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Deliverable D3.2:
Data infrastructure requirements for the StepUP Methodology

Public Document

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1 Executive summary

The present public deliverable **D3.2 – Data infrastructure requirements for the StepUP Methodology** is divided into 3 main topics:

- A data collection infrastructure review
- The development of a protocol for data collection in line with StepUP methodology
- The Data monitoring and control as a service domain in the Smart Readiness Indicator (SRI)

After a short introduction (**Chapter 2**) of the Deliverable, the **Chapter 3** makes a review of the main devices used in building monitoring procedures for the measurement of final energy (electricity and gas), thermal comfort, indoor air quality (IAQ) and lighting and occupancy control. After this, some of the main characteristics of these devices are explained to be considered when implementing the protocol for the data collection developed in the next chapter (**Chapter 4**). As a final section of **Chapter 3**, a brief review of the most relevant current communication and network technologies are presented as potentially suitable for the data collection approach of the protocol.

Chapter 4 describes the Protocol for the data-related building acquisition framework and infrastructure to deploy monitoring systems, leveraging the data for design and in use optimization by the **StepUP Data Intelligence Tool**, and **StepUP Life Cycle Platform Tool**. The former is a tool developed for data management and analytics and to visualize performance through dashboards. The latter is a tool for managing the renovation process throughout the entire lifecycle and forecast performance via physics-based modelling.

The aims of the present protocol are:

1. Enable to establish the initial baseline building model required by the StepUP methodology,
2. Minimize building performance gap between predicted and real-time measured data performance, and
3. Allow to carry out a continuous commissioning for any corrective or follow-up actions after the implementation of the ECMs as well as the for the optimization of operations.

The protocol is fully in line with the StepUP methodology in all its phases, once the building renovation is decided: from the initial retro-commissioning data collection, through design and deployment, to the post-installation monitoring and optimal operation.

Furthermore, having data collection infrastructure implemented in building will improve the score achievable according to the Smart Readiness Indicator (SRI) scheme adopted by the European Commission, in particular with respects to the Data and monitoring domain service defined in the SRI methodology. This is explained in the last **Chapter 5**.

This deliverable contains a glossary for some terms included in this document.

2 Introduction

In the context of energy efficiency evaluation in buildings, the purpose of the data acquisition is to accurately collect the data required to estimate the savings attributable to the implementation of the selected energy conservation measures (ECMs).

Within the StepUP methodology, described in deliverable **D1.2 Integrated draft of the methodology**, data collection is foreseen, as it will be required to feed solutions (StepUP **Life Cycle Platform** and **Data Intelligence** tools) developed during the project to carry out the renovation, with the final goal of reducing energy performance gap, while having a continuous understanding of the building performance, building/systems operational performance and user needs, and of course, verifying the expected impacts of the ECMs.

This required data collection in the StepUP methodology has three main typologies: historical data from the building, streaming data from sensors and user-related data. The historical data will be gathered from meters and utility bills by on-site surveys to the building, and user-related data thorough specifics surveys and feedback services, as referred in deliverable D1.2. Regarding the data collection from sensors, this document describes a protocol (**Chapter 4**) for planning data monitoring in line with the StepUP methodology.

Before going into data monitoring planning, a preliminary explanation of electricity and gas metering devices existing in the buildings are exposed in the **Chapter 3**, as well as some devices available in market to be used for reading and gathering the energy data from the existing meters. After this, a review of sensors and a summary table with their main features are in Table 1. At the end of the chapter, the main communication and network technologies are briefly explained.

3 Data collection infrastructure

3.1 Metering and monitoring devices

Instrumentation is used to measure and record physical parameters. For this document, the focus will be on devices used for the measurement of primary energy (electricity and gas), thermal comfort, indoor air quality (IAQ) and lighting and occupancy control, as they have an impact on the selected ECMs following the StepUP renovation methodology (chapter 4.3 of the deliverable **D1.2**).

Based on a literature review, the following chapters will briefly describe the physical properties associated to the metering and monitoring devices, the operative principles of these devices, and the types of each that can be found in the market for building sensing.

3.1.1 Electricity metering

Electric power and energy are among the most important measurements for savings evaluations. The common unit of power is kilowatts (kW). The common unit of energy is kilowatt-hour (kWh), as energy is power used during a unit of time. Other electrical measurements are voltage (V), current in amperes (A), and power factor (PF). Although direct current voltage (Vdc) is used to power some types of equipment, utility transmission to customers occurs in the form of alternating current voltage (Vac), and the values measured or recorded are the root mean square (RMS) values. The actual electric power is equal to alternating current voltage by the power factor.

Electricity meters measure energy use by continuously sensing the instantaneous values of current and voltage. The most common type of electricity meter, mainly in both residential and commercial buildings, is the **electromechanical watt-hour meter**, which derives electricity use from the movement of a mechanical dial as in mechanical meter, which is then digitalized with encoders to provide an electronic or pulse output. Unlike the mechanical meter, the electromechanical meter does allow for data storage and communication but with ancillary equipment and costly configurations works.

Nowadays the utility industry is based on **advanced electricity meters** of high accuracy, which don't require moving elements (based on typically current and voltage transformers) and are able to store and manage data. For these reasons, utilities are gradually replacing the old electromechanical meters but also paving the way for next generation meters, called **smart meters**, with the capability of bidirectional communication between the meter (consumer's side) and the utility provider, enabling wider integration of energy and information and communication technologies (ICT).

In addition to smart meters, regarding **systems for reading energy meters**, at present there are power analysers, current meters, optical port readers and other types of wireless communication technologies:

- **Power analysers** can measure the flow of energy in either alternating current power or direct current power systems and are able to measure parameters including: voltage; current; power; peak, mean and RMS parameters; harmonics; phase, and a variety of other parameters. They can measure simultaneously both the voltage and current signals for each of the phases, one phase or three phases, they can determine the demand angle and therefore the installation's active and reactive power. They have a high precision in their measurements, but in contrast, they are invasive devices when measuring.
- **Optical port readers**: Among various communication options, optical ports are more common. An optical reading head or Optical Probe is an interface. It is intended for two-way data exchange between a counter such as an electric meter, electricity meter, gas meter, heat meter, water meter, etc. and a peripheral device via infrared optical waves.

Figure 1. Example of optical probe (source: German metering)

- With respects to **wireless communication systems**, different methods exist. An example are methods based on wireless communication with use of a RF transceiver and GSM module. The power consumption is measured with digital energy meter in terms of units and then the power measurement readings are transmitted with use of RF transmitter from energy meter to the centre node which contains a RF receiver and GSM module.

3.1.2 Gas metering

Regarding the gas metering, traditional gas meters used broadly by distribution companies uses dynamic mechanisms to measure the gas flow, like the **diaphragm gas meter**, which is composed by chambers where the gas flows through by expanding and contracting movable diaphragms. Other kinds use static mechanisms, like ultrasonic flow meters, which have shown significant results regarding accuracy and non-intrusiveness.

Another kind are the **rotary meters**, used when high gas-flow levels and higher accuracy are required. This type of meter consists of two rotors that spin in precise alignment and let a specific quantity of gas pass at each complete turn. The gas flow information correspondent to each rotation is then recorded using electrical pulses or mechanical counters.

