Deliverable: D1.1
List of ranked hardware infrastructure options

Public Document

Deliverable Info

Deliverable Reference	D1.1
Deliverable Version	2.0
Title	List of ranked hardware infrastructure options
Due Date	31/12/2020
Delivery Date	18/12/2020
Nature of Document	Open Research Data Pilot
Document Status	Draft
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Dissemination Level	PU - Public

Version History

Version:	Date:	Status:	Author:	Reviewer:	Comments:
1.0	29/07/2021	Draft	Niall Byrne [IES R&D]		First draft
2.0	29/07/2021	Final	Matteo Verdoni [Schneider Electric]		Partially reviewed by quality control

Project General Information

Grant Agreement #.	101000169
Project acronym	Auto-DAN
Project title	Deploying Augmented Intelligence solutions in EU Buildings using Data Analytics, an interoperable hardware/software Architecture and a Novel self-energy assessment methodology
Starting date	01.10.2020
Duration in months	48
Call (part) identifier	H2020-LC-SC3-EE-2020-1
Topic	LC-SC3-EE-1-2018-2019-2020 Decarbonisation of the EU building stock: innovative approaches and affordable solutions changing the market for buildings renovation
Coordinator	IES R&D [IESR&D]
Partners	Technological University Dublin [TU Dublin] Rina Consulting SPA [RINA-C] ARCELIK A.S. [ARCELIK] Fundacion CARTIF [CARTIF] Msemicon Teoranta [MSEMICON] CIVIESCO SRL [CIVIESCO] FlairBit SRL [FLAIRBIT] O Cualann Cohousing Alliance Company Limited by Guarantee [OCUALANN] Universidad de Burgos [UBU] Schneider Electric SPA [SE] Delta Ecopolis – Società Cooperativa [DELTA ECOPC]
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Executive summary

The present public deliverable D1.1 – List of ranked hardware infrastructure options will list all hardware options that can collect real-time data from building products that the Auto-DAN partners and external smart technology providers will potentially provide.

The ranking is finalized to the Task 1.1 goal, i.e. the assessment of all market-ready smart technologies options available to consortium. This task will also identify weaknesses in the current state-of-the-art for smart building hardware both from the technological and non-technological point of view and ensure that the project steers away from any common pitfalls. There is a strong connection between the Task 1.1 goal and the overall objective of Auto-DAN project, which is to enable homes and small businesses across the EU to optimize their energy consumption and provide an assessment of the live energy performance of a building: the optimization delivered should start from smart appliances/systems available. This implies the analysis of the smart technologies available and of their market value: indeed, the offer listing will be integrated by an evaluation of the market values (regarded as answers to final users' needs). The values taken into account are cost-effectiveness, user-friendliness, non-invasiveness, product quality, lifetime, reliability of the vendor as well as the ability not to affect the existing warranties of building products. Only in the perspective of the value perceived by the users any smart application or solution has the chance to be utilized by the final users. The scope of the analysis will include, as much as possible, all building types and features, to ensure maximum replicability of the Auto-DAN solution across the EU building stock, which is one of the general requirements of the project. Technologies that will be assessed will include appliances, ICT equipment, building energy management solutions and smart building technologies. The assessment has been leaded by SE with support from other partners with a stake in the hardware components (MSEMICON, TU Dublin, FlairBit and ARCELIK).

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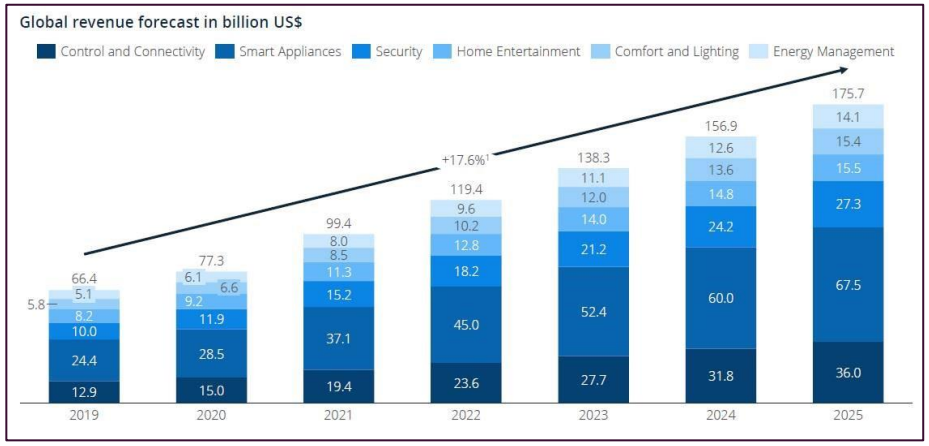
1.1 Smart buildings: state of the art

1.1.1 General assumptions

The recent trends of digitization and electrification, to move towards a more sustainable world, has helped the notion of 'smart homes' now become a reality. In addition, the urgent need to deliver more sustainable homes to fight climate change is felt as a priority by a large part of population in EU and other developed countries. This requires a shift of investments (public and private) to a residential smart solution approach and the need to leverage connectivity to bridge the applications at home at the global scale.

Table 1: Global revenues forecast for Smart Home market



- 25% would pay more for a home, condo, or rental if it came equipped with smart home technology,

It is estimated that by 2025, the overall Smart Home market will reach $175.7 M with a compound annual growth rate (CAGR) of +17.6%[1]. A vision of smart and sustainable homes of the future is growing and becoming a reality.

A 2021 survey of over 4,000 consumers conducted by Schneider Electric[2], revealed that equipping new buildings with smart home devices is definitely a widely desired move:

- 41% would expect a newly built home or apartment to be equipped with smart home products,
- 90% of them are willing to invest an average of € 2,500 in the coming years to make their homes more energy efficient.

Indeed, another important market trend is the growing involvement of consumers in the purchasing process along with ecommerce platform booming, which are taking market share from traditional "physical" point of selling.

The digitalization of the business is removing the barriers between smart home solution providers, sales channels and go-to-market: new player were born, with completely new offers based on affordability of the offer and 'plug & play' features, choosing a direct selling channel through e-commerce; many traditional market player (like Legrand, Siemens, Schneider Electric, ABB, General Electric) have seen the importance and criticality of having a strong and focused activation plan, with the awareness that connectivity will contribute to an increase in the average price of homes. For the majority of the giant players[2] the activation plan is based on:

[1] See https://www.statista.com/forecasts/887554/revenue-in-the-smart-home-market-in-the-world

[2] Internal source.

- strengthen the IoT values of their traditional portfolio,
- leveraging value chain presence, developing a focused technical support for electrical distribution partners, installers and home builders to support them during the transformation, safety
- pursuing new go-to-market strategies and sales channels, adapting to the new reality with the associated sales channels including eCommerce, do-it-yourself stores and others.

1.1.2 Smart building offer and market consistency

The global market for smart building solutions has experienced double-digit growth in the past decade. The same for Europe which is a mature market and shows a growth with an expected CAGR of 13.7 over the years 2021-2030.

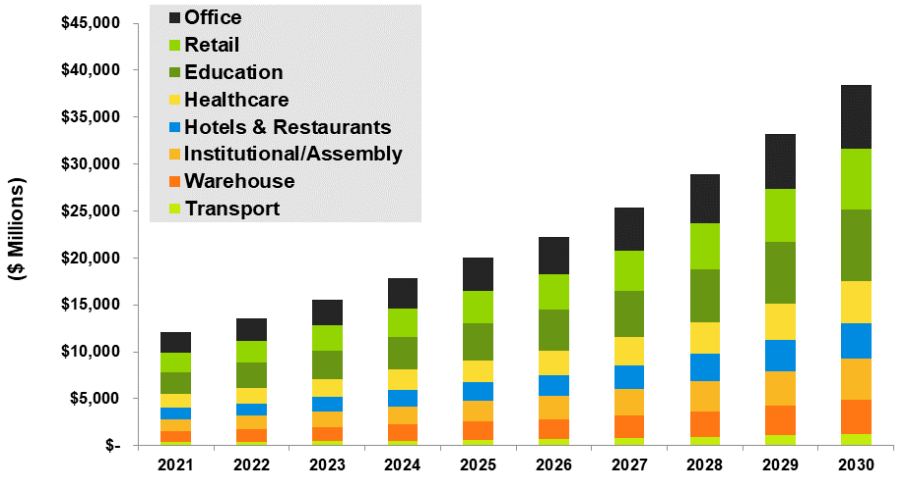


Figure 1: Smart Building Solutions Revenue by Building Type, Europe: 2021-2030. Source: Guidehouse Insight 2021

The reason for motivating the forecast are:

- smart building solutions have a strong financial business case, reducing OPEX (operational expenditure) and preserving capital equipment, so investors prefer smart building rather than non-smart ones;
- the presence of smart building solutions reduces the environmental impact of the building and supports safety initiatives that address coronavirus safety concerns such as monitoring indoor air quality, so investors see smart solutions in building as risk mitigators;
- operational efficiencies, determined by the integration between multiple technological systems inside the buildings granted by smart solutions, which offer tools for building management as well and help better manage capital assets;
- the global building market has shown its willingness to confront challenges by investing in technology rather than taking the conservative approach and delaying costs.

Smart building solutions assist in managing the trade-offs associated with the competing priorities of operational efficiency, tenant comfort, and health and safety.[3]

For the residential segment, which is set apart, according to a Markets and Markets 2021 research[4], the global smart home market size is expected to grow from USD 78.3 billion in 2020 to USD 135.3 billion by 2025, at a CAGR of 11.6%. The growth of the market is driven by many factors, such as an increasing number of internet users, increasing disposable income of people in developing economies, the rising importance of home monitoring in remote locations, and the growing need for energy-saving & low carbon emission-oriented solutions. Moreover, the rapid proliferation of smartphones & smart gadgets, expansion of smart home product portfolio by a large number of

[3] See Guidehouse Insights, 2021, "Market Data: Intelligent Buildings Combining Building Automation Systems with Remote Monitoring and Control Systems: Global Market Analysis and Forecasts"

[4] Markets and Markets 2021, "Smart Home Market with COVID-19 Impact Analysis by Product (Lighting Control, Security & Access Control, HVAC Control, Entertainment, Home Healthcare), Software & Services (Proactive, Behavioural), and Region - Global Forecast to 2025"

players, growing concern about safety, security, and convenience among the general population will fuel the demand for smart home solutions.

According to the research, major players in the market are:

1. Amazon, Inc. (US),
2. Apple Inc. (US),
3. Google (US),
4. ADT (US),
5. Robert Bosch Gmbh (Germany),
6. ASSA ABLOY (Sweden),
7. ABB Ltd. (Switzerland),
8. Ingersoll-Rand PLC (Ireland),
9. ABB (Switzerland),
10. Legrand S.A. (France),
11. GE (US),
12. Comcast Corp. (US),
13. Hubbell Inc. (US),
14. Samsung Electronics Co., Ltd. (South Korea) among others.

The smart home market is currently dominated by Johnson Controls International (Ireland), United Technologies Corporation (US), Schneider Electric (France), Honeywell International, Inc. (US), and Siemens AG (Germany).

The smart speakers market is likely to grow at a high rate during the 2020-2025 period. The growth of the smart speaker market is driven primarily by the increasing adoption of smart homes, high disposable income, the popular trend of personalization, and the rapid proliferation of multifunctional devices. Factors such as increasing focus of companies on enhancing customer experience and consumer preference for technologically advanced products over traditional products are expected to provide opportunities to smart speaker providers. Further, recent developments in artificial intelligence and natural language processing to enhance voice recognition capabilities have increased the overall demand for smart speakers in smart homes.

The proactive type software and services segment is expected to grow at a higher rate during the 2020-2025 period. Proactive type software and services facilitate the transmission of data, along with the best possible solutions, to end-users for actions to be taken after receiving the information. The proactive type enables the transfer of a larger volume of data than the behavioural type; it can provide inputs to end-users regarding effective energy usage and required actions on the physical parameters to reduce energy consumption.

Proactive solutions are more beneficial than the behavioural type as they can also send recommendation signals to end-users to take necessary actions to reduce energy consumption. Moreover, based on the user's actions, measures to control electronic devices can be implemented. Due to these advantages, the market for proactive type software and services is expected to grow at a higher rate during the forecast period.

1.1.3 Smart buildings require smart business models?

Recent research issued by Omdia research group[5] shows that the transactional revenue model, selling hardware and software with a margin through different channels, remains the main source of revenues for BMS platform providers and should remain unchanged throughout the foreseeable future.

Some BMS platform manufacturers (Schneider Electric, Johnson Controls and Siemens among the others) tend to go more directly to the market ("solution" providers) than others by doing the integration work on projects. The rest primarily use the Value-Added-Partner channel of system integrators (Honeywell). In recent years, the partner channel has been growing in the smart building industry thanks to the complexity of use cases, which require more and more expertise in both OT and IT. In addition, the master system

[5] Thomas Barquin, Omdia Smart Buildings Senior Analyst, 2019. See complete paper in: https://omdia.tech.informa.com/OM004609/Smart-building-business-model-insights

integrator role, integrating systems across multiple domains, has been emerging in the market.

The trend towards the "as-a-service" model should intensify in the near future, as BMS platform vendors attempt to introduce more software and remote service offerings to the market to ensure future revenue growth. For now, these services only represent a small share of the BMS platform providers' revenues, as vendors work to redefine their individual strategies from a go-to-market point of view. At this stage, mostly value-added services and subordinate domains in building management systems are offered through a subscription model, but not BMS platforms.

Another research done by Navigant Research drive to the same conclusions: "Vendors in the intelligent buildings market are developing business models to grow the market—and their market share—with new value-added services, end-to-end solution offerings, and strategic partnerships. Customers are also playing a role in this market evolution with increased expectations for products and services that add value across the organization, and vendors are responding with diverse solutions that go beyond energy-related benefits to include individualized occupant comfort solutions, enterprise-level business metrics, indoor wayfinding, integrated security solutions, and other services."[6]

Both researches demonstrate that the partnership business model will be a key factor of success: the creation of an ecosystem of value chain stakeholders, partnering strategies, is a key to expanding the offerings in the commercial intelligent buildings market, because no one vendor has all the capabilities to develop a complete end-to-end solution. Strategic partnerships will empower smaller vendors to enter these markets, leveraging their niche knowledge to amplify existing skill sets and round out a more complete solution.

1.1.4 Smart buildings and protocols: the importance of integration

Since the interaction of Internet Technologies and Operation Technologies has started to dominate the discussion about the model of smart building solutions, the value of communication protocols has risen even more. The IT-OT integrations indeed start from protocols: only if the systems can communicate either upward (towards the software layer or the in-cloud applications), downward (towards the field) and at the same level with other device on the same layer, we can talk about real "integration". And to make this possible, the main way is to use open protocols of communications: "In making the Intelligent Building, the most important thing becomes the communication between the different devices. It is very important to choose the right communication protocol for the communication between the devices."[7]

Inhibitors to intelligent building solutions are not only cybersecurity and cost barriers, but also differences in communication protocols which limit the integration between systems and layers of systems. Building Automation Protocols are the rules and standards because of which communication is possible between different devices used for building automation. But as is the case for any type of communication between entities, we need to establish some standards between them, or protocols. Until today, in most of the building automation systems, proprietary protocols are used. Within these protocols also, different protocols are employed on different products of the same company.[8] Most smart building solutions connect to a variety of building automation systems. The most convenient situation is where the smart building solution is familiar with a given interface from one of the automation systems. If the smart solution is a retrofit, it is likely that some automation

[6] Tom Machinchick, Emerging Business Models for Intelligent Buildings, Navigant Research 2018.
[7] See Lohia K., Jain Y., Patel C., Doshi N., "Open Communication Protocols for Building Automation Systems", in Procedia Computer Science 160, 2019.
[8] *Ibidem*.

systems involve older generations of technology and have different interfaces than current models. If an interface is obsolete and unfamiliar, it is necessary that the smart building solution manufacturer or a systems integrator develops and tests the new interface. This process is typically costly and time consuming.[9]

The biggest challenge in using proprietary protocols is to add a new third-party subsystem into the original system, as the protocols are not flexible enough to easily integrate a new subsystem. The role of open protocols is to simplify this task: an open communication protocol allows vendors' equipment to interoperate without the need for proprietary interfaces or gateways. As a result, the main advantage of using open protocols is ease of expanding.

Another way is the use of gateways: gateways are used to integrate two different protocols. A gateway helps in converting from one protocol to other protocol. The development of a gateway is not as straightforward as it sounds, as the developer should have knowledge about both the protocols. Also, because of gateways there is a lot of time wastage in conversion, hence it slows down the response. The biggest challenge in using proprietary protocols is to add a new third-party subsystem into our system, as the protocols are not flexible enough to easily integrate a new subsystem.[10]

This in turn gives rise to the role of Open Protocols. An open communication protocol allows vendors' equipment to interoperate without the need for proprietary interfaces or gateways. The main advantage of using open protocols is ease of expanding. The open protocols are not interchangeable but are interoperable, that is, if one device implementing one protocol fails we cannot simply change it with another device using different open protocol.[11]

1.1.5 Communication protocols listed in the present research

In the present research, we have listed more than 500 products (appliances and smart devices) available for completing the several goals of Auto-DAN project, dividing them in two main groups: Smart Home Systems and Building Management Systems. For each product we have reported the main communication protocols among many other specifics and features.

Corresponding to this grouping, the protocols listed are represented in the following graph (Figure 2). We can observe the different articulation of the % distribution of the main communication protocols between the two main group of products:

- Smart Home Systems: Wi-Fi IEEE 802 protocol plays the major part, with a score of almost 50%, followed by z-wave, ZigBee and Bluetooth, all with a score around 15%;
- Building Management Systems: Wi-Fi IEEE 802 protocol decreases to 27% and several wired protocols, not present in the Smart Home group, rise up to around 10% (KNX, LoraWan and ModBus).
- "Closed" (non-open) wired standards compare only in Building Management System group, while in wi-fi standards the "clonesess" of the protocols relies on the type of protocol of communication between the devices and gateway, all nominally on Wi-Fi "physical layer" but each having its own communication language of transmission. In fact, the integrability in Smart Home system happens mainly at the level of gateway, which normally has the capability of receiving signals from a variety of devices of different vendors.

From the point of view of the so-called "physical layer", the results over the product examined in the present research shows a majority of wireless protocols in both Smart Home Systems and Building Management Systems (see Figure 3).

[9] See Guidehouse Insights, "Market Data: Intelligent Buildings", 2021.
[10] Wang S., Xu Z., Li H., Hong J., & Shi W. (2004)., "Investigation on intelligent building standard communication protocols and application of IT technologies" in Automation in Construction, 13(5).
[11] Schneps-Schneppe M., Maximenko A., Namiot D., Malov D., "Wired Smart Home: Energy metering, security, and emergency issues", 2012, in IV International Congress on Ultra Modern Telecommunications and Control Systems.

This signifies that the advantages of the wireless connections traditionally dominated by BMS (commercial buildings, hotels, healthcare, retail) have started to be appreciated also in the market segments, due likely to the growing of the brown field projects. Among the more diffuser wired interfaces we have IP, KNX and the physical layers of several closed standards like SCS (a proprietary bus developed by b-Ticino, part of Legrand Group), By-Me (VIMAR), Cresnet (developed by Crestron).

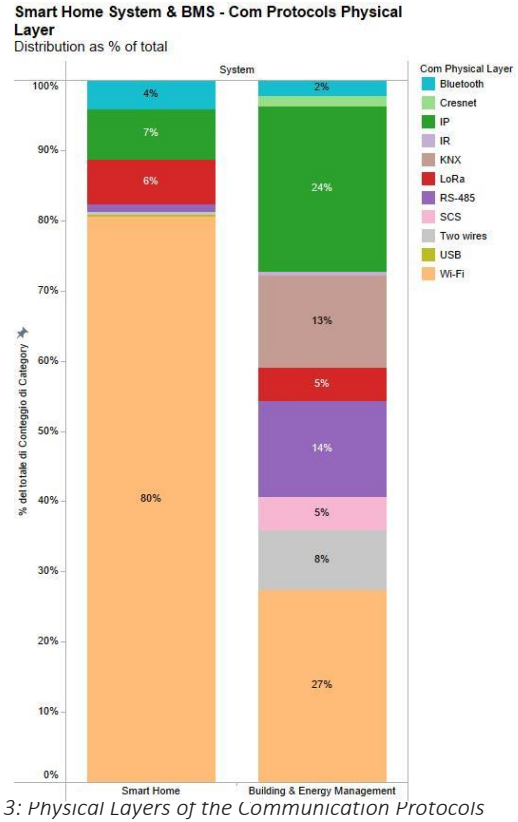


Figure 3: Physical Layers of the Communication Protocols listed in the present research

Smart Home System & BMS - Com Protocols conting and distribution

	System					
	Building & Energy Management		Smart Home		Grand Total	
Com protocol	% of Tot..	Count of ..	% of Tot..	Count of ..	% of Tot..	Count of ..
Grand Total	100,0%	272	100,0%	358	100,0%	630
Wi-Fi IEEE	22,4%	61	45,0%	161	35,2%	222
ZigBee Pro	5,5%	15	13,1%	47	9,8%	62
z-wave	1,8%	5	15,1%	54	9,4%	59
Bluetooth	4,0%	11	11,5%	41	8,3%	52
Lora Wan	7,4%	20	5,3%	19	6,2%	39
KNX	12,9%	35	0,3%	1	5,7%	36
Modbus RTU	7,7%	21	0,3%	1	3,5%	22
Modbus TCP/IP	7,0%	19			3,0%	19
By-Me	6,3%	17			2,7%	17
RTS			4,5%	16	2,5%	16
M-Bus	3,7%	10			1,6%	10
SCS	3,7%	10			1,6%	10
BACnet - MS/TP	3,3%	9			1,4%	9
NFC			2,2%	8	1,3%	8
io-homecontrol			2,0%	7	1,1%	7
BACnet - IP	1,8%	5			0,8%	5
Cresnet	1,5%	4			0,6%	4
EnOcean	1,5%	4			0,6%	4
Impulses	1,5%	4			0,6%	4
Can-Open	1,1%	3			0,5%	3
IR	0,4%	1	0,6%	2	0,5%	3
LonWorks	1,1%	3			0,5%	3
3G/4G	0,7%	2			0,3%	2
Dali	0,7%	2			0,3%	2
EQ-Bus	0,7%	2			0,3%	2
Profibus	0,7%	2			0,3%	2
IGMP	0,4%	1			0,2%	1
infiNET EX	0,4%	1			0,2%	1
LonTalk - TP/FTT-10	0,4%	1			0,2%	1
NB-IoT	0,4%	1			0,2%	1
Optical port	0,4%	1			0,2%	1
Other proprietary			0,3%	1	0,2%	1
Profinet	0,4%	1			0,2%	1
SNMP	0,4%	1			0,2%	1

Figure 2: Communication Protocols counting of the products listed in the present research

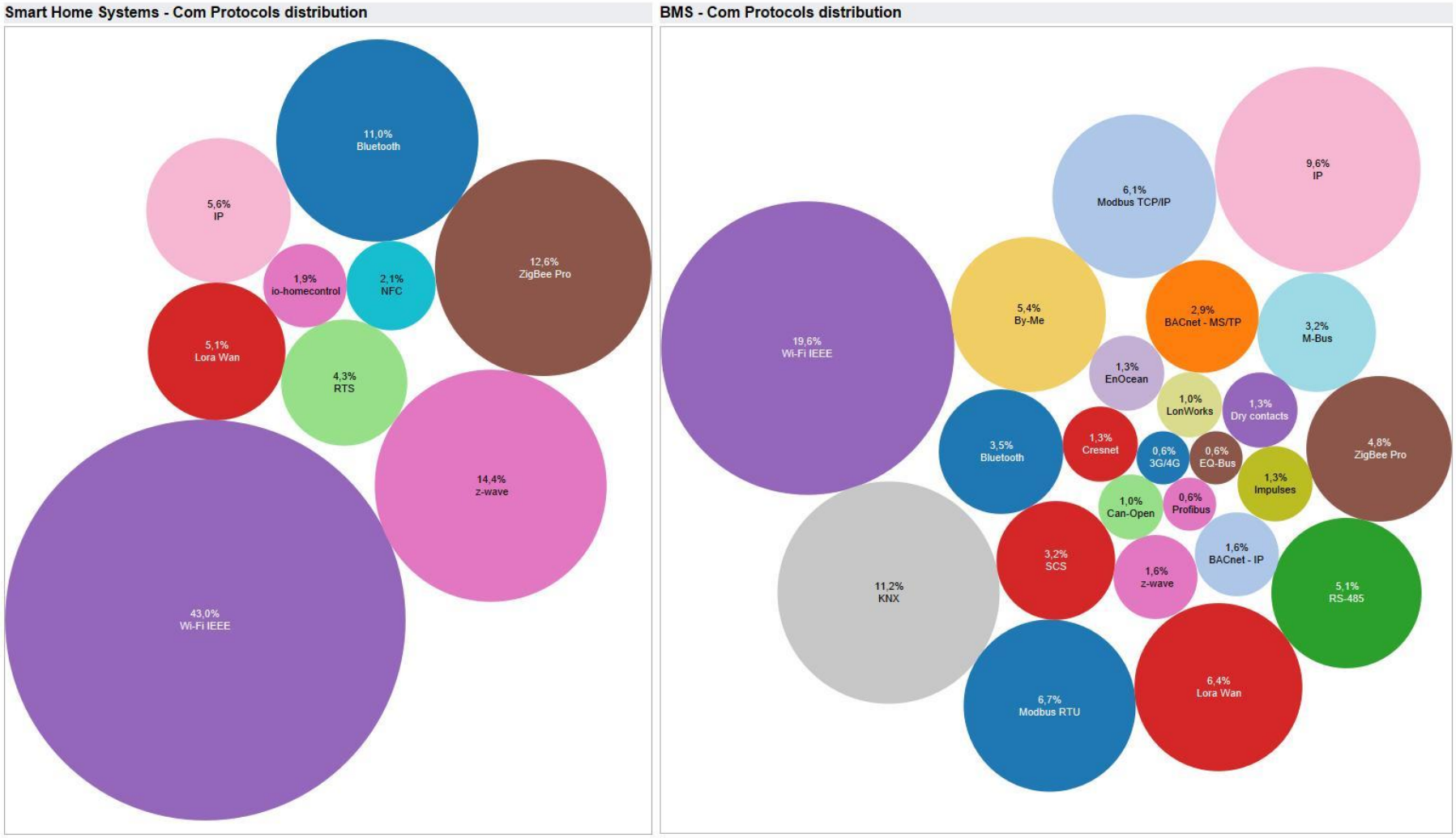


Figure 4: Products listed in the present research: Communication Protocols distribution in % (NB: the% < 0.5% have been taken off)

1.2 Smart building: what makes "smart" the offer

Stating that many technologies are required to make a smart device "smart", the question about the intrinsic characteristics of "smart readiness" arose. In the following section, a simple list of topics to be considered in order to get a first guidance regarding smart readiness is presented as follows:[12]

- Security: one key change that has happened over the more recent past is the need for product and device security. As the growth of IoT and Smart Device proliferation continues, so does the opportunity for those with malicious intent to focus their efforts on this industry. Security is only as strong as its weakest link. Server farms have invested millions of dollars on back-end security and standards-based protocols to encrypt all wireless communication.
- Protocols: define how devices can work with and alongside other devices. Selecting standards-based protocols typically enables longer term interoperability with other vendors. This is because they are developed through an alliance of companies dedicating thousands of man-years into their specification. Proprietary-based approaches tend to offer greater optimization for given design concerns, but they don't offer multi-vendor, multi-product interoperability.
- Computing and storage: the protocols and services required, as well as what data will be stored or analysed locally, will drive the selection of microcontrollers and memory requirements for smart devices.
- Certification: failure to observe requirements as laid out in a standard may invalidate a product's certification with the appropriate protocol alliance organization. This in turn can prevent a vendor from advertising compatibility (and interoperability) with other products.
- Connectivity: can be achieved through wired or wireless options. The choice may be made depending on product location and what other devices are communicating with the actual product. Depending on the application, some options may be more suitable than others.
- Capability: regarding the kind of data the device can work with (i.e. control temperature, vibration, humidity…). This question also requires an understanding of the device's computational and storage requirements, power consumption expectations and connectivity bandwidth.
- Interoperability: devices may need to communicate with each other and therefore need to be interoperable. Typically, an ecosystem will define how these products will interact through device profiles. Device profiles are typically defined by the technology, such as Z-Wave or Zigbee.
- Services: devices on a common network may not need to communicate with each other, but when they do, they will use common services to share data, commands, and actions (e.g., a device may permit a web server to allow smartphones to access them via web browser).
- Energy usage: while considering protocols, services and computing power, developers need to consider energy consumption. For example, some protocols can be extremely "chatty" while others tend to be much more "sleepy". Most protocols have implemented various mechanisms to reduce power consumption. However, inherent network rules may limit how successful a given protocol may be when compared to other protocols.

