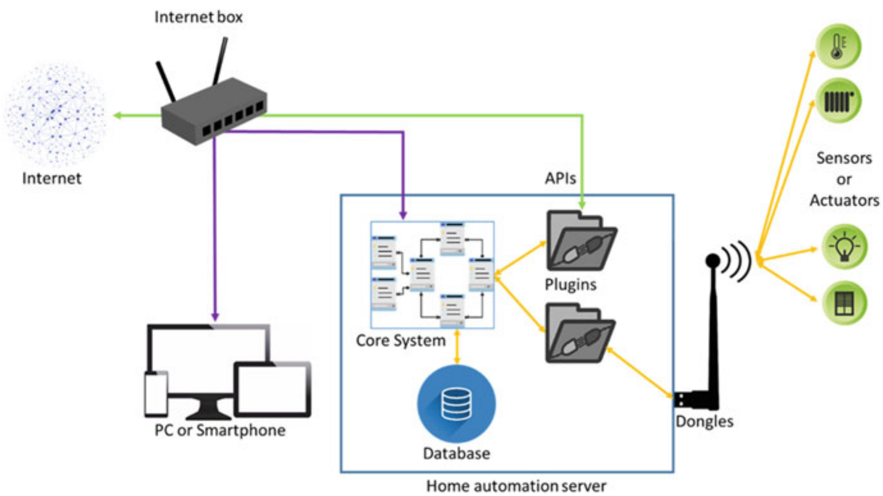



**Fig. 46** Smart Home solution with local server implement of low-cost nano-computer

[11] https://ubidots.com/blog/open-source-home-automation/

**Table 8** Smart Home open-source project programming standards and technologies

| | Programming language | Database | Configuration |
|---|---|---|---|
| Openhab | Java | RRD4J | Textual and graphic |
| Home Assistant | Python | SQLite | Yaml files |
| Jeedom | PHP | Mariadb | Web interface |
| Domoticz | LUA | SQLite | Web interface |

which must therefore communicate in all the protocols involved, and have physical equipment supporting the communication. Conventionally, a module (expansion card or dongle) is required per protocol, hence the need to limit the number of protocols in a single installation to facilitate interoperability.

The software is then able to code/decode the communication frames transmitted to/by the IoT. This layer can be provided with the device, available as OSS (OpenZWave), or reimplemented in specific environments. This is the case, for example, with openHAB and Jeedom where the EnOcean drivers have been written from specifications. The main feature of these environments is to integrate the different technologies in an agnostic way (Abras, [52]) in order to treat them in the upper layers independently of the wireless communication layer.

They generally allow to interact directly with the system in read/write (sensor/actuator), to archive the data in databases, and to visualize them. OSS generic solutions are also available for time series database (e.g., InfluxDB) and for visualization (e.g., Grafana).

Most of home automation project use similar architecture but with different standards and technologies for programming language, database, and configuration (Table 8).

Programming technologies are becoming major characteristics for OSS since users are interested in understanding the code and may contribute to the software. If a user wants a plug and play system without having to do much programming, he will probably choose Jeedom or Domoticz, while another user wants to fully customize its interface, he will probably choose openHAB or Home Assistant.

This can also bring third-party commercial services. For instance, the simplicity of Jeedom is counterbalanced through some plugins which are not free (e.g., EnOcean protocol), while it is free in openHAB, but require more time and tips to be implemented.

### 5.1.2 Low-Cost Hardware

As already illustrated with nano-computer and the success of Raspberry Pi for home automation servers, recent advances in wireless technologies and embedded systems, based on Open-Hardware (Arduino), ANT wireless technology (nRF24L01+ module), low-cost wireless sensors and actuators network (WSAN) for building energy services is available [53]. Moreover, unlike commercial products, this WSAN is customizable and easy to be extended for adapting different research


**Fig. 47** Arduino Pro mini and nRF24L01+ module

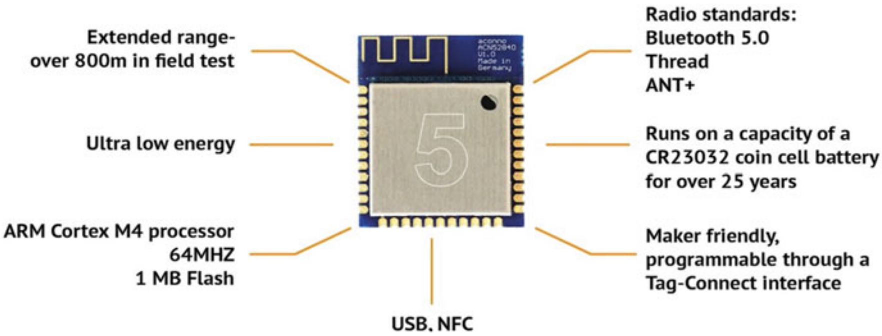



**Fig. 48** nRF52 chip and its communication antenna which can also be used for energy harvesting

situations. RF24Network is a network layer for Nordic nRF24L01+ radios running on Arduino-compatible hardware (Fig. 47).