Recently, as in the case of electricity meters, gas meters have also experienced a development to **smart meters** which contain electronic devices that convert the pulse information into an energy consumption reading, and then store the reading or send it to a server. Due to the large number of traditional meters that are already installed, many manufacturers have also developed AMR (Automatic meter reading) solution to be directly connected to the pulse output of traditional meters. In this way, the conventional meter can be upgraded to a smart meter in a simple, quick, and non-invasive way.

Regarding other systems for monitoring gas consumption there are the **heat meters**, which measures thermal energy on the supply side or return side of a heat generating or heat exchanging device, by measuring the flow rate of the heat transfer fluid and the change in its temperature (ΔT) between the supply and return legs of the system. It can be used to measure the heat output of a heating boiler, and there are many different types of heat meters including: Impeller, Electromagnetic, Vortex, Fluidic Oscillator and Ultrasonic, which is the most popular. Regarding **ultrasonic heat meters** with ultrasonic flow sensor, they are suitable for recording accounting data for measuring energy consumption, and they can be of automated meter reading via radio or M-bus. The wear-free ultrasonic technology is impervious to debris, stable over the long term and is also reliable for very low volume flow rates.

Figure 2. Example of ultrasonic heat meter (source: meter zelsius® C5 IUF)

3.1.3 Air temperature

The temperature of the air always refers to the dry-bulb temperature, which can be measured by a wide variety of techniques, but the most common sensors are based on mechanical and electrical principles. **Mechanical devices** are in general cheap and reliable but are usually used for direct control purposes and/or visualisation rather than for metering and monitoring (e.g. domestic thermostats). Instead, **electrical sensors,** like **thermocouples** or **RTDs** (Resistance temperature devices), based on thermoelectric and electrical resistance principles, have the capability to convert the measured value into a digitally encoded signal for direct communication for control and measurement purposes.

3.1.4 Mean radiant temperature

Following ISO 7726 [1], the mean radiant temperature (MRT) is defined as "the uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure", which refers about the exchanging radiant energy between two bodies to be approximately proportional to their temperature difference multiplied by their ability to emit and absorb heat (emissivity). Thermal comfort in a space is directly related to the influence of both the air temperature and the temperature of surfaces in that space.

MRT measurement is suitable for short term evaluations, and particularly to examine the thermal comfort in places where there may be significant differences in radiant and air temperatures, for example, near a large window.

MRT can be estimated with the measure of the globe temperature (GT) of a **globe thermometer** device and some formulae detailed in ISO 7726. The measurement is affected by the air movement because GT depends on convection and radiation heat transfer, as well as by the shape of the sensor; the spherical shape of the device gives an approximation to a seated person and a ellipsoid sensor for standing people.

3.1.5 Indoor air velocity

Indoor air velocity is also directly related to the thermal comfort as it affects the heat flow on a body, and so its body temperature. A commonly used principle is to calculate the air velocity from the cooling (or heating) produced by air moving across the instrument, like the **hot wire anemometers**, that measure the cooling capacity of air moving across a "hot" wire: an electric current is sent through the wire causing the wire to become hot, and when a fluid (typically air) flows over the device, it cools the wire, removing some of its heat energy. The velocity of the fluid can be determined by solving the equations of heat transfer of the wire.

Other sensors exist for measuring air velocity based on pressure measurements, but they are suitable when flow air direction is determined, such as in air ducts.

[1] ISO 7726. Ergonomics of the thermal environment - Instrument for measuring physical quantities". Geneva, Switzerland: International Organization for Standardization. November 1998.

3.1.6 Relative humidity

Humidity refers to the content of water vapour in gases (e.g. air) and can be measured in terms of relative humidity (RH), absolute humidity, and dew point. Relative humidity is expressed as a percentage of the amount needed for saturation at the same temperature.

Electronic devices detect the change in electrical capacitance or resistance to measure humidity differences. The materials used in humidity sensors that exploit variations of electrical parameters can be classified into electrolytes, organic polymers, and ceramics. The **capacitive sensor** is composed of two metal plates, or electrodes, separated by a thin layer of non-conductive polymer film. The film attracts moisture from the air and when the moisture makes contact with the metal plates it creates a voltage change. The **resistive sensor** uses a moisture-absorbing material similar to the capacitive system, but the difference is that the measurement is of the resistance change in the material rather than the capacitance.

3.1.7 Indoor air quality (IAQ)

Indoor air quality (IAQ) is concerned with two of the three core requirements in terms of human comfort when occupying an indoor space: 1. Acceptable temperature and relative humidity, 2. adequate ventilation, and 3. normal concentrations of pollutants gasses (CO_2, volatile organic compounds (VOC), CO).

Modern devices for **CO_2 concentration** measurements are based in the principle of gas-absorption at a particular wavelength with the non-dispersive infrared (NDIR) method, and the information can be directly used in building automation to increase the natural or mechanical airflow, or to inform the occupants of the increasing concentration in a room, etc. CO_2 is the IAQ parameter most common monitored, as the main source of CO_2 in buildings is people.

Modern devices for **VOCs and CO concentrations** measurements are based in the principle of gas-absorption on semi-conductors by their high sensitivity to changes in the air composition resulting in a change of electrical conductivity of the sensor's material. VOC sensor captures substances that are emitted completely naturally from humans, but also captures a number of other unpleasant contaminants, which are emitted from objects and building materials, e.g. formaldehyde from paint, alcohols and aldehydes from adhesives and solvents, as well as benzene and styrene from copiers and computers. The VOC captures thousands of subjects, and instead of setting limit values for all these substances as CO_2, the VOC sensor is constantly calibrated to distinguish what is background level and what are changes, that is, the addition of contaminants. Otherwise, it can also be used in a modern system for demand-controlled ventilation.

3.1.8 Occupancy sensors

As well as building occupancy (presence and number of occupants) affects the indoor comfort, building occupancy clearly influences energy efficiency of HVAC systems as it determines heating/cooling loads on the demand side by varying conditioning periods and settings. So, it is an important fact to consider if the renovation project includes changes in the HVAC systems or for establishing the baseline scenario. However, sensing occupancy in a building, especially in residential buildings, can interfere with privacy and security aspects of the tenants; thus, they must be especially consulted for their agreement when planning the monitoring project.

Different types of occupancy sensing can be found in the market, especially after the COVID-19 crisis, when collecting real-time occupancy data is key to understanding how offices are being utilized and ultimately providing both a safe and cost-efficient workplace for the employees. On the market, occupancy sensors technology can be found that provides real-time space utilization data including occupants' locations, count, and movements, as well as precise reading of ambient lighting and motion sensing.

Occupancy sensors employ motion sensing techniques to detect the presence of occupants in a given range of space; passive infrared (PIR) detection systems and ultrasonic sensors are the most common. **PIR sensors** use a pyroelectric detector to detect a change in the temperature pattern in the observed space, but they can lead to false values if the occupants are far from the sensor site. Instead, **ultrasonic sensors** use the principle of Doppler effect by emitting ultrasonic waves and comparing them to reflected signals, and they are more reliable for long distances.

Other types of sensors are based on radio frequency identification (RFID) and imaging techniques such as camera and body recognition, but they are mostly used in offices for personnel identification.

3.1.9 Daylight sensors

A daylight sensor is a device that reads available light and sends a signal to the lighting control system for dimming or turning off electric lights based on the natural daylight entering the space. This device is called a **photosensor**. It is composed of a light-sensitive photocell, input optics and an electronic circuit used to convert the photocell signal into an output control signal. Photosensors may be mounted on walls, ceilings and even as a part of light fixtures, and it is most effective in areas that consistently receive ample daylight, such as lighting adjacent to windows or near skylights.