[12] See Silabs Smart Home solutions, in: https://www.silabs.com/solutions/smart-home.

1.3 Smart building: offer reliability and continuity

After more than a decade of market evolution, the affordability of devices and systems, one of the most valuable features of the smart home offer and the main reason of its marketability, seems to crash with basic values like reliability and continuity. News of discontinuity of offer and lacking customer support strike the users who has paid a lot of attention and practice to became used to a specific system.

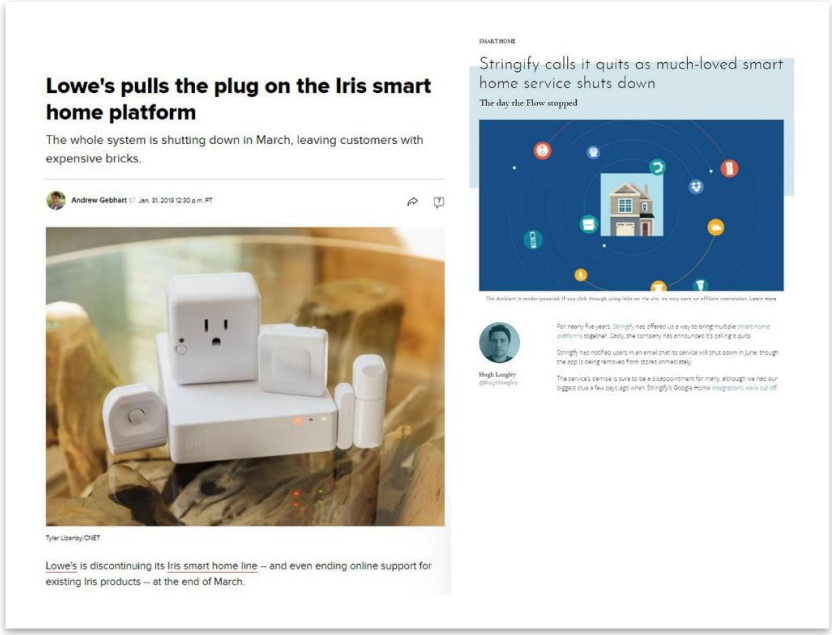


Figure 5: example of discontinuation of smart home ranges

The issue seems to be broader than simply technological. Researches put it in a cultural perspective rather than economical, where important mitigation factors seem to be regulations and policies: "In the global market, a relevant problem appears the innovation fever against any continuity exigency. The companies bet on product innovation more than on the continuity of its preservation, in fact they promptly cannibalize the products with saturated penetration. IoT contributes to the globalization as a planetary complex of different levels of connected services, where the reference system must remain the human society. IoT creates the possibility of an evolution of human society towards collective dynamic microsystems able to face traditional dominant macrosystems. Innovations and efficient sustainability need adequate global regulatory changes."[13]

1.4 Smart Offer Ranking: general assumptions and criteria for the present analysis

The scope of the present ranking in to identify and list all hardware solutions potentially available to Auto-DAN project: appliances, ICT equipment, building energy management solutions and smart building technologies that have features of connectivity (IoT readiness) and can provide real-time data to superior layers of the system. Accordingly, the present research has no focus on software or on smartphone applications.

In order to proceed to the ranking, the Auto-DAN partners, as a first step, provided a qualitative analysis of the customer need per each market where the project had a pilot site: Residential, Commercial or Retail and some Tertiary or Office. As output, we have considered the needs of each ideal customer per market. Several of these needs have been taken as main criteria for evaluating and ranking the offer available (ICT equipment, appliances, energy

[13] G. Parise, D. Mohla, L. Parise and M. Lombardi, "Forensic Implications in the Continuous Discontinuity of IoT Innovations," 2020 IEEE Industry Applications Society Annual Meeting, Detroit, MI, USA, 2020, pp. 1-6, doi: 10.1109/IAS44978.2020.9334906.

management systems, etc.), which is the scope of the present research. For an analytical view of the market needs identified, see Chapter 5.2 "Building Management Systems: market overview, maturity of the offer and new business models" and Chapter 6.2, "Smart Home Systems: market analysis".

1.4.1 Methodology of analysis for releasing a ranking of the smart offer

Regarding ICT equipment and building management solutions, we reported firstly some basic features of the products/ranges listed (functions, communication protocols, power, preferred sector of application). Secondly, we identified 13 categories in order to evaluate all the main features of the hardware. The evaluation is made generally on a qualitative scale because a quantitative approach isn't possible on each category. For each qualitative evaluation we have set up a quantitative scoring, in order to make possible quantitative analysis (sums, averages, ranking).

The 13 categories have been grouped in two main axes, in order to polarize the evaluation over the basic features of hardware: easiness of installation and user-friendliness. The former analyses mainly the capacity of the hardware to be installed by technicians, a characteristic of the hardware present on the market since a long time and developed mainly by major multinational companies for a multi-segment market (commercial buildings, retail, hotel, healthcare, luxury residential). The latter is a characteristic typical of the newest ICT devices which address the smart home market.

We integrated this methodology with the findings which came out from a recent market research made by Schneider Electric[14] over the ideal smart home target. The research relies on a survey fielded among 4,000 homeowners from USA, France, Germany, and Sweden (1,000 from each country). The key findings show that ease of use, the possibility to gain energy savings and, indirectly, price, are their top motivators for purchasing. Regarding price, the research shows that just under half of consumers think that smart home tech is just too expensive: so we can argue that price is a sensitive point.

Regarding current smart appliances offerings, the analysis has been made, primarily over the energy saving capacity, because the smart features (interoperability, possibility to be integrated in a higher layer system and user-friendliness) are the basic value, present throughout all major brands, so they aren't a real differentiation factor. For a deeper focus, see Chapter 2, Smart appliances.

1.4.2 ICT equipment and building management systems: categories of analysis

Easiness of Installation axis

1. Needs a gateway: Yes, No, Direct to cloud, N/D (used for gateways themselves)
2. Needs configuration: Yes, Plug & play, No
3. "Do it by yourself (DIY)" features: High (installable by non-trained people), Medium (installable by trained people), Low (only by specialists)
4. Technical support availability: Tollfree line and online supports, Tollfree (or dedicated) line, Online chat and blog/user group, Only online chat, Blog, FAQ and user group, FAQ or Blog or user group
5. Has a Partner program? (i.e. a program dedicated to train and support technical partners and installers): Yes, No
6. Effects the existing warranties of building products: Yes, No

User-Friendliness axis

7. User-friendliness: High (understandable and usable from any user), Medium (understandable and usable from any user after having attended a simple

[14] Schneider Electric 2020, "Smart Home Thought Leadership - Quantitative Findings Report" (internal report).

tutorial), Low (understandable and usable from a practiced user), Very low (understandable and usable only from a highly skilled user)
8. Cost effectiveness: High, Medium, Low
9. Product quality: High, Medium, Low
10. State of Technology: Mature, Diffused, In growth, New offer
11. Invasiveness: Invasive technology (the ambient of installation need to be hardly adapted), Somewhat invasive (the ambient of installation need to be smoothly adapted), Non-invasive technology (no need to adapt the ambient of installation)
12. Lifetime: Low duration (less than 1 y), Low to Medium duration (1 to 5 yy), Medium to Long duration (5 to 10 yy), Long (more than 10 yy)
13. Interoperability - Runs 3rd party SW/HW: in cloud only, on the hub in the building, in cloud and/or on the hub in the building, No.

For a complete view of the scores associated to each criterion, see Table 2 and Table 3.

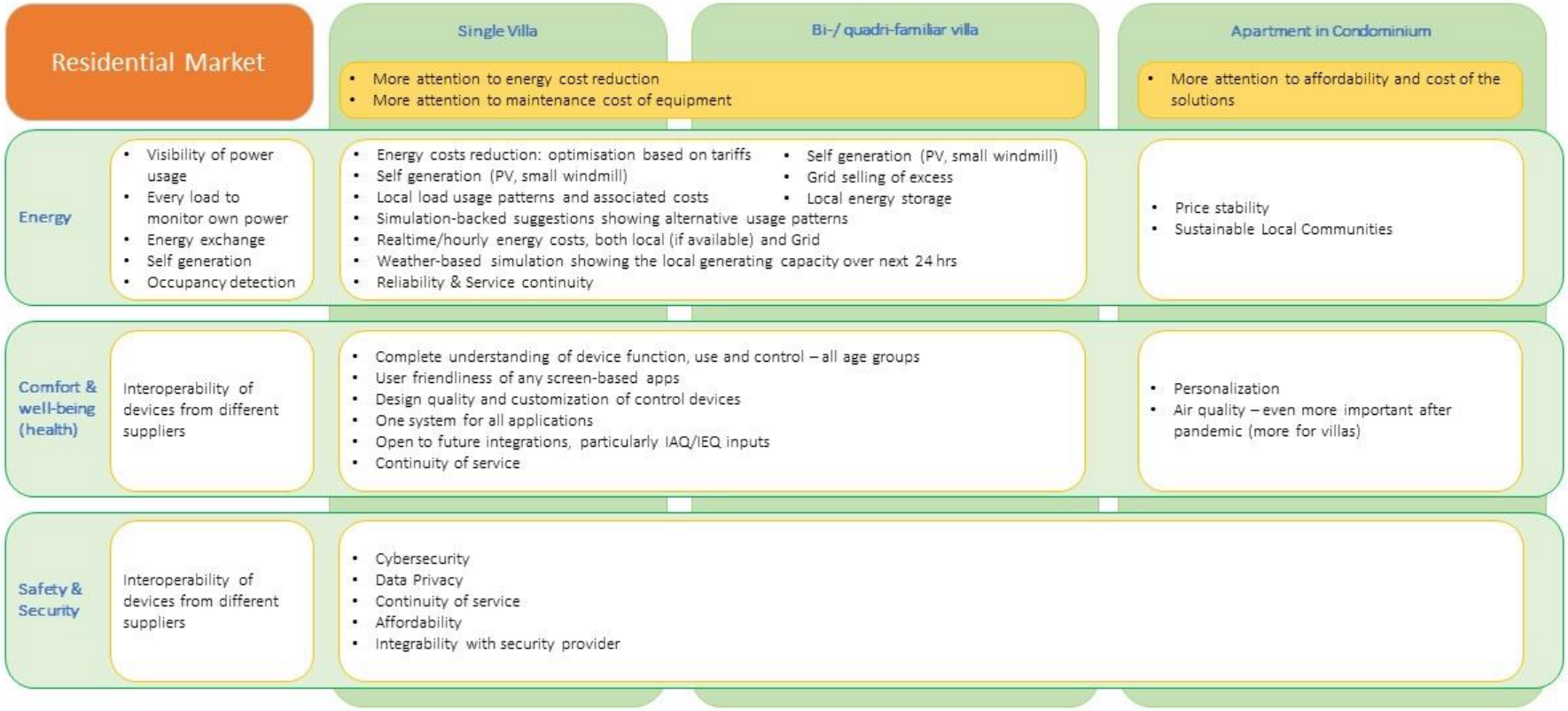


Figure 6: market analysis of customer need in Residential Market

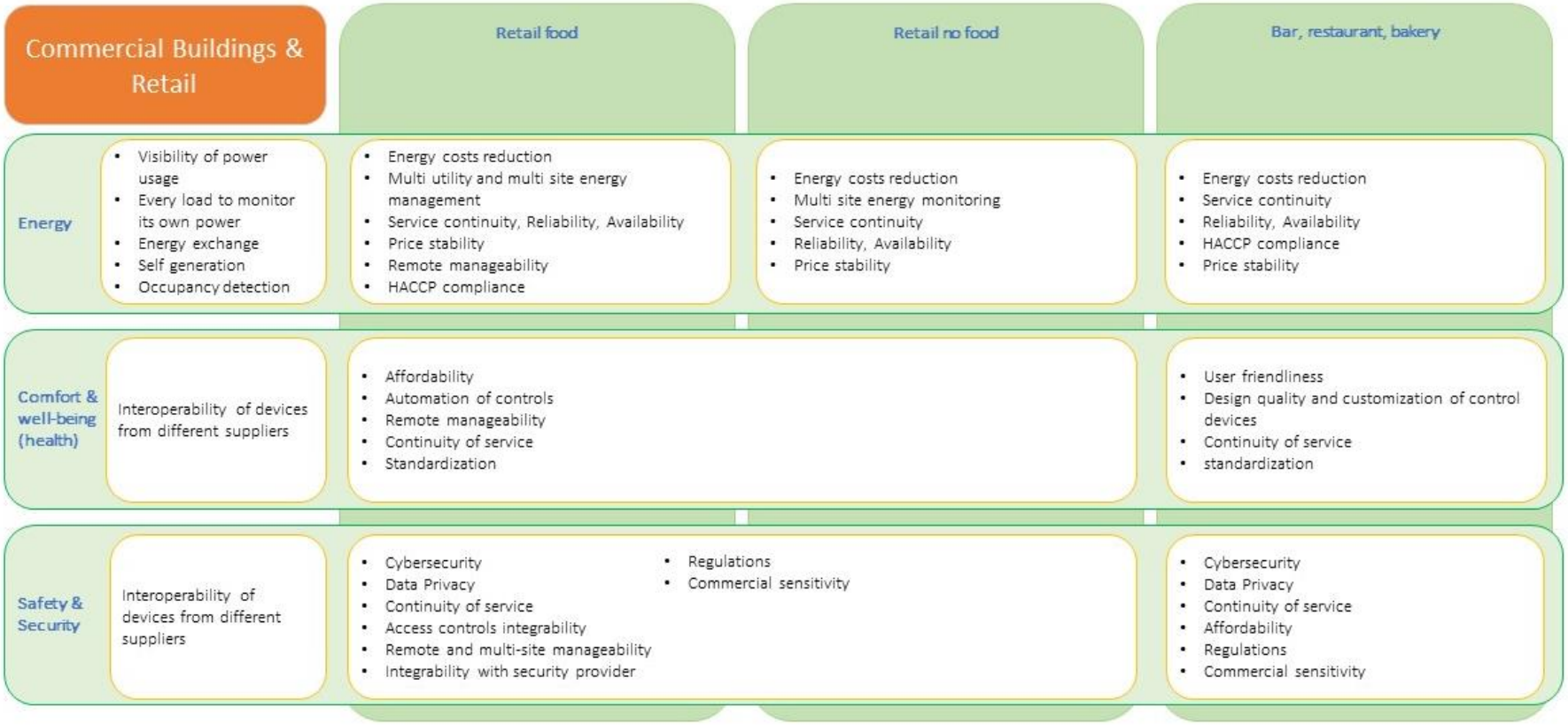


Figure 7: market analysis of customer need in Commercial & Retail Market

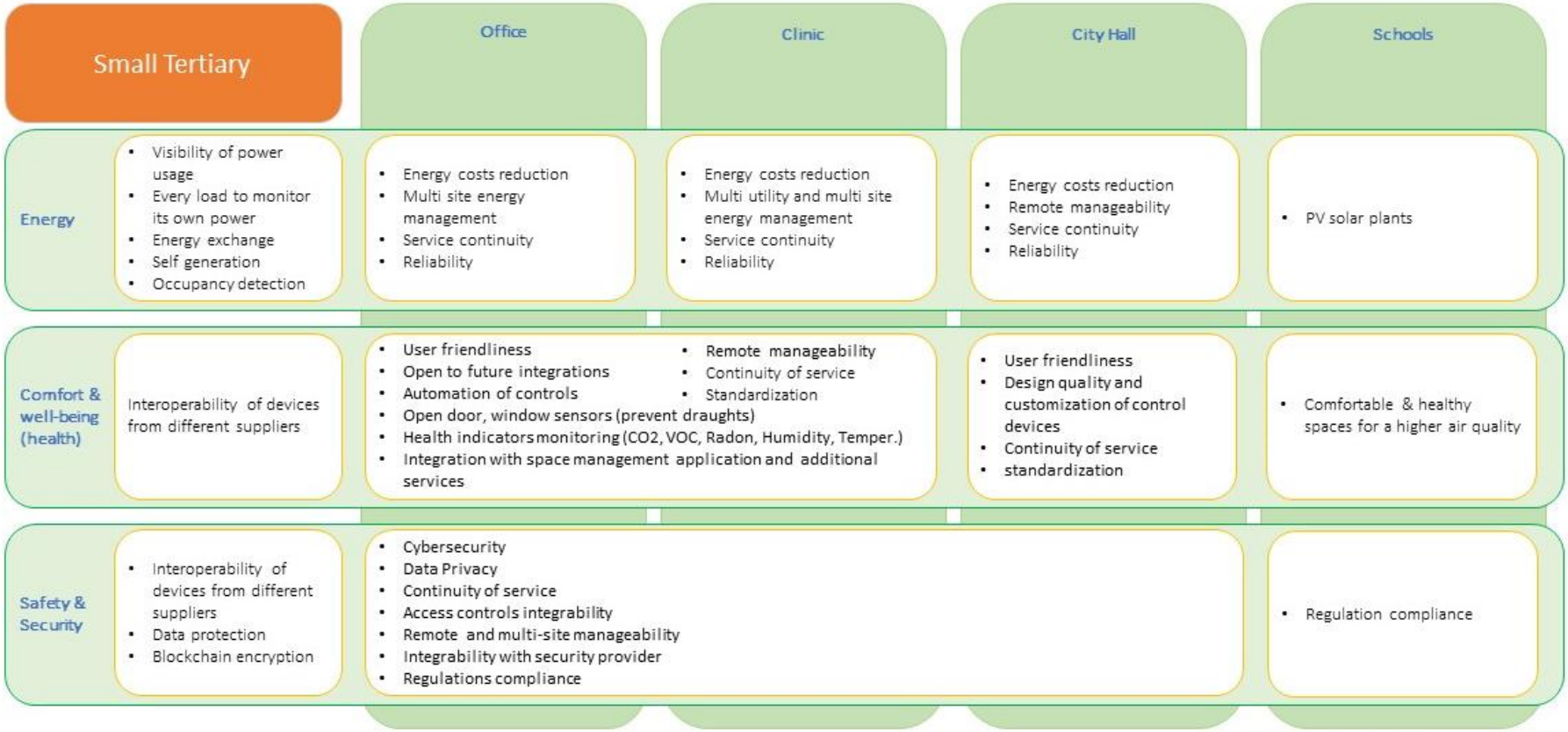


Figure 8: market analysis of customer need in Small Tertiary Market

Table 2: Easiness of Installation axis - Categories and scoring

Items	Value	Score	Value	Score	Value	Score	Value	Score	Value	Score	Value	Score
Needs a gateway	Direct to cloud	3	No	2	Yes	1	N/D	1				
Needs configuration	No	3	Plug & play	2	Yes	1						
DIY features	High (installable by non-trained people)	5	Medium (installable by trained people)	3	Low (only by specialists)	1						
Technical support availability	Tollfree line and online supports	6	Tollfree (or dedicated) line	5	Online chat and blog/ user group	4	Only online chat	3	Blog, FAQ and user group	2	FAQ or Blog or user group	1
Has a Partner program	Yes	5	No	0								
Effects the existing warranties of building products	No	2	Yes	0								

The criteria of "easiness of installation" gives a higher value to those features of the offer which makes the products easier to install: the possibility to connect the devices directly to the cloud, the possibility to install without a configuration, the low complexity of installation (DIY), the absence of impact on the warranties of devices already installed in the building. DIY features receive 2-units increases because it's particularly important for Smart Home offers, which have been developed mainly for auto-installation by the user. On the other hand, the availability of the technical support is particularly important for the installation phase, so the more there's a support, the more the product/range has a higher rate. Examples of technical support: the presence of a tollfree line and of an online support like video-tutorials, FAQ, technical documentation, a partner portal. Similarly, the presence of a partnership program increases the valuation, with a high weight (5) due to the high commitment taken by a company to set up a partnership program.

Table 3: User-friendliness axis - Categories and scoring

Items	Value	Score	Value	Score	Value	Score	Value	Score
User-friendliness	High (understandable and usable from any user)	7	Medium (understandable and usable from any user after having attended a simple tutorial)	5	Low (understandable and usable from a practiced user)	3	Very low (understandable and usable only from a highly skilled user)	1
Cost effectiveness	High	7	Medium	5	Low	1		
Product quality	High	5	Medium	3	Low	1		
State of Technology	Mature	4	Diffused	3	In growth	2	New offer	1
Invasiveness	Non-invasive technology (no need to adapt the ambient of installation	3	Somewhat invasive (the ambient of installation need to be smoothly adapted),	2	Invasive technology (the ambient of installation need to be hardly adapted)	1		
Lifetime	Long (more than 10 yy)	4	Medium to Long duration (5 to 10 yy)	3	Low to Medium duration (1 to 5 yy	2	Low duration (less than 1y)	1
Interoperability - Runs 3rd party SW/HW	in cloud and/or on the hub in the building	3	on the hub in the building	2	In cloud only	1	No	0

The criteria of "user-friendliness" gives a higher value to those features of the offer that makes the products easier to use for the final user: dwellers, homeowners, tenants. Like several market research reports[15], these criteria contain the most important categories as perceived by final users: user-friendliness, cost-effectiveness among all, quality (perceived both as design of the product and overall functionality). So, the scores applied enhance these three criteria as the most important.

[15] Guidehouse Insights, 2020, "Market Data: Smart Home IoT": "Consumers find value in products that can deliver convenience, energy efficiency, and greater security", "Smart products that offer convenience are in demand".

2. Smart appliances

2.1 Smart appliances listing

Smart appliances are major components when it comes to identifying the market-ready smart technology options available to the consortium. In the logical sense, all the other technologies that are to be utilized to reach the core target of the project are going to be built on smart appliances. Hence, it is vital to make a comprehensive listing of available smart appliances before and during the development of the project. The importance of this aspect can be intensified on system level energy regulations. The energy utilization of Smart Appliances can be reduced if they are managed and controlled on a system level [16]. Furthermore, to control the appliances, they need to have a connectivity interface (wireless or wired). Within the scope of this project, 'Smart Appliances' mean also 'Connected Appliances'. It goes without saying that for a gadget to be considered as smart, it needs to be connected as well, but to prevent any confusion on the matter, all the smart appliances that are mentioned in this project are assumed to be connected.

Assessment of most market-ready smart technologies options, including smart appliances, available to the consortium is made during Task 1.1.3 - Survey Studies. The study covers most of the major home appliances, such as refrigerator, oven, microwave oven, vacuum cleaner, dryer, dishwasher and washing machine etc. with their available connectivity interfaces.

The interfaces that are available are important from developers' standpoint because of two reasons. Firstly, the interface determines the available commands and interactions to the associated smart appliance. Secondly, it puts a limit to the flexibility of the system level operations. Because, usually, an interface means a new hardware node, hence a new tool to develop and integrate to system to. The more hardware and more interface introduced to the system, the more it gets harder to sustain interoperability and reliability as well as the overall the administration of the system. Given that interoperability and reliability are two of the main key issues in front of dissemination of smart appliances[17], it can be inferred that both simplification and standardization of hardware and their interfaces' will provide important contributions to both development and dissemination activities of the project.