On the other hand, connected things are not necessarily intended to fit into such a wireless network, but can simply be connected to the Internet through the mobile phone using bluetooth then 4G, or through the home automation box using Wifi then ADSL or fiber. Solutions integrating this type of communication become very affordable with the rise of the IoT and announce very low consumption. For example, Nordic Semiconductor’s NRF52 (Fig. 48) is based on an ARM Cortex-M4 processor incorporating a 2.4 GHz transmitter for Bluetooth Low Energy (BLE) communication, as well as the Thread protocol. For its part, the Chinese company Espressif offers the ESP32 (about 5 €), a more powerful solution (double heart clocked at 240 MHz backed by 4 MB flash memory) integrating in addition to BLE, WiFi and a cryptographic chip supporting the latest data security standards.

Both software bricks and hardware components are available on the shelf in order to create innovative open-source project, with active community, in order to promote energy efficiency, sobriety and make our home smarter and ready for the energy transition.

### 5.1.3 Definition and History of Open-Source Projects

First of all, it is important to understand the difference between OSS and free software. OSS can be the base of commercial software (e.g., sold with hardware and/or services), and free software can be proprietary software. The key difference between OSS and proprietary software is that the OSS publishes the source code whereas the proprietary software retains the source code.

Motivations to create OSS are various among a desire for improved transparency, or new business models based on service rather than in software, but it is probably mainly for involving many people within a dedicated home energy management community. In the current context of struggle against climate change, it is a great challenge to develop new collaborative and open organizations, involving citizen through energy communities. A good home automation needs an equally strong community that is willing to back it up and improve upon its initial state.

The general idea of Open Source (OS) dates back to the 1970s through projects driven by electronic enthusiasts such as the Homebrew Computer Club[12], which aimed to exchange ideas and components in order to create computers. In the 1980s, the movement weakened as most activists joined Silicon Valley businesses. Although Open-Source Software (OSS) was well established, it was not until the early 1990s that Open-Source Hardware (OSH) regained a second youth thanks to the advent of FPGA (Field-Programmable Gate Array).

Since the concept of OS, it has widened and has touched more and more areas. In recent years and with the advent of the Arduino project [54], we have seen an explosion of Do It Yourself (DIY) projects where the spirit of open source is a real driver. This OSS and OSH card project opened access to the “smart” part of the projects because it was designed like a real electronic Swiss Army knife and can be made by anyone with a minimum of hardware and programming knowledge.

It is important to distinguish hardware from software because OSH only covers the creation of material products[13]. However, if software is necessary to operate OSH, it may be required by the various existing licenses that the interfaces be sufficiently detailed to allow writing OSS to ensure its essential functions.

In recent years, a debate has been animating the community through to find out the difference between the term free software and OSS. Fortunately, the nuance is clearer with regard to the hardware because an OSH is supplied with plans and diagrams allowing everyone to be able to reproduce it, while an open hardware is supplied with complete specifications allowing a user to interact with it without necessarily knowing what is going on inside. Most of the time, OSHW depends on open hardware.

As an example, 3D printers use stepper motors which one can have all the specifications to operate them without needing the information necessary for their production.

[12] https://www.computerhistory.org/revolution/personal-computers/17/312

[13] https://www.oshwa.org/definition/

### 5.1.4 Efficient Open-Source Projects

The community structure that is generally found in Open-Source project is called a contributor funnel[14]. It is like the four basic sales funnel stages (Awareness, Interest, Decision, Action) but applied on members roles (Users, Contributors, Maintainers) as described in Fig. 49. It means that the project has to bring awareness and interest to users, which can decide to become a contributor and make actions until becoming a maintainer, with higher rights on the project.

In order to bring user from the top of the funnel to the way down, it is important to ensure that users have easy victories as a contributor to encourage them to do more. Efforts are also made in terms of documentation because the majority of open-source contributors are "occasional contributors," because they do not necessarily have time to get to know the whole project.