3.1.10 Weather stations

Modern all-in-one weather stations usually include the following sensors:

- Solar radiation
- Wind speed, direction, maximum wind speed
- Air temperature
- Relative humidity, internal sensor temperature

Outdoor temperature measurements are notably vulnerable to the surrounding environment, so it requires these additional precautions:

- Protect the temperature sensor from moisture, such as blowing rain
- Use a radiant shield to protect the sensor from direct sunlight and reflected surfaces
- Place the sensor in a well-ventilated location so that neither air stagnation nor stratification affects the temperature measurement

3.2 Features of the metering and monitoring devices

General main characteristics of the metering and monitoring devices are developed in the next sections. In the last section, a summary table of main sensors is presented.

3.2.1 Accuracy

Instrument accuracy is typically not represented by a single value. In most cases, accuracy is provided as a plus or minus (±) percentage of the reading and is only appropriate for a prescribed range of values from the full-scale reading. It can be said that the accuracy of a measurement is typically proportional to the cost of the instrument and the installation method, and aspects like sensor location, monitoring duration, and sampling interval also impact the accuracy of the results.

3.2.2 Granularity/resolution

Granularity or resolution represents the level of detail that can be collected, the minimum level of data. The data resolution depends of the resolution of the equipment, the data collection interval and the number of equipment connected to the system, so it is important to take it into account what data resolution has to be defined for monitoring periods; e.g. typical data interval for physical metering and data monitoring in non-domestic buildings set up in BMS (Building Management Systems) or BEMS (Building Energy Management Systems) in 30 min and 15 min with few changes in lighting, HVAC functioning is considered to be representative enough due to the few changes in the demand, but when considering energy consumption of computers with more frequent changes in power states, a more frequent interval of data may be required.

3.2.3 System deployment

Deployment of metering and sensing solution can offer different installation, visual and architectural disruption, and networking challenges (e.g. wireless sensors reduce the installation cost and labour and provide greater flexibility than wired).

In general, a few guiding principles should be followed:

- Sensors locations should be representative of areas to be controlled, therefore avoiding unrepresentative heat sources, stationary air pockets, draughts, or doorways. They should never be in direct sunlight.
- Sensing and metering location should be of easy access.
- New sensors and meters need to be interoperable with the existing installation in the building including BEMS/BMS, IT network, communication protocol and transport layers.
- Having into account that the choice of a given technology directly affects the complexity of the architecture supporting the monitoring system and providing the integration with the rest of the system monitoring.
- Confirm that the wireless capability of any new sensors and the all system have no limited coverage; at present, the modelling of different network options can be simulated in a virtual environment.
- Safety legislations and regulations regarding metering installation should be complied.

3.2.4 Uses

Sensors can be used for different purposes: for HVAC functioning, for direct control purposes and/or visualisation, as part of the instrumentation installed in the building, i.e. temperature, relative humidity, indoor environmental quality, etc. which form part of the building management system (BMS), for comfort test (thermal, mental or visual), for the knowledge of how spaces are utilized, etc.

In the following summary table of sensors Table 1, main uses of sensors are indicated.

3.2.5 Building types

Some particularities regarding the different types of buildings targeted in the StepUP project can be faced:

Multi owned residential buildings: when planning the monitoring system in multi owned residential buildings, one of the main difficulties can be dealing with and getting consensus with the homeowners' association about the choice of the monitoring infrastructure and its cost, what spaces/apartments are going to be measured, etc. as well as planning an effective system installation with the affected homeowners in order to reduce time consuming. Foreseeing time to deal with the community and assuring to have contact with a key association representant like the president of the homeowners' association can be of great help.

Public non-residential buildings (healthcare, school, academic, cultural buildings, event halls, offices, and administration buildings): it may be possible to find an existing sensing installation in the building. As exposed previously, the new sensors and meters need to be interoperable with the existing installation in the building including BEMS/BMS, IT network, communication protocol and transport layers.

Rented offices: in rented offices it may not be possible to install permanent measurement devices. Then an evaluation of the building performance can be done with spot measurements like:

- Measurements taken in a representative space, where people are expected to be most of the time,
- Measurements should be taken for a representative period of time (10 days)
- Measurements should be taken in the heating season and in the cooling season.

Also, monitoring in rented offices may not be possible if intrusive works on the buildings systems are needed. In these cases, non-intrusive devices can be found on the market.

Table 1. Summary table of sensors

Measured parameter	Type of sensor	Accuracy	Response time	Comm. Tech	Use	Approx. price [€]	Measuring range	Advantages	Disadvantages
Room temperature	Thermistor (RTD)	±0.1−0.5 ◦C	10−30 s	Wired	Direct visualisation	20−60	−50 to 180 ◦C	Low cost and good accuracy.	Problems of drift and requires proper calibration.
				Wireless	BMS				
					HVAC				
Room temperature	Thermocouple	±0.8−4 ◦C	10−80 s	Wired	BMS	10−50	−100 to 300 ◦C	Low cost, simplicity, robustness, temperature range and size and no requirement of power supply.	Low accuracy.
				Portable	HVAC				
Room temperature	PRT[2](RTD)	±0.25−0.6 ◦C	3−8 min	Wired	Direct visualisation	30−80	−50 to 100 ◦C	Great accuracy, reliability and stability.	High cost and very high time response.
				Wireless	BMS				
					HVAC				
Relative humidity	Capacitive polymer	±2−4.5% RH	10−50 s	Wired	Direct visualisation	40−170	0−100% RH	Accurate and stable.	High cost.
				Wireless	BMS				
					HVAC				
Relative humidity	Ceramic resistance	±2−5% RH	10−50 s	Wired	Direct visualisation	30−130	10−90% RH	High surface-volume ratio, which allows it to measure humidity changes in the environment up to 90% relative humidity at room temperature.	Not optimal for measuring values below 5% RH.
				Wireless	BMS				
					HVAC				

[2] PRT (platinum resistance thermometer)

Measured parameter	Type of sensor	Accuracy	Response time	Comm. Tech	Use	Approx. price [€]	Measuring range	Advantages	Disadvantages
Mean radiant temperature	Globe-thermometer	±1–3 °C	8–30 min	Wired	Thermal comfort test	30–130	20–120 °C	Low cost and high traceability.	High response times and overestimation of radiative contribution related to horizontal surfaces (floors and ceilings).
				Portable					
Indoor air velocity	Hotwire	±2–5% of reading	0.2–5 s	Wired	HVAC	40–150	0.05–20 m/s	Easily recording data for later analysis	Directional in response and can be inaccurate in low air velocities due to the natural convection of the hot wire
				Wireless	Airflow control Thermal comfort test				
CO_2 concentration	NDIR[3]	±30–80 ppm	30–50 s	Wired	Airflow control	170–400	0–2000 ppm	High durability, reliability and accuracy	High energy consumption
				Wireless					
CO and VOC concentration	MOSFET[4]	±50–100 ppm	<60 s	Wired	Airflow control	170–400	400–2000 ppm CO2 eq.	High and stable sensitivity	High electric consumption
				Wireless					
				Portable					
Occupancy	PIR	-	10 s–15 min	Wireless Wired Standalone[5]	HVAC Indoor lighting	20–70	3–5 m radius or 5–12 m front and 3–8 m lateral	Low cost	Limited range, and coverage, which means more sensors required

[3] NDIR (Non-dispersive infrared)
[4] MOSFET (Metal–oxide–semiconductor field–effect transistor)
[5] Standalone sensor connected to an actuator to switch on/off or dim artificial lighting.