The available smart appliances from within the project partners and the demo sites seem limited at the moment but it is sufficient to give an insight on opportunities to build an interoperability relations hierarchy. For instance, it is clearly seen that three communication protocols are most commonly utilized: Wi-Fi, z-Wave and Lora-Wan. It doesn't necessarily determine the roadmap of interoperability architecture, but it is an indication.

The study that took place in task 1.1.3 presented a limited listing. There are many other commercially available smart appliances. The major house appliances manufacturers are leaning toward marketing their own smart appliances hub as much as their smart appliances. For example, Arçelik promotes its smart appliances platform, HomeWhiz[18]. This is a hub that provides interconnectivity between some smart appliances and also grants almost full control over all HomeWhiz enabled smart appliances to the user via smart phones or a dedicated panel which has a graphical user interface that allow the user to interact with. Currently in Arçelik, while smart refrigerator, washing machine, dryer, dishwasher, oven, stove, ventilation hood, small domestic appliances, air-cleaning appliances, and air conditioners are under development, HomeWhiz is currently being developed by Arçelik partnered

[16] ETSI TS 103 264 V1.1.1 (2015-11) SmartM2M; Smart Appliances; Reference Ontology and oneM2M Mapping

[17] European smart home market development: Public views on technical and economic aspects across the United Kingdom, Germany and Italy *Article in Energy Research & Social Science · September 2014*

[18] https://www.arcelikglobal.com/en/technology/rd/homewhiz/

with Open Connectivity Foundation[19] whose mission is to connect the next 25 billion devices for the Internet of Things by providing secure and reliable device discovery and connectivity across multiple OSs and platforms.[20] The consortium includes other major home appliances manufacturers such as LG and Samsung.

The other major home appliance vendors who have their own platforms to control smart appliances and to support a foundation on smart home technology include Bosch and Siemens, who promote Home Connect as their own platform for remotely controlling and monitoring of their smart appliances[21]. They may integrate this with their smart home division[22], however, for now, they have separate solutions for controlling small or large appliances groups. For example, a smart sensor[23] acts as a controller hub for air purifier and water heater. They are small solutions for partially smart home modules. Samsung, interestingly, promotes Family Hub™ which is particularly focusing on weekly meal planning and convenience, with features such as photo sharing and note keeping on the fridge cover currently[24]. They have made no announcement yet on how they will integrate more smart appliances into the system and develop a main hub for it or whether the hub will be the fridge itself, however, they also have a market ready solution that enables partial monitoring and control for some home appliances called SmartThings[25]. Lastly, from major home appliances vendors, LG, promotes ThinQ[26]. LG ThinQ works with Amazon Echo and other Alexa-enabled devices to allow remote, hands-free control of LG appliances and TV.

It can be clearly observed that there is currently no universally accepted protocols and platforms to connect a large number of IoT enabled appliances as a network. The market is newly shaping: major appliances vendors are promoting their platform and IoT gateways along with their appliances. And that makes the interoperability aspect of the project more challenging.

To make a comprehensive listing and identify the opportunities and rooms for development and to build a roadmap towards a standardization, whether smart or not, all popular appliances are listed in the table below. The appliances are divided by dimension in major and small appliances.

Table 4: list of energy consumption per most popular appliances

	Appliance	Wattage (W)	Daily usage (Hours)	Daily Energy Consumption (kJ)	How many weeks ain a week	How many weeks a year	Yearly energy consumption (KJ)
Major appliances	Freezer	500	24	43,200	7	52	15,724,800
	Refrigerator	800	24	69,120	7	52	25,159,680
	Water cooler	20	0.5	36	1	30	1,080
	Ice maker	230	1	414	1	12	4,968
	Oven / Kitchen Store	3000	1	10,800	3	52	1,684,800
	Microwave oven	1200	0.1	432	5	52	112,320
	Washing machine	1000	2.2	7,920	2	52	823,680
	Dryer / Drying cabinet	3000	2.5	27,000	2	40	2,160,000
	Dishwasher	1800	2	12,960	2	52	1,347,840
	Television	120	4	1,728	7	52	628,992
	Air conditioner	3500	8	100,800	7	16	11,289,600
	Water heater	4000	24	345,600	7	16	38,707,200
	Air ventilator	50	6	1,080	7	16	120,960
	Air cooler	200	6	4,320	7	16	483,840

[19] https://openconnectivity.org/
[20] https://openconnectivity.org/foundation/
[21] https://www.home-connect.com/global/smart-home-appliances
[22] https://www.bosch-smarthome.com/xc/en/index
[23] https://www.todo-control.com/rds110-siemens-Wi-Fi-thermostat
[24] https://www.samsung.com/us/explore/family-hub-refrigerator/connected-hub/
[25] https://www.samsung.com/tr/apps/smartthings/
[26] https://www.lg.com/us/discover/thinq

	Appliance	Wattage (W)	Daily usage (Hours)	Daily Energy Consumption (kJ)	How many weeks ain a week	How many weeks a year	Yearly energy consumption (KJ)
	Oil heater	2000	24	172,800	7	16	19,353,600
Small appliances	Toaster	900	0.2	648	5	52	168,480
	Grill	2000	1	7,200	3	30	648,000
	Bread machine	1200	1	4,320	1	40	172,800
	Electric kettle	1200	0.5	2,160	7	52	786,240
	Rice cooker	500	0.5	900	1	20	18,000
	Coffee machine	800	2	4,320	7	52	1,572,480
	Egg cooker	350	0.12	151	5	52	39,312
	Waffle machine	1000	0.5	1,800	2	24	86,400
	Electric baking tray	1500	1	5,400	2	40	432,000
	Induction cooker	2000	2	14,400	5	52	3,744,000
	Juicer	160	0.5	288	3	40	34,560
	Whisk	150	0.2	108	1	12	1,296
	Food processor	700	0.2	504	1	12	6,048
	Meat cutter	250	0.2	180	1	12	2,160
	Air fryer	1500	0.5	2,700	1	12	32,400
	Fryer	1200	0.5	2,160	1	12	25,920
	Smoke exhauster	100	2	720	4	52	149,760
	Air purifier	50	12	2,160	4	26	224,640
	Air humidifier	50	12	2,160	4	26	224,640
	Dehumidifier	350	12	15,120	1	26	393,120
	Iron	1200	1	4,320	1	52	224,640
	Vacuum cleaner	1400	1	5,040	2	52	524,160
	Lighting solutions	60	10	2,160	7	52	786,240

As one can see, all the popular appliances that are commercially available and widely used are evaluated by their yearly energy consumptions based on assumptions. The assumptions are mostly trivial to the calculations of yearly energy consumptions (given it will be different from country to country and even from town to town) and cannot be taken as a merit to project but the method itself is useful to envision a broader perspective on optimisation opportunities. Identifying the average usage on daily, weekly and yearly separately is useful to classify the data. For example, yearly energy consumption of both oil heaters and freezers are close to each other with oil heater's being bigger. However, while a freezer is used every day of the week and every week of the year, an oil heater is only used for 16 weeks of the year (in many countries). In that point, it might be wiser to focus on optimization of the freezer rather than oil heater even though oil heater has the higher consumption.

2.2 Air Conditioning and Smart Home

Internal climate management is part of the overall "smart building" technological challenge. Indeed, indoor climate management is a major field of application of IoT and smart technologies: comfort-linked plant components are priorities for every smart building. This happens for three main reasons: 1. for the important impact in terms of energy consumption; 2. for the role in indoor comfort; 3. for gaining more control of the indoor air quality.

Air conditioning appliances are a fundamental component of modern building plant, in both the commercial and residential sectors. As a consequence, major producers are going to enlarge their portfolio of offerings with a new generation of connected and interoperable products, ideal for IoT systems. For the users this new generation of offerings, advantages in terms of more comfort control and more energy savings can be provided, while for producers, it opens new possibilities to service proposition, because connectivity enables remote maintenance. Furthermore, it reinforces their reputation by forming part of their corporate sustainability strategy. Smart home systems are today the norm in the Residential market, being driven in many EU countries by fiscal incentives, so air conditioners producers introduce apps for the control of the appliances (i.e. Daikin's Residential Controller) with features like climate control, scheduler, cloud monitoring and integration in

vocal controls. Many producers (Daikin, LG, Toshiba, Mitsubishi) have also open-standard driven controllers in order to allow integration in more complex installations. The standards are KNX for Residential and Tertiary sectors, Modbus and Bacnet for the Tertiary sector.

Some major manufacturers like LG for instance, have a broader offering of appliances beyond air conditioners, have integrated the smart control of air conditioning into an App dedicated to the energy monitoring of the appliances present in a home (i.e. LG ThinQ App). Beyond the "classic" functions of climate control and programming, this app offers maintenance features as well (smart diagnosis): air filters efficiency monitoring, alert management, maintenance scheduling.[27]

2.3 Smart appliances: ranking

In the below table, the list of appliances is evaluated by yearly energy consumption and their ability to be regulated (their flexibility / time window to organize their operations). It is simply calculating daily usage of each appliance and taking their flexibility to postpone their operations (the flexibility must be evaluated from the user's perspective) into account, then calculating the total optimisation opportunity weight by simply multiplying all the factors:

Yearly Energy usage x (Flexibility ~ Time Window).

Table 5: appliance evaluation per energy consumption

Appliance	Yearly energy consumption (KJ)	Time Critic Rating	Total Weight on Energy Optimization
Water heater	38,707,200	2	77,414,400
Refrigerator	25,159,680	2	50,319,360
Oil heater	19,353,600	2	38,707,200
Freezer	15,724,800	2	31,449,600
Air conditioner	11,289,600	1	11,289,600
Dryer / Drying cabinet	2,160,000	4	8,640,000
Induction cooker	3,744,000	2	7,488,000
Dishwasher	1,347,840	5	6,739,200
Washing machine	823,680	5	4,118,400
Oven / Kitchen Stove	1,684,800	2	3,369,600
Coffee machine	1,572,480	2	3,144,960
Vacuum cleaner	524,160	5	2,620,800
Iron	224,640	5	1,123,200
Electric baking tray	432,000	2	864,000
Electric kettle	786,240	1	786,240
Lighting solutions	786,240	1	786,240
Dehumidifier	393,120	2	786,240
Bread machine	172,800	4	691,200
Grill	648,000	1	648,000
Television	628,992	1	628,992
Air cooler	483,840	1	483,840
Air purifier	224,640	2	449,280
Air humidifier	224,640	2	449,280
Microwave oven	112,320	2	224,640
Toaster	168,480	1	168,480
Smoke exhauster	149,760	1	149,760

[27] See https://elettricomagazine.it/news-tecnologia/edifici-intelligenti-comfort-efficienza/ and Energy & Strategy Group, Polytechnic of Milan, Smart Building Report 2020, in https://www.energystrategy.it/eventi/smart-building-report-2020.html.

Appliance	Yearly energy consumption (KJ)	Time Critic Rating	Total Weight on Energy Optimization
Air ventilator	120,960	1	120,960
Waffle machine	86,400	1	86,400
Egg cooker	39,312	1	39,312
Rice cooker	18,000	2	36,000
Juicer	34,560	1	34,560
Air fryer	32,400	1	32,400
Fryer	25,920	1	25,920
Food processor	6,048	2	12,096
Ice maker	4,968	2	9,936
Meat cutter	2,160	2	4,320
Whisk	1,296	2	2,592
Water cooler	1,080	1	1,080

The newly introduced factor here is the Time Critic Rating, meaning the bearable time window that the user permits the appliance to organize its operation. Of course, the operation, in fact, will be organized on a higher level so the appliance will simply be waiting for commands to run its operation. This is how the regulation and the overall optimization in an individual house and in higher level, in a city or even a region will be executed. In the study, Time Critic Rating means blow weighted factors.

1: there is no time window (tw*)
2: tw is up to 2 Hours
3: tw is up to 4 hours
4: tw is up to 8 hours
5: tw is up to 16 hours

It indicates the time duration for arranging the operation of the appliance, which is acceptable and affordable by the user. Each of the parameters and threshold values can be optimized by regular surveys on the demo sites. After that, one can prioritize the appliance listing by ranking their scores. For example, on the table, which used bare assumptions, water heater and the refrigerator have the highest priority based on their annual energy consumption multiplied by their time window indicator, therefore, they seem to be a good starting point for optimization.

2.4 Smart appliances: maturity of the offer and level of adoption

To enable an optimisation over households via controlling smart appliances, the maturity of the technology and the adoption level must be evaluated from a broader perspective. Even though, due to the evolving privacy legislations over the last 4 years, it is extremely difficult to estimate the level of adoption of smart appliances, it is known that the demand is growing. It is said “the global smart home appliances market size is anticipated to reach USD 92.72 billion by 2027”[28].

Although it is beyond our limitation to make a comprehensive study on the adoption level of smart home and smart appliances technology over the globe, recent consumer opinion studies with respect to the the smart readiness indicator, which assesses a building’s ability to adapt to advanced technologies in terms of its performance capacity and energy flexibility[29] indicate that the collective opinions of the residents (from a sample group) think the major obstacle in front of the adoption of smart buildings (which is the core

[28] https://www.businesswire.com/news/home/20200911005283/en/Global-Smart-Home-Appliances-Market-2020-to-2027---Size-Share-Trends-Analysis-Report---ResearchAndMarkets.com

[29] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12364-%E2%80%98Smart%E2%80%99-buildings-smart-readiness-indicator-definition-and-calculation-_en

implementation plan of the project) are, in summary , that there are too many vendors that have too many different solutions[30].

Given the study's conclusion, evaluating broadly available smart appliances with their interface and technologies is the most logical task to assess the maturity of the offer.

The data in Table 6 is gathered from an online marketplace of the major home appliances manufacturers. The table shows the available smart products that are listed on a smart appliance list from leading vendors in the market. It is seen that a great portion of the listing is released on market by the leading vendors. And more to follow given the announcements on their websites.

Besides the major vendors, one can find the smart versions of each item in the listing. For example, one can even find smart grill online[31]. However, it is unwise to overlook the fact that the important indicator and factor of the adoption is how much the leading vendors invest in. Therefore, focusing on leading vendors smart catalogues will give a better idea of adoption and will give more opportunity to build a base for demonstrations.

The current table actually confirms the findings of the studies, there are, indeed, too many different technologies from many vendors as people think as one of the main obstacles in front of the adoption of smart buildings, hence, in a broad sense, smart appliances.

From the interoperability perspective, connectivity technologies and the interfaces need to be evaluated carefully and it might be better to implement all in the overall architecture of the system.

2.5 Smart appliances market

"The growing smart home IoT market is helping drive new interest in the typically sluggish smart appliances subsegment. The smart appliance market segment is now ready for a healthy growth spurt over the next decade as appliance manufacturers, retailers, and utilities embrace smart appliances, and then convince buyers of the benefits that include enhanced energy efficiency, improved maintenance capabilities, and greater convenience through connectivity."[32]

The Europe smart home appliances market was valued at 4.08 Bn$ in 2018 and is expected to grow at a CAGR of 13.9% during the forecast period 2019 - 2027, to generate 12.94 Bn$ by 2027. Furthermore, the other key diving factors behind fast adoption and growth rate of smart home appliances in the European market includes universal access to high speed internet, introduction of smart meters, Energy efficiency and energy savings, and favourable EU policies to support digital economy in Europe. Another important reason behind rising demand of smart home appliances is tech savvy young generation in Europe. Young people find more value in the concept of smart homes and connected devices mainly because of the convenience that these devices offer. Some of the most common household goods that have potential to be converted into smart home appliances include refrigerators, air conditioners, dishwashers, ovens, stoves, washing machines, dryers, heating systems and others. [33]

[30] Energy & Strategy Group, Politecnico di Milano, 2021, "Smart Building Report 2020", in https://www.energystrategy.it/osservatorio-di-ricerca/smart-building/?2021
[31] https://smart.lynxgrills.com/

[32] N. Strother, Navigant Research. See: https://guidehouseinsights.com/news-and-views/the-smart-appliances-market-is-finally-poised-for-growth
[33] See Report Linker "Europe Smart Home Appliances Market to 2027 ", 2020, in

Table 6: major home appliances manufacturer (online marketplace)

	Arçelik		LG		Samsung		Bosch-Siemens	
	Status	Technology	Status	Technology	Status	Technology	Status	Technology
Water heater							Market-Ready	Wi-Fi
Refrigerator	Market-Ready	HomeWhiz	Market-Ready	ThinQ	Market-Ready	FamilyHub; Wi-Fi	Market-Ready	HomeConnect
Air conditioner	Market-Ready	HomeWhiz; Wi-FiReady	Market-Ready	ThinQ	Market-Ready	Wi-Fi		
Induction cooker							Market-Ready	HomeConnect
Dryer / Drying cabinet	Market-Ready	HomeWhiz	Market-Ready	ThinQ	Market-Ready	Wi-Fi	Market-Ready	HomeConnect
Oven / Kitchen Stove			Market-Ready	ThinQ	Market-Ready	FamilyHub	Market-Ready	HomeConnect
Coffee machine	Market-Ready	HomeWhiz					Market-Ready	HomeConnect
Dishwasher	Market-Ready	HomeWhiz	Market-Ready	ThinQ	Market-Ready	FamilyHub; Wi-Fi	Market-Ready	HomeConnect
Washing machine	Market-Ready	HomeWhiz	Market-Ready	ThinQ	Market-Ready	Wi-Fi	Market-Ready	HomeConnect
Lighting Solutions					Market-Ready	Wi-Fi		
Television	Market-Ready	Wi-Fi; BT; HomeWhiz	Market-Ready	Wi-Fi; BT	Market-Ready	Wi-Fi; BT		
Vacuum cleaner	Market-Ready	HomeWhiz	Market-Ready	ThinQ	Market-Ready	Wi-Fi		
Air cooler			Market-Ready	ThinQ	Market-Ready	Wi-Fi		
Dehumidifier			Market-Ready	ThinQ	Market-Ready	Wi-Fi		
Air purifier	Market-Ready	HomeWhiz	Market-Ready	ThinQ	Market-Ready	Wi-Fi		
Air humidifier			Market-Ready	ThinQ	Market-Ready	Wi-Fi		
Smoke exhauster							Market-Ready	HomeConnect
Microwave oven					Market-Ready	FamilyHub		

3. Smart meters

3.1 Smart meters: market consistency and drivers, evolution of the offer and level of adoption

Smart meters are electronic devices that accurately monitor electricity, gas, thermal energy and water usage: any kind of energy can be measured, monitored, stored and reported in local memory devices (data logger) connected to the meter or in a higher level of data bank like a cloud repository or an on-premise software (often provided by analytical features in order to group data per typology and to compare historical trends).

Energy meters devices measure energy data, like the amount of electric energy consumption, current and power factor and voltage levels, or amount of thermal energy or water volume. Smart meters are energy meters which have connectivity features inside, like I/O ports and communication protocol compatibility: in this aspect, they are the same of any other smart device like sensors, controllers or actuators. They are part of an IoT network.

The smart energy meter market is a mature market: the offer is wide, every country in the world is covered and the market player are major multinationals companies as well as local players. The estimation of the units sold worldwide in 2020 is around 136 million, with the forecast to growth until 198 million in 2026.[34]

The size of the smart meters market surpassed USD 21 Bn (9 Bn for the electrical ones) in 2019 and is set to grow to 39 USD Bn with a CAGR of 8.8% from 2020 to 2027 (5% for the electrical ones), fuelled by the introduction of favourable regulatory policies both in EU and in USA to replace conventional meters with smart metering systems to effectively monitor and govern power consumption. In addition, rising investments by public and private players toward smart grid deployment will positively stimulate the business scenario.[35] The value projection of the smart electric meters in 2026 is worth 12.4 USD Bn worldwide.

The evolution of smart metering systems is primarily attributed to flourishing real estate sector and rapid digital transformation of power utilities. Introduction of energy codes in order to develop energy efficient buildings, to decrease utility bills and to save electricity will further enhance the product adoption. Additionally, a growing demand of high-tech equipment to monitor and control energy consumption will boost the market revenue.

The smart electric meter market share is forecasted to grow through 2026 thanks to the expansion of renewable energy network and increasing integration of smart grid infrastructure. Flexible product configurations including immediate fault detection, effective monitoring and remote access will further escalate the market value. Wide adoption of these units across the oil & gas industry, construction sector and data centres will boost the technology penetration. Increasing investments by utilities to deploy IoT enabled grid infrastructure aimed at providing real-time and accurate consumption information will foster the industry size. Moreover, these systems offer two-way communication that acts as a bridge between utilities and consumers.

The ongoing and continuous development of the communication network infrastructure contributes toward the manufacturing of the advanced level of smart meters. The availability of the network infrastructure such as 5G, 4G, radio frequency, and others, boosts the development of the smart meters. The

[34] See Mordor Intelligence market report about global smart meters market, in https://www.mordorintelligence.com/industry-reports/global-smart-meters-market-industry

[35] See Allied Market Research, 2020, "Smart Meter Market By Product and End Use: Global Opportunity Analysis and Industry Forecast, 2020–2027",in https://www.alliedmarketresearch.com/smart-meters-market . See also Global Market Insights, 2020, "Smart Electric Meter Market Report 2026 - Global Industry Statistics", in https://www.gminsights.com/industry-analysis/smart-electric-meter-market .

manufacturers are continuously engaged in production of advanced level of smart meters according to the growing network infrastructure; thus, contributing to the growth of the smart meter industry.

Regarding the Residential sector, single phase smart electric meter market is poised to exceed USD 1.5 billion by 2026. Increasing power consumption across residential establishments including apartments and multi storey buildings along with expanding commercial sector will drive the segment growth. Rapid expansion of distributed generation technology coupled with the advancement of microgrid networks will further spur the market growth trends.

Three phase meter segment accounted for more than 85% market share in 2019. Rising adoption of energy efficient systems across the commercial sector (hospitality, healthcare, education, logistics) will positively influence the industry growth, as well as the expansion of large-scale industries along with favourable government schemes and incentives toward grid enhancement.

Europe and Asia Pacific collectively held above 80% of the smart electric meter market share in 2019. Shifting focus toward the adoption of energy efficient technologies coupled with increasing investments toward replacement of conventional systems with IoT based metering technology will augment the regional industry growth. Moreover, ongoing government incentives and subsidies toward the integration of smart systems across the grid infrastructure will fuel the product demand. Public and private players are investing extensively to integrate cloud-based applications and technologies into residential and commercial establishments, strengthening the technological adoption.

3.2 Smart meters: vendors listing

Eminent players operating across the smart electric meter market include Itron, Kamstrup, Aclara Technologies, Siemens, Honeywell Elster, Osaki Electric, Sensus, Circutor SA, Iskraemeco Group, Apator, Landis+Gyr AG, Schneider Electric, General Electric and Larsen & Toubro Limited.

The ongoing and continuous development of the communication network infrastructure contributes toward the manufacturing of the advanced level of smart meters. The availability of the network infrastructure such as 5G, 4G, radio frequency, and others, boosts the development of the smart meters.

In the present research, we selected a limited number of manufacturers, according to the overall goals of the Auto-DAN project. In Figure 9 the number of energy meters mapped per manufacturer.

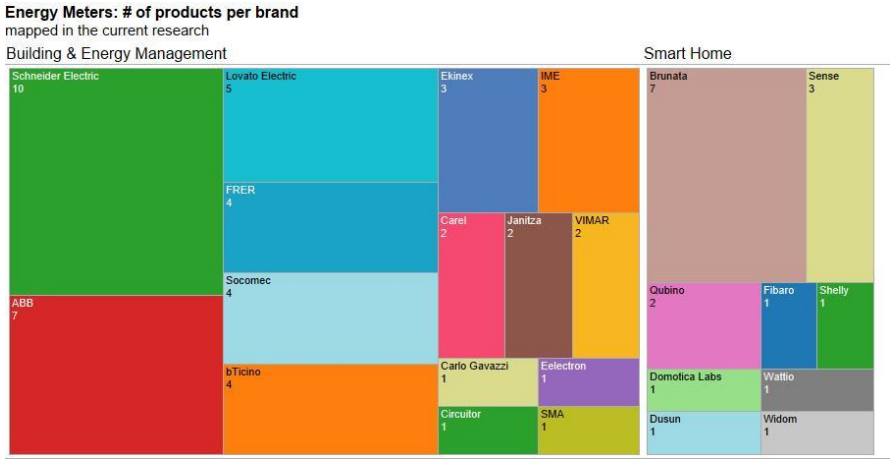


Figure 9: Smart Meters manufacturers mapped in the present research

3.3 Smart meters: ranking

In Figure 9 we reported the number of energy meters analysed in the present research (the total number is 68), per each brand, divided between building and energy management and smart home systems. The ranking here developed takes in account the same criteria used in analysing the rest of the smart offer: 13 categories of analysis grouped in 2 axes: Easiness of Installation and User Friendliness (see Figure 10).