In 2017, GitHub conducted a survey on open source[15] and demonstrated that incomplete or confused documentation is an obstacle for most open-source users. This is why the projects that work have good documentation, invites people to interact with the project and to contribute to it. Gathering points are also created through the establishment of forums and are also an important part of this kind of

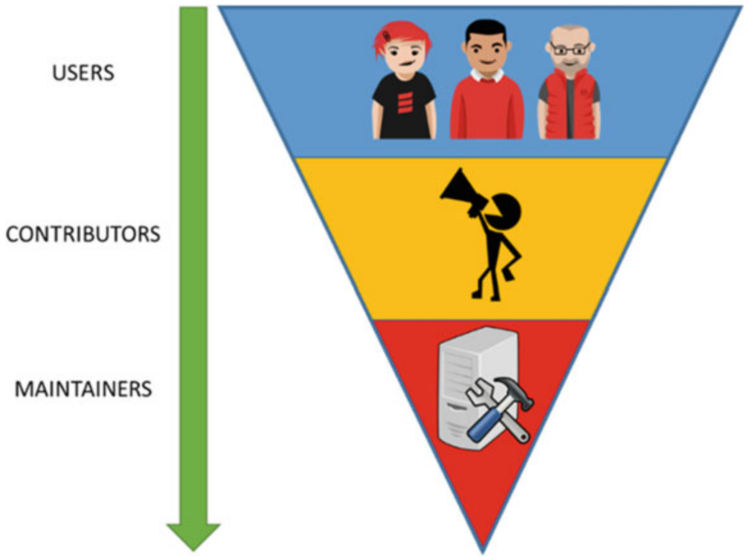



**Fig. 49** Open-source community, contributor funnel. (Source: McQuaid [55])

[14] https://mikemcquaid.com/2018/08/14/the-open-source-contributor-funnel-why-people-dont-contribute-to-your-open-source-project/

[15] https://opensourcesurvey.org/2017/

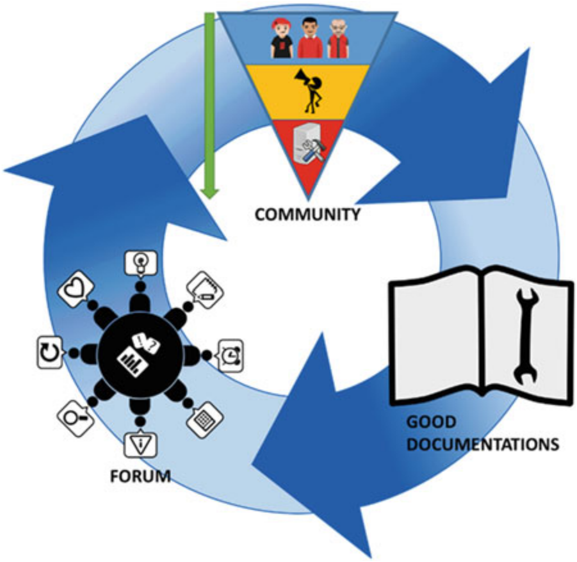



**Fig. 50** Ingredients for an effective open-source project

community because they allow to open debates on the project and to submit ideas on the future of it (Fig. 50).

It is through these three pillars (community, good documentation, and forum) that the virtuous circle of open-source projects exists. In recent years, this scheme has encouraged more and more manufacturers to open up the sources of their product and to offer well-documented APIs (Application Programming Interfaces). Companies find the advantages of having feedback from their users, of being more reactive to competition, and of increasing their brand image. At the user level, this also translates into increased confidence in the purchased products and a feeling of listening to their needs.

### 5.1.5 How to Protect This Model?

Most of the time when a creative work is done (code, plans, ...) the law indicates that only the author has an exclusive copyright by default. This implies that no one else can use, copy, distribute, or modify this work without risking litigation and legal consequences. Regarding open source, the author expects just the opposite because he wants others to use, modify, and share his work. It is because of this legal flaw that the author of an open-source project needs a license that explicitly states these permissions.

There are several types of licenses more or less open rights to the use, modification, and distribution of the work that has been made by a contributor. There are

**Table 9** Creative commons licensing

| | (BY) Attribution | (ND) No Derivatives | (NC) Non-Commercial | (SA) Share Alike |
|---|---|---|---|---|
| CC0 | | | | |
| CC-BY | X | | | |
| CC-BY-ND | X | X | | |
| CC-BY-NC-ND | X | X | X | |
| CC-BY-NC | X | | X | |
| CC-BY-NC-SA | X | | X | X |
| CC-BY-SA | X | | | X |

different criteria in order to choose the appropriate open-source license[16]; it will depend on the strategy, commercial and/or community aim of the project.

In the software domain, there are two main licenses:

- The MIT License which is the simplest and most permissive because it allows people to do almost anything they want with your project, like making and distributing closed source versions.
- The GNU GPLv3 license which will protect and ensure that improvements and modifications made by someone are always distributed open.

In the non-software domain, there are also creative commons licenses[17] which, depending on the options chosen, will more or less authorize certain rights of use, modification, or distribution. It is thanks to these licenses that Open-Source projects have a legal framework and guarantee freedom to share the ideas emerging in them. The six main ones are listed in Table 9 based on the following criteria:

- Attribution (BY): Licensees may copy, distribute, display, and perform the work and make derivative works and remixes based on it only if they give the author or licensor the credits (attribution) in the manner specified by these.
- Share-alike (SA): Licensees may distribute derivative works only under a license identical ("not more restrictive") to the license that governs the original work (copyleft).