Measured parameter	Type of sensor	Accuracy	Response time	Comm. Tech	Use	Approx. price [€]	Measuring range	Advantages	Disadvantages
	Ultrasonic	-	30 s–30 min	Wireless Wired Standalone	HVAC Indoor lighting	120–240	185 m2	High reliability in detecting presence over long distances	High cost
Daylight	Photosensor	±8–10% of illum	N/A	Wireless Wired	Indoor lighting	80 - 200	0-5000lx	Switching is simple. Particularly effective for energy management applications such as automatic shutoff or reduction in vacant spaces. Dimming is flexible as it changes intensity with smooth transitions between light levels.	Switching is limited in flexibility and can be disruptive in spaces occupied by more than one user.

3.3 Communication and network technologies

Communication and network technologies are the part of the data collection infrastructure aimed for the data transmission. They can be used between utility meters and utility providers, building energy management system and indoor environmental monitoring sensors, building users and smart appliances, etc. They use well-defined formats for exchanging information. Their protocols define the rules, syntax, semantics and synchronization of communication and possible error recovery methods. Protocols may be implemented by hardware, software, or a combination of both.

Nowadays, commercially available meters offer a wide range of communication and network compatibility that permits flexibility of connectivity with most existing systems. On the other hand, commercially available sensors are made IoT connectable to communication networks with standard and interoperable communication protocols.

There is an extensive range of communication and network technologies to transfer sensing data. Examples of this are RS485, WiFi, LoRa, ModBus, M-Bus, GPRS GMS, PLC, BACNet, etc. and they can be wired and wireless. These two connectivity options have advantages and disadvantages. Wired solutions are not impacted by other radio waves at similar frequencies, but wireless technology has high flexibility and scalability, is low-cost solutions, of easy deployment and maintenance, reduce construction costs by eliminating time and material costs over long distances in new and renovation control projects, etc.

Some of the widely used communication and networks technologies for metering and sensory purposes in the buildings are discussed in the following chapters.

3.3.1 LoRa

LoRa (short for long range) is a wireless technology (like WiFi, Bluetooth, LTE, SigFox or Zigbee) that uses a type of radio frequency modulation patented by Semtech, a major radio chip manufacturer. Semtech's LoRa devices and wireless radio frequency technology is a long range, low power wireless platform that has become the de facto technology for Internet of Things (IoT) networks worldwide.

The modulation technology is called Chirp Spread Spectrum (or CSS) and has been used in military and space communications for decades. The technology can be utilized by public, private or hybrid networks and provides greater range than Cellular networks. LoRa Technology can easily plug into existing infrastructure and enables low-cost battery-operated IoT applications. At present, LoRa technology is administered by the "LoRa Alliance", which certifies any hardware manufacturer that wishes to work with this technology. LoRa is an ideal technology for long-distance connections and for IoT networks in which sensors that do not have electrical current from the network are needed. LoRa uses LoRaWAN as the communication protocol and LPWAN for low power and wide area networks (Low Power Wide Area Network) to communicate and manage LoRa devices. The LoRaWAN protocol is made up of gateways (in charge of receiving and sending information to the nodes) and nodes (the end devices that send and receive information towards the gateway, e.g. LoRa sensors).

Semtech's LoRa chipsets are incorporated into devices manufactured by a large ecosystem of IoT solution providers, and connected to LoRaWAN-based networks around the globe.

3.3.2 ZigBee

ZigBee was built on the IEE 802.15.4 standard (Semtech, s.f.) (standard defines the physical layer and medium access control sub-layer specifications for a low rate and cost personal area networks) and operates in the 2.4 GHz and 900 MHz bands. ZigBee provides a low cost, reliable data transfer, short range, low power consumption home area wireless network solution, and it is used for building automation and remote meter readings. Due to its low power and rate, and also short-distance nature, it is not recommended to be used for applications with a strong real-time component and large amounts of transferred data.

3.3.3 ModBus

ModBus was introduced by Modicon Corporation and used it as a point-to-point connection with EIA-232C interfaces of Programmable logic controllers. It is one of the widely used communication protocol due to its simplicity and reliability. It includes RTU (Remote Terminal Unit), TCP (Transmission Control Protocol) and ASCII mode of transmission and supports RS-232, RS-422, RS-485 and Ethernet based equipment. For data communication ModBus is based on called Master/Slave method; an information request is sent by the Master and Slave produces the response to the requested information.

ModBus, because of its simplicity and open source availability, is more popular for local communication in buildings and has become standard for industrial SCADA systems. One of the primary concerns of ModBus is that it does not support authentication nor encryption, which means it is less secure and more vulnerable to cyber-attacks, but at present, new security features of Modbus/TCP protocol have been incorporated, like the change from master/slave to client/server, among others.

3.3.4 BACnet

BACnet stands for building automation and control network and was initiated by ASHRAE (American Society of Heating, Refrigeration and Air-conditioning Engineers) and is now an American National Standard (ANSI/ASHRAE 135-1995) and ISO Standard (ISO16484-5) standard protocol. The advantage of using BACnet is its ability to be integrated with different types of equipment without having any need for additional hardware. A wireless version of BACnet using short range wireless networks has also been developed, and by using ZigBee as a communication protocol for BACnet permits to take advantage of reduced installation cost, flexible extension, and mobile device connectivity.