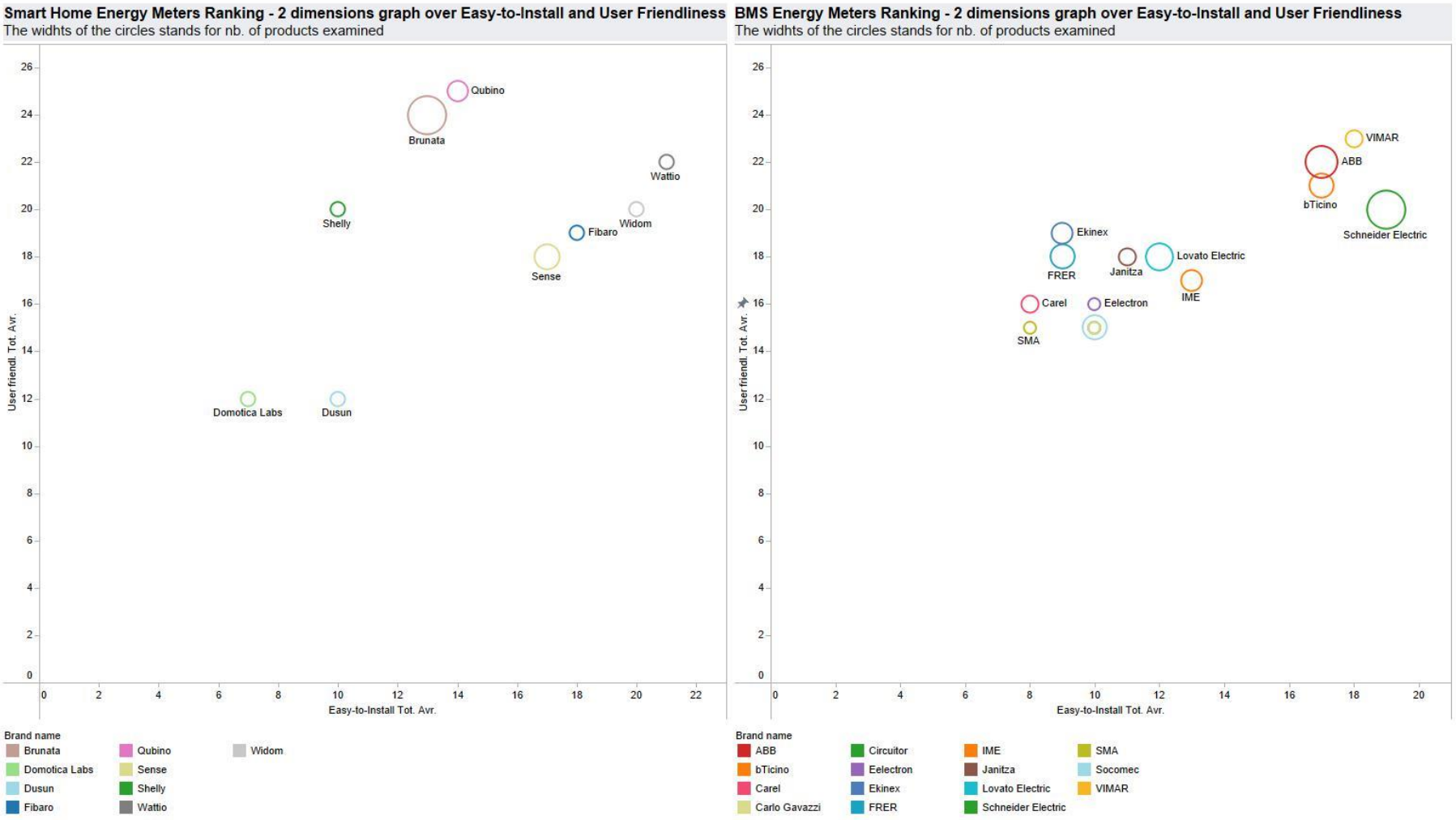


Figure 10: Energy Meters Ranking over 2 dimensions graph

For the scope of Auto-DAN, products like Power TAG by Schneider Electric, Qubino smart meter and Wiser for KNX gateway and energy controller have polarised the attention, due to their characteristic of compatibility with wireless or wired standard protocols, narrow dimension and quality (MID certification and ability to measure current, voltage, power, power factor, energy). In particular, the Qubino smart meter is the only energy meter on the market through which the current flows, without the need for current clamps, and measures 9 different values: V, A, W, var, PF, kWh import, kWh export, kVAh, kvarh. Power TAG a compact and easy-to-install Class 1 wireless communication energy sensor that monitors and measures energy and power in real-time; it has Rogowsky rings inside and it has to be installed over or under the DIN-rail switches, with no need of clamps; in addition, has a Modbus TCP/IP port for the integration in BMS.

Furthermore, Wattio presents a very affordable and easy to install solution for energy measuring, Bat, which is an electricity monitor (located within the electrical panel) that allows to control electrical circuits with basic features.

3.4 Smart meters features and listing

The energy meters listed and analysed are 68 in total, for 24 manufacturers. In the following Figure 11 Error! Reference source not found.one can see the main features in terms of function and sector of preferred application. We primarily selected energy meters that are suitable for Residential and small Tertiary applications.

From the point of view of the communication protocols, Figure 12 highlights the large presence of Modbus protocols for Building & Energy Management offers and of Wi-Fi and z-wave for the Smart Home offers. This reflects the overall distribution of the rest of the offer, with the difference of LoraWan protocol, which is more frequent in Smart Meters offer. LoraWan has been adopted by several residential market operators in big cities as the main public wi-fi network protocol, due to its characteristics of long-distance coverage and affordability. Manufactures like Brunata, for example, developed a dedicated offer just for this segment of market.

Energy Meters features

Brand name	Functions	Preferred application sector	Building & Energy Management	Smart Home
Grand Total			50	18
ABB	Metering	All sectors	5	
		Residential/Little Tertiary	2	
Brunata	CO2	Residential		1
	Liquid detection	Residential		1
	Metering	Residential		3
	Multi-function (temperature, humidity)	Residential		1
	Temperature	Residential		1
bTicino	Metering	Residential/Little Tertiary	1	
	Metering, control, power	Residential/Little Tertiary	3	
Carel	Metering	All sectors	2	
Carlo Gavazzi	Metering	All sectors	1	
Circuitor	Metering	All sectors	1	
Domotica Labs	Metering	Residential		1
Dusun	Metering	Residential		1
Eelectron	Metering	Residential	1	
Ekinex	Metering	Residential	2	
	Power control	Residential	1	
Fibaro	Metering, control, power	Residential		1
FRER	Metering	Tertiary/Retail	4	
IME	Metering	All sectors	3	
Janitza	Metering	All sectors	2	
Lovato Electric	Metering	All sectors	5	
Qubino	Metering	Residential		2
Schneider Electric	Heath, cold, pressure	All sectors	2	
	Metering	All sectors	8	
Sense	Metering	Residential		3
Shelly	Metering	Residential		1
SMA	Metering	All sectors	1	
Socomec	Metering	All sectors	4	
VIMAR	Metering, control, power	Residential/Little Tertiary	2	
Wattio	Metering	Residential		1
Widom	Metering, control, power	Residential		1

Figure 11: Energy Meters features per segment of application

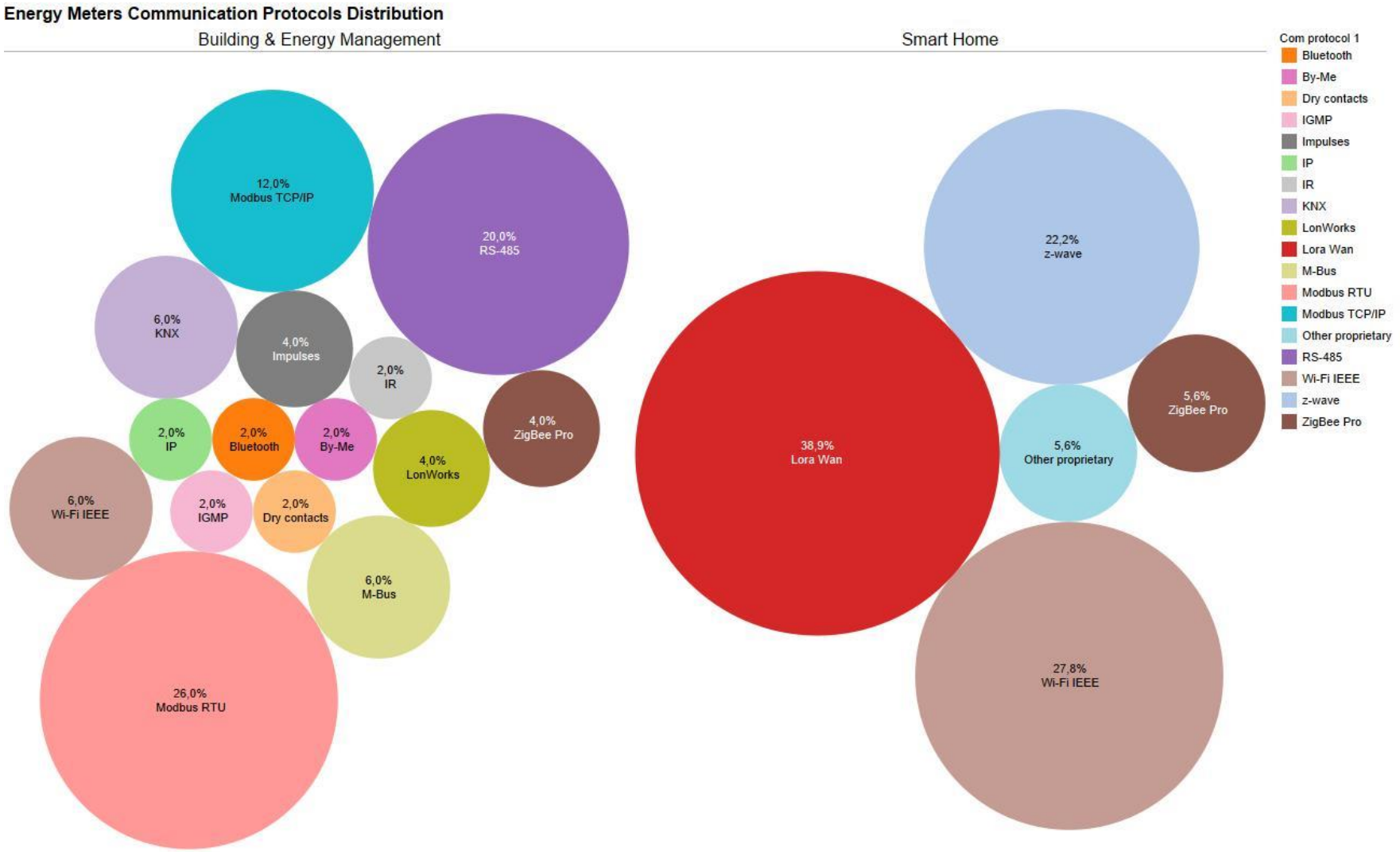


Figure 12 Energy Meters Communication Protocols Distribution in %

4. Gateways

4.1 Building Automation and Gateways: functions and communication protocols

A building automation system (BAS) allows operators to access, control, and monitor all connected building systems from a single interface. With BAS technology, one can gain centralized control over building's systems via networked electronic devices. In the past, fine-tuning HVAC, lighting, power, and access control systems required extensive manual effort. With new building automation solutions, it is possible not only to integrate these historically siloed systems, but also gain visibility and control over them from a single view. All building automation systems shares the following common elements:

- Software
- Field controllers
- Communication bus and protocols
- Network controllers and gateways
- Downstream end-devices for occupant control and ambient intelligence (thermostats, room controllers, etc.).

To maximize the benefits and efficiency it is important to integrate the widest range of data sources and actuators. To this end, two BAS components are primarily involved: software and the gateways. In this section we focus on the gateways and they capabilities in terms of supported protocols and communication buses.

Unlike traditional communication routers, IoT gateways can integrate data from devices that communicate with various network protocols, including cellular, Wi-Fi, LoRA, Ethernet, Bluetooth, ZigBee, and more.

Industrial IoT gateways also offer more industrial interfaces than standard communication routers, including RS485, RS232, USB, I2C, SPI, or digital GPIOs for communications between field devices.

They also offer customizable application firmware, when needed, to adapt the gateway to the required application. With rugged housing and long-life components, they can endure the most demanding environments, including extremes of temperature, vibration, and humidity.

The advanced capabilities provided by IoT Gateways may vary depending on deployment model and the specific use case requirements. Some of the typical advanced capabilities provided by the IoT Gateways may include:

- Communications Management: the device automatically maintains any configured connection, and the user should not have to intervene.
- Security and Authentication: a gateway needs to wrap layers of security around any data that will be transmitted onwards.
- Data Enrichment: one of the fundamental principles of IoT is that data needs to be semantically valid, consistent and searchable.
- Data Aggregation: to reduce noise, redundant records and meaningless data.
- Event Detection: event detection provides a mechanism to report significant events as they occur and generate corresponding alarms and notifications.
- Protocol Translation: many legacy systems use protocols that are not compatible with modern packet switched communications networks.
- User Applications: one of the real benefits of edge intelligence is the ability to make decisions locally and act upon them automatically even if cloud connection is severed or temporarily unavailable.
- Device Management and FOTA: having these capabilities is highly desirable and there must be a mechanism to remotely manage many devices at once and upgrade the firmware.

The offering of gateways to manage smart-building IoT devices is vast and the range of supported communication protocols is wide. The most established telemetry protocols include KNX, BACnet, Modbus, M-Bus, LoRa, SNMP, Bluetooth, ZigBee and MQTT. One of the main challenges in building data ingestion workflows is related to this fragmentation. This section provides a

review of different IoT Gateways that can be used to integrate different building management and smart building protocols in order to overcome and address this challenge. As it will emerge from the discussion there isn't a clear industry leader and the choice of gateways to use largely depends on the specific project requirements and on the installation sites constraints and characteristics.

4.1.1 Gateway and communication protocols

To conclude this introductory paragraph, a list of the protocols support provided by the gateways are described in the following sections.

BACnet is a communication protocol for Building Automation and Control (BAC) networks that leverage the ASHRAE, ANSI, and ISO 16484-5 standard protocols. BACnet was designed to allow communication of building automation and control systems for applications such as heating, ventilating, and air-conditioning control (HVAC), lighting control, access control, and fire detection systems and their associated equipment. The BACnet protocol provides mechanisms for computerized building automation devices to exchange information, regardless of the particular building service they perform.

The BACnet protocol defines a number of data link/physical layers including Ethernet and BACnet/IP.

Bluetooth is a short-range wireless technology standard used for exchanging data between fixed and mobile devices over short distances using UHF radio waves in the ISM bands, from 2.402 GHz to 2.48 GHz, and building personal area networks (PANs).

Digital Addressable Lighting Interface (DALI) is a trademark for network-based products that control lighting. The underlying technology was established by a consortium of lighting equipment manufacturers and as an open standard alternative to several proprietary protocols. The DALI, DALI-2 and D4i trademarks are owned by the lighting industry alliance, DiiA (Digital Illumination Interface Alliance). DALI is specified by a series of technical standards in IEC 62386. Standards conformance ensures that equipment from different manufacturers will interoperate.

KNX is an open standard (see EN 50090, ISO/IEC 14543) for commercial and domestic building automation. KNX devices can manage lighting, blinds and shutters, HVAC, security systems, energy management, audio video, white goods, displays, remote control, etc. KNX evolved from three earlier standards; the European Home Systems Protocol (EHS), BatiBUS, and the European Installation Bus (EIB or Instabus). It can use twisted pair (in a tree, line or star topology), powerline, RF, or IP links.

LonWorks is a networking platform and protocol specifically created by Echelon Corporation for networking devices over media such as twisted pair, powerlines, fiber optics, and RF. It is used for the automation of various functions within buildings such as lighting and HVAC. Additionally, the LonWorks platform uses an affiliated Internet protocol (IP) tunneling standard—ISO/IEC 14908-4 in use by a number of manufacturers to connect the devices on previously deployed and new LonWorks platform-based networks to IP-aware applications or remote network-management tools.

M-Bus (Meter-Bus) is a European standard (EN 13757-2 physical and link layer, EN 13757-3 application layer) for the remote reading of water, gas or electricity meters. M-Bus is also usable for other types of consumption meters. The M-Bus interface is made for communication on two wires, making it cost-effective. A radio variant of M-Bus Wireless M-Bus is also specified in EN 13757-4.

Modbus is a data communications protocol originally published by Modicon (now Schneider Electric) in 1979 for use with its programmable logic controllers (PLCs). Modbus has become a de facto standard communication protocol and is now a commonly available means of connecting industrial electronic devices. The Modbus protocol uses character serial communication lines, Ethernet, or the Internet protocol suite as a transport layer.

The **Message Queuing Telemetry Transport (MQTT)** is a lightweight, publish-subscribe network protocol that transports messages between devices. The

protocol usually runs over TCP/IP; however, any network protocol that provides ordered, lossless, bi-directional connections can support MQTT. It is designed for connections with remote locations where a "small code footprint" is required or the network bandwidth is limited. The protocol is an open OASIS standard and an ISO recommendation (ISO/IEC 20922).

OPC UA is a machine-to-machine communication protocol for industrial automation developed by the OPC Foundation. It is a TPC/IP based protocol with client-server communication and a very rich set of features.

Zigbee is an IEEE 802.15.4-based specification for a suite of high-level communication protocols used to create personal area networks with small, low-power digital radios, such as for home automation, medical device data collection, and other low-power low-bandwidth needs, designed for small scale projects which need wireless connection.

Z-Wave is a wireless communications protocol used primarily for home automation. It is a mesh network using low-energy radio waves to communicate from appliance to appliance, allowing for wireless control of residential appliances and other devices, such as lighting control, security systems, thermostats, windows, locks, swimming pools and garage door openers.

4.2 Gateways listing

4.2.1 ABB i-bus KNX

Figure 13: ABB i-bus KNX gateway

ABB i-bus KNX provides different components for KNX automation as well as integration capabilities through gateways to other system such as IP, EnOcean or optical fibre end device. In particular, the IPR (i-bus IP Router) and IPS (IP Interface) devices connect the KNX bus to the Ethernet network. ABB i-bus features many end devices, providing support for power supply management, room automation, shading control, automation, logic and time control, visualization, display and signaling, detection of motion and presence, lighting, display and operation, heating, ventilation and air conditioning and safety.

4.2.2 ADLINK MXE Gateways

Figure 14: ADLINK MXE gateway

ADLINK's new Matrix MXE-210 series of ultra-compact embedded platforms, based on the Intel Atom® x5-E3930/x7-E3950 Processor, delivers optimum I/O design for maximum connectivity.

With two GbE LAN ports, two COM ports, two USB 2.0 and two USB 3.0 host ports, and dual mPCIe slots and USIM socket support communication with connections via Wi-Fi, BT, 3G, LoRa (SX1276), and 4G LTE, the MXE-210 series enables seamless interconnection, ensuring interoperability between systems. Rugged construction criteria assure operation in harsh environments with operating shock tolerance up to 100 G and extended operating temperatures of -40°C to 85°C available.

Software support includes

- Windows 10 IoT Enterprise 64Bit
- Ubuntu Linux 16.04 LTS 64Bit
- Wind River Pulsar Linux LTS 17
- Debian 8.5 64Bit

4.2.3 Advantech Wise Gateways

Figure 15: Advantech Wise gateway

WISE-710 series devices are durable industrial protocol gateways that support various mount options (DIN rail, wall, and pole) for diverse industrial automation applications.

The latest model, WISE-710-N600A, is equipped with a NXP i.MX 6 1GHz Dual-core processor, 1 GB DDR3 RAM, dual GbE LAN, three serial ports, four digital input, four digital output, one Micro USB, and one Micro SD slot. One of the serial ports can be configured to terminate CAN protocol.

The Wise gateways support Yocto 2.1 Linux kernel 4.1.15 and Ubuntu 16.04.

4.2.4 Dell IoT Gateway

Figure 16: Dell IoT Gateway 300 Series

The Dell IoT Gateway 3000 Series provides diverse and expandable I/O to connect, aggregate, relay and track data from many sensors and network protocols, including wireless mesh networks and legacy serial equipment. Dell IoT Gateways natively supports ZigBee and 802.15.4 protocols as well as Bluetooth LE but they include fieldbuses as well through CAN bus controller and RS232/422/485 serial connectors. WWAN/Cellular connectivity is supported as well (3G and 4G).

The Dell IoT Gateway can also be used as an edge gateway to bridge KNXnet and BACnet/IP protocols towards MQTT.

It supports both Linux and Windows 10 operating systems.

4.2.5 Eurotech ReliaGATE series

Based on the NXP i.MX 8M Mini Cortex-A53 quad core processor, with up to 4GB of RAM, up to 32GB of eMMC and a user-accessible microSD slot, the ReliaGATE 10-14 is a low power gateway suitable for demanding use cases: it supports a 9 to 30V power supply with transient protection, Display Port video output, two protected and isolated RS-232/422/RS-485 serial ports, two noise and surge protected USB ports, six optoisolated digital and two isolated analog interfaces.

This gateway supports carrier certified LTE configurations with 2G/3G fallback and provides communication modules for Wi-Fi, BLE, Gigabit Ethernet and Fieldbus interfaces, supporting Modbus, S7, OPC UA, and many more protocols.

Figure 17: ReliaGate Gateway

ReliaGATE gateway guarantees extended operating temperature, wide range of power supply options with transient protection, optoisolated analog in and digital I/Os, protected USB, protected and isolated serial ports, DIN bar and wall mounting options.

Operating System: Linux.

4.2.6 INSYS icom SCR-Series

Figure 18: INSYS icom SCR gateway

The programmable SCR series features versatile devices for IoT applications, retrofitting and remote services. The VPN routers for WAN communication are available in 4G and LAN versions – both optionally as I/O variants. IP and serial devices as well as data points can be locally connected via Modbus TCP/RTU.

Besides the INSYS operating system icom OS, the icom SmartBox is also on board, an integrated Linux environment that allows to execute scripts and programs directly on the router based on so-called containers

This VPN router offers the following features:

- Serial interface RS232
- RS232, RS485 and 2+2 digital I/Os
- Sleep mode for energy self-sufficient applications
- Wall and DIN rail mounting
- Installation in control cabinets and small distributors.

It also supports 4G/LTE SIM connectivity through 1 Mini-SIM card (2FF). Advanced FOTA is supported as well via incremental, fail-safe, automated procedures via update server (http, ftp, https, ftps).

4.2.7 Neousys IoT Gateway IGT-20 / IGT-30 Series

Figure 19: Neousys IoT IGT 20 gateway

Neousys IGT-20 series, equipped with AM3352 from Texas Instrument's Sitara AM335x family, is an ARM-based Box PC aimed at Industrial Internet of Things (IIoT) Gateway and Industry 4.0 applications. As required by any industrial applications, IGT-20 series is shipped as a ready system preinstalled with Debian and is compliant with common industrial certifications such as CE/FCC, shock and vibration. It has a power input range of 8 to 25 VDC and a wide operating temperature from -25°C to 70°C to ensure IGT-20 series continues to function under harsh industrial conditions.

IGT-20 series has I/Os that are applicable to a range of industrial grade sensors. It features one USB2.0, one 10/100M LAN, COM ports and an optional CAN bus port (IGT-21 only). In addition to the ports mentioned, there are built-in isolated digital input channels that accept discrete signals from various sensors, buttons or switches. There are also built-in isolated digital output channels to control actuators and indicators.

Communication wise, IGT-20 series has a mini PCIe slot and an external USIM holder allowing it to transmit acquired data and system status via 3G, 4G or Wi-Fi (mini PCIe Wi-Fi module). There is an opening on top of IGT-20 series for users to mount the SMA connector of the wireless module. In terms of storage,

IGT-20 series has dual microSDHC slots, one internal and one external. This design allows users to separate system/ user data and can expedite in OS deployment for mass production. IGT-20 series also provides six LED indicators and two function buttons that can be programmed by users. The function buttons can act as controls for IGT-20 series and exclude the need for external input devices, such as keyboard/mouse.

4.2.8 Kontron embedded box-PC

Kontron's IoT-ready KBox family offers industrial computer platforms, designed for process optimization in challenging and harsh environments. The Embedded Box PCs can be used for a large variety of applications e.g. in fieldbus environments, as system controller, for process control, as industrial firewalls or other embedded applications.

The IoT Gateways in this family feature a rich set of IO interfaces:

- Serial interfaces RS232 / RS422/RS485
- CAN
- PROFIBUS
- PROFINET
- ETHERCAT

Additionally, this family of gateways can provide different types of hardware profiles, ranging from Arm A53 processors with 1 GB RAM up to 9th Generation Intel Celeron with 64GB RAM.

4.2.9 Schneider Electric Wiser for KNX

Figure 20: Schneider Electric Wiser for KNX gateway

The KNX range from Schneider Electric offers push-buttons, binary inputs, movement detectors, environmental sensors, switch actuators, blind/switch actuators, dimming actuators/control units, control and display devices, room temperature control units as well as electrical protection and control components such as circuit breakers and switches, light switches and electrical sockets, uninterruptible power supply (ups), medium voltage switchgear, variable speed drives and soft starters, motor starters, contactors and protection relays. All end devices are accessible via dedicated gateways such as the LSS100100. This gateway supports the KNX standard as well as other communication buses and protocols, namely BACnet, KNX and Modbus.

4.2.10 Schneider Electric SmartX AS

Figure 21: Schneider Electric SmartX gateway

The Schneider's SmartX gateways are the core of the EcoStruxure BMS. The SmartX AS-P server performs key functionality, such as control logic, trend logging, and alarm supervision, and supports communication and connectivity to the I/O and field buses. Each SmartX AS-P server has the following ports:

- Two 10/100 Ethernet ports
- Two RS-485 ports
- One LonWorks TP/FT port
- One built-in I/O bus port
- USB

The SmartX gateway can natively communicate with three of the most popular standards for buildings: BACnet, LonWorks, and Modbus. This allows full access to third party products and the range of Schneider Electric products that communicate on the Modbus protocol, such as power meters, UPS, circuit breakers, and lighting controllers. The SmartX AS-P server also supports integration and communication with Schneider Electric supplied BMS systems and devices that use the following standards for buildings: I/NET, MicroNet, NETWORK 8000, and Andover Continuum Infinet.

Data can be exported towards third party Software and applications via Postgres RDBMS using the EcoStruxure Building Operation companion software provided by Schneider.