[16] https://choosealicense.com/

[17] https://creativecommons.org/

- Non-commercial (NC): Licensees may copy, distribute, display, and perform the work and make derivative works and remixes based on it only for non-commercial purposes.
- No Derivative Works (ND): Licensees may copy, distribute, display, and perform only verbatim copies of the work, not derivative works and remixes based on it.

## *5.2 Review of Some Smart Home Projects*

In this last part, we would like to detail some existing open-source projects relative to smart home.

### 5.2.1 Smart Citizen Kit

The main objective of the Smart Citizen project[18] is to offer citizens easy-to-access measurement tools so that they can get involved in local environmental pollutions. This project gives free access to an Open-Source kit capable of capturing and analyzing various environmental data in real time. This project offers the possibility of purchasing the components and/or of assembling them itself as well as of making modifications in the code provided. Measures are about weather conditions (Temperature, Humidity, Air pressure), Light pollution, Air Quality (Indoor/Outdoor), Noise Pollution.

It is a project resulting from the collaboration between the Institute of Advanced Architecture of Catalonia and the "Fab Labs" of Barcelona. Currently, there are 230 active stations around the world that can be localized in a map[19] (Fig. 51).

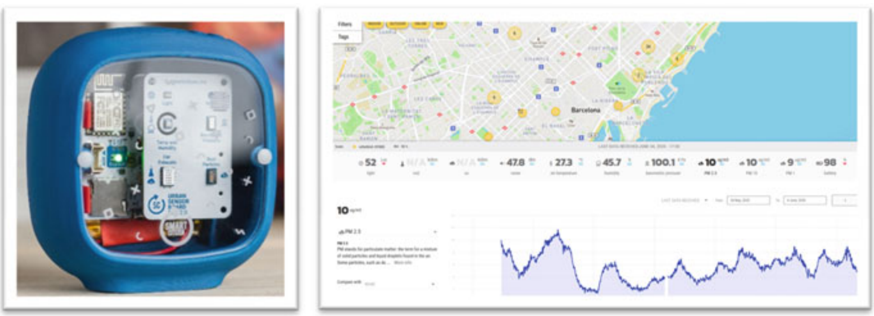


**Fig. 51** Smart Citizen kit and Internet world map for online monitoring

[18] https://www.seeedstudio.com/smartcitizen

[19] https://smartcitizen.me/kits/1352


**Fig. 52** Open Energy Monitor device with four current measurement, and monitoring

### 5.2.2 Open Energy Monitor

This project[20] aims to develop tools to help people who want to understand energy systems and their use. It is aimed at all types of profiles, from the novice who can buy the material already made to the expert who can adapt the source codes as well as the hardware in order to match his needs.

It is more a project aimed at monitoring and understanding energy in the building than a system dedicated to home automation.

The measurement systems currently available are:

- Electricity, gas, and water consumptions monitoring
- PV production
- Electric vehicle charging monitoring
- Monitoring for heat pump
- Monitoring of climatic conditions

This project is supported by fifteen participants from all backgrounds and draws on feedback from its user community (Fig. 52).

### 5.2.3 A4H Smart Home

The smart home of Amiqual4Home[21] is a space of about 90 $m^2$ simulating a home. It serves as a tool for usage experiments actors who work in the field of research and innovation on smart housing. The 87 $m^2$ was renovated and equipped with home automation systems, multimedia, water and electricity meters, and means for observing human activity. It is also equipped with all the actuators capable of controlling all the devices present such as the kettle, the lights, or the roller shutters. All measurements and equipment are linked to a central home automation system which allows an operator to act as the wizard of OZ during the experiments.

[20] https://openenergymonitor.org/

[21] https://amiqual4home.inria.fr/tools/smart-home/

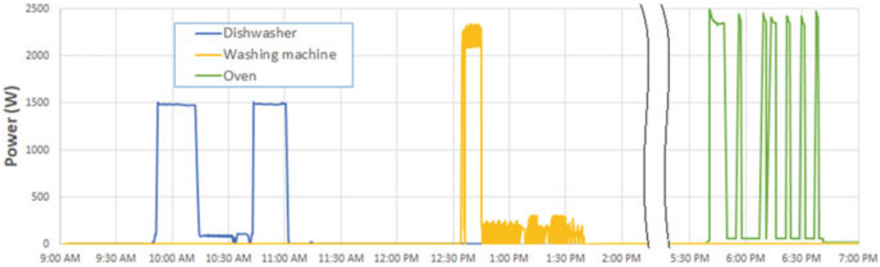



**Fig. 53** Three main power consumption profiles of home electric appliances

This smart home was for instance used to publish open dataset[22] (CC-BY) containing real-life sensor data of a person living in a smart home. It is a high-quality dataset with a dense but nonintrusive sensor infrastructure [56]. A deep sensing approach was used with over 200 variables measured. These include all doors (rooms, cabinets, fridge) state, light states, temperature, $CO_2$ levels, noise levels, weather, appliances (oven, stove, TV, coffee maker . . . ) state. Nine daily living activities are self-annotated (taking shower, using toilet, sleeping, cooking, going outside, washing dishes, eating, and working).