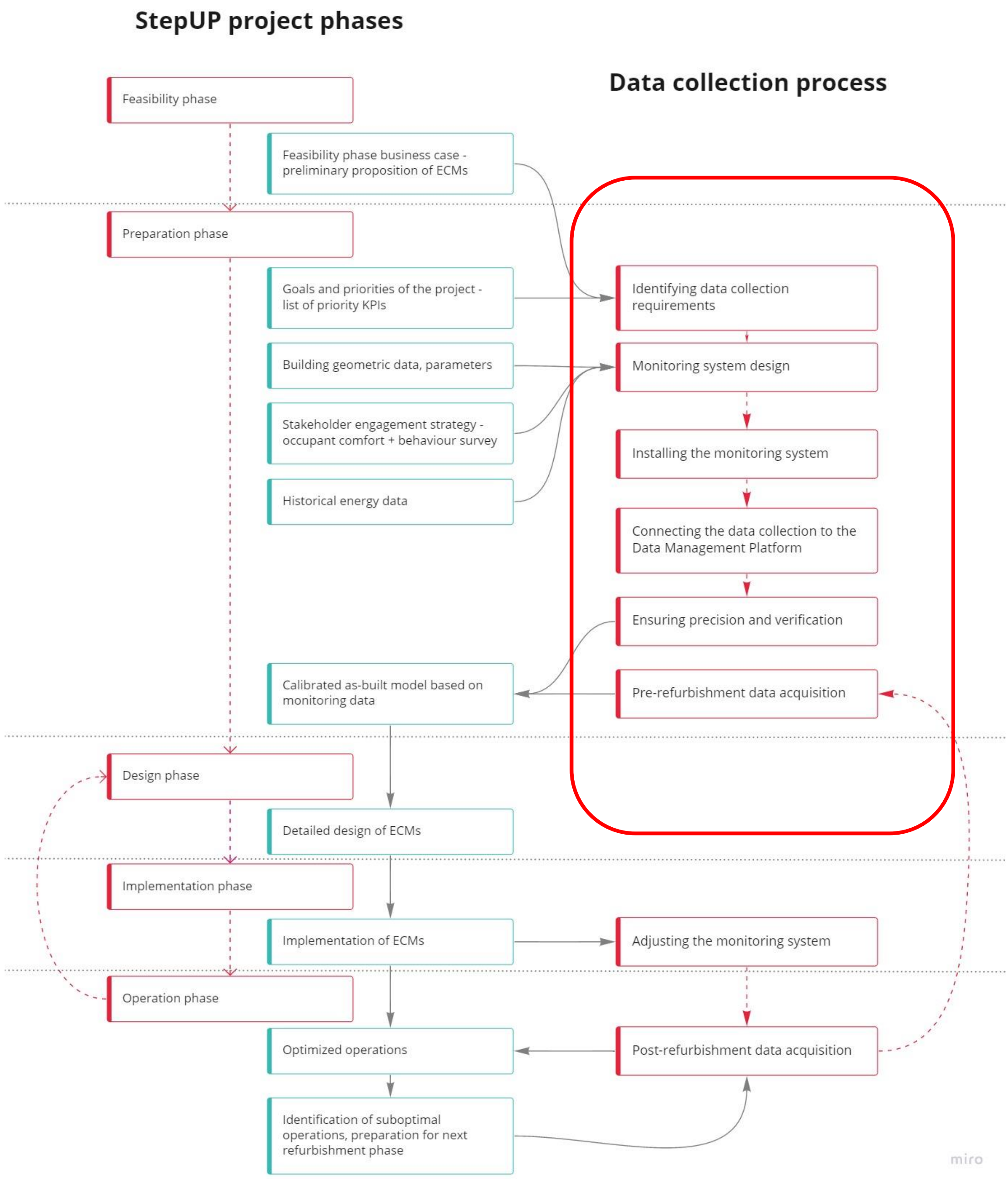
3.3.5 M-Bus

M-Bus (Meter-Bus) is a European standard (EN 13757-2:2019 physical and link layers, EN 13757-3 application layer) and applies to communication systems for meters and remote reading of meters, used for transmitting gas, heat, oil, etc. meter readings to utility providers. M-Bus permits many devices to be connected with each other, and there can also be the possibility of network expansion. At the present, M-Bus also have wireless applications, and recent research has been focussed on Wireless M-Bus.

4 Protocol for data collection to apply the StepUP methodology

The Data collection protocol is closely related to all phases of the StepUP renovation methodology (see D1.2), and it is line with the iterative character of the methodology. The data infrastructure supports the determination of areas of low performance in an operating building and the accurate design of energy conservation measures (ECMs) through long-term monitoring of the existing building. After the implementation of the designed ECMs it also supports the continuous commissioning and the optimization of operations to minimize the building performance gap between predicted and real-time measured data and to guarantee the users' comfort. The data collection process also relies on information coming from the design of the retrofitting. The following chapters address the data collection process with the StepUP methodology step by step.

Figure 3. Data collection flowchart



4.1 Identifying data collection requirements

Set up on Feasibility and Preparation phase of StepUP methodology.

The main result of the **Feasibility phase** is the early business case that proposes a **preliminary list of ECMs** based on a quick expert assessment of the existing building and its operations from a simple building data collection. This building data can be collected based on first site surveys and building plans. Then at the beginning of the **Preparation phase** the goals and priorities of the renovation project are already determined, which can be translated to the selection of the **most relevant KPIs** for the project, described in **D1.2.**

This two information items (preliminary list of ECMs and the high priority KPIs) serve as the basis for identifying the data collection requirements for the monitoring system by selecting the **parameters and its data interval** to be monitored on the building and the analyses needed, regarding energy consumption, thermal, visual and mental comfort, climatic conditions and use of installations (in terms of both occupancy and comfort requirements). These parameters and the sensors associated defined in the previous chapter 3, are summarized in the next table:

Table 2. List of measurements for a monitoring system building

Aspects	Parameters to be measured	Required sensor	Functionality	Typology	Duration of monitoring
Energy consumptions	Electricity metering	Electricity meter	Analysing energy consumptions patterns and energy use, as well as operational profiles of energy systems.	Required	Long period[6]
	Gas metering	Gas meter		Required	Long period
Comfort level	Indoor air temperature	Indoor air temperature sensor	Analysing thermal comfort by measuring dry-bulb temperature of air in indoor spaces. Also, for controlling HVAC systems.	Required	Long period
	Relative humidity	Relative humidity sensor	Analysing thermal comfort by measuring relative humidity of air in indoor spaces. Also, for controlling HVAC systems.	Required	Long period
	Mean radiant temperature	Globe thermometer	Analysing thermal comfort by measuring radiant heat in indoor spaces.	Optional	Short period[7]
	Indoor air velocity	Hot wire sensor	Analysing thermal comfort by measuring the cooling capacity of air moving across a 'hot' wire.	Optional	Short period
	Indoor air quality (IAQ)	CO_2, VOC and CO concentrations	Analysing air quality (thermal and mental comfort) produced by human occupancy by measuring and recording.	CO_2 required, VOC and CO optional	Long period
	Daylighting	Photo sensor	Analysing the impact of daylighting in the building energy use.	Optional	Long period
Occupancy level	Occupancy	Occupancy sensor	Analysing the impact of the human performance in the building energy use and air quality.	Optional	Long period
Weather conditions	Solar radiation	Pyranometer	Analysing the impact of weather conditions in the building use.	Optional	Long period
	Wind speed, direction, maximum wind speed	Anemometer		Optional	Long period
	Air temperature	All in-one sensor		Required	Long period
	Relative humidity				

[6] "Long period" is considered 1 natural year at least of monitoring period.
[7] "Short period" is referring to spot measurements, but for a representative period of time (10 days), and during the heating season and in the cooling season.

It may be that the building has some level of building metering or sub-metering in place (e.g. some BMS/BEMS) and/or utility bills with **historical data** gathered. When this is the case, as explained in **chapter 5.1 of deliverable D1.2** in the **Feasibility phase**, an on-site survey to the building will be necessary to collect this data and evaluate its suitability and implementation with the monitoring plan for the project. Tasks like identifying the type of meters and sensors, its location, operating status, capabilities, and actual data collection and communications network will complete the survey.

Also, as explained in the **chapter 5.2 of the deliverable D1.2**, **geometric data** of the building is another kind of data required to plan the monitoring design, jointly with the **location of the occupied spaces** and **its regime of use** for the occupancy monitoring, especially in case the building is not residential, as the different uses of the spaces are not obvious. For this task is necessary the supporting of the stakeholder engagement strategy as presented in D1.2, especially the early stage occupant comfort and behaviour surveys and interviews.

4.2 Designing the monitoring system

Set up on Preparation phase of StepUP methodology.

