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Operating System for Smart Services in Buildings

D2.2 Report on In-Building Infrastructure for Smart Services

WP2 IoT for Smart Buildings

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Terms, definitions, and abbreviated terms

BD	Building Description
BMS	Building Management System
CO_2	Carbon Dioxide
GA	Grant Agreement
ICT	Information and Communication Technology
IoT	Internet of Things
IETF	Internet Engineering Task Force
PLC	Programmable Logic Controller (automation) Power Line Communication (in-building wired communications)
ROI	Return On Investment
TD	Things Description
WoT	Web of Things

Executive Summary

Smart buildings can now become a reality as the IoT rapidly penetrates our homes. The challenge is to make good use of energy-saving devices, services, and processes to help reducing energy consumption and thereby CO_2 emissions of running the buildings. To be relevant in this approach, it is essential to avoid adding unnecessary equipment, and to find ways to adapt existing equipment to keep it in operation as long as possible.

In this document, we describe the devices and processes with the greatest potential for energy savings. These devices and processes should provide both financial and energy savings and can sometimes allow for flexibility in the power distribution system. Processes that meet these constraints are rare and generally focused on thermal power generation.

An analysis of the network infrastructure needed for IoT in buildings concludes that the current technologies are suitable for use in the domOS project, and also for operation in real life.

Refactoring of existing devices in order to save resources is possible, even on old and closed devices. In this case, additional sensors must be installed to access missing information.

1. Introduction

1.1. Purpose of This Document

Major improvements in the energy efficiency of buildings are mostly achieved through deep renovations. These renovations are costly and often complicated to carry out. However, significant results can be achieved through less expensive actions based on smart technologies. These technologies are widely implemented in the construction of large buildings, i.e., of several thousand square metres. In this case, the intelligence is centralised in a BMS provided by a recognised market player, and the components are linked together by wired systems. In this document we analyse the possibility of installing similar technologies in existing buildings. We focus on residential buildings such as housing blocks or villas, but the results can easily be extended to administrative or commercial buildings.

1.2. Document Structure

This document is divided into three parts:

- The first section of this document shows the current state, the benefits, and challenges of introducing IoT in buildings.
- The second section enumerates the devices consuming, producing, and storing energy in a home, and their related processes. Relevant processes for smart energy services are extrapolated.
- The third part reviews the different ways to interface smart systems in a building and proposes best practices for adding communications to old systems.

1.3. IoT and Smart Buildings

1.3.1. Smart Buildings and Energy Efficiency

On July 14, 2021, the European Commission adopted a series of legislative proposals setting out how it intends to achieve climate neutrality by 2050 (European Commission, 2021). According to the Commission, buildings account for more than 40% of energy consumed and more than 36% of energy-related greenhouse gas emissions (European Commission, 2021). Among the proposed measures are the decrease of emissions, and energy savings. Smart buildings help achieve these measures by increasing energy efficiency and allowing better integration of buildings into energy grids, and will require sensors, actuators and communication tailored for these tasks. However, the direct energy footprint of digital technology is significant: it already accounts for about 5% of global greenhouse gas emissions and is likely to become more important than the potential greenhouse gas savings generated by digital technology (Coroama, et al., 2019). To be relevant, technology in smart buildings needs to enable large energy savings while maintaining its energy footprint as small as possible.

1.3.2. Current Smart Budlings

At present, the field of intelligent buildings is mostly reserved for newer, larger, commercial buildings and requires trained personnel for maintenance. In general, the building is designed to be intelligent throughout its lifetime and therefore proven solutions are used. These solutions are based on recognised market players such as Siemens, Honeywell, or Schneider Electric, to name a few. In these cases, the building systems are monitored and controlled by a PLC and all the information is gathered in a BMS. Heat and ventilation systems are the main target of the BMS, but more and more other functions are being integrated, such as access control, fire safety and photovoltaic production. The functions of the BMS require remote devices that are connected to the central units by dedicated wire busses. As the market is held by a few traditional players, innovation is not very fast in this domain, and is driven by a few innovative actors.

1.3.3. The Rise of IoT in Buildings

During the last five years, the IoT has appeared in our homes in the form of connected devices that could be used by smart buildings. However, if one can easily find a large set of devices in the market, it is still difficult to obtain a coherent set of devices for energy efficiency. For example, it is almost impossible to find shaders, temperature and window sensors, lightning, and gateway within the same IoT standard and able to act together. To be relevant in this sector, the actors of IoT should either develop all the required devices under a single protocol or allow interoperability between devices working with different protocols.