Figure 53 plots three main home appliances consumption, namely the dishwasher, the washing machine, and the oven, extracted for this open data base.

### 5.2.4 G2Elab Smart Home and Open-Source Tutorials

G2Elab Smart Home project provides data from a 120 $m^2$ household where a five people family is living in. This project grant an access to about 340 measuring points for scientists, accessible in real time through a Grafana portal with Influxdb database. There are measures of:

- Electricity, gas, and water consumption of each device
- Temperature, humidity, brightness of each common room
- Opening position of each door and window
- Motion sensors
- The state of each light
- Air analysis of each room
- Outdoor weather conditions

Expe-Smarthouse is developed based on Open-Source Hardware and Software. Many tutorials have been made based on this house and from students projects from G2Elab (Grenoble Electrical Engineering lab), and posted in miniprojets.net website

[22] https://data.mendeley.com/datasets/fcj2hmz5kb

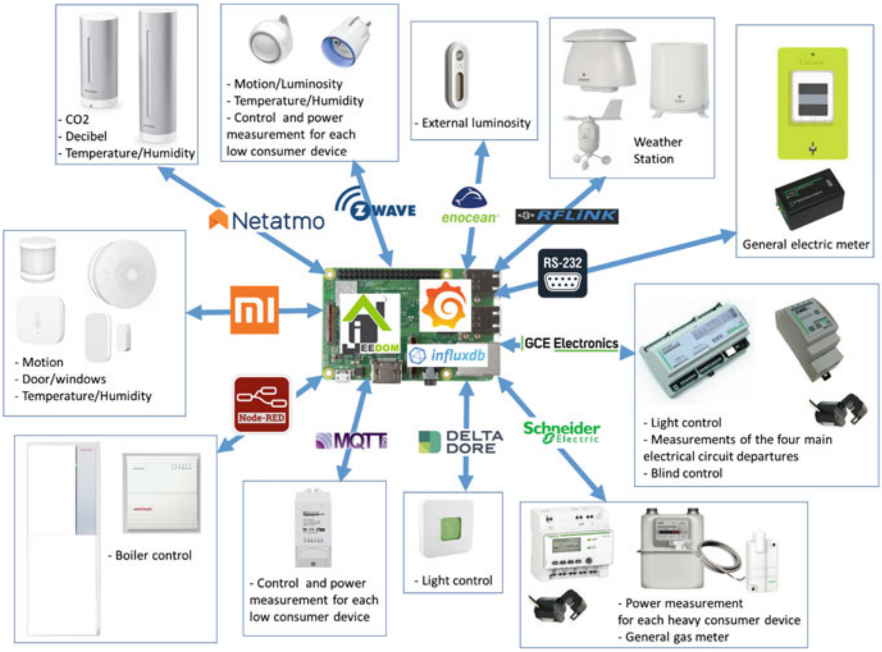



**Fig. 54** G2Elab Smarthouse devices and multi-protocol gateway

(in French). It is then accessible for citizens who want to set up their own smart home with commercial or homemade hardware and software (Fig. 54).

## 6 Conclusions

Is open source the solution of the future for the democratization of the smart home? We wanted to finish with this last part on open source to show that movements complementary to commercial solutions could find their place in this highly technological field. The massive arrival on the market of low-cost IoT, connecting directly to the Internet, or through home automation gateways greatly modifies the previous monolithic paradigm of a single solution provider.

Interoperability and the openness of standards has for several years shown its interest, and now open-source continues this advance to offer ever more accessible services to citizens. Standards from the world of building automation, necessary to structure and optimize an industrial organization, have given way to agile solutions exploiting plug-and-play and cloud infrastructure. These solutions do not require the intervention of experts in situ, and thus optimize the benefits.

IT players have entered this market historically occupied by manufacturers from building management systems. Today, developments and innovations are largely driven by these new players, and the smart home is distinguished from home automation by the arrival of end-users services. These can be artificial intelligence based predictive energy management, as well as new interaction modes such as voice assistants or chat bot. The myriad of sensors, pushing data back into the cloud from a targeted consumer service provider, raises the question of privacy. European people can be more confident than other countries thanks to the General Data Protection Regulation (GDPR), but the citizens have still to be aware about IoT they bring in their own information system, even if there are from well-known companies, or verifiable open-source solutions.