4.2.11 Schneider Electric PowerTag

Figure 22: Schneider Electric Power Tag gateway

The Schneider's PowerTag system is used to monitor the electrical distribution installation through any supervision system. The wireless devices in the PowerTag system are used to monitor and measure the electrical switchboards and busbar trunking systems via a Modbus TCP/IP communication network. The typical deployment model is represented in the following picture:

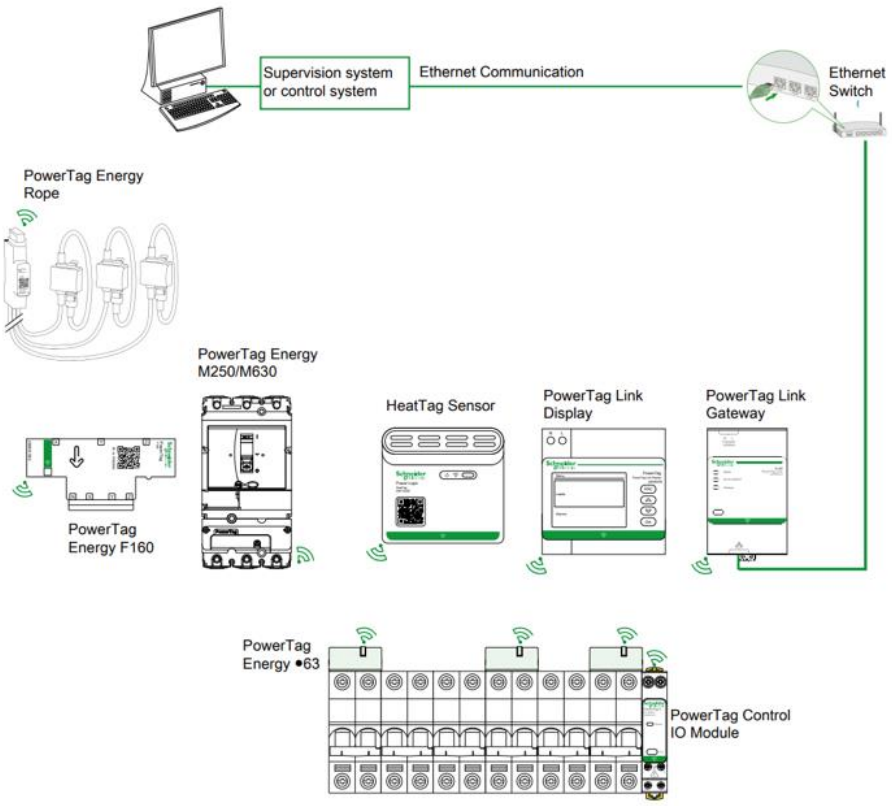


Figure 23: Architecture of Power Tag measure system

PowerTag Link permits the following operations:

- Concentration of PowerTag Energy wireless sensor data
- Ethernet connection via the RJ45 port
- Load monitoring:
- Alarm sent by the energy sensor in the event of a voltage loss, pre-alarms on predefined thresholds (50 %, 80 %) or customized thresholds (thresholds on currents, power, voltages and cumulative energies)
- Load running time counter
- Power synthesis (kW)
- Alarm management on current/voltage/load level thresholds by email
- Send control orders to PowerTag Control output to operate a load remotely and get load status thanks to feedback loop on associated input
- Collect status of contact from PowerTag Control input
- Display of alarms and pre-alarms on PowerTag Link embedded web pages
- Easy integration into system with Com'X 200, Com'X 510 and other Schneider Electric software and third party Building Management Systems (BMS) thanks to EcoStruxure Power Commission report in pdf format. This report provides dynamically all the Modbus registers and associated meanings for an easy integration into the system
- Remote metering capability using the PowerTag Link monitoring page.

4.2.12 Siemens Gamma Instabus

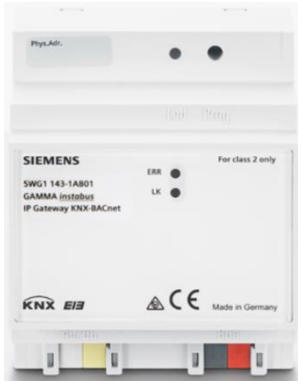


Figure 24: Siemens Instabus Gateway

GAMMA Instabus from Siemens is based on the KNX standard for home and Building Control, which guarantees interoperability with all certified KNX devices on the market. The comprehensive product portfolio consists of smart field devices and enables networked applications. GAMMA instabus end devices offers support for lighting, solar protection, display and operation,

energy monitoring, system products as well as heating, ventilation and air-conditioning. GAMMA instabus modules IP Router N 146/02, IP Interface N 148/22 and IP Control Center N 152 also provide support for KNXnet over IP to interconnect KNX networks with IP LAN and the BMS software.

Finally, Siemens Building Control systems, through the Desigo system, include support for OPC, Modbus and M-Bus communication buses as well.

4.2.13 Tridium Niagara and Jace 8000

Figure 25: Tridium Niagara Jace8000 gateway

Tridium Niagara framework provides many drivers to integrate different communication buses and to translate their corresponding protocols into OASIS oBIX (Open Building Information Xchange) standard protocol. The following picture describes the typical deployment scenarios for the JACE gateway and related hardware components:

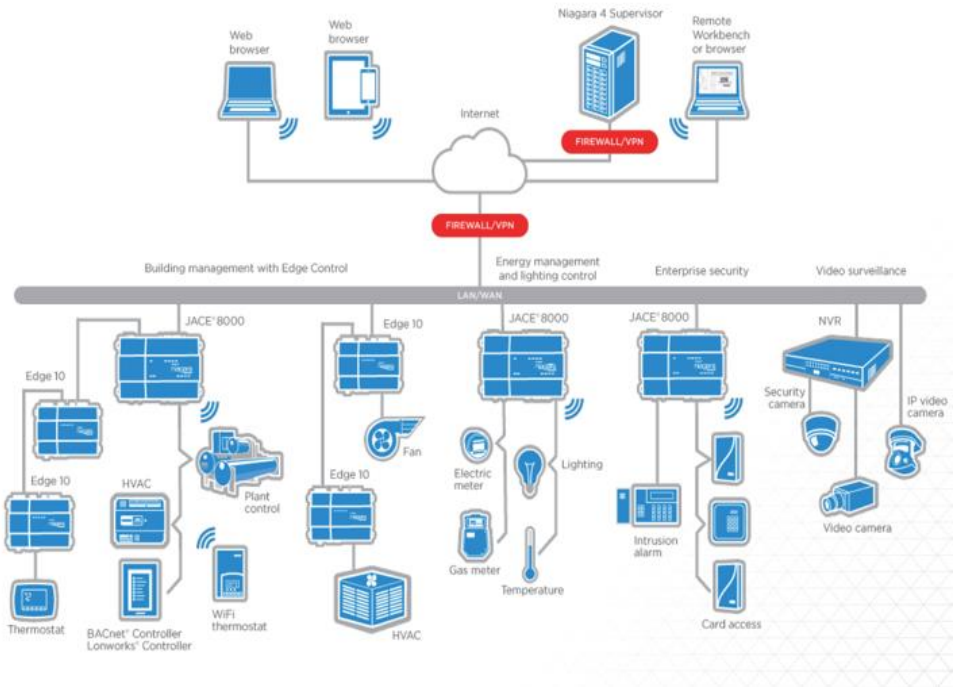


Figure 26: Tridium Niagara framework

The following table summarizes a partial list of some supported protocols:

Figure 27: Niagara and partners: list of supported protocols

Protocol Driver	Developer
BACnet	Tridium
DALI	Control Network Solutions
KNX	Tridium
IEC 61850 MMS Driver	Forest Rock Systems Ltd

Protocol Driver	Developer
iLON Driver	Tridium
M-Bus	Tridium
MQTT	Tridium
Modbus RTU	Tridium
Modbus TCP	Tridium
oBIX	Tridium
OPC DA	Tridium
OPC UA	Tridium
Profinet	QuickLink Solutions
SNMP	Tridium
Z-Wave	Tridium

4.3 Gateways: maturity of the offer and level of adoption

According to a recent market analysis of Tecnavio[36] the industrial IoT gateway market is expected to grow by USD 1.12 billion, progressing at a CAGR of over 15% during the forecast period 2020-2024. According to the report, the key markets for the industrial IoT Gateways are US, China, Germany, Canada and UK.

Despite the large margins for further growth, the IoT Gateways offering is already mature and their adoption is widespread and consolidated. Depending on the specific application domains, vendors provide wide range of features, communication protocols support and edge processing capabilities. Industrial IoT gateways are moving from simple devices that bridge OT and IT networks to intelligent edge-computing systems that can learn, react and control edge environments. Given the huge number of potential applications and use cases, it is impossible to identify a "one size fits all" solution: some products target industrial automation and shop-floor, other vendors are focused on energy management, transportation and automotive or building management: each application domain poses very different requirements in terms of communication protocols, deployment models, operating environmental conditions, edge-to-cloud connectivity and required hardware and firmware resources. Most flexible solutions are based on open standards, protocols and open-source software such as Linux OS but this flexibility comes at a cost in terms of hardware and operational complexity and required system integration activities. On the other end, highly specialized solutions are more cost effective but sometimes relies on proprietary HW and FW architectures and require different tools and software to operate in real production-grade scenarios. This may introduce potentially risky lock-ins and additional recurring operating expenses through critical features management such as FOTA (firmware upgrades) and SIM management: it is important to analyse all the implications of the selected trade-offs between flexibility versus proprietary solutions and identify the right balance for each use case.

Therefore, while both maturity and adoption of IoT Gateway are still growing, the market is very fragmented: the term "IoT gateway" means very different things in distinct application contexts, both in terms of hardware, firmware, connectivity options and resources. There is little chance this fragmentation will reduce any time soon given the great number of technologies and application scenarios encompassed by the Industrial Internet of Things.

[36] See https://www.technavio.com/report/industrial-IoT-gateway-market-industry-analysis

4.4 Gateways: the quest for a "universal protocol"

The open issue due to the large and largely diverse number of communication protocols in Building Management Systems seems to also reverberate to Smart Home systems; and it seems to be more visible and urgent when one comes to analyse the available offer of gateways. Comparing to the electrical world, the issue can be described with a joke, well-known between electricians: "When I will see a unique standard for plugs and sockets, it will be surely the end of the world!". Summarizing, diversity between communication protocols sets an issue[37] for the following reasons:

- increases the technological fragmentation,
- creates confusion of consumers when choosing a product for their house,
- inserts a necessity to verify compatibility between components in a smart home system and likely adaptors/transcoders.

Quoting a recent MDPI article[38], one can say that "one possible solution for this fragmentation is to make a gateway to handle the diverse protocols as a central hub in the home. However, this solution brings about another issue for manufacturers: compatibility. Because of the various smart devices on the market, supporting all possible devices in one gateway is also an enormous challenge."

A recent good news comes along on this topic, revealing how much is felt as strategic by the IT giants Apple, Amazon, Google, Zigbee Alliance and Comcast: the launch of CHIP program[39] (acronym stands for "Connected Home over IP"), a new home automation connectivity standard, which features compatibility among different smart home and IoT products and software. The project (born in late 2019) aims to unify the currently fragmented systems, setting a proprietary (owned by Zigbee Alliance) but royalty-free standard.

The standard is designed to be based on Internet Protocol. CHIP will be able to enable smart home devices, mobile apps, and cloud services to communicate and to define a specific set of IP-based networking technologies for device certification. Practically, CHIP is another communication protocol but it's open, it's based on the more universal one (IP) and it comes from one of the most popular alliances for smart home communication protocols, Zigbee Alliance. "Its potential is to create a USB-like "plug-and-play" protocol for the home" like says Google in its webpage dedicated to developers.[40]

The scope of CHIP project is to open the doors to smart home devices manufactures, relaying on the attractivity of a simpler development and of an increased compatibility for the products. The promised benefits are:

- an easily adoptable application standard for a set of network technologies, including Wi-Fi, Thread, and Bluetooth Low Energy
- end-to-end data security and privacy among in-home and mobile devices, and cloud services,
- a unified and standardized baseline set of out-of-box setup components,
- platform and ecosystem-agnostic technology for any device and any ecosystem,
- reducing one-off gateways and translators by building upon IP,
- a consistent programming model for devices, mobile, and cloud.

The project group is also expected to be joined by board member companies of Zigbee Alliance, including IKEA, Kroger, LEEDARSON, Legrand, MMB Networks, NXP Semiconductors, Resideo, Samsung SmartThings, Schneider

[37] Here we follow Linh-An Phan and Taehong Kim in their paper recently published by MDPI: "Breaking Down the Compatibility Problem in Smart Homes: A Dynamically Updatable Gateway Platform", MDPI 2020, in https://www.mdpi.com/1424-8220/20/10/2783/pdf.

[38] Ibidem.

[39] See official CHIP project webpage: https://www.connectedhomeip.com/.

[40] See https://developers.googleblog.com/2019/12/project-connected-home-over-ip.html.

Electric, Signify, Silicon Labs, Somfy, and Wulian.[41] We point out that Zigbee Alliance until now gathers 22 "promoter" companies[42], 172 "participants" and 131 "adopters", being the third alliance in the field of IoT with the largest number of associates worldwide: in fact, Enocean has more than 400 members, KNX Association and LoRa Alliance have 500 members each[43].

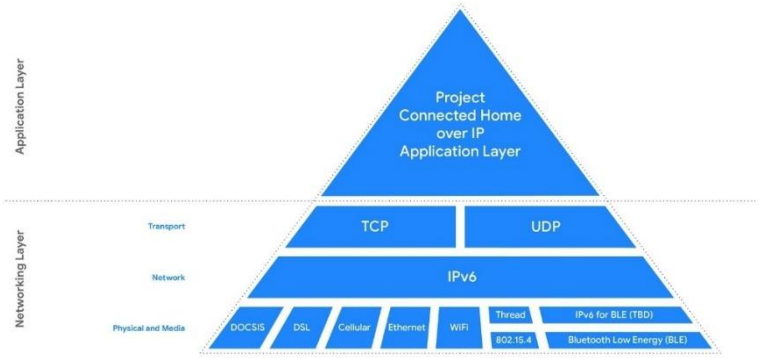


Figure 28: the structure of CHIP project

4.5 Gateways: ranking

It is hard to identify an appropriate ranking among IoT Gateways as they typically provide different features and they are often designed with special purposes in mind. The ranking provided here is also based on the specific requirements of the projects and the native protocols support provided by the gateways in terms of IoT protocols that are required by AutoDAN implementations.

Gateway	Note
Schneider Electric Wiser for KNX	Schneider Electric's devices are used on different demonstration sites and they are natively supported by this gateway
Schneider Electric SmartX AS	Schneider Electric devices are used on different demonstration sites and they are natively supported by this gateway
Schneider Electric Power TAG	Schneider Electric devices are used on different demonstration sites and they are natively supported by this gateway
Kontron Embedded Box PC	Kontron provides industrial grade IoT gateways with no lock in and recurring costs. Its flexible architecture helps tailoring hardware gateways resources to a wide range of specific use cases
Tridium Niagara and Jace 8000	Tridium features a rich set of IoT protocols support. Niagara software platform is needed to configure and operate the gateway
ABB i-bus KNX	No particular criteria to be highlighted
ADLINK MXE Gateways	No particular criteria to be highlighted
Advantech Wise Gateways	No particular criteria to be highlighted
Dell IoT Gateway	No particular criteria to be highlighted
Eurotech ReliaGATE serie	No particular criteria to be highlighted
INSYS icom SCR-Serie	No particular criteria to be highlighted
Neousys IoT Gateway IGT-20 / IGT-30 Serie	No particular criteria to be highlighted
Siemens Gamma Instabus	No particular criteria to be highlighted

Figure 29: Gateways ranking

[41] See "Apple, Google and Amazon decide to 'play nice' over smart home tech", BBC news 2019-12-18, in https://www.bbc.com/news/technology-50842062.

[42] Promoter companies are: Amazon, Apple, Assa Abloy, Comcast, Google, Huawei, IKEA; Kroger, Leedarson, Legrand, Lutron, NXP, Resideo, SmartThings, Schneider Electric, Signify, Silicon Labs, Somfy, ST, Texas Instruments, Tuya, Wulian.

[43] In this ranking we consider only the manufacturers members.

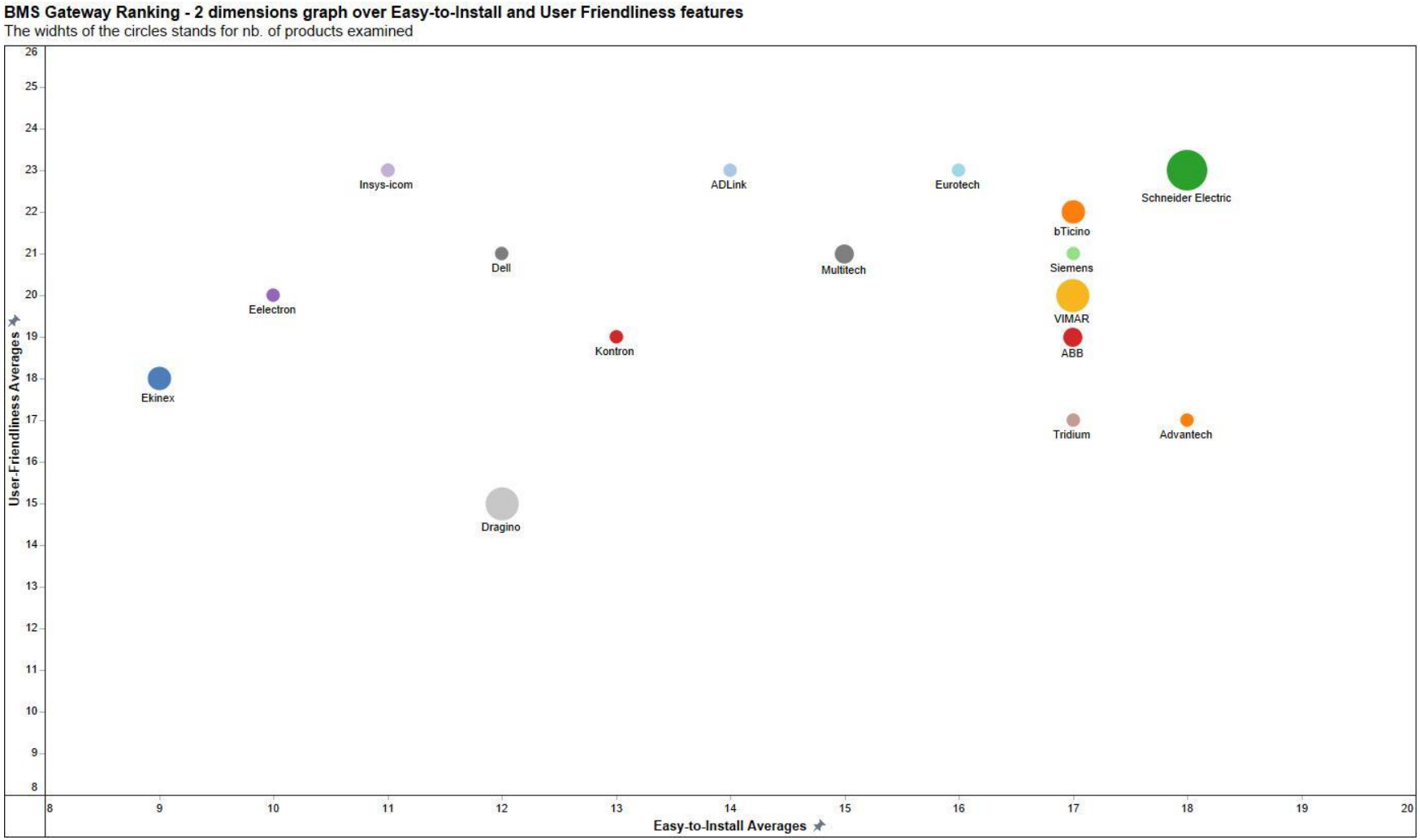


Figure 30: Ranking of Gateway of BMS offer per Brands

5. Building Management Systems

5.1 Building Management Systems listing

Traditionally Building Management Systems control functions of HVAC, lighting, fire and life safety, security and access controls, and supervision and automation of the control functions. In the present research we listed and analysed 203 products under the group of Building and Energy Management Systems. The main functions of these systems are energy & metering, lighting control and regulation, HVAC and multi-function control and actuation, Safety & Air Quality sensing, Security and Supervision. Energy & metering offer has been analysed in the dedicated chapter 3 “Smart meters”; the same so for Supervision (in chapter 4, “Gateways”). For the consistency of the offer analysed, see Figure 31: BMS Offer - # of product listed per functions and categories.

We have avoided to take in account special systems like fire detection and signalling, emergency lighting as they are subset of the BMS offer which are out of the scope of Auto-DAN project.

For the reference of the final sector of application of the BMS offer analysed, see Figure 32: Consistency of the BMS offer analysed per sector of application.

BMS - Nb. of Ranges/products listed

	Categories Group			
Preferred application sector Group	Comfort	Gateway & SW	Safety & Security	Grand Total
Residential	6	5	3	14
Tertiary	142	44	2	188
Heavy duty/Industrial		1		1
Grand Total	148	50	5	203

Figure 32: Consistency of the BMS offer analysed per sector of application

BMS - # of products listed

Functions Gro..	Category	
Energy & Metering	Actuator	1
	Energy meter	48
	Gateway	3
	Relay	1
	Smart Plug	2
	Socket	1
	Switch	2
Lighting control and regulation	Actuator	5
	Controller	1
	Gateway	2
	Gateway & Controller	1
	Relay	3
	Sensor	8
	Smart Plug	1
	Switch	12
	Transmitter	1
Multi-function control and actuation	Actuator	4
	Controller	6
	Energy meter	2
	Gateway	11
	Relay	4
	Sensor	12
	Siren	1
	Switch	4
	Thermostat	5
Safety & Air Quality	Sensor	10
Security	Button	1
	Camera	4
	Gateway	3
Supervision	Controller	3
	Gateway	16
	Gateway & Controller	5
	Router/Modem	1
	Transmitter	3
	Valve command	1

Figure 31: BMS Offer - # of product listed per functions and categories

5.2 Building Management Systems: market overview, maturity of the offer and new business models

The building automation solution market is undergoing a large structural change. Although the building automation technology is seeing increased adoption throughout the global building stock, large BMS providers are contending with IT-focused innovation, promoted by a new set of intelligent building competitors. Traditional BMS control devices are increasingly embedded with computing and digital communications tools and therefore are more remotely-accessible. However, they are competing with smart building solutions that use Internet of Things and other innovative approaches for data collection, communications, and analytics. Another segment of market is coming, called "Intelligent Building" (IB), in which the automation functions are managed through Artificial Intelligence and a maximum level of integration between the technological systems, thanks to IoT. European BMS Market is expected to growth over the same period at a CAGR of 1.8% from 9.8 Bn $ in 2020 to 11.6 Bn in 2029.[44]

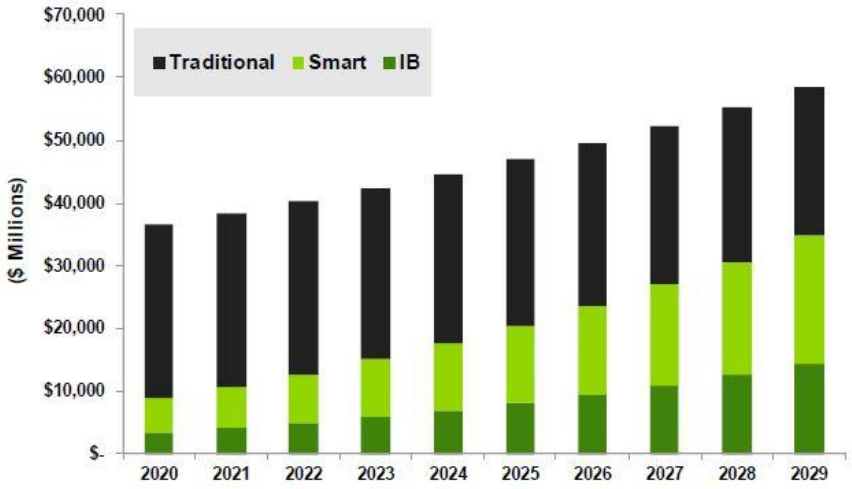


Figure 33: Total Market Revenue by Market Segment, Worldwide

On a 10-year timeline, this transition means traditional BMS is no longer a default solution for large buildings and enterprise customers, though traditional BMS incumbents are anticipated to integrate or develop standalone technologies similar to those offered by market entrants. Traditional product revenue is expected to contract from $27.9 Bn to $23.7 Bn at a compound annual growth rate (CAGR) of 1.8% between 2020 and 2029. During the same period, the smart building market is expected to expand from $5.4 Bn to $20.5 Bn, at a CAGR of 15.9%. Also, over the forecast period, the IB market is anticipated to expand from $3.3 billion to $14.3 billion, at a CAGR of 17.6%.[45]

The opportunity to generate energy savings remains the foundation of BMS market demand, but growing value exists in data ownership, advanced operations efficiency, and occupant engagement. Subsystem integration is also becoming more common with BMS, starting with the coordinated control and optimization of HVAC and lighting. These and other advancements are helping traditional BMS remain competitive with new smart building solutions, which offer holistic business optimization capabilities enabled largely by advanced data collection, analytics, and services.[46]

A point apart must be set for the role of BMS in energy efficiency renovations of buildings. Building Management Systems are required in energy renovations, which entail various intervention measures both on the envelope of a building and on the technical systems (passive energy efficiency and active energy efficiency). The energy efficiency improvements are an important pillar for achieving the EU energy efficiency target for 2030 and the transition

[44] See Talero, D., Maxwell, K., "Building Automation Solutions for Commercial Buildings", Guidehouse Insights, 2020

[45] *Ibidem*.
[46] *Ibidem*.

towards climate-neutral Europe by 2050.[47] Nevertheless, actual energy renovations taking place today neither meet the rate, scale nor the depth aligned with their energy efficiency potential. To address the issue of underinvestment in energy efficiency, revisions in 2018 to the Energy Performance of Buildings Directive 2010/31/EU and Energy Efficiency Directive 2012/27/EU, have strengthened the existing policy and financial framework.[48]

The BMS market is changing corporate business executives and sustainability professionals need customized, comprehensive, and cost-effective networked building solutions. Innovative business models seek to address the rapidly evolving technology landscape within buildings and the networked buildings ecosystem. New market entrants, incumbent manufacturers, and software vendors are challenging the status quo relationship between customer and vendor, shifting the one-time hardware purchase to a recurring financial business relationship.[49]

The emergence of new business models that ensure recurring revenue and continued customer engagement has gained attention from players outside of the traditional building technology incumbents. Additionally, the goal of networked building solutions to provide offerings outside of historical building offerings, to incorporate energy, IT, and transportation offerings, among others, has led to various entry points for new market players. These market players range from service providers to platform providers, and IT and communications firms to building technology manufacturers.[50]

5.3 Building Management Systems: what does it mean to be an "Open" BMS

As societal and business pressures continue to push building owners and operators to improve the efficiency, sustainability, productivity, and tenant experience of their buildings, the role of the BMS is growing beyond its traditional role of building heating, ventilation, and air conditioning (HVAC). The term "open" is often used to describe desired functionality of a Building Management System (BMS). It is thought to be essential in achieving the ambition of a smart building. But interestingly, that term itself, while used often by building owners/operators as requirements for their system, as well as by vendors to describe attributes of their systems, generally creates much confusion and ambiguity, since the industry lacks a standard definition. Here we propose a guideline so that decision makers can make a more informed system selection based on the desired outcome(s) of the building.