Due to the fragmentation and specialization of companies, the development of multiple devices under a single protocol is unlikely in the short term. The Connectivity Standards Alliance[1] (formerly ZigBee Alliance), with major actors of the market, is currently finalizing an implementation, known as Matter[2],

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[1] https://csa-iot.org
[2] https://buildwithmatter.com

that could render this possible. However, valuable devices already in the field will not benefit from this protocol and could be discarded for more recent hardware, at the cost of more greenhouse gas.

Allowing interoperability between devices is an ongoing task for multiple actors. Initiatives like IFTTT (IFTTT, Inc.), HomeKit (Apple, Inc.), Google Home (Google, Inc.) and Alexa (Amazon.com, Inc) try to find a solution by connecting all devices in the cloud and offering programming interfaces. This approach has benefits for end-users but require a mandatory certification (Apple, 2021) (Goggle, 2021) creating a high entry barrier.

The constatation is that there is already a lot of IoT-capable hardware in buildings, but that this hardware is not well exploited. Enabling this existing hardware to better communicate in a homogenous ecosystem is a smart way to reinforce the building's intelligence without consuming resources.

1.3.4. Devices Currently Excluded from IoT

To be able to participate to IoT, devices must have a way to communicate. With the quantity of devices existing in a typical European house, only a small part is already able to communicate. This situation is mainly due to the large lifespan of some home appliances that may have been manufactured before the widespread use of IoT and may still be used for many years. These appliances are usually costly and energy-intensive, like fridges, ovens, central heater, washing machine, etc., and may be installed in remote rooms. Refactoring these devices to enable them to communicate is vital to so that they do not have to be thrown away because of lack of functionality, it is also necessary to reuse these old devices to save energy, but is a challenge because of multiple factors:

- The remote location of these devices may render wireless communication impossible, adding wiring costs to the refactorization.
- There is no connection possible, even in the form of analogue signals.
- The benefits of enabling these devices for IoT are not sufficient to make the transformation.

In this document, we address these devices in Section 3.3 “Monitoring and Control Approaches”.

1.4. Scope of the Work Package

WP2 “IoT for Smart Buildings” addresses two specific areas of smart buildings:

1. The question of the equipment of existing buildings, either residential or tertiary, with systems for smart energy services is addressed. Finding a way to make old equipment smarter is a priority but is not mandatory. Relevant appliances and their internal processes are identified, appropriate ways to interface them for monitoring and control are elaborated. In-door communication systems are assessed.
2. The question of the interoperability of smart building solutions is addressed. The vision is that any smart Application can make use of any smart infrastructure, independently of its technology. This will boost the development of smart applications as they can have access at a large building basis, potentially without investing in hardware appliances, devices, or communication gateways.

2. In-House Energy Equipment and Processes

2.1. Introduction

The many devices that make our lives easier at home all consume energy. The way these appliances consume energy differs according to their use and design. Some devices are always active, such as routers and Wi-Fi, others are in standby most of the time, such as TVs, and others are only turned on when they are being used. Some devices consume visibly, such as the oven, which is turned on voluntarily, while others are running without the user noticing.

Among all these appliances, it is necessary to focus on those that have potential in our project, and to look at their operating processes. This section describes the methodology for identifying interesting devices and lists them. typical home possesses

2.2. Methodology

Identifying relevant in-house energy equipment and processes should be done to find ways to reduce energy with a reasonable price. As stated in Section 1.5 “Objectives and Success Criteria” of D2.1 “Report on Requirement Analysis for IoT Ecosystem”, the overall cost must be in-line with the expected benefits. Also, the overall energy consumption of the IoT ecosystem installed shall be lower than the overall energy saved with this IoT ecosystem. Finally, with a growing quantity of homes equipped with electric and thermal solar panels, as well as homes equipped with automotive chargers, flexibility is becoming critical.

2.2.1. Economic Criteria

Electricity prices in 2020 for households in Europe are typically €0.2/kWh but can range from €0.1 (Bulgaria) to €0.3 (Denmark) per kWh. Gas prices for households in Europe for the same period are cheaper at €0.07/kWh, with a maximum for Sweden (€0.12/kWh) and a minimum for Hungary (€0.04/kWh) (European Commission, 2020). In this analysis, the typical values of €0.2/kWh for electricity and €0.07/kWh are used, but these values could be tuned to local conditions.