## References


1. L. Biljana, R. Stojkoska, K.V. Trivodaliev, A review of Internet of Things for smart home: challenges and solutions. J. Clean. Prod. **140**(Part 3), 1454–1464 (2017)
2. J.J. Greichen, Value based home automation or today's market. IEEE Trans. Consum. Electron. **38**(3), 34–38 (1992)
3. A.J. Bernheim Brush, B. Lee, R. Mahajan, S. Agarwal, S. Saroiu, C. Dixon, Home automation in the Wild: Challenges and Opportunities, in CHI'11 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (2011), pp. 2115–2124
4. M. Wigginton, J. Harris, *Intelligent Skins* (Routledge, London, 2002). https://doi.org/10.4324/9780080495446
5. A. Ghaffarianhoseini, U. Berardi, H. Alwaer, S. Chang, E. Halawa, A. Ghaffarianhoseini, D. Clements-Croome, What is an intelligent building? Analysis of recent interpretations from an international perspective. Archit. Sci. Rev. **59**, 338–357 (2015). https://doi.org/10.1080/00038628.2015.1079164
6. C. Wilson, T. Hargreaves, R. Hauxwell-Baldwin, Smart homes and their users: a systematic analysis and key challenges. Personal Ubiquitous Comput. **19**(2), 463–476 (2015). https://doi.org/10.1007/s00779-014-0813-0
7. H. Obara, Schneider Electric – "Standardization in EE in buildings, in Sustainable Places 2015 Conference, Savona, Italy, 16–18 September 2015
8. D.S. Leitner, N.C. Sotsek, A. de Paula Lacerda Santos, Postoccupancy evaluation in buildings: systematic literature review. J. Perform. Constr. Facil. **34**(1) (2020)
9. G.M. Di Giuda, L. Pellegrini, M. Schievano, M. Locatelli, F. Paleari, BIM and post-occupancy evaluations for building management system: weaknesses and opportunities, in *Digital Transformation of the Design, Construction and Management Processes of the Built Environment*, ed. by B. Daniotti, M. Gianinetto, T. S. Della, (Research for Development. Springer, Cham, 2020)
10. W. Jiang, X. Zhao, Trust and the intent to cooperate in energy performance contracting for public buildings in China. Eng. Constr. Archit. Manag. **28**, 372–396 (2019). https://doi.org/10.1108/ECAM-07-2019-0385e
11. A.G. Aoun, Blockchain application in energy performance contracting. Int. J. Strat. Energy Environ. Plann. **2**(2) (2020)
12. K. Ehrhardt-Martinez, K.A. Donnelly, J. Laitne, *Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities* (American Council for an Energy-Efficient Economy, Washington, DC, 2010)
13. T. Märzinger, D. Österreicher, Supporting the smart readiness indicator—a methodology to integrate a quantitative assessment of the load shifting potential of smart buildings. Energies **12**, 1955 (2019)