5.3.1 Criteria for assessing openness

Every building is unique and openess is a complex topic. (It is much more than a discussion of open protocols although that's commonly where the conversations go). The framework introduces three distinct layers defining criteria to assess open. Each layer has its own expectations and challenges, and each layer builds from the previous layer. This means the capabilities from layer 1 are pre-requisites for achieving the capabilities of layer 2, and layer 2 are pre-requisites for achieving layer 3.

[47] See Economidou, M., Todeschi, V., Bertoldi, P., "Accelerating energy renovation investments in buildings – Financial & fiscal instruments across the EU", EUR 29890 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-12195-4, doi:10.2760/086805, JRC117816, available in https://publications.jrc.ec.europa.eu/repository/handle/JRC117816

[48] *Ibidem*.

[49] See Maxwell, K., Wedekind, S., Woods, E., "Ecosystem Strategy for Networked Buildings: Business Model Innovation Beyond the Status Quo", Guidehouse Insights, 2021.

[50] *Ibidem*.

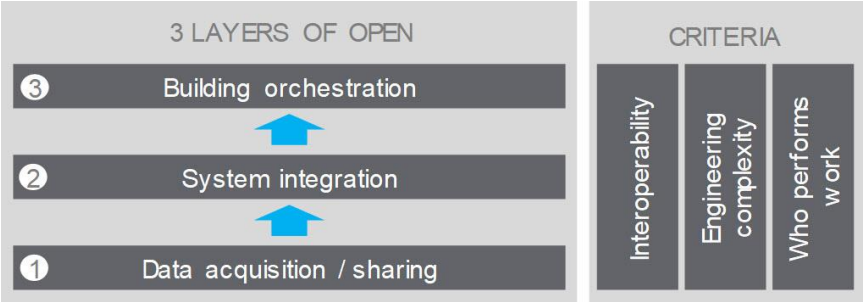


Figure 34: 3 layers of openness in BMS

For each of the three layers in the framework, we have defined three criteria for assessing how open the system:

- **Interoperability** – assesses the ability for one part of the system to work with another part, or one system to work with another system
- **Engineering complexity** – assesses how difficult it is to achieve the interoperability; i.e. how much customization and programming is a key consideration
- **Who performs the work** – assesses whether specialized skills and individuals are necessary to achieve the objectives; i.e. does work require certified, specialized skillsets?

There are often trade-offs with these criteria. For instance, you might be able to achieve a highly open system in terms of interoperability by sacrificing engineering simplicity; or work can be done without engineering complexity, but only by a vendor's certified technician. Having this construct for discussing a BMS's degree of "openness" brings these important topics and trade-offs into the picture.

5.3.2 Layer 1 – Data acquisition and sharing

Data acquisition and sharing is the critical foundation for BMSs. Within the conventional scope of controlling the HVAC of a building, the system must be capable of sending and receiving data to and from sensors and actuators and other building controllers. Sensors/actuators are easiest to integrate as they are one-way devices that share or receive data to/from a controller. Examples are simple sensors for pressure, temperature, etc.

Controllers require protocols to communicate. More and more, controllers use open protocols, and to consider a BMS open, it should be interoperable across multiple OT protocols (i.e. BACnet, LonWorks). But just because it uses an open protocol, doesn't mean it is interoperable. The needed data must be exposed by the vendor. The system should also support the extension of native protocols, in order to limit the number of gateways required to serve as "translators" to the sensors, actuators, and controllers. The BMS should not depend on calling in "experts" for day-to-day operations like modifying a room temperature set point or updating schedules.

5.3.3 Layer 2 – System integration

As the BMS scope expands beyond HVAC control, it must integrate with other systems within the building, such as the lighting system. The BMS must now be able to consume data in a different way. It must be able to push data to other systems and query data from those systems. It may also need to tie in with analytics services that may communicate to a proprietary cloud. One key topic here is the use of APIs vs files/databases vs OT protocols. APIs are a means of a vendor exposing the data for another system's use. Semantic tagging (labelling) and ontologies (relationships of things) are critical for interoperability. Without the right context of the data, it becomes difficult to use it. Brick and Haystack are two examples of semantic standards that help expose data in a standard way.

During system integration, another important consideration is authentication mechanisms. These can be a limiting factor and increase the complexity of integrating the systems together. It's helpful to look for a system that supports non-obscure authentication types like OAuth, as well as allows custom development of middleware to access 3rd parties that use proprietary authentication. An open system minimizes the time required to integrate systems together and simplifies integration with teams of experts.

Figure 35: example of an operator workstation with integration software

5.3.4 Layer 3 – Building orchestration

Building orchestration is complete coordination across all building systems. Think of this as Layer 2 at scale. It's what gets us to the ambition of a smart building where everything is integrated and tied together. It helps achieve optimized energy efficiency, tenant well-being, and productivity by streamlining and automating complex building tasks. These integrations are generally bi-directional, so it's likely to include complicated object types and data structures like time schedules. This increases the likelihood of semantic differences between systems and a need for custom rules and workflows to fill in the gaps. A more open BMS would have a toolset that supports these custom rules and workflows.

In the white-paper "Smart Buildings: A Framework for Assessing the Openness of a Building Management System"[51], the authors discuss how presentation, point discovery/mapping, programming, and APIs can determine how much complexity is needed here. The paper also discusses common integration activities that can occur that require varying skills and expertise. For instance, setting up workflows in most cases can be accomplished using a tool with minimal amount of training. However, complex workflows may require the help of a software developer.

The conclusions are:

- The role of the BMS is evolving. Its scope reaches far beyond the traditional function of HVAC control. It now must play a key role in reaching the ambition of a smart building. "Open" is a commonly stated requirement during the discussion and selection of a BMS, but the industry lacks clear definitions, categorizations, and criteria to allow for intelligent conversations on this subject.
- That missing framework consists of 3 layers: data acquisition, system integration, and system orchestration. Every building is unique and has different objectives. At each layer, there are varying expectations and challenges the system exhibits, and each layer builds from the previous layer.

Schneider Electric developed a full-stack solution "EcoStruxure Building" based on these three layers of connected products on the basis, edge controls in the middle and services based on advanced analytics on the top. It's a scalable architecture, based on open standards, capable of integration of 3rd party systems and of leveraging the full potential of automation and IoT in order to address the "Intelligent Building" segment of market.[52]

[51] Jeffrey Bowman, Chris Megede, Wendy Torell, "Smart Buildings: A Framework for Assessing the Openness of a Building Management System", in: https://download.schneider-electric.com/files?p_enDocType=White+Paper&p_File_Name=WP501_V1_EN.pdf&p_Doc_Ref=Buildings_WP501_EN

[52] See https://www.se.com/ww/en/work/campaign/innovation/buildings.jsp

Table 7: Key takeaways, for each layer of the Open BMS framework provides key takeaways regarding "open" in the context of each layer of the framework.

Table 7: Key takeaways, for each layer of the Open BMS framework

Layer	An "open" BMS should…
1 – Data acquisition / sharing	be interoperable across multiple OT protocols
	support extension of native protocols, limiting the number of gateways required to communicate with sensors, actuators, and controllers
	not depend on "experts" for day-to-day operations
	have the ability to integrate system-to-system through any means required
2 – System integration	minimize the time required to integrate systems together
	simplify integration between systems with a vendor provided team of experts
	be able to implement custom rules and workflows, as the orchestrator
3 – Building orchestration	be able to support customization with the presentation, point discovery/mapping, programming, and APIs
	allow for programmers to expand functionality with setting up workflows, setting up custom UIs, and connecting to third party applications

5.4 Building Management Systems: ranking

The brand with the major number of categories listed are major players like Honeywell, bTicino (part of Legrand Group), Vimar and Schneider Electric. A minor player like Dragino is highly valuable because presents a wide range of products. The focus is essentially EU market. See Figure 36: # of products vs categories for BMS Offer in order to see the variety of categories offered by the several manufacturers.

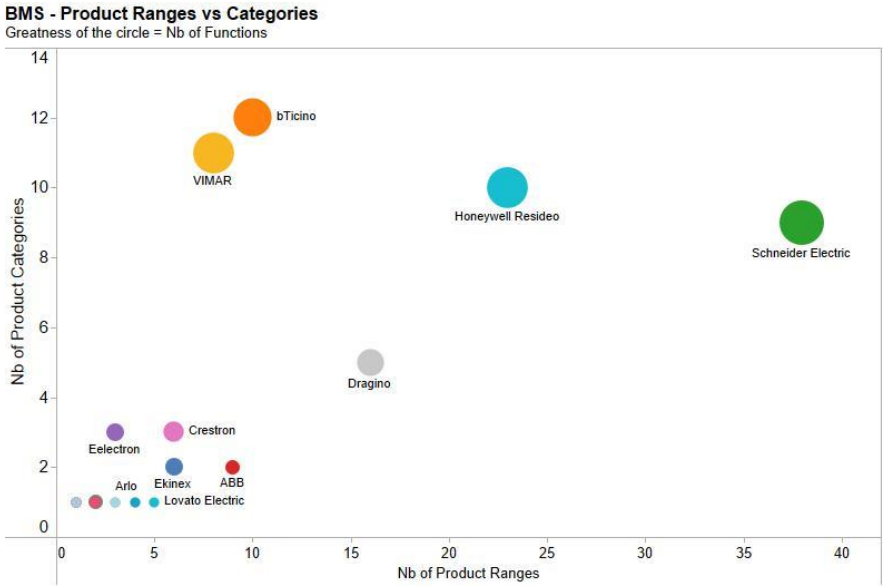


Figure 36: # of products vs categories for BMS Offer

In Figure 37 we reported the result of the ranking of the BMS offer here analysed. All manufacturers are visualised. On top right we have a set of major player, like VIMAR, Schneider Electric, bTicino, Honeywell due to offer quality, presence of a partner program, technical assistance to installers, user experience, lifetime of the company. On the bottom left we have little layer, manly newcomer or major player which diversified their offer towards BMS only recently. On the middle top we have little companies which developed a very valuable offer thanks to their market agility and IoT orientation, like Tago, Multitech, Eurotech, ADlink.

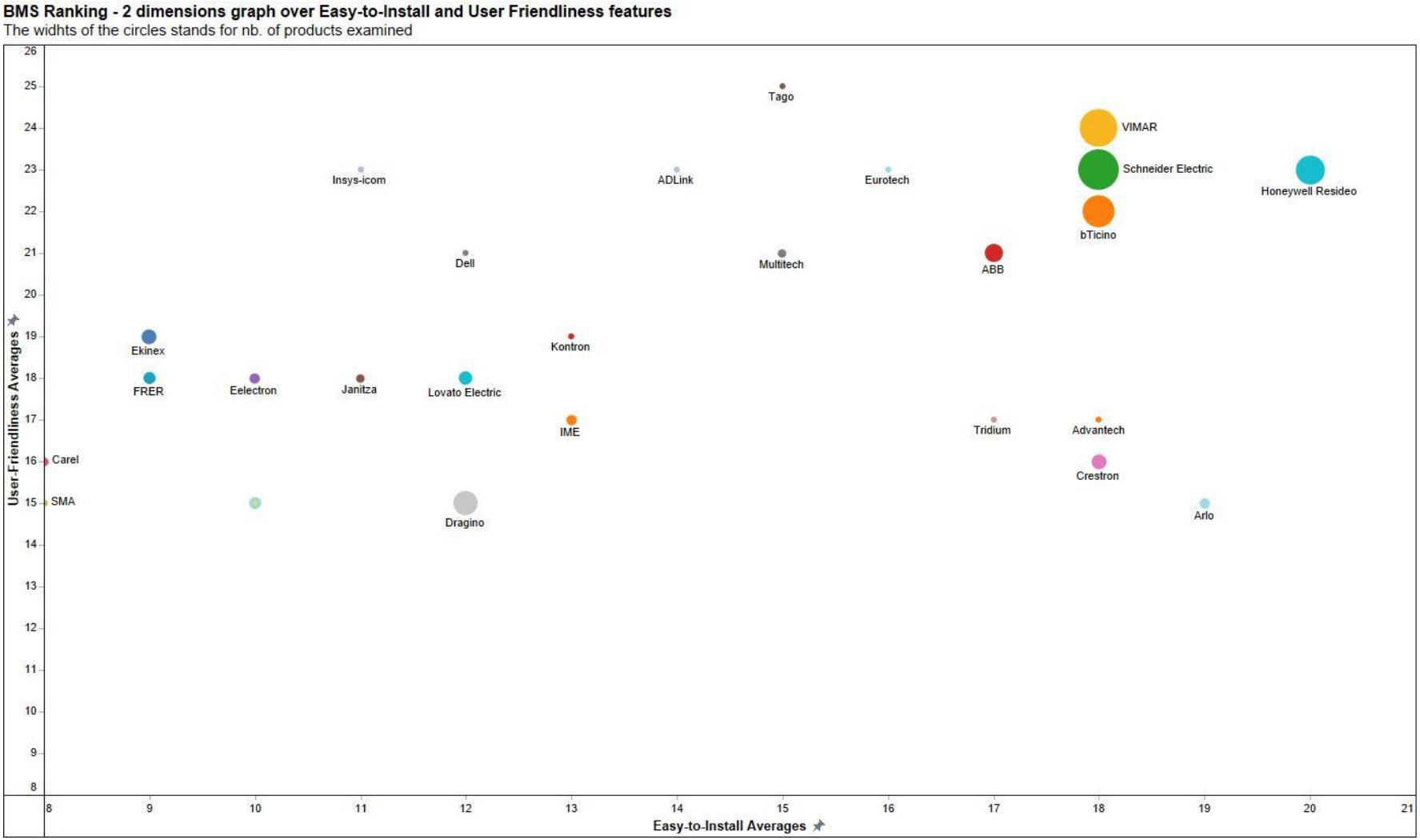


Figure 37: BMS ranking via a 2-dimensions graph

6. Smart Home Systems

6.1.1 Overview

Buildings can be managed in many different ways. The traditional method does not involve any outside communication, while the most advanced systems, used at multi-site corporation level, comprise of some of the most sophisticated cloud computing solutions on the market. For the purposes of this study, building management systems can be characterised under two main categories:

- Traditional systems with no external cloud connection (BMS), traditionally present in several markets: offices, healthcare, hotel, industrial building…
- Systems that have an interaction with the cloud, here classified as Smart Home because they have been developed mainly for Residential market.

N. of Brands and Products per type of Systems and Preferred application sector

System	Preferred application sector	Distinct count of Brand name	Distinct count of Range/Product
Building & Energy Management	Residential	4	14
	Residential/Little Tertiary	6	71
	Tertiary/Retail	3	7
	All sectors	21	80
	Heavy duty/Industrial	1	1
	Total	30	173
Smart Home	Residential	41	233
	Residential/Little Tertiary	4	20
	Total	45	253

Figure 38: N. of Brands and Products per type of Systems and Preferred application sector

Smart Home cloud systems can be further subdivided into two broad subcategories:

- Simple Cloud Solutions (IoT Systems)
- Enterprise Cloud Solutions (in-cloud Smart Home systems).

6.1.2 Traditional systems

Standalone systems are generally considered traditional. They are most commonly found in homes and older commercial buildings. A typical timer or thermostat system operating in a closed loop would be a common solution for climate control, for example. Nobody other than the occupant of the building concerned is aware of what the temperature is, or whether or not the heating system even works. Older security systems operate the same way: they generate a local alarm only. If there is any automation of appliances or lighting, it is only as a separate system unconnected to anything else. Most electricity and gas metering also fall into this category: the meters need to be read in situ, by a human. In fact, building management is really carried out by a physical person, not some autonomous algorithm running on specialised equipment. That person is in effect the BMS, and he or she uses devices and equipment that are specific to each parameter of concern in order to run the system.

Suppliers of devices would include Danfoss, Honeywell, and many more, for HVAC thermostats and timers. For the security function, there are many companies, mostly small and local. Lighting is typically not controlled by any automated system. Other than for the use of timers for cooking and delayed starts on machines like dishwashers, appliances are typically not automated.

6.1.3 Simple Cloud Solutions – IoT Systems

With the arrival of widespread and reliable internet over the last ten years or so, many systems that were previously operating as standalone systems now boast some degree of cloud operability. Modern climate control systems, which are central to BMS, are an example. They tend to operate at some level with a cloud connection, but the degree to which this occurs can vary to a significant extent. For example, clocks can be kept synchronized with real time, and users can operate their systems from their mobile phones if they so desire. There may also be a user dashboard showing some salient operating features such as total energy consumption over a recent billing period. Examples are the Nest, Hive and Climote, but there are many many more. Similarly, in the lighting space, other companies, notably Philips with their Hue, have systems

that allow consumers to operate their lighting systems from their phones. Such solutions can be classified as "IoT systems", rather than just BMS systems, as they are devices that focus on a specific task but with the added dimension of being controllable through the internet. The main function of Hue is to conveniently control lights from phones, although recently some other functions have been added.

In the security arena, monitored alarms are now quite widespread, especially in businesses, where remote surveillance of buildings is possible through the use of a cloud connection, usually through a GSM link, with a battery for added reliability. In fact, precisely for security reasons, these systems tend not to use the same communications infrastructure as other internet connected devices in the building, so they are purposely often not part of any formal BMS.

In another aspect of security, one veteran operator, Yale, through its August brand has developed a set of secure access solutions based on IoT technology. Users can manage building access through their phones. However, the applicability of this solution does not extend beyond security.

Electricity meters are becoming increasingly smart too, meaning that not only can they be read remotely, but the prospect of variable time-related charging or demand response systems are increasingly viable, if not yet implemented.

There are plenty of examples of systems that function using the cloud as part of their operating structure. In fact, Auto-DAN itself could fall into this category. The function of the hardware being deployed in homes and small businesses is to monitor and identify electrical loads, and furthermore to recommend ways in which the overall consumption can be optimised. Most of the computational effort is performed in the cloud, though. However, there is no attempt to manage all aspects of buildings, such as security, for example. It is merely an aspect of building management. The BMS function is still performed by a physical person operating at a higher level, using the input provided by Auto-DAN and other devices and systems.

One characteristic that all these systems share is that they need a local hub of some description at the location concerned. They may operate on Wi-Fi (e.g. Nest), or they may have their own application-specific gateway, (Yale-August, HKC, and many more). Only in exceptional cases can they communicate directly to the host (e.g. smart meters, security systems) over IoT/GSM networks or power line carrier (e.g. Devolo). More significantly, though, is the fact that they are still standalone systems in the sense that they operate independently, meaning that users need to install separate apps on their phones as well as install the associated hardware sequentially each time. Each function has its own identity as far as the user in concerned. This can be frustrating and tedious once the enthusiasm associated with the possibilities of cloud operation wears off. Of course, they do have the advantage of being operated locally without any cloud connection too.

Solutions that are geared towards family homes need to deal with several challenges. First of all, in order to keep costs manageable, it should be possible to self-install the systems. In particular, no special skills should be required. August (Yale) scores well in this category, as do Philips (Hue) and some of the simpler Honeywell solutions. Secondly, they need to be easy to use. This is more difficult to gauge, since it depends so much on the degree of familiarity of the particular individual involved with technology.

Another factor of importance in a residential context is the degree of maturity of the technology concerned. This can be indicative of reliability, since mature systems imply that they have been tested over a sustained period and in different environments. VIMAR (Italy) is a mature company with a broad range of IoT products, including IoT blind and curtain controls. Their system, which works with Bluetooth or ZigBee, does require some training as well as a likely professional installation.

A risk associated with new solutions is that the companies behind them are often not well established, meaning that they may not be around for years to come. One of the difficulties they have is that there are many competitors offering similar solutions, and not all will survive. For services that depend on long-term operation in the cloud, this can be a problem; if cloud server fees are no longer paid, the IoT service will stop abruptly denying the consumer the service for which he or she signed up for at installation.

Some newer companies succeed in managing both growth and stability at the same time. August (Yale) is a new company, but it has the backing of a long-term player, Yale. Other IoT solution companies on a growth path include Dragino (China), Tago, and Awair.

Most households nowadays operate a mix of traditional solutions and simple cloud solutions, e.g. a cloud-based HVAC system with a traditional electricity meter and an unmonitored alarm. Each is a standalone system in the eyes of the homeowner. In this situation, the need for a unified building management system is beginning to be felt but is not yet indispensable except to a few.

There are thousands of companies worldwide that have developed systems for the home that operate with cloud functionality. Each has developed a method to adapt its existing traditional application, be it an appliance, heating system, security, etc., to work with the cloud. Some have even entered the space from the technology angle (e.g. Nest) rather than the traditional route, in a manner similar to what has happened most notably in the automotive sector where newcomers have appeared quite dramatically offering valid electric vehicle solutions. Many of these companies, having invested great resources in their cloud efforts, see an opportunity to extend the reach of their new technology to cover applications that appear related. For example, a heating system solution provider may seek to extend its reach to provide a security solution too.[53]

Companies may perceive that adding new functions to an already existing communication and cloud infrastructure is not that much of a challenge. There have been many instances of this phenomenon, such that there are now multiple suppliers overlapping in the market with broadly competing offerings, some even using the same hardware sourced from third parties, especially Chinese made remote power switches. It is now possible to commission home automation systems from multiple types of suppliers.

One House – One Cloud

While many companies have not succeeded in providing true multifunctional solutions using the cloud (having underestimated the effort and cost required as well as not having been able to service the market adequately) they have nevertheless demonstrated that the tendency is without doubt towards integrated solutions involving multiple parameters and systems, where effectively full building management systems under one single umbrella are the ultimate goal. In fact, this is where the cloud element becomes truly relevant and indispensable, as it is only there where all the data from all the various sources can come together. It is entirely logical, therefore, that these solutions should eventually migrate to the cloud and become integrated with each other. There are many providers chasing this market. Samsung and Xiaomi (Mi) are examples.

Big Tech – Smart Building Solutions

The big tech companies, especially Google, Amazon and Apple (Home kit), have all entered the in-cloud smart building space. Microsoft supports it with their back-end tools. Their solutions, which consist of simple hubs, are easy to deploy, and connect directly to the cloud through the local internet. Rather than exclusively supply a set of own brand devices that control, for example, lighting, they certify third parties who make sure their respective smart products are compatible with the host systems. These solutions are platforms in which separate smart systems can work together and, in the process, they are gradually becoming building management systems. However, they are not open systems and cannot accommodate products that are not certified.

- The Google Nest started as a device to control heating and cooling. For that to work, it requires the addition of a boiler module which communicates with the main unit through a 868MHz link.

[53] Take SONOFF, a Chinese manufacturer of IoT devices, as an example. They stared with a simple remote switch and now have a complete home automation system, even some industrial gear. Similarly, Hue started with light control and is now attempting to expand its area of competence to motion sensing and more

- D-Link is another operator in the in-cloud smart building space. They have a set of easy to deploy closed circuit TV security systems that connect to the cloud through the homeowner's Wi-Fi system. Other players include BeNext, who offer smart plugs. They have a solution based on a z-wave gateway. Their system is not as easy to use and deploy, though.
- A company called Brilliant offers a set of products that fall into the in-cloud smart building category, specialising in supervisory and intercom products. They require a local gateway, but do work through Wi-Fi. Some skill is required to set the system up.
- bTicino, the well-known Italian supplier of domestic electrical fittings, also offers a smart in-cloud software solution, targeted at professional installers.
- Control4 (USA) is another significant player in the building management arena. Their system, which uses many different communication technologies, boasts of the ability to control a broad set of loads in the typical home. Their goal is a "unified smart home system to automate and control connected devices including lighting, audio, video, climate control, intercom, and security."
- Homeseer is another significant player in the in-cloud smart building control. Their solutions are based on z-wave communication, and include video monitoring, sensors and smart switches. Installation requires some professional knowledge. Another player, in a crowded field, is Dusun, with a broad set of devices, including CO sensors, metering, alarms, networking, and more.

Home Assistant – The open source solution

All the commercial solutions are characterised by the restriction that only devices that are certified to work with their respective systems can be used. Home Assistant is the open source response to the in-cloud smart building phenomenon. This is a popular system, which aims to unite many systems, requires a gateway to operate, and works on z-wave, Zigbee, Wi-Fi, and more. It is not as easy to use and deploy as the Google Nest, for example, but it does have the advantage of being open, which means that anyone who can program a Raspberry Pi single board computer can connect into it or design a new product that is compatible with the system. It might be described as a hobbyist's solution to BMS, but it also can serve as a platform for new market entrants to develop solutions quickly.

6.1.4 In-cloud BMS Systems

In-Cloud Solutions for the Home

Real in-cloud BMS is still by and large a corporate phenomenon, but it is making inroads into the residential arena. There are several solution providers whose product offerings more squarely fall into this category rather than smart building system technology.