With target values of €100 for a communication gateway and €100 for a connected appliance (domOS, 2021), and a ROI of 5 to 10 years, the order of magnitude of money saved per year with such a setup should be in the €20-40 target which is equivalent to 100-200kWh of electricity saved per year, or 300-600kWh of gas saved per year.

Depending on the energy provider and energy tariffs, it is also possible to reach energy savings by consuming at the right time. This subject is related to flexibility, which is explained in Section 2.2.3

2.2.2. Energetic Criteria

2.2.2.1. Challenge

Applying the highest price (€0.3/kWh) to the minimal target economy (€20) conducts to 66kWh saved per year which is roughly equivalent to a device consuming 10W during all the year. As a comparison, this is the order of magnitude of a Wi-Fi router. The IoT ecosystem should consume less energy, meaning that there will be multiple use cases where the energy savings will not make up for the extra energy invested.

For example, we take the case of a typical Philips Hue installation, which is a very popular intelligent lighting system, composed of 3 LED bulbs and one mandatory Hue bridge. According to Philips, the power consumption of the bridge is 3W, the power consumption of the bulbs when powered off is 0.5W and 10W when powered on. Assuming that the lights are powered on for 8 hours a day, the breakdown of the power consumption is presented in Table 1:

TABLE 1: POWER CONSUMPTION OF A TYPICAL HUE INSTALLATION

Device	Power OFF [W]	Power ON [W]	ON hours/day	Energy/year [kWh]
Bridge	0.0	3.0	24.0	26.3
Bulbs (3)	1.5	30.0	8.0	96.4
TOTAL				**122.7**

Comparing to a traditional setup composed of 3 LED bulbs, the Bridge is adding 26.3 kWh/year and the 3 bulbs are adding 8.8 kWh/year when not activated. The power overhead per year is 35.1 kWh. According to these very simple hypotheses, the use of a smart system will not generate energy savings, and a distracted person should forget to turn off the lights for 73 days a year to offset this overhead, which is very unlikely. This installation should find other ways to save energy, that will be explained later.

2.2.2.2. Nature of Energy Savings

The introduction of a smart system in a building can conduct to different energy savings: a better regulation can drive to a better efficiency, detecting a faulty system can reduce energy waste, and some systems can induct indirect savings. Those three natures are explained in the following chapters.

2.2.2.3. Regulation

Regulation of a system can lead to energy savings by a better adaptation of the system to its external conditions. This can be done through better algorithms, more sensors, and a better control.

Using the example of smart lamps again, it is possible to improve the regulation by various means, as explained in Table 2:

TABLE 2: POSSIBILITIES FOR IMPROVING THE CONTROL OF A LIGHTING SYSTEM

Improvement	Acting on
Rules between weekdays and weekends	Better algorithms
Presence detection and lighting adaptation	More sensors and better algorithms
Brightness detection and dimming	More sensors, better control, better algorithms

In our work, we assume that the regulation can save 5% of the total energy of a system, which is a commonly accepted value (Pan, et al., 2011), but examples of more energy savings exist, especially in the aera of building heating (energo).

2.2.2.4. Fault Detection

All devices will fail at some point. Some of these failures will be visible and unacceptable to the user: the TV has no picture, the shower is freezing, or the device simply does not work. In most of these cases, the appliance is rendered unusable, and the energy impact is negligible. However, some malfunctions can be invisible and lead to over-consumption. For example, a fan timer failure in a low-traffic area will take a long time to be detected. In this work, we focus on these cases and estimate that the energy saving potential of fault detection is half of the annual consumption.

2.2.2.5. Indirect Savings

The introduction of a new appliance can lead to energy savings in other areas, creating indirect savings. The most striking example is automatic blinds which can improve solar heat gain in an unoccupied house and greatly reduce heating consumption.

In this work, we sought to determine the indirect energy savings of appliances. For the few cases where savings could be made, they were calculated on an ad hoc basis.

2.2.2.6. Final Remarks

Ideally, energy savings should be assessed over the whole life cycle of the installation and considering the whole IT infrastructure needed to operate it. This assessment has not been done as it is outside the scope of the project.

2.2.3. Flexibility Criteria

In the context of this project, flexibility is defined as the ability for a device to be activated or deactivated at the right time to be useful for the consumer, by allowing a better tariff, or useful for the energy network, to offset peaks in supply or demand. Flexibility can be reached by storing energy or by starting a process at the right time. In both cases, the utility of the flexible device should not be affected.