14. N. Wang, Transactive control for connected homes and neighbourhoods. Nat. Energy **3**, 907–909 (2018). https://doi.org/10.1038/s41560-018-0257-2
15. H.-S. Jin, B.-H. Choi, J.-K. Kang, S.-I. Kim, J.-H. Lim, S.-Y. Song, Measurement and Normalization Methods to Provide Detailed Information on Energy Consumption by Usage in Apartment Buildings. Energy Procedia **96**, 881–894 (2016). https://doi.org/10.1016/j.egypro.2016.09.161
16. J. Salom, A.J. Marszal, J. Widén, J. Candanedo, K.B. Lindberg, Analysis of load match and grid interaction indicators in net zero energy buildings with simulated and monitored data. Appl. Energy **136**, 119–131 (2014). https://doi.org/10.1016/j.apenergy.2014.09.018
17. IEA, *Building Energy Performance Metrics* (IEA, Paris, 2015)., https://www.buildingrating.org/sites/default/files/1448011796IEA_IPEEC_BEET4_Final_Report.pdf
18. D. Van Orshoven, D. van Dijk, EPB standard EN ISO 52003: How to put the EPB assessment outputs to intelligent use, REHVA J. (2016)
19. S. Verbeke, Y. Ma, P. Van Tichelen, S. Bogaert, V. Gómez Oñate, P. Waide, K. Bettgenhäuser, J. Ashok, A. Hermelink, M. Offermann, et al., *Support for Setting Up a Smart Readiness Indicator for Buildings and Related Impact Assessment, Final Report; Study Accomplished under the Authority of the European Commission DG Energy 2017/SEB/R/1610684* (VITO NV, Mol, Belgium, 2018)., https://smartreadinessindicator.eu
20. J. Hogeling, The set of EN and EN ISO EPB standards: supporting the implementation of the EPB Directive in Europe, in EBC-Annex 71 Symposium The Building as Cornerstone of our Future Energy Infrastructure, Bilbao, Spain, 10–11 April 2019. https://dynastee.info/wp-content/uploads/2019/06/6_Hogeling-Presentatie2019-04-Bilbao-EBC-Annex71.pdf
21. H.A. Gabbar, *Building Energy Management Systems (BEMS), Part1, Chapter2 in Energy Conservation in Residential, Commercial, and Industrial Facilities* (Wiley, 2018). https://doi.org/10.1002/9781119422099.ch2
22. Research and Markets, Global Building Management System Market 2016–2023 (2017). https://www.prnewswire.com/news-releases/global-building-management-system-market-2016-2023-300492250.html
23. M. Manic, D. Wijayasekara, K. Amarasinghe, J.J. Rodriguez-Andina, Building energy management systems: the age of intelligent and adaptive buildings. IEEE Ind. Electron. Mag. **10**, 25–39 (2016). https://doi.org/10.1109/MIE.2015.2513749
24. Elizabeth Gasiorowski-Denis, ISO 52000 leads the way on clean energy building solutions, ISO News, 28 June 2017. https://www.iso.org/news/ref2196.html
25. GIMELEC, Mener à bien un projet d’efficacité énergétique Bâtiments et collectivités, Guide De Bonnes Pratiques, Efficacité Energétique. https://www.ac-paris.fr/portail/jcms/p1_529163/guide-ee-batiment-avril2008
26. N. Artiges, A. Nassiopoulos, F. Vial, B. Delinchant, Calibrating models for MPC of energy systems in buildings using an adjoint-based sensitivity method, Energy and Buildings, 109647 (2020). ISSN 0378-7788. https://doi.org/10.1016/j.enbuild.2019.109647
27. K. Verbert, R. Babuška, B. De Schutter, Combining knowledge and historical data for system-level fault diagnosis of HVAC systems, Engineering Applications of Artificial Intelligence **59**, 260–273 (2017). ISSN 0952-1976. https://doi.org/10.1016/j.engappai.2016.12.021
28. Calvert Controls, Internet of Things – “IoT” – the next evolution in smart building management (2020). http://calvertcontrols.com/index.php/2019/05/21/internet-of-things-iot-the-next-evolution-in-smart-building-management/
29. A. Totonchi, *Internet of Things for Smart Home: State-of-the-Art Literature Review* (2018)
30. O. Nývlt, Buses, Protocols and Systems for Home and Building Automation, Department of Control Engineering Faculty of Electrical Engineering Czech Technical University in Prague. 2009–2011. http://www.tecnolab.ws/pdf/Buses,%20Protocols%20and%20Systems%20for%20Home%20and%20Building%20Automation.pdf
31. Siemens Building Technologies. Communication in building automation, Answers for infrastructure and cities. https://www.downloads.siemens.com/download-center/Download.aspx?pos=download&fct=getasset&id1=A6V10209534