- Wattio (Spain) offers a broad range of devices, including sensors, meters and actuators, that target residential applications. Their system covers automatic gate opening, curtain operation, meter reading, smart plugs, lighting and much more. It operates on Wi-Fi or z-wave and is easily set up and used.
- Closed circuit TV monitoring is another aspect of BMS. Two players in this space are Amazon and Arlo. Their Wi-Fi-based solutions are easy to deploy.
- Elsys (Sweden) has a set of indoor environmental sensors, but unlike most applications use the LoRa-Wan communications network solution. Their monitors include air quality, occupancy, movement and parameters of that nature. The solution does require some level of professional assistance in the installation.
- Fibaro (Italy) offers a broad range of sensors and actuators, all controlled and sensed through their own z-wave-based hub. Their system can control gates and blinds, heating and cooling, security as well as lighting, so it covers quite a broad range of the applications involved in the typical residential dwelling.
- Ring is another player in building management. As their name suggests, their origin is in the doorbell function, a semi-security related function. They have extended the range of products to include camera and other associated items. The Ring system is easy to install.
- Yesly is another market participant. Part of the Finder (Italy) group, best known for their relays, their products include smart switches for typical domestic loads as blinds, shutters, lighting, and more. It is an easily configurable system that can be controlled from a phone. The solution is based on bluetooth.

Appliances

It is interesting to note that even the most comprehensive smart cloud solutions cannot include many of the typical major electrical loads in houses, with the exception of heating and cooling. Washing machines, dishwashers, fridges, cookers and many of the lesser countertop appliances can't be so easily integrated into third party building management systems. This is partly due to the fact that many of them require human presence to operate them anyway (e.g. washing machines need to be loaded and then physically switched on) or that there is not so much that can be done with automation (e.g. fridges need to run continuously anyway). The fact that they are so relatively inexpensive does not make it easy to add such functionality either. In any case, appliance manufacturers, such as Auto-DAN partner Arçelik, are dealing with the challenge by developing their own cloud connected systems.

Enterprise Cloud Solutions – Professional Smart Home Systems

A true cloud-based building management system is one in which multiple (even all) building parameters are monitored in real-time and fed to the cloud together for processing and visualisation to whomever is responsible for a building. This is far more complicated than it sounds. It is not a matter of just reporting an alarm or simply recording energy consumption but rather helping to relate the information gathered by a multitude of sensors to the building concerned, processing it and packaging it for presentation and decision making. This requires operation at a level above simple IoT systems that just use the cloud to convey and present basic data.

It is quite challenging to provide comprehensive enterprise cloud solutions that cover everything from energy (in all its forms), security, occupancy, air quality, appliances, lighting, etc. There are at least two challenges: the provision of all the monitoring hardware for each parameter and function (along with the associated know-how and installation capability) as well as the cloud-based integration and analysis of all the information being collected. Not many companies can boast having all the hardware for each set of parameters to monitor, for example. One solution is to offer an open solution that allows monitoring devices from multiple suppliers to be used, and instead concentrate on the truly innovative aspect of the system, which is in fact the cloud element. The real challenge is managing all the data that is provided by the various monitoring assets, making sense of it all and presenting a coherent interface and reporting mechanism to the user. Not many suppliers have achieved this level of sophistication, with the field being limited to the likes of Auto-DAN partner Schneider Electric, as well as ABB, Honeywell, and a few others. The solutions they have developed are necessarily sophisticated and costly. They are geared, at least for the moment, to the enterprise market, i.e. large organisations, often with multiple facilities, not the single homes or small businesses being considered in Auto-DAN. However, the tendency is clear. Cloud solutions are becoming more common and will likely extend their application in time to smaller businesses and homes, where the advantages of unified management of buildings can also be equally valid. From the point of

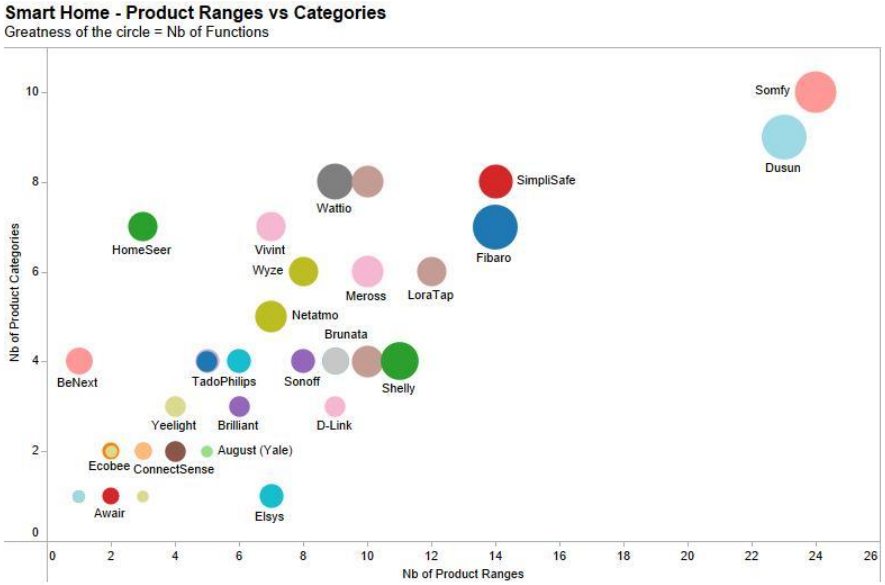


Figure 39: Smart Home systems, product ranges vs categories

view of the diversity of functions, the Smart Home systems present a wide number of functions (see width of the circles in Figure 39).

Advantages of true Cloud Smart Home Solutions

The advantages of true cloud-based Smart Home systems, as featured in enterprise cloud solutions, are many. They include the following:

- No need for local high-performance hardware: most buildings with traditional BMS systems need to have local advanced IT systems in operation, with staff to maintain them too. That represents an expensive overhead and risk. Even with such systems in place, there is usually some remote usage of cloud services such as storage anyway. By migrating the whole system to the cloud, the need for local management of hardware mostly disappears. It is relegated to making sure sensors and monitors work, and especially that the communication gateway is operational. It is much simpler and far easier to maintain as the various patches and enhancements typical of IT systems are taken care of by an external service provider.[54]
- Security: related to the issue of not having local advanced IT hardware resources is the fact that the latest features in security are implemented in the cloud as a matter of course. Cloud security levels must be, and are, among the best available, with encryption offered as standard. Records and backups are kept in the cloud, and they are safe. The user need not be concerned about having the latest security in place as this is part of the cloud service being provided.
- Processing of data is much easier: the computational resources of the cloud are virtually limitless. Far greater processing is possible than can be achieved with an in-house system. Many computational processing modules already exist too, meaning that application and development is more straightforward.
- Integration of systems is much easier: It is far more convenient to bring all data together in the cloud than on the company in-house server. In fact, one of the greatest advantages of cloud-based enterprise solutions is that they make it so easy to bring together data from multiple sites or buildings belonging to the same company. Each facility is integrated when and only it is appropriate to do so.
- Customisation: cloud-based enterprise solutions are usually customised for particular settings. While many of the components in the systems are standard, they can be and are usually are adapted so that the user can extract the maximum benefit from the information being collected. The data coverage is whatever is available, and can be enhanced all the time. Not just temperature and energy, but building layout information, current occupancy, potential maintenance issues, and so on. New parameters are easy to add as monitors are added, the information is live too and alerts are raised and transmitted as they happen.
- Accessibility and visualisation: anyone who is authorised can have access to building information for the whole organisation, from anywhere and on any device. All the issues related to device compatibilities are taken care of part of the cloud package. There is no need to enforce a corporate standard on hardware either, since the cloud handles all the issues related to different devices. Authorisation levels can easily be configured to suit particular individuals' areas of competence and responsibility. They can be tiered or partitioned as appropriate.
- Disaster-proofing: compared to running everything on a local server, with all the risks that that entails, the cloud solution represents an excellent disaster management solution. The reliability of the cloud far exceeds anything that most corporations can provide with their own resources. Everything is backed up constantly so recovery, if it ever is necessary, is a straightforward process.
- It is less expensive: When all the costs of running one's server and system are considered, the total cost of the cloud solution is usually much lower. And when there are multiple facilities involved, it can be even more dramatic.

[54] It is analogous to the transition in the nature of email, both corporate and personal, which has virtually completely moved to the cloud, having been all stored locally just 10 or 15 years ago. This transition is happening for BMS systems too and it makes sense.

Risks

There are some risks associated with cloud-based Smart Home systems, but some of them are also present in traditional solutions. Some considerations include:

- Power cuts: When there is a power cut at a facility and there is no backup generation in place, clearly the system will not operate. But neither will be building be capable of operating, except for whatever emergency systems are in place, e.g. for lighting, backup power
- Communication interruption: When power is lost, the management of the building can clearly not happen in the cloud. There are several ways in which this scenario is dealt with:
  - Redundant communications channels
  - Default temporary operating modes

Eventualities such as these are catered for in cloud-based Smart Home systems. Disruptions are minimised to the largest extent possible, and when they do happen local systems have enough autonomy to be able to manage during a break in communication with the cloud. They are fault tolerant.

Auto-DAN partner Schneider Electric is very active in the in-cloud BMS market. It offers a very broad range of products that cover the many parameters that need to be monitored or controlled in an industrial environment, including power, lighting, blinds/curtains, temperature, occupancy, and much more. Being a versatile provider, many different communications technologies are employed in the Schneider solution. Reflecting its industrial focus, the solutions are not generally designed to be self-installed; they are strictly for professional installation, with few exceptions. The ideal market reference for this solution are mission-critical buildings (like Hospitals, for example) or multi-site and complex installation (like supermarkets, industrial sites, points-if-sales of the same retail brand, hotel, offices owned and managed by real estate developers).

Some of Schneider Electric's products are focused on the Residential sector, mainly those provided with KNX standard, but they too rely on professional installers to fit them. The devices can monitor air quality, temperature, occupancy, movement, leakage and several other parameters, are open to 3rd party integration and easy to use. But they are not designed for DIY applications and they oblige to use residential gateway (integrations are possible via API at cloud level, but this is a remote possibility for a home application developed by a home owner).

Summary

Systems that do have an internet element can be subdivided depending on the degree to which functionality is shared or delegated to the cloud. Broadly speaking, less sophisticated systems geared towards the domestic market usually function at a local level and just report operating status to the cloud for the purpose of report generation. They also allow for remote functionality as well as some other features. In addition, they operate, as they must, as standalone systems, in order to cover cases where communications are lost.

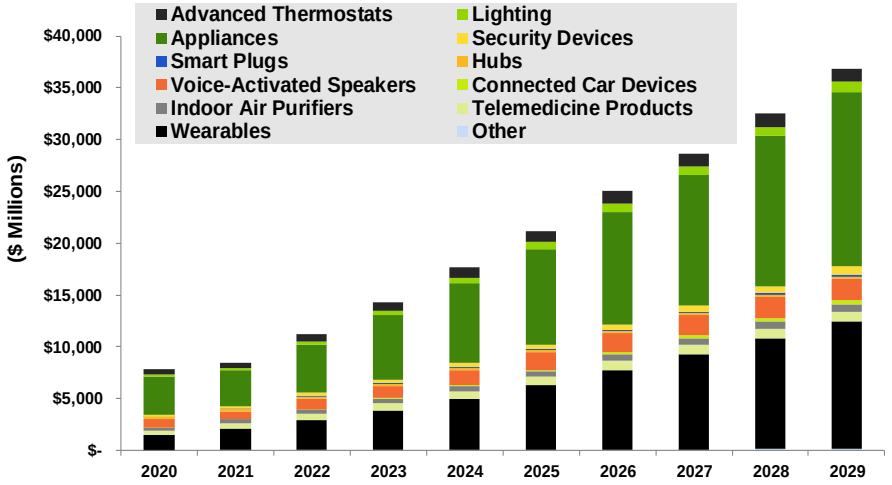


Figure 40: Smart Home Revenue by Device Type, Europe: 2020-2029

More advanced systems, geared towards enterprises, use the cloud in order to process information but also to unify data from a variety of locations, in a consistent and comparable format. Such systems are very attractive options

for facilities managers, as they can allow for gradual integration of various buildings as resources permit. They also have the advantage of allowing the outsourcing of the computational challenges to third parties operating in the cloud too, meaning that internal capabilities do not need to develop for this.

It should be borne in mind that no cloud system can operate without local hardware in place. Gateways on site are required, for example, in order to communicate. In addition, a minimum amount of control hardware is required in order to perform at least rudimentary supervision of operations when communications to the cloud are lost. The cloud is therefore adding to the capabilities of traditional systems.

6.2 Smart Home Systems: market analysis

The smart home device market globally generates 24.8 Bn$ in 2020 and is forecasted to grow to 108.3 Bn$ in 2029, at a CAGR of 17.8%. Europe's CAGR (see Figure 40) is expected to be 18.8% with revenue in 2029 reaching 36.8 Bn$. Sustained demand among consumers recognizes the value of smarter technology.[55]

Market drivers are:

- Energy efficiency: Smart products are expected to reduce energy costs by home owners.
- Automation: devices and solutions that automate tasks have a strong appeal for consumers; for instance, people prefer thermostats that adjust on their own to changing occupancy and outside temperatures and connected lights that automatically adjust to motion or occupancy.
- Convenience: smart products that offer convenience are in demand; for example, smart speakers are attractive because they can control thermostats, lights, or connected appliances besides playing music.
- Affordability: prices continue to drop as adoption increases.
- Health and wellness: smart home products that enhance wellness drive the market (devices for telemedicine and wearables).

6.3 In-cloud Smart Home Systems: maturity of the offer and level of adoption

Enterprise cloud-based systems are sophisticated and costly. They are maturing but are restricted to the large corporate environment where the advantages they offer are clear: consistent, organised, centralised, immediate and expandable systems that can cover multiple facilities, a perfect solution for companies with many operations. All data is available virtually on demand. Company-wide trends can be easily monitored. Inefficiencies can be identified, and action taken if appropriate.

Homes and Small Businesses

Auto-DAN is focused principally on family homes and small businesses. These two categories do not operate what could typically be described as enterprise level building management systems. Rather, the occupants of their respective buildings, if there is any degree of automation or management at all, would most likely list a series of separate systems, such as their HVAC, monitored security, but very little else. Most people do not yet think in terms of a unified system to manage their homes and places of business.

When these systems are employed, they tend to be limited to a few select items in buildings and limited to those systems to which they can connect. Appliances are usually excluded, for example. They all require a hub in the building, as well as the gateway to the internet.

There are several home automation frameworks in the market, several of which are open. They hold the promise that home automation is cost-

[55] See Strother, N., Maxwell, K., "Market Data: Smart Home IoT", Guidehouse Insight, 2020.

effective, easy-to-use, capable of deliver energy cost savings, open to future integration, respectful of the privacy of the user.[56]

Enterprise cloud BMS systems are sophisticated and expensive. They are not yet at the level where they are suitable for small enterprises or homes.

6.3.1 Adoption

Over the last five years or so, solutions such as Alexa and Nest have become commonplace. This has been driven by competition in the retail energy space, where various electricity and gas suppliers have been offering free devices, typically Nest or Alexa, to new customers. Since users can switch suppliers every year or two, many people have profited from the opportunity to obtain a free device and system. Alexa is used in the first instance by people to control their heating systems.

Uptake is quite popular among younger more tech-savvy people. While many of these would be renters in their respective homes, and therefore not typically the type who would invest in building improvements, the fact that the solutions are cloud-based and by definition mobile means that there is little reluctance to invest. It is not perceived as a lost cost.

Nest has been in the market for a mere 10 years, but already can be considered a mature and tried product and platform. Alexa is also in the same category. Enterprise solutions, such as those provided by Schneider Electric, are also mature.

However, most of the solution providers in the market are not mature, being in a growth phase for most of their existence. The trend towards greater adoption is being assisted by the drive to integration. Devices continue to be more connected. It is now possible for the Samsung solution to talk to Hue, for example.

6.4 Smart Home Systems: ranking

The following Figure 41 shows Smart Home Systems ranking, with total of averages of all categories of analysis, per category of product. Blue colour emphasizes the higher rating, whilst red colour the lower. Figure 42 illustrates the Smart Home System ranking via the usual 2-dimensions graph. Independently form the number of products examined, we have some player which are in the top right quadrant, which are Brilliant, Wattio, Simplisafe, Widom, Fibaro, Remo+, Philips. From the point of view of the amplitude of the offer, Somfy and Dusun are the major players. We note the high number of players on the graphs, which signifies the attractivity of the Smart Home market.

[56] These are the drivers and values of smart home offer as perceived by final users. See Schneider Electric survey result, previously quoted: “Smart Home Thought Leadership Quantitative Findings Report”, 2020. These drivers and values have been integrated within the categories of analysis of the HW offer in the present research.

Smart Home Systems Ranking - Total of averages of all items
per categories of product and manufacturer (brand)

Brand name

Categories Group	Category	Brilliant	Philips	SimpliSafe	Tado	Wattio	Netatmo	Widom	OpenHAB	Qubino	Remo+	Ring	Somfy	Control4	Vivint	Arlo
Comfort	Button			43												
	Controller			43	43	43	41	41					38	38		
	Energy meter					43		40		39						
	Interface															
	Lamp		44													
	Motor for blinds												39			
	Relay													38		
	Sensor		44	43	43	43	41					39	38	38	38	
	Smart Plug	44				43		41		39			41		38	
	Socket															
	Switch	44	44										38	38		
	Thermostat				43	43	41						40	38	38	
	Valve															
Gateway & SW	Gateway		44	43	43		39	41				39	39		38	37
	Gateway & Controller	44				43								38		
	Software								39					38		
	Transmitter												38			
	Wi-Fi bridge															
Safety & Security	Camera			45		43	46				39	39	47		38	
	Intercom			43							39	39		40	38	
	Siren			43		43							40			
	Smart Lock			43											38	

Categories Group	Category	BeNext	Brunata	Fibaro	Meross	August (Yale)	Ecobee	Google Nest	HomeWhiz	Sense	Amazon	D-Link	MC88	Yesly	Home Assistant	Yeelight
Comfort	Button															
	Controller			38	37			36								30
	Energy meter		37	37						35						
	Interface															
	Lamp				38											36
	Motor for blinds															
	Relay													34		
	Sensor	37		38	38		36					37				
	Smart Plug	37			38							37	34			
	Socket			38												
	Switch			38	38									34		
	Thermostat						36									
	Valve		37													
Gateway & SW	Gateway	37									36			34		30
	Gateway & Controller			36	38										33	
	Software								36						33	
	Transmitter													34		
	Wi-Fi bridge					37										
Safety & Security	Camera										34	33				
	Intercom			38												
	Siren		38													
	Smart Lock					36										

Categories Group	Category	Awair	Elsys	HomeGenie	HomeSeer	Hubitat	LoraTap	ConnectSense	Shelly	Iotty	Wyze	SharpTools	Sonoff	Dusun	Domotica Labs	Homey
Comfort	Button															
	Controller			31	32		30	30								
	Energy meter								30					22	19	
	Interface				31						25					
	Lamp						35							24		
	Motor for blinds															
	Relay						30		30							
	Sensor	31	31		31				30		25		25	23		
	Smart Plug						35	30					25	21		
	Socket													24		
	Switch				31		31			26			23	24		
	Thermostat										25			22		
	Valve															
Gateway & SW	Gateway				31	31	29				25			21		19
	Gateway & Controller								30							
	Software				32							25				
	Transmitter															
	Wi-Fi bridge															
Safety & Security	Camera				29						29		29			
	Intercom															
	Siren													24		
	Smart Lock										25					

Figure 41: Smart Home Systems ranking, total of averages of all categories of analysis, per category of product

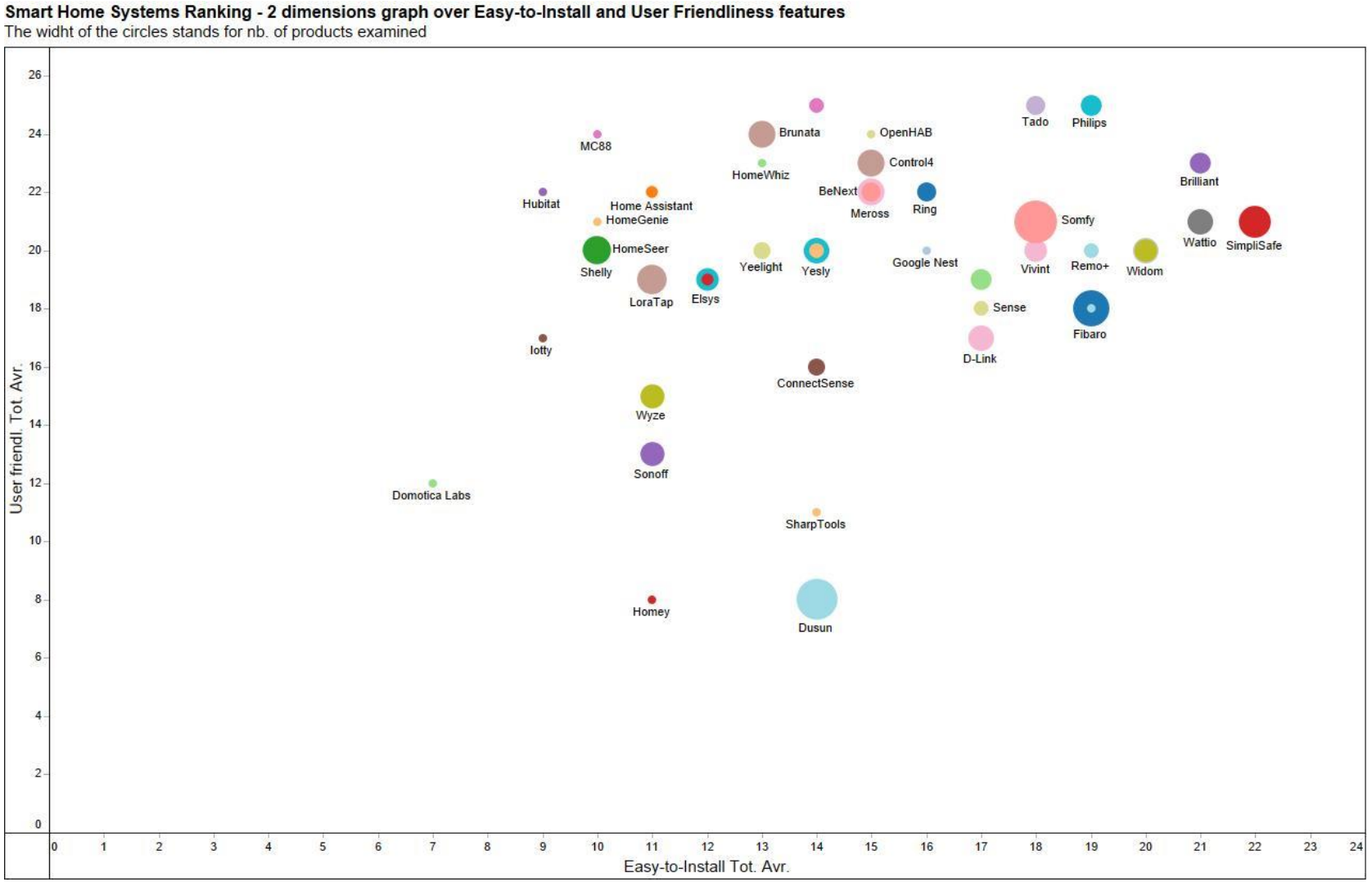


Figure 42: Smart Home Systems ranking via a 2-dimensions graph

7. Conclusions

As a conclusion, a simple list of recommendation and observation. BMS and Smart Home system offers available on the market is really very large, due to the presence of a high number of market players, both multinational and local, and to the long time that BMS offer has been developed for. Our research focused on energy meters, communication protocols and gateways, because these elements are a key element for creating a valid and interoperable architecture of systems which allows energy management and energy savings, through AI and high-level of SW-driven analytics, which is the scope of Auto-DAN.

- Higher openness, higher value. Open standards are better because they grant interoperability between different layers of the system and between the functional systems.
- Larger offer, more functions, higher value. Companies which invest in developing a multi-functional system are more reliable, the offer has a longer life and normally offer a better technical assistance.
- Price depends on quality, quality relies on R&D (which is a cost). So the evaluation of the cost depends on the functions and quality of the product or system.
- User experience is key. Whether the user is a home-owner or a high-skilled facility manager, the usability of a system (app, SW, HW) is fundamental in order to permit to the user to extract the maximum value from the system: which is not the system itself, but its function (energy cost saving, lights dimming, remote management, etc).
- Cloud systems are (obviously) the future; they allow to exploit the real power of IoT, which is to create new functions independently and after the ones designed by manufacturer and configured by installer. But hybrid systems are likely better, because they leverage on the presence of a local edge control (like a gateway) which grant for the running of the systems when the network is done.

In the followings tables and graphs we reported the overall ranking of all products listed suitable for Auto-DAN, excluding products which effect the existing warranty of systems. The criteria of ranking are the same: 13-categories scoring, summarized in two axes each reporting the averages of the scores (“Easiness to install” and “User friendliness”) and, finally, a synthetic value which is the sum of the score of the two axes ”Sum of 13 categories”).

Before overall ranking we reported three 2-way graphs, each illustrating a functional area of all the offer considered (i.e. BMS and Smart Home systems) per group of functions. The “functional groups” are composed by:

- Comfort: Contactor, Valve, Valve command, Button, Interface, Motor for blinds, Socket, Actuator, Lamp, Relay, Smart Plug, Thermostat, Controller, Switch, Energy meter, Sensor
- Gateway & SW: Router/Modem, Wi-Fi bridge, Transmitter, Software, Controller, Gateway
- Safety & Security: Siren, Smart Lock, Intercom, Camera

There are many possibilities valid for the scope of Auto-DAN, all capable to collect real-time data from building products; the offer can be provided by the Auto-DAN partners but also by external smart technology providers.