Storing electrical energy can be reached with processes that have not to be immediate. For example, when taking a shower, the hot water has already been prepared and is stored for a few hours. For the user the moment the water has been prepared is not important if the water is there when he needs it. More than that, the user could benefit if the water is prepared when cheap energy is available. For the energy network, it can also be a benefit if a lot of boilers are activated when there is more supply than demand. The main vectors of energy storage are found in the thermal processes (building heating, hot water preparation).

Flexibility can also be obtained if a device waits until favourable conditions are reached. For example, a washing machine can be loaded and ready to start but wait until the solar panels are producing energy. In this case, the user benefits of self-consuming without any penalty, as long as the washing is finished when he needs it.

In general, flexibility will not save energy: processes require the same amount of energy, whatever the moment they are done. More than that, the total energy needed by a flexible device can increase by a small fraction due to more losses or a lower efficiency. But flexibility can bring other benefits:

- financial benefits, by allowing a better tariff
- better use of the grid, by consuming energy at a time that is profitable for the grid
- larger self-consumption, by starting processes when photovoltaic power is available
- allow the use of decarbonated energy, by substituting fossil energy sources by sun radiation.

Estimating these benefits cannot be done easily and must always consider the local situation. These reasons explain why there will be only an estimation of flexibility potential in this work.

2.3. Inventory of Equipment

Firstly, every participant listed the devices consuming energy that were found into its proper home. With this data, a complete list was established, and presented in Table 3:

TABLE 3: INVENTORY OF DEVICES IN A TYPICAL HOME

Equipment
Electric water heater
Ventilation
Heated towel rack
Washing machine
Dryer
Oven
Microwave
Dishwasher
Vacuum cleaner (central or independent)
Hotplate
Kettle
Coffee machine
Fridge
Toaster
Juicer machine
Multicooker
Computer / monitor …
Printer/scanner
TV / Home cinema / Beamer
Access point / router / Internet (domOS) gateway
Treadmill and sport equipment
Massage
Central heating
Central cooling
Lighting
Small electronics and chargers
Garage door
Intercom door
Blower
Ceiling ventilator
Window blinds
Shower head

For each device, the typical yearly energy consumption has been estimated. These values were derived from the literature, data sheets of different manufacturers and energy labels. In cases where energy labels exist for a device, the average value (C) was used. In other cases, hours of use per day have been estimated and were multiplied by the power of the device. Energy savings have been calculated based on the assumptions described in the previous paragraphs, and an energy saving potential per house has been considered interesting if the total savings can be higher than 50 kWh/year. The value of 50 kWh/year was decided based on the value of 66kWh/year described in Section 2.2.2.1 “Challenge”, which is the smallest value to be achieved between financial and energy savings, and which was adjusted slightly downwards. On the other side, average energy consumption in a European home can be estimated at 1500 kWh/year per person. Based on this figure and a saving of 10%, the possible savings for a 4-person household could reach €200/year.

Table 4 shows the equipment that have been retained and the reason for having been retained:

TABLE 4: INVENTORY OF EQUIPMENT WITH POTENTIAL FOR SMART HOME

Equipment	Reason
Electric water heater	Energy (regulation) and flexibility potential
Ventilation (only in remote rooms)	Energy (fault detection) potential
Heated towel rack	Energy (regulation) potential
Washing machine	Flexibility potential
Dryer	Flexibility potential
Dishwasher	Flexibility potential
Fridge	Energy (fault detection) potential
Central heating	Energy (regulation) and flexibility potential
Central cooling	Energy (regulation) and flexibility potential
Window blinds	Energy (indirect) potential
Shower head	Energy (regulation) potential

Three items have been added to this list, as they are identified as very likely to be found in several homes soon: solar panels, batteries, and electric vehicles. These items are very specific as they are not only consumers, but also producers and storage of energy.

2.4. Processes Related to Equipment

It must be stressed that almost all equipment referenced in table 6 works in the field of heat or cold production, and therefore involve a thermal process (heating or cooling). As a rule of thumb, optimizing thermal energy in a home presents the most potential for saving energy, and developers should focus on this subject, which is exactly the focus of WP6 and WP7.

3. IoT Communication Interfaces in Buildings

3.1. Overview

In order to allow a device to enter the domOS ecosystem, it must be able to be monitored and controlled remotely. This requires that information from the device and commands to the device can be transported between the Service, which contains the intelligence, and the device, which has to react. This problem can be divided into two parts: a first part that deals with the transport to the proximity of the device, and a second part that deals with the final transfer to the device to react. In former part we address both topics: the topic of the infrastructure needed to transmit data within the building to the direct vicinity of the device (Section 3.2) and the topic of interfacing the equipment to allow them to transmit information and receive commands (Section 3.3). Figure 1 represents the two transfers explained in this section. Finally, the interruption of communications has to be managed. The strategies to manage these interruptions exist and will have to be used, but this is not the purpose of this document to list them.