32. D. Bonino, F. Corno, D. Russis, Luigi, A semantics-rich information technology architecture for smart buildings. Buildings **4**, 880–910 (2014). https://doi.org/10.3390/buildings4040880
33. Gartner, Inc., Market Insight: The Move From the Connected Home to the Intelligent Home, Technical Report G00355564, Jul. 2018. [Online]. https://www.gartner.com/doc/3876868/market-insight-connected-home-intelligent
34. O. Hamdan, H. Shanableh, I. Zaki, A.R. Al-Ali and T. Shanableh, IoT-based interactive dual mode smart home automation, in 2019 IEEE International Conference on Consumer Electronics (ICCE), Las Vegas, NV, USA, 2019, pp. 1–2, https://doi.org/10.1109/ICCE.2019.8661935
35. Smart Homes Market Report: Trends, Forecast and Competitive Analysis, Research and Markets, Global Report n°4846240, September 2019. https://www.researchandmarkets.com/reports/4846240/smart-homes-market-report-trends-forecast-and
36. Z. Yang, J.H. Cho, Application and development trend of smart home in residential interior design Journal of Physics: Conference Series, Volume 1487, in 2020 4th International Conference on Control Engineering and Artificial Intelligence (CCEAI 2020) 17–19 January 2020, Singapore (2020)
37. B. Qolomany et al., Leveraging machine learning and big data for smart buildings: a comprehensive survey. IEEE Access **7**, 90316–90356 (2019)
38. G. Lobaccaro, S. Carlucci, E. Lfstrm, G. Lobaccaro, S. Carlucci, and E. Lfstrm, "A review of systems and technologies for smart homes and smart grids," Energies, vol. 9, no. 5, p. 348, 2016. https://www.mdpi.com/1996-1073/9/5/348
39. ITU-T SSCIoT 2, *Unleashing the Potential of the Internet of Things* (Implementing ITU-T International Standards to Shape Smart Sustainable Cities, International Telecommunication Union (ITU), 2016). https://www.itu.int/pub/T-TUT-SSCIOT-2016-2/fr
40. Vision and Challenges for Realizing the Internet of Things, CERP-IoT (Cluster of European Research Projects on the Internet of things), Publication Office of The European Union, March 2010. http://bookshop.europa.eu/en/vision-and-challenges-for-realising-the-internet-of-things-pbKK3110323/
41. C. Perera et al., Context aware computing for the internet of things: a survey. IEEE Commun. Surveys Tutorials **16**(1), 414–454 (2014)
42. V.M. Tayur, R. Suchithra, Review of interoperability approaches in application layer of internet of things, in International Conference on Innovative Mechanisms for Industry Applications (ICIMIA 2017)
43. M. Uslar, S. Rohjans, M. Specht, Technical requirements for DER integration architectures. Energy Procedia **20**, 281–290 (2012). https://doi.org/10.1016/j.egypro.2012.03.028
44. A. Sajid, H. Abbas, K. Saleem, Cloud-assisted IoT-based SCADA systems security: a review of the state of the art and future challenges. IEEE Access **4**, 1375–1384 (2016). https://doi.org/10.1109/ACCESS.2016.2549047
45. O. Alrawi, C. Lever, M. Antonakakis, F. Monrose, SoK: security evaluation of home-based IoT deployments, in 2019 IEEE Symposium on Security and Privacy (SP), San Francisco, CA, 2019, pp. 1362–1380. https://doi.org/10.1109/SP.2019.00013
46. E. Byres, M. Franz, D. Miller, The use of attack trees in assessing vulnerabilities in SCADA systems, in Proc. IEEE Int. Infrastruct. Survivability Workshop (IISW), Lisbon, Portugal, Dec. 2004
47. B. Fouladi, S. Ghanoun, Security evaluation of the Z-wave wireless protocol", Black Hat USA, vol. 1, pp. 1–6, Aug. 2013 "Black Hat 2013 – Honey, I'm Home!! – Hacking Z-Wave Home Automation Systems." Online video clip. YouTube. YouTube, 19 Nov 2013. Web 1 Nov. 2016. https://www.youtube.com/watch?v=KYaEQhvodc8
48. D. Caputo, L. Verderame, A. Ranieri, A. Merlo, L. Caviglione, Fine-hearing Google Home: why silence will not protect your privacy. J. Wireless Mobile Netw. Ubiquit. Comput. Depend. Appl. **11**, 35–53 (2020). https://doi.org/10.22667/JOWUA.2020.03.31.035
49. S. Wachter, Normative challenges of identification in the Internet of Things: Privacy, profiling, discrimination, and the GDPR. Comp. Law Secur. Rev. **34**(3), 436–449 (2018). https://doi.org/10.1016/j.clsr.2018.02.002
50. B.I. Gartner, Summit Summary: Internet of Things (IoT)—Buttigieg.org (2015)

51. G.M. Toschi, L.B. Campos, C.E. Cugnasca, Home automation networks: a survey. Comput Stand. Interf. **50**, 42–54 (2017). https://doi.org/10.1016/j.csi.2016.08.008
52. A. Shadi, C. Thomas, P. Stephane, D. Benoit, W. Frederic, M.P. Singh, Power management of laptops batteries in dynamic heterogeneous environments using iPOPO, IBPSA, 20–21 mai 2014, Arras (2014)
53. B. Delinchant, H.A. Dang, H.T.T Vu, D.Q. Nguyen, Massive arrival of low-cost and low-consuming sensors in buildings: towards new building energy services, in 2019 IOP Conf. Ser.: Earth Environ. Sci., Vol. 307, Conf. 1, 2019. https://doi.org/10.1088/1755-1315/307/1/012006
54. D. Kushner, The Making of Arduino, in IEEE Spectrum, Oct. 26th, 2011. https://spectrum.ieee.org/geek-life/hands-on/the-making-of-arduino
55. M. McQuaid, The Open Source Contributor Funnel: Turning Users Into Maintainers, in CodeConf 2016
56. P. Lago, F. Lang, C. Roncancio, C. Jiménez-Guarín, R. Mateescu, N. Bonnefond, The ContextAct@A4H Real-Life Dataset of Daily-Living Activities, in *Modeling and Using Context. CONTEXT 2017. Lecture Notes in Computer Science*, ed. by P. Brézillon, R. Turner, C. Penco, vol. 10257, (Springer, Cham, 2017)