When the data collection requirements are determined, the next step is to design a cost-efficient monitoring system. It is important to consider what spaces are representative in location, orientation, and occupancy profile to be monitored to achieve an accurate knowledge of the building performance, as well as suitable for the expected impacts of the ECMs, before and after its implementation. The next table shows an approach of the parameters to be measured according to the StepUP building typology targeted:

Aspects	Parameters to be measured	Multi owned residential buildings	Public non-residential buildings[8]	Rented offices
Energy consumptions	Electricity metering	Required	Required	Required
	Gas metering	Required	Required	Required
Comfort level	Indoor air temperature	Required	Required	Required
	Relative humidity	Required	Required	Required
	Mean radiant temperature	Optional	Optional	Optional
	Indoor air velocity	Not required	Optional	Optional
	Indoor air quality (IAQ)	Required	Required	Required
	Daylighting	Not required	Optional	Optional
Occupancy level	Occupancy	Optional	Optional	Optional
Weather conditions	Solar radiation	Optional	Optional	Optional
	Precipitation	Optional	Optional	Optional
	Lightning strike count, average distance	Optional	Optional	Optional
	Wind speed, direction, maximum wind speed	Optional	Optional	Optional
	Air temperature	Required	Required	Required
	Vapor pressure	Optional	Optional	Optional
	Barometric pressure	Optional	Optional	Optional
	Relative humidity, internal sensor temperature	Required	Optional	Optional
	North wind speed, east wind speed	Optional	Optional	Optional
	Illuminance	Optional	Optional	Optional

[8] Healthcare, school, academic, cultural buildings, event halls, office and administration buildings.

If the data concerns a critical aspect of the estimated savings calculation or occupants comfort perception point of view, a redundant measurement, or an additional proxy measurement for the parameter of interest may be considered. However, such considerations should be made within the context of ensuring a practical and cost-effective monitoring process.

Also staffing resources must be considered which includes the staff necessary to start up the monitoring system as well as the staff or contracted support for the ongoing operations, possible repairs, and maintenance of the installed system.

For a general purpose, the design of the monitoring system hardware application needs to:

- Satisfy current functional requirements
- Establish accuracy needed for each type of sensors
- Define a system architecture
- Anticipate future available technology products
- Develop equipment specifications
- Review and refine the cost estimate to purchase and install the monitoring system

4.3 Installing the monitoring system

Set up on Preparation phase of StepUP methodology.

When installing the monitoring system, there are some key points to be considered:

- Follow all manufacturers' guidelines of meters and sensors
- Decide the sensor location to be representative to the area to be controlled, not exposed to direct sun or any heat source, and if possible, at least 0.5m from corners or vertical intrusions to avoid recording temperature in a stagnant air pocket

Before installing a meter or sensor, it is important to test it to ensure it is working properly and making the intended measurement. The following checklist (extracted from NREL: Chapter 9: Metering Cross-Cutting Protocol) can be used as a guide:

- If meter or sensor operates on batteries, are the batteries in good condition? Is the meter or sensor properly powered?
- Is the meter or sensor clock synchronized to the official time and local time zones?
- Are all the settings on the meter or sensor correct?
- Are meters or sensors properly attached and in place?

4.4 Connecting the data collection to Data Management Platform

Set up on Preparation phase of StepUP methodology

Once installed the hardware infrastructure, the data stream must be imported to the Data Management Platform through the iSCAN tool.

Different data sources of the sensing infrastructure can feed the data collection of the renovation project: data from a BMS network, an automatic meter reading, a smart meter, a sensor or an IoT sensor, a weather station, etc. and all of them can be imported by different options of the system configuration:

- By setting the system to periodically export histories of points to a local folder in the client's network (CSV, XML, Json or oBIX). This requires the installation of a service (iSCAN-robot[9]) on the network that automatically gathers the file at regular intervals and uploads the data to iSCAN.
- By setting the system to export periodically histories of points to an FTP server. The vendor will create a program to retrieve data periodically from the FTP directory and upload it to iSCAN.
- By setting the system to send exported files to an iSCAN generated email address. This will allow automated data upload to iSCAN.
- If the system can function as an MQTT client, data can be uploaded in iSCAN using the MQTT protocol.

For any of the previous importing options, an internet connection is required.

Manual data imports are also possible if the data is collected from the site and transferred to a machine that can communicate with iSCAN. While no internet connection is required at the source of the data, this approach will require physical access to the machine where the data is being collected. Typically, manual uploads would fall into the CSV, XML, oBIX and JSON data formats.

For the purposes of the StepUP methodology, a continuous data collection is strongly recommended.

4.5 Ensuring precision and verification of measurements

Set up on Preparation phase of StepUP methodology

Once the data can be visualized on the Data Management Platform and before beginning the data acquisition for the calibration of the building baseline model, the collected data must be verified, as it is an essential aspect of ensuring an accurate metering process. Key best practices for data verification are the following (extracted from NREL: Chapter 9: Metering Cross-Cutting Protocol):

- Review the data to: (1) verify that they are complete and correct, and (2) identify readings that appear inappropriate or notably atypical for the specific system.
- If the readings appear to be incorrect, conduct cross-checks with other sensors or meters. Additionally, review the assumptions that were made when planning the metering to assess their validity and appropriateness.
- If the cross-checks do not validate the data, calibrate the equipment to match other metering instruments. Alternatively, determine whether the sensor or meter needs to be replaced.
- Validate the metering equipment results with building-installed instruments, as needed, as another method of cross-checking. If the building has data recording capability or a BMS),

[9] iSCAN-robot is a supporting service that can be downloaded from the online iSCAN page of a specific project.

readings from those systems can be used for reference. Ultimately, however, these measurements must be objectively validated against independent metering equipment.

- Review the retrieved data for completeness and accuracy before incorporating it into the final analysis.

4.6 Pre-refurbishment data acquisition

Set up on Preparation phase of StepUP methodology.

In the last step of the Preparation phase, the monitoring system is ready to collect, store and visualize data to set up the baseline building dynamic energy model with the current conditions of weather, occupancy profiles and operational profiles. This calibration process will take at least 1 natural year of monitoring data, needed to enable a continuous commissioning and to create the baseline for performance monitoring and verification.

This calibration process will help the designing of reliable ECMs and to minimize the energy performance gap between predicted and actual measured performance.

4.7 Adjusting the monitoring system

Set up on Implementation phase of StepUP methodology.

Once the ECMs have been designed, the monitoring system may need some adjustments, adding sensors as needed (e.g.: to install an electric meter for the heat pump consumption of the newly implemented SmartHeat system).

4.8 Post-refurbishment data acquisition

Set up on Operation phase of StepUP methodology.

The energy model of the building will incorporate the ECMs as in the real building. The performance will be monitored for at least 1 natural year, to allow for a continuous commissioning and a performance monitoring and verification in order to assess the impact of the ECMs.

5 Data monitoring and control in smart readiness indicator (SRI) schemes

5.1 Basics of the Smart Readiness Indicator (SRI)

In the last amendment (2016) of the Energy Performance of Buildings Directive (EPBD), one of the focus points was to reinforce the implementation of the potential of the smart technologies in the building sector, as smart technologies in buildings can be a cost-effective means to assist in creating healthier and more comfortable buildings with a lower energy use and carbon impact, while also facilitating the integration of renewable energy sources in future energy systems.

As a result of this approach, the EC has adopted the **Smart Readiness Indicator** (SRI) scheme[10], which will be optionally implemented in the Member States, as an instrument for rating the smart readiness of buildings, accompanied by a series of SRI calculation methods and components for its assessment. This technological rating for buildings regarding smart technologies will assess the level of smart interaction of the building with their occupants and with connected energy grids, and how to operate the building more efficiently. In fact, the aim of the SRI is to raise awareness of the benefits of smarter building technologies and functionalities and make their added value more tangible for building users, owners, tenants, and smart service providers. It is expected to become a cost-effective measure.