Overall Offer Ranking - Comfort - 2 dimensions graph over Easy-to-Install and User Friendliness features
Only suitable for Auto-DAN products.
The widths of the circles stands for nb. of products examined

Figure 43: ranking of Comfort offers per brand

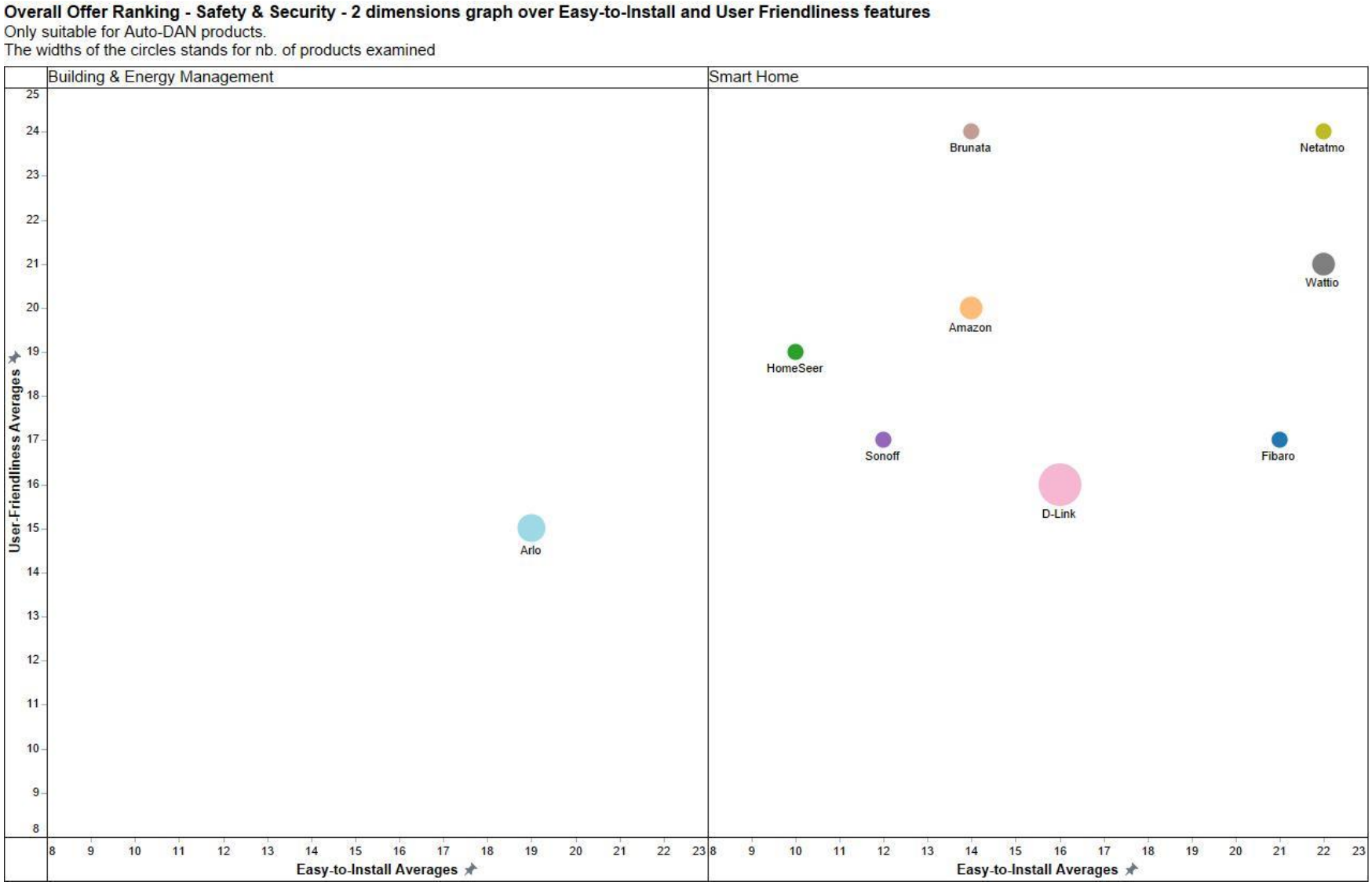


Figure 44: ranking of Gateway & SW offers per brand

Overall Offer Ranking - Gateway & SW - 2 dimensions graph over Easy-to-Install and User Friendliness features
Only suitable for Auto-DAN products.
The widths of the circles stands for nb. of products examined

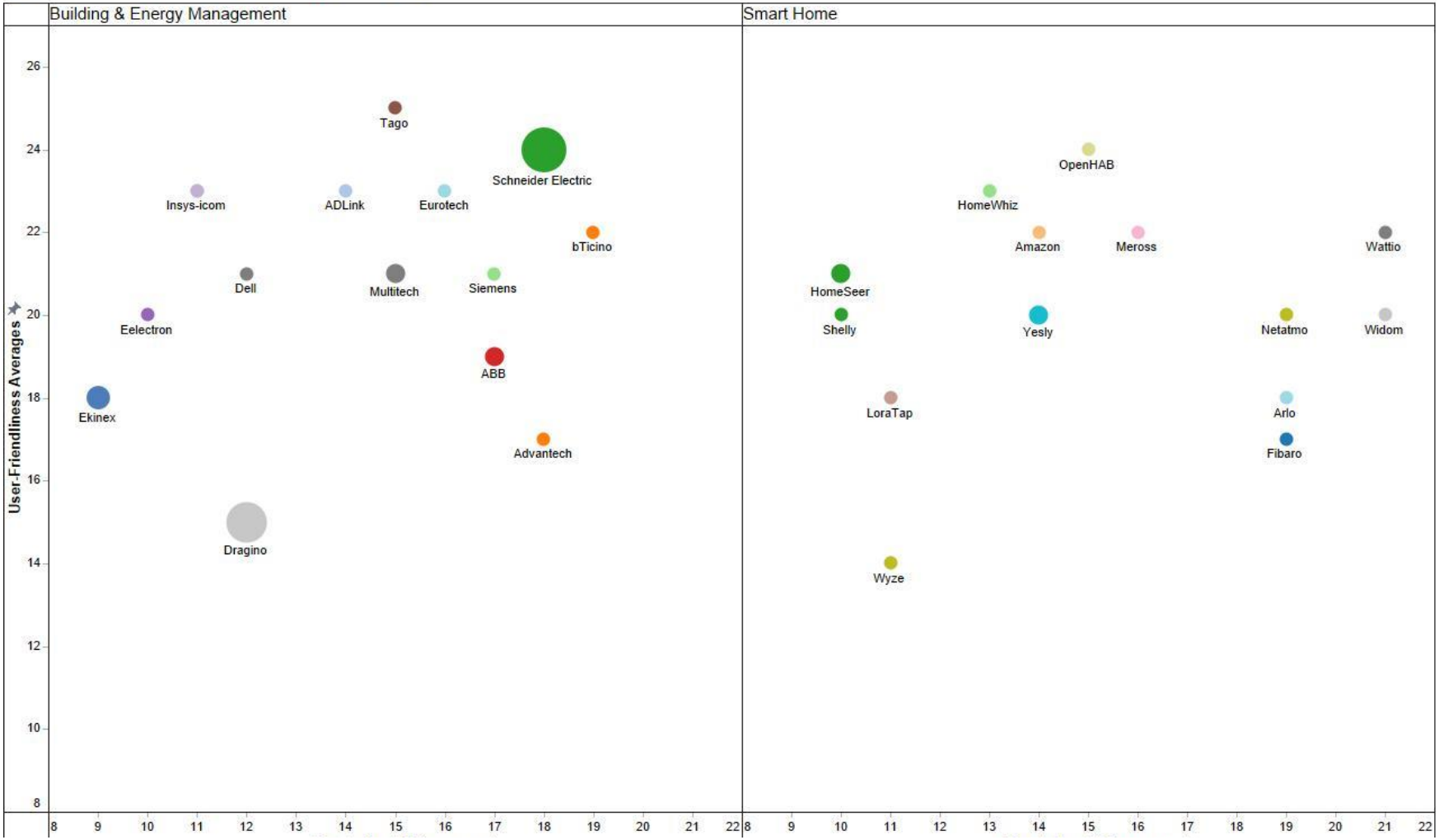


Figure 45: ranking of Safety and Security offers per brand

System	Category	Range/Product	Functions	Brand name	Easy-to-Install Tot. Avr.	User Friendl. Tot. Avr.	SUM over 13 categories
Building & Energy Management	Actuator	SpaceLogic KNX	Blinds/Curtains controlling	Schneider Electric	18	27	45
			Lighting	Schneider Electric	18	27	45
			Temperature	Schneider Electric	18	27	45
		IO32D01KNX	Command, dimmering	Eelectron	10	18	28
	Camera	Essential	TVCC	Arlo	20	18	38
		Pro3	TVCC	Arlo	19	14	33
		Ultra VMC5040	TVCC	Arlo	19	14	33
	Controller	SpaceLogic KNX	Lighting	Schneider Electric	18	27	45
			Valve command	Schneider Electric	18	27	45
		Fancoil Controller SER8300	Multi-function (temperature, CO2, humidity, presence…)	Schneider Electric	19	26	45
		Multitouch Pro	Multi-function (lights, temperature, blinds, scenarios)	Schneider Electric	18	27	45
		Smart X Controller SXWASB…	Controller	Schneider Electric	17	22	39
		SpaceLogic Smart-X Room Controller	Supervision (control, integration, automation)	Schneider Electric	17	22	39
	Energy meter	L4531C	Metering, control, power	bTicino	19	22	41
		Acti 9 iEM3100	Metering	Schneider Electric	20	24	44
		Acti 9 iEM3400	Metering	Schneider Electric	20	24	44
		Acti 9 iEM3200	Metering	Schneider Electric	21	22	43
		Acti 9 iEM3500	Metering	Schneider Electric	19	24	43
		CI Impulse Counter	Metering	Schneider Electric	23	20	43
		Acti 9 iEM2000	Metering	Schneider Electric	19	22	41
		Power TAG E	Metering	Schneider Electric	21	20	41
		B21 111-100	Metering	ABB	17	23	40
		B23 212-600	Metering	ABB	17	23	40
		FC80CC	Metering, control, power	bTicino	17	22	39
		Energy Meter 02963	Metering, control, power	VIMAR	17	21	38
		Ultrasonic Heat-Cool Metering - KD Series	Heath, cold, pressure	Schneider Electric	18	16	34
		Ultrasonic Heat-Cool Metering - KE Series	Heath, cold, pressure	Schneider Electric	18	16	34
		DME D121	Metering	Lovato Electric	12	19	31
		DME D122	Metering	Lovato Electric	12	19	31
		DME D301	Metering	Lovato Electric	12	19	31

	DME D332	Metering	Lovato Electric	12	19	31
	DME D100 T1	Metering	Lovato Electric	13	17	30
	EK-ME1-06T	Metering	Ekinex	9	20	29
	EK-ME1-80M	Metering	Ekinex	9	20	29
	EK-CF2-TP	Power control	Ekinex	10	18	28
	PM10D01KNX	Metering	Eelectron	10	16	26
Gateway	Power TAG Link	Metering	Schneider Electric	21	24	45
	Com'X 510	Metering	Schneider Electric	18	24	42
	Multi-purpose manager MPM-UN-E04-5045	Controller	Schneider Electric	19	22	41
	Multi-purpose manager MPM-UN-EI4-5045	Controller	Schneider Electric	19	22	41
	Conduit	Networking	Multitech	17	23	40
	Acti9 SmartLink	Metering	Schneider Electric	19	20	39
	iBus KNX IPR/S3.5.1	Controller	ABB	17	22	39
	ReliaGATE	Controller	Eurotech	16	23	39
	Gamma Instabus 5WG1143-1AB01	Controller	Siemens	17	21	38
	Matrix MXE-210	Controller	ADLink	14	23	37
	WISE-710	Controller	Advantech	18	17	35
	IoT Gateway IGT-20 / IGT-30 Series	Supervision (control, integration, automation)	Neousys	11	23	34
	SRS Serie	Supervision (control, integration, automation)	Insys-icom	11	23	34
	iBus KNX IPR/S3.1.1	Controller	ABB	17	16	33
	IoT Gateway 3000 Series	Controller	Dell	12	21	33
	IN00B02WEB	Supervision (control, integration, automation)	Eelectron	10	20	30
	EK-BH1-TP-TCP	Supervision (control, integration, automation)	Ekinex	9	20	29
	LG-01	Networking	Dragino	12	17	29
	LG-02	Networking	Dragino	12	17	29
	DLOS8	Networking	Dragino	12	15	27
	EK-BM1-TP-20	Supervision (control, integration, automation)	Ekinex	9	18	27
	EK-BN1-TP	Supervision (control, integration, automation)	Ekinex	9	18	27
	LIG16	Networking	Dragino	12	15	27
	LPS8	Networking	Dragino	12	15	27
	OLG01-N	Networking	Dragino	12	15	27
Gateway & Controller	SpaceLogic KNX	Lighting	Schneider Electric	18	30	48
	Space LYnk	Supervision (control, integration, automation)	Schneider Electric	18	30	48
	Wiser for KNX	Supervision (control, integration, automation)	Schneider Electric	18	30	48
	FC80GT	Power control	bTicino	19	22	41

	SmartX AS-P Edge Server	Supervision (control, integration, automation)	Schneider Electric	17	21	38
Relay	3584C	Lighting	bTicino	19	22	41
	Netatmo Valve	Valve command	bTicino	19	22	41
Router/Modem	LM502	Trasmitter / transcoder / beacon	Dragino	12	15	27
Sensor	SpaceLogic Smart X Sensor SXWSCBPSELXX	Presence detection	Schneider Electric	17	22	39
		Temperature	Schneider Electric	17	22	39
	Living Space Room Units DALI multi-sensor MTN880641	Lighting	Schneider Electric	17	28	45
	Living Space Room Units Thermostat TC907 - TC903	Temperature	Schneider Electric	17	28	45
	Water Leakage Sensor SED-WLS-G-5045	Liquid detection	Schneider Electric	20	22	42
	Window Contact Sensor SED-WDC-G-5045	Status detection	Schneider Electric	20	22	42
	Wireless Sensor SED-CO2-G-5045	Multi-function (temperature, CO2, humidity)	Schneider Electric	20	22	42
	Wireless Sensor SED-MTH-G-5045	Multi-function (temperature, movement, light)	Schneider Electric	20	22	42
	3585C	Movement	bTicino	19	22	41
	Power TAG A9XST114	Temperature	Schneider Electric	21	20	41
	SpaceLogic Smart X Sensor SXWSBTHCXSXX	Multi-function (temperature, CO2, humidity)	Schneider Electric	17	22	39
	SpaceLogic Smart X Sensor SXWSBTHXXSXX	Multi-function (temperature, humidity)	Schneider Electric	17	22	39
	SpaceLogic Smart X Sensor SXWSBTXCXSXX	Multi-function (temperature, CO2)	Schneider Electric	17	22	39
	SpaceLogic Smart X Sensor SXWSC4XSELXB	Multi-function (lights, temperature, blinds, scenarios)	Schneider Electric	17	22	39
	SpaceLogic Smart X Sensor SXWSCDXSELXW	Multi-function (lights, temperature, blinds)	Schneider Electric	17	22	39
	LAQ4	Air Quality	Dragino	12	15	27
	LDDS20	Liquid detection	Dragino	12	15	27
	LDS01	Status detection	Dragino	12	15	27
	LHT65	Multi-function (temperature, humidity)	Dragino	12	15	27
	LSN50v2-D20	Temperature	Dragino	12	15	27
	LSN50v2-S31	Multi-function (temperature, humidity)	Dragino	12	15	27
Smart Plug	Z5OUTLET	Lighting	Honeywell Resideo	23	28	51
	RF-AZK1ST.01	Power control	Schneider Electric	19	23	42
	4141PC	Metering, control, power	bTicino	19	20	39
Socket	L4531C	Metering, control, power	bTicino	19	22	41
Software	EcoStruxure Facility Expert Small Business	Metering	Schneider Electric	20	22	42
	Tago.io	Dashboard	Tago	15	25	40
Switch	L4003C	Blinds/Curtains controlling	bTicino	19	24	43
	L4027C	Lighting	bTicino	19	24	43
	L4411C	Command, dimmering	bTicino	19	22	41

		L4570CW	Multi-function (lights, temperature, blinds, scenarios)	bTicino	19	22	41
	Thermostat	Netatmo XG8002	Multi-function (temperature, humidity)	bTicino	19	22	41
		Netatmo Smarther 2	Temperature	bTicino	17	22	39
	Transmitter	SpaceLogic KNX	Blinds/Curtains controlling	Schneider Electric	18	27	45
		BCN01	Trasmitter / transcoder / beacon	Dragino	12	15	27
		NBSN95	Trasmitter / transcoder / beacon	Dragino	12	15	27
	Valve command	LBT-1	Trasmitter / transcoder / beacon	Dragino	12	15	27
Smart Home	Camera	Smart Indoor Camera	TVCC	Netatmo	22	24	46
		Cam	TVCC	Wattio	23	20	43
		DCS-8000LHV2	TVCC	D-Link	18	17	35
		DCS-8325LH	TVCC	D-Link	18	17	35
		DCS-8526LH	TVCC	D-Link	18	17	35
		Blink Indoor	TVCC	Amazon	14	20	34
		Blink Outdoor	TVCC	Amazon	14	20	34
		DCS-8515LH	TVCC	D-Link	16	17	33
		DCS-8525LH	TVCC	D-Link	16	17	33
		DCS-8600LH	TVCC	D-Link	16	17	33
		DCS-2802KT-EU	TVCC	D-Link	16	13	29
		GK-200MP2-B	TVCC	Sonoff	12	17	29
		HS-CAM-O	TVCC	HomeSeer	10	19	29
	Controller	Air	Controller	Wattio	21	22	43
		Energy Driven Double Switch L	Power control	Widom	21	20	41
		Energy Driven Double Switch N	Power control	Widom	21	20	41
		Energy Driven Switch S	Power control	Widom	21	20	41
		Smart Dry Contact Switch	Power control	Widom	21	20	41
		Smart Radiator Valve	Thermostatic radiator head	Netatmo	21	20	41
		Smart Smart Roller Shutter	Blinds/Curtains controlling	Widom	21	20	41
		Smart TE Dimmer	Command, dimmering	Widom	21	20	41
		Heat Controller	Thermostatic radiator head	Fibaro	19	19	38
		Roller Shutter 3	Blinds/Curtains controlling	Fibaro	19	19	38
		Smart Implant	Controller	Fibaro	19	19	38
		Smart Wi-Fi Garage Door Opener MSG100	Blinds/Curtains controlling	Meross	16	22	38
		Smart Thermostat Valve MTS150	Thermostatic radiator head	Meross	15	22	37
		Nest Hub	Supervision (control, integration, automation)	Google Nest	16	20	36

	HomeSeer Home Troller	Controller	HomeSeer	11	21	32
	HomeGenie	Controller	HomeGenie	10	21	31
	TV & Air-com & Fan Control	Controller	LoraTap	13	18	31
	EZ Lamp Controller	Lighting	ConnectSense	14	16	30
	Fan Light Switch	Fan and Light control	LoraTap	10	20	30
	Internet Rebooter	Controller	ConnectSense	14	16	30
	Wifi Garage Door Opener	Blinds/Curtains controlling	LoraTap	10	20	30
Energy meter	Bat	Metering	Wattio	21	22	43
	Energy Driven Switch C	Metering, control, power	Widom	20	20	40
	3-Phase Smart Meter	Metering	Qubino	14	25	39
	Energy meter	Metering	Brunata	13	26	39
	Smart Meter	Metering	Qubino	14	25	39
	CO2 meter	CO2	Brunata	14	24	38
	Humidity and temperature meter	Multi-function (temperature, humidity)	Brunata	14	24	38
	Dimmer 2	Metering, control, power	Fibaro	18	19	37
	Electricity meter	Metering	Brunata	13	24	37
	Leakage sensor	Liquid detection	Brunata	13	24	37
	Radiator meter	Temperature	Brunata	14	22	36
	Water meter	Metering	Brunata	12	24	36
	Flex Sensors	Metering	Sense	17	18	35
	Sense (monitor)	Metering	Sense	17	18	35
	Sense Solar	Metering	Sense	17	18	35
	Energy Mater	Metering	Domotica Labs	7	12	19
Gateway	HomeSeer	Networking	HomeSeer	10	21	31
	Multi Sensor Room Controller	Networking	Widom	21	20	41
	Netatmo Relay	Networking	Netatmo	19	20	39
	Arlo Smart Hub	TVCC	Arlo	19	18	37
	Blink Add-On Sync Module 2	Controller	Amazon	14	22	36
	Gateway	Networking	Yesly	14	20	34
	ZigBee Hub	Trasmitter / transcoder / beacon	LoraTap	11	18	29
	Sense Hub	Networking	Wyze	11	14	25
Gateway & Controller	Gate	Networking	Wattio	21	22	43
	Smart Hub	Trasmitter / transcoder / beacon	Meross	16	22	38
	Home Center 3	Supervision (control, integration, automation)	Fibaro	19	17	36

Intercom	Intercom	TVCC	Fibaro	21	17	38
Interface	HomeSeer	Networking	HomeSeer	10	21	31
Lamp	Smart Wi-Fi Ambient Light MSL430	Lighting	Meross	16	22	38
	Smart Wi-Fi LED Bulb MSL120	Lighting	Meross	16	22	38
	Smart LED Light	Lighting	LoraTap	15	20	35
Relay	13.22	Controller	Yesly	14	20	34
	13.72	Controller	Yesly	14	20	34
	Relay Module	Power control	LoraTap	10	20	30
Sensor	HomeSeer	Multi-function (temperature, CO2, humidity, presence…)	HomeSeer	10	21	31
	Temperature Sensor	CO	Fibaro	19	19	38
		Temperature	Fibaro	19	19	38
	Door	Status detection	Wattio	21	22	43
	Motion	Presence detection	Wattio	21	22	43
	Smart Door and Window Sensor	Status detection	Netatmo	21	20	41
	Smart Home Weather Stataion	Multi-function (temperature, CO2, humidity)	Netatmo	21	20	41
	Smart Indoor Siren	Signalling	Netatmo	21	20	41
	Door/Window Sensor	Status detection	Fibaro	19	19	38
	Flood Sensor	Liquid detection	Fibaro	19	19	38
	Motion Sensor	Movement	Fibaro	19	19	38
	Smart Temperature and Humidity Sensor MS100	Multi-function (temperature, humidity)	Meross	16	22	38
	Smoke Sensor	Smoke	Fibaro	19	19	38
	DCH-S161	Liquid detection	D-Link	18	19	37
	EMS DESK	Occupancy, temperature and humidity monitoring	Elsys	12	20	32
	EMS Door	Movement	Elsys	12	20	32
	ELT Series	Multi-function (temperature, CO2, Humidity, presence…)	Elsys	12	19	31
	EMS Series	Occupancy, temperature and humidity monitoring	Elsys	12	19	31
	ERS Series	Multi-function (temperature, CO2, Humidity, presence…)	Elsys	12	19	31
	ESM5k	Multi-function (temperature, CO2, Humidity, presence…)	Elsys	12	19	31
	ERS CO2	Multi-function (temperature, CO2, humidity, presence…)	Elsys	12	18	30
	Sensore PIR 2	Movement	Sonoff	12	13	25
Siren	Siren	Signalling	Wattio	21	22	43
	Smoke alarm	Smoke	Brunata	14	24	38

Smart Plug	Smart Plug	Power control	Widom	21	20	41
			Qubino	14	25	39
	Pod	Power control	Wattio	21	22	43
	Smart Wi-Fi Plug Mini MSS110 EU	Power control	Meross	16	22	38
	Smart Wi-Fi Plug MSS310H IT	Metering, control, power	Meross	16	22	38
	DSP-W118	Power control	D-Link	18	19	37
	Socket Plug	Power control	LoraTap	15	20	35
	Smart In-Wall Outlet	Power control	ConnectSense	14	16	30
	Smart Outlet2	Power control	ConnectSense	14	16	30
	Spina Intelligente WiFi S26	Power control	Sonoff	12	13	25
Socket	Walli	Power control	Fibaro	19	19	38
Software	HomeSeer	Supervision (control, integration, automation)	HomeSeer	11	21	32
	OpenHAB	Multi-function (temperature, CO2, humidity, presence…)	OpenHAB	15	24	39
	HomeWhiz	Supervision (control, integration, automation)	HomeWhiz	13	23	36
Switch	HomeSeer	Command, dimmering	HomeSeer	10	21	31
	Walli	Blinds/Curtains controlling	Fibaro	19	19	38
		Command, dimmering	Fibaro	19	19	38
		Power control	Fibaro	19	19	38
	Double Switch	Metering, control, power	Fibaro	19	19	38
	Single Switch	Metering, control, power	Fibaro	19	19	38
	Smart Wi-Fi 3 Gang Wall Switch MSS530 IT	Power control	Meross	16	22	38
	Smart Wi-Fi Wall Switch MSS510 EU	Power control	Meross	16	22	38
	Lamp Holder	Lighting	LoraTap	15	20	35
	13.S2	Blinds/Curtains controlling	Yesly	14	20	34
	15.21	Lighting	Yesly	14	20	34
	15.71	Lighting	Yesly	14	20	34
	Beyon	Power control	Yesly	14	20	34
	SERIE 1Y	Power control	Yesly	14	20	34
	Kinetic Light Switch	Lighting	LoraTap	15	18	33
	Boiler Ware Heater Switch	Power control	LoraTap	10	20	30
	Light Switch	Lighting	LoraTap	10	20	30
	Roller Shutter Switch	Blinds/Curtains controlling	LoraTap	10	20	30
	BASIC R3	Power control	Sonoff	12	13	25
	D1 Smart Dimmer	Command, dimmering	Sonoff	12	13	25

	Dual R2	Power control	Sonoff	12	13	25
	4CHPROR3	Power control	Sonoff	9	13	22
	4CHR3	Power control	Sonoff	9	13	22
Thermostat	Thermic	Temperature	Wattio	21	22	43
	Smart Thermostat	Temperature	Netatmo	21	20	41
Transmitter	1Y.P2	Controller	Yesly	14	20	34
Valve	Radiator valves	Thermostatic radiator head	Brunata	13	24	37

Table 8: Overall Ranking of all products listed suitable for Auto-DAN