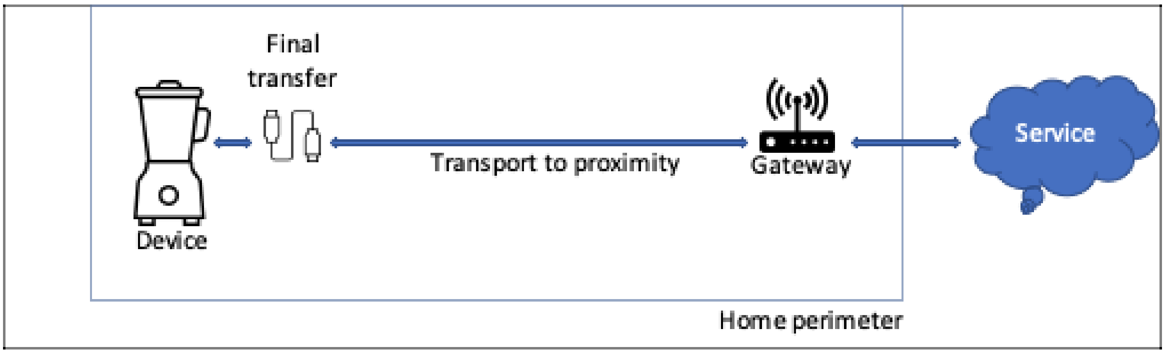

FIGURE 1: REPRESENTATION OF THE DATA COMMUNICATION BETWEEN A DEVICE AND THE SERVICE

3.2. Indoor Infrastructure

3.2.1. Wired or Wireless Communication

In Europe, a wired connection exists for almost every household. This connection, either copper or optical fiber, connects the household to the outside world (internet, telephony, video, etc.) through a gateway. In most cases, this wired connection stops at the gateway and people use wireless connections to access the gateway, and subsequently the outside of the building. Thus, wired data networks in buildings are almost non-existent. Installing a wired communication system in an unequipped building involves significant costs and unnecessary resource expenditure. Power Line Communication (PLC) technology can exploit electrical distribution cables, but with significant limitations. With these findings, the use of a wireless network seems to be the best solution, both from an economic point of view and in terms of resource savings.

3.2.2. Licence-Free Wireless Communications

Establishing an exhaustive list of free radio frequency bands in Europe is a difficult task as each country has established its own rules. However, several systems are sufficiently deployed worldwide to be present in all European countries. For this reason, we only present those that are commercially relevant and easily deployable. Table 5 shows the most widely used free frequencies and their main commercial uses:

TABLE 5: LICENCE-FREE RF AND NOTABLE USES

Frequency band	Notable use
13 MHz	RFID, NFC
169 MHz	Wize
433 MHz	Car keys and remotes, walkie-talkie
868 MHz	z-Wave, ZigBee, LoRa
2.4 GHz	Bluetooth, WiFi, ZigBee
5.1 GHz	WiFi
5.4 GHz	WiFi 25mW max

3.2.3. Bandwidth Choice

3.2.3.1. Influence on Speed

Using a higher frequency allows for a higher transmission speed as well. With a higher transmission speed, more information can be transferred per second. This is very important for the transmission of images and video, which are big consumers of bandwidth. However, energetic processes require only a small amount of information to be transferred.

Another point to consider in speed is the number of messages that can be transmitted. With a higher frequency, more messages can be transmitted per unit of time. In the case of energy use, one message per second per device is a transmission frequency that can occur.

3.2.3.2. Influence on Power Consumption

The energy consumption of a wireless transmission medium is directly related to its frequency. The higher the transmission frequency, the higher the energy consumption. In the case of energy use, it is in the interest of the user to keep the power consumption as low as possible, in order not to compromise energy savings on the one hand, and to allow the implementation of measuring or activating devices that can be controlled by battery or rechargeable battery.

3.2.3.3. Influence on Range

The range of a wireless transmission is generally inversely proportional to the frequency: the higher the frequency, the lower the range. The range is also influenced by the topology of the location: low frequencies tend to penetrate walls better.