A "**smart ready[11] technology**" is considered to be an active component which could potentially:

- raise energy efficiency and comfort by increasing the level of controllability of the technical building systems (TBS) - either by the occupant or a building manager or via a fully automated building control system
- facilitate the energy management and maintenance of the building including automated fault detection
- automate the reporting of the energy performance of buildings and their TBS (automated and real time inspections)
- use advanced methods such as data analytics, self-learning control systems and model predictive control to optimise building operations
- enable buildings including their TBS, appliances, storage systems and energy generators, to become active operators in a demand response

"**Smart ready[11] services**" are considered to satisfy a need from the user (occupant/owner) of a building or the energy grid it is connected to. Services are enabled by (a combination of) smart ready technologies, but are defined in a technology neutral way, e.g. 'provide temperature control in a room'. Many of the services listed in the catalogue are based on international technical standards, for example BACS control functions (EN 15232-1:2017), lighting control systems (EN 15193-1:2017) and Smart Grid Use cases (IEC 62559-2:2015).

The technical study "Smart Readiness Indicator for Buildings" (SRI), started in March 2017 until July 2018, in order to further investigate the scope, definition and calculation of this SRI, also with the aim of a more detailed assessment of its possible impact at EU level. In the final report the technical study team proposed a consolidated methodology to calculate the SRI of a building.

[10] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12365-Smart-buildings-smart-readiness-indicator-arrangements-for-rollout-of-scheme-

[11] The term "ready" indicates that the option to take action exists, but is not necessarily realized, e.g. due to cost constraints, legal or market restrictions, or occupant preferences. However, the equipment needed to implement the service has to be present in the building.

The methodology is a flexible and modular multi-criteria assessment method which builds on assessing the smart ready services present in a building. The proposed calculation methodology is structured amongst 9 technical domains and 7 impact criteria.

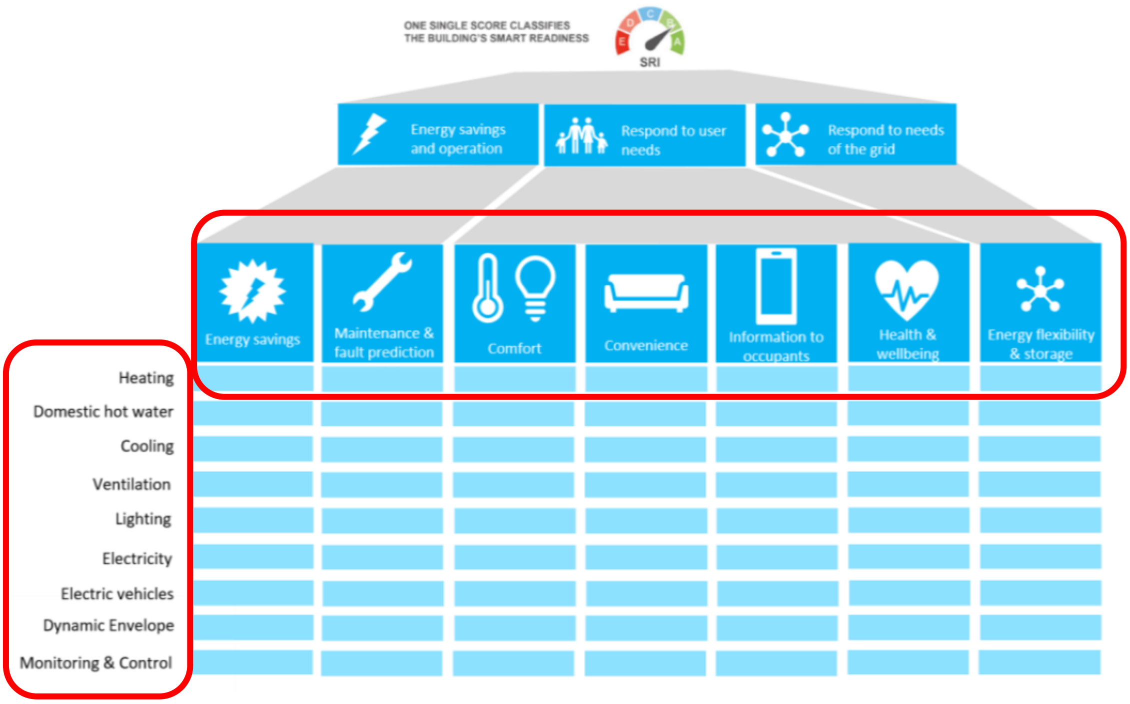
In the SRI Framework, a general service catalog has been agreed with the interested parties on a hierarchical structure, classifying the services within the following **domains**:

- Heating: storage, generation, distribution, and emission of heat.
- Cooling: accumulation, control of emitters, generation, and consumption.
- Domestic hot water: efficiency of distribution, generation, and accumulation.
- Mechanical ventilation: control of air flow and indoor air temperature.
- Lighting: control of the level of artificial lighting and natural light.
- Dynamic envelope: control of windows, their blinds, or elements of solar protection.
- Power generation: on-site generation and possible local use, as well as the flexibility provided to the grid.
- Electric vehicle charging: vehicle charging, storage or network injection.
- Monitoring and control: data recording through sensors integrated in the TBS (Technical Building System) for control and decision making.

Each service is then evaluated on a set of **impact** criteria, defined as:

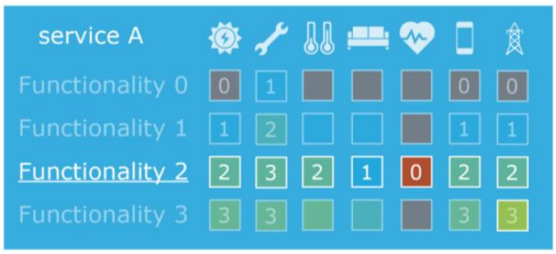
- Energy savings
  This impact category refers to the impacts of the smart ready services on energy saving capabilities. It is not the whole energy performance of buildings that is considered, but only the contribution made to this by smart ready technologies, e.g. resulting from better control of room temperature settings.
- Flexibility for the grid and storage
  This impact category refers to the impacts of services on the energy flexibility potential of the building. The study proposes to not solely focus on electricity grids, but also include flexibility offered to district heating and cooling grids.
- Comfort
  This impact category refers to the impacts of services on occupant's comfort. Comfort refers to conscious and unconscious perception of the physical environment, including thermal comfort, acoustic comfort, and visual performance (e.g. provision of sufficient lighting levels without glare).
- Convenience
  This impact category refers to the impacts of services on convenience for occupants, i.e. the extent to which services "make life easier" for the occupant, e.g. TBS requiring fewer manual interactions.
- Well-being and health
  This impact category refers to the impacts of services on the well-being and health of occupants. For instance, smarter controls can deliver an improved indoor air quality compared to traditional controls, thus raising occupants' well-being, with a commensurate impact on their health.
- Maintenance and fault prediction
  Automated fault detection and diagnosis has the potential to significantly improve maintenance and operation of technical building systems. It also has potential impacts on the energy performance of the technical building systems by detecting and diagnosing inefficient operation.
- Information to occupants
  This impact category refers to the impacts of services on the provision of information on building operation to occupants.

