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Self Assessment Towards Optimization of Building Energy

Deliverable 1.6

Evaluation Framework for SATO concept and Business Model

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Revision history

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DISCLAIMER

EXECUTIVE SUMMARY / ABSTRACT / SCOPE

The work developed in this report characterizes SATO pilot sites, referring to the different sensors and equipment available, highlights key performance indicators that can be used for SATO solution evaluation, and details the Evaluation Framework methodology to be used in SATO.

Using methodology based on concepts already defined in the literature and widely used, the Evaluation Framework developed in this report is transparent and easily applicable, providing a good basis for its replication in buildings beyond SATO. The methodology is a 6-step approach based on the aggregation of key performance indicators using unit and scale normalization, and weighting methods.

To develop this Evaluation Framework, the different characteristics of the pilots were taken into consideration, namely the different weather conditions or monitoring points available. As a result, the Evaluation Framework developed had to be flexible enough to support these different conditions. The application of a weighting method provides a flexible solution by creating different weights for the different scenario conditions. The weighting method used, the budget allocation process, works by collecting expert opinion on what are the most relevant indicators, a method that has a great advantage of adjusting to correlation between indicators. To ensure a good application of this method it is essential that the expert panel selected has a wide spectrum of knowledge and experience on the topic under analysis.

The key performance indicators suggested in this report consider the monitoring capacity of the pilots, but other indicators may be used using the same methodology. Using the unit and scale normalization all indicators used will be converted to the same scale, which should be simple so that non-technical people can extract information on the value obtained.

The Evaluation Framework will ensure that all SATO solutions and business models can be evaluated and compared to similar solutions that are already in the marketed, highlighting the added value of SATO solutions in a transparent way.

1. Objectives of the task

The development of an Evaluation Framework that enables the evaluation of the different SATO solutions and Business Models is a key part in understanding the potential of SATO in terms of energy efficiency, profitability, and replicability. To achieve these objectives, the Evaluation Framework needs to have an easily understandable scale, that can be used even by non-technical people, while maintaining a rational that values the important parameters of the building. For that, the Evaluation Framework developed in this task will be based on the project key performance indicators (KPI's).

While the evaluation based on KPI's allows us to evaluate the key parameters of the building and the impact of SATO solutions and business models, the KPI's are very technical indicators that only experts in the topic may draw conclusions. This task focussed on implementing a methodology that allows to elucidate the KPI's by putting them in a comprehensible scale and, at the same time being agnostic to local factors that influence the results, such as the weather conditions that influence the amount of heating and cooling required in a building.

To achieve the stated, this task has three main objectives:

1. Gather detailed information on the project pilot sites;
2. Identify the key performance indicators that should be used in the evaluation;
3. Develop an Evaluation Framework with a simple scale and agnostic to local conditions.

The first objective aims to collect information to support the selection of KPI's, such as information of what metrics will be measured in each pilot. This enables the second objective, to identify the KPI's that will be used for the evaluation as it is important the whenever SATO implements a specific solution, there are monitoring points to allow to characterize the impact of that solution. The third objective is to describe the methodology of the Evaluation Framework for SATO, according to the constrains identified.

This document aims to support the evaluation of SATO solutions and business models throughout Work Package 6. It is expected that the Evaluation Framework will be applied in several stages during this Work Package. In the end, the application of the Evaluation Framework should lead to conclusions on the commercial potential of SATO solutions and business models, when compared to what is already on the market.

2. SATO Pilots Description

This section focus on a detailed description of all SATO pilot sites, expanding on what was firstly described in the proposal of the project. The description focuses on the main energy consuming equipment in each pilot as well as the monitoring and control solutions that are or will be deployed during the project.

2.1. Milan Multi-Apartment Residential Pilot

2.1.1. General description

The Milan Multi-Apartment Residential Pilot is a pair of buildings, built in 1980, located in Milan, northern Italy. The buildings are currently being retrofitted, in an effort to modernise the infrastructure and extend the lifespan of the building. The retrofit of the building is currently on-going, and works should be finished by 2022.

Between both buildings, the net floor area is 2160 m^2 and each building has three floors. In total there are 66 apartments, ranging from 2 to 4 bedrooms, and housing around 210 people.

The energy consumption in this pilot site is around 55 MWh per year for electrical energy and 9.6 MWh_{th} per year for thermal energy (used for domestic hot water and space heating).

Comune di Milano is the building owner and also the responsible partner for this pilot site, with support from Politecnico di Milano. Figure 1 shows the Milan Multi-apartment pilot site.

Figure 1 – Street view of Milan Multi-apartment pilot building

2.1.2. Building equipment