To achieve a long range indoors with a high frequency, several possibilities can be implemented: increasing the transmission power or adding repeaters. This is exactly what is done to enable high Wi-Fi speeds in large buildings. Another possibility is to use each participant in the wireless network as a repeater. This is done in mesh networks and allows low transmission powers to be maintained with automatic range extension.

In the case of energy use, the need is to cover the whole area of the building, with the lowest energy consumption. It is not advisable to have a range that goes far beyond the limits of the building, as this increases the risk of disturbances in the neighbourhood, which is not a desired effect.

3.2.3.4. Conclusion

When using wireless networks for energy smart buildings, the lowest usable frequency should be preferred. This has the advantages of lower power consumption, adapted range and sufficiently fast message transmission. The most suitable frequency range is 800 MHz to 2.4 GHz, allowing an overview of the protocols that could be used in the building infrastructure. Two points should be noted in relation to this analysis: the first is that parsimonious use of messages should be required, and if possible, should be implemented in the specifications. The second is that the authors do not wish to limit this infrastructure to the proposed frequencies alone, which are a recommendation. If new technologies should emerge with the required qualities, they could be accepted.

3.2.4. Currently Proposed Wireless Protocols for Indoor Communication

3.2.4.1. ZigBee and Z-wave

The Zigbee and z-wave protocols were developed to enable the manufacture of low power, connected devices. These protocols can operate in the 860 MHz and 2.4 GHz bands, have a range of a few tens of meters outdoors and data rates in the order of 200kbit/sec. They use mesh topology to allow range extension over several hundred meters. Zigbee and Z-wave devices can typically run for several years on a single battery. Currently, these protocols are not internet compatible, and it is necessary to transform the signals in a gateway, usually vendor-specific, to connect to a computer, smartphone, or a remote server.

3.2.4.2. Thread

Thread is based on the same wireless layer than Zigbee (801.15.4), therefore it is relatively close to Zigbee in terms of bandwidth, range and topology. It is internet compatible and based on IPv6, and now backed by a hundred of companies, including the major players such as the GAFA. However, its development is relatively recent and there are only a handful of compatible products currently on the market.

3.2.4.3. Wi-Fi

Wi-Fi is probably a protocol known to everyone. It was originally developed in the 1990s and is still actively being developed. The latest developments allow data rates in the GB/sec range with ranges of up to 100m outdoors. Wi-Fi networks operate in the 2.4-5.4 GHz band. Network extension can be done with repeaters. Because of its power, the energy consumption of Wi-Fi is higher, and it is considered that a Wi-Fi terminal can run several days on a battery. Due to its high energy consumption and the power requirements of the terminals, this technology is not ideal for very simple connected objects. However, its presence in almost every household makes it impossible to ignore.

The Wi-Fi protocol is developed for the internet and can allow a connection with a computer, a smartphone, or a remote server.

3.2.4.4. Bluetooth

The Bluetooth protocol allows short-range data communications and operates in the 2.4 GHz band. Depending on the output power of the radio system, Bluetooth devices can have a range up of a hundred meters outdoors and data rates up to 30 MB/sec but in real conditions, the range is about 10 meters with data rate of 3mbit/sec. Bluetooth devices can run for several month with a battery charge. The new Bluetooth LE (Low Energy) specification allows small devices to run for up to one year on a CR2032 battery. Currently, these protocols are not internet compatible but can be directly connected to a computer or smartphone because these devices have the radio equipment embedded. It is not possible to connect directly to a remote server, but bridges between internet and Bluetooth exist already.

3.2.4.5. Dealing with Different Protocols: Matter

Very recently, the ZigBee alliance transformed itself into the connectivity standards alliance (CSA) and unveiled the Matter protocol. This is an initiative to bring together multiple data transfer media to enable manufacturers to build smart home compatible devices and associated services. The first Matter protocol specification uses Wi-Fi, Thread and Bluetooth Low energy, and it is expected to be extended to other protocols. Currently, there are no compatible devices, but it is anticipated that Wi-Fi and Thread devices can be made compatible through software updates, and that compatible devices will be available in the near future.

3.2.5. Need for Gateway in Buildings

All the protocols presented have ranges from a few metres to a few hundred metres. The domOS project requires collecting all signals from field devices and using intelligence to process them. To achieve this, it is possible to install this intelligence inside or outside the building. In all these cases, an additional device in each building will be needed, either to transform these signals so that they can be transmitted over long distances via the internet, or to process these signals in-situ. These two possibilities are presented in Figure 2.