Figure 4. Proposed structure of domains and impacts criteria



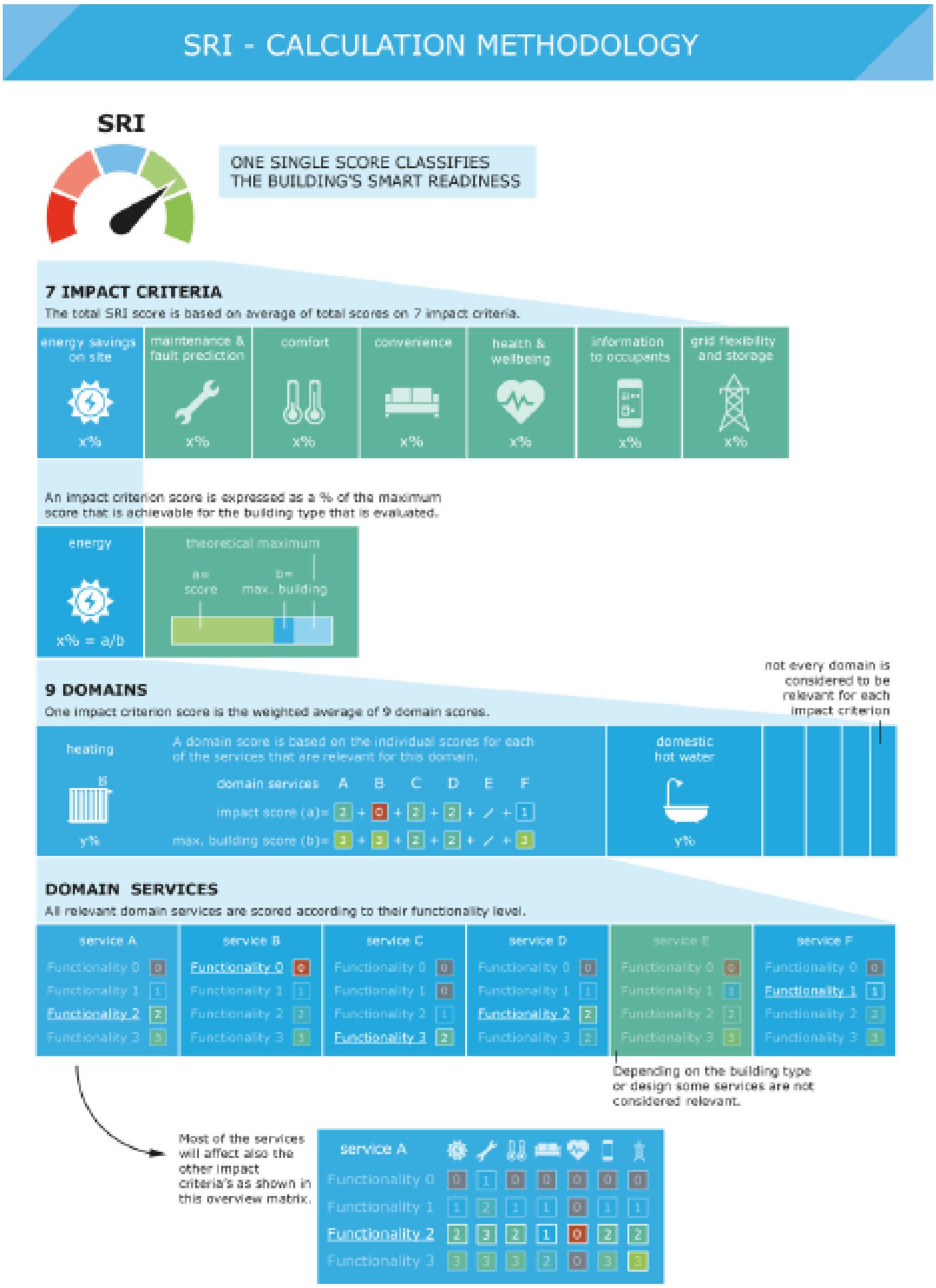
For each of the smart ready services in the catalogue, provisional impact scores have been defined for their respective functionality levels according to a seven-level ordinal scale. While most of the impacts are positive, the scale also provides the opportunity to ascribe negative impacts. A higher functionality level reflects a "smarter" implementation of the service, which generally provides more beneficial impacts to building users or to the grid compared to services implemented at a lower functionality level.

Figure 5. Matrix displaying the impact scores for the seven impact categories of a fictitious "service A"



The smart service catalogue was elaborated for both a detailed and a simplified assessment. The simplified Method A would be mainly oriented towards small buildings with low complexity (single family homes, small multi-family homes, small non-residential buildings, etc.), whereas the more detailed Method B is mainly oriented towards buildings with a higher complexity (typically large non-residential buildings, potentially large multi-family homes). For either method an informative self-assessment could be made available as an alternative to a formal certificate.

Figure 6. Summary of the calculation method



5.2 StepUP Data collection infrastructure implementation & SRI

The Data collection infrastructure implemented throughout all the steps of the Data collection protocol described in **Chapter 4** paves the way for obtaining a robust well-scored SRI for buildings under the implementation of the StepUP methodology, as the impacts developed in the SRI calculation method are in line with the benefits of the data collection infrastructure approached in the Data collection Protocol. This is specifically true for the services within the monitoring and control domain - Monitoring and control: data recording through sensors integrated in the TBS (Technical Building System) for control and decision making. Several of these domain services regarding data management are specified in the standard EN15232:2017 and thus their impacts with regard to on-site energy use are readily attributable via the BACS factor methodology derived from extensive building simulation results.

The list of services within the monitoring and control domain of the SRI methodology and the data collection infrastructure implementation suggested in the Protocol (**Chapter 4**) are cross-checking in the following table:

Table 3. Services within the monitoring and control domain and suggested implementation in StepUP Data collection infrastructure

Services within the monitoring and control domain of SRI methodology	Implemented in the Data collection infrastructure
Heating and cooling set point management	No
Control of thermal exchanges	No
Run time management of HVAC systems	No
Detecting faults of technical building systems and providing support to the diagnosis of these faults	Yes
Reporting information regarding current energy consumption	Yes
Reporting information regarding historical energy consumption	Yes
Reporting information regarding predicted energy consumption	Yes
Occupancy detection: connected services	Yes
Occupancy detection: space and activity	Yes
Remote surveillance of building behaviour	Yes
Central off-switch for appliances at home	No
Central reporting of TBS performance and energy use	Yes

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7 Glossary

ASCII
: ASCII, abbreviated from American Standard Code for Information Interchange, is a character encoding standard for electronic communication., 19

Automatic meter reading (AMR)
: Automatic meter reading is the technology of automatically collecting consumption, diagnostic, and status data from water meter or energy metering devices (gas, electric) and transferring that data to a central database for billing, troubleshooting, and analyzing., 9

Building Management System (BEMS)
: A BEMS monitors and controls energy-related building services such as HVAC and lighting., 13

Building Management System (BMS)
: A BMS is a control system that can be used to monitor and manage the mechanical and electrical services in a building or facility. Such services can include power, access control, lifts and lights, heating, ventilation, air-conditioning., 13

GSM module
: A GSM modem or GSM module is a hardware device that uses GSM mobile telephone technology to provide a data link to a remote network., 9

Remote Terminal Unit (RTU)
: A RTU is a microprocessor based device that monitors and controls field devices, that then connects to plant control or SCADA (supervisory control and data acquisition) systems., 19

RF transceiver
: Transceiver is the term used for device which houses both transmitter and receiver in single module. Such device which transmits and receives Radio Frequency (RF) signal is called as RF Transceiver., 9

SCADA
: Supervisory control and data acquisition (SCADA) is a system of software and hardware elements that allows industrial organizations to directly interact with devices such as sensors, valves, pumps, motors, and more through human-machine interface (HMI) software., 19