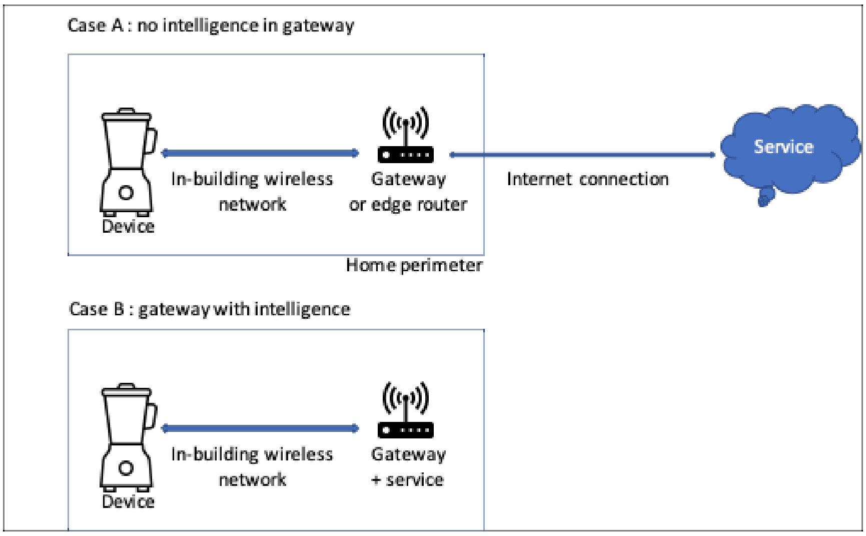

FIGURE 2: IN-BUILDING COMMUNICATION INFRASTRUCTURE

3.2.6. Solving the Diversity: domOS Philosophy

As it is important to reuse as much as possible all the existing devices in a building, domOS do not want to impose one of the above-described protocols, nor does it want to prohibit a new protocol that may emerge. For an installation that is already operated with an internet bridge, it is preferable to use this device and to document its connection.

The Things Description (TD) already described in a previous report (domOS, 2021) allows the server to make the link to the protocol used in a transparent manner and to avoid the need to impose an existing protocol. By referencing all the TDs in a single building document and enriching this document with metadata, it is possible to create a building description (BD), that will be the entry point to the knowledge of the building and its installations. By using the Web of Things (WoT) specification, a fully standards-compliant package can be created. It is also possible to imagine that several systems connected by different protocols are linked to the servient by a bridge adapted to each protocol, or better still by a single multiprotocol bridge. Figure 3 shows a representation of the merging of TDs in a BD and the benefits for the service.

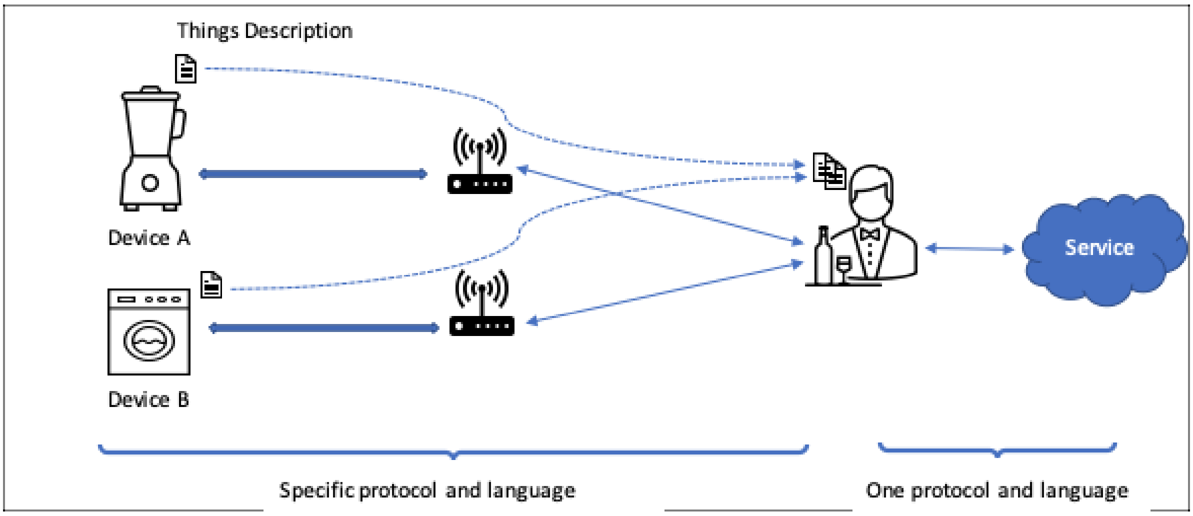

FIGURE 3: DOMOS THINGS DESCRIPTION AND INFRASTRUCTURE

3.3. Monitoring and Control Approaches

We are dealing here with the second part of data transfer, which is to use the data to physically make the device you want to control react. In this area, there are a large number of possible scenarios, ranging from a closed device to very user-friendly interfaces. In general, the older systems are closed, and the newer and more luxurious systems have a digital interface. Below, we outline these different cases from the most open to the most closed, and we give hints on how to avoid the pitfalls and how to be as efficient as possible in implementing these commands.

3.3.1. Open Appliances

3.3.1.1. Digital Interface

Devices with a digital interface, i.e., capable of binary coded data transfer, are probably the easiest. Ideal cases appear when the device can be directly integrated into the building's communication infrastructure, such as a device with its own Wi-Fi. There are also cases where the interface is present but not documented, such as interfaces dedicated to the service of the device, and it is possible to take advantage of it with good engineering.

Two difficulties must be overcome when dealing with a digital interface. First is to assure that the internal data model of the device matches the domOS core ontologies. Second is the security: in many cases these interfaces have not been developed for internet, and therefore have weak security mechanisms.

3.3.1.2. Non-Digital Interface

Non-digital interfaces can take many forms: usually on/off signals or analogue setpoints. In many cases, these signals have been provided by the device designer to add optional functionality and they are easily exploited. The most common external signals found are an external analogue setpoint and an on/off activation control signal. It is also possible to replace existing external sensors on the device with false signals to trick the controller into making new settings. An example of such a use can be found frequently in the heating field, where the external temperature sensor is modified to change the setpoint of a boiler. This trick could also be used in domOS, with the necessary precautions.

3.3.2. Closed Appliances

Some devices have no sensors that can be modified, no on/off or analogue signals and no digital connector. In this case, the simplest solution is to add a smart plug that will measure the energy consumption and be able to cut the power supply to the device to stop it. Measuring the energy consumption, in addition to giving valuable information on the energy level, will make it possible to know if the appliance is in use or not. Particular care should be taken when switching off the power supply when the appliance is in use. On the one hand, any sparks produced when the power supply is cut off could damage the appliance, and a smart plug should be chosen to avoid such sparks, which is not always the case. On the other hand, the power cut may disrupt or even remove the safety features of the device and cause it to enter a dangerous mode. Finally, shutting down an appliance in the middle of an operating cycle can be problematic, and care must be taken to ensure that the appliance controlled in this way can resume its cycle cleanly when the power returns.

In general, household appliances respond well to power cuts because they have been developed with this issue in mind.

3.3.3. Additional Sensors

In all the above cases, the information available to ensure effective control of the device may not be sufficient. In these cases, the addition of new sensors, or the operation of existing sensors on another system will be necessary. When adding additional sensors, the choice of sensors that best fit into the existing ecosystem should be preferred.

4. Conclusion

This document outlines the relevance of the rapid implementation of smart buildings to support the European Commission's objectives in its energy reduction plans. With a large number of IoT devices being integrated into our homes, and almost all households having internet, the basis of the ecosystem is being put in place. However, the current trend is towards more and more convenient devices that do not reduce energy consumption. Unfortunately, the most energy-saving devices are costly, tend to have a long-life span and are therefore old. For this reason, if they are old, they do not have the necessary interfaces and are excluded from the IoT infrastructure if they are not modified.

The energy savings possible with the support of the IoT are currently difficult to achieve due to the fact that a large number of domestic appliances are energy efficient. These savings can be achieved through better process control, fault detection or indirect savings. Potential energy savings devices have been identified and usually involve thermal processes.

An analysis of the best in-building communication infrastructure needed to connect devices was conducted. It was found that the implementation of wireless networks is preferable and is possible by using public frequencies and technologies already available. Particular attention should be given to emerging technologies (Matter) promoted by the major technology players. To avoid bridges proliferation and to keep power consumption low, it is preferable to use as few types of wireless networks as possible and to favour mesh networks. By using the Things Description in combination with a servient, the domOS ecosystem can free itself from the technological constraints of the field and adapt to any type of network and device, present or future.

The connection of older domestic appliances to the communication infrastructure was also investigated. It is possible to categorise the type of connection into three main families and to define the pitfalls to be avoided in each case. Due to the large number of models available, an approach adapted to each situation is necessary. If device data is missing, it can be obtained by means of external sensors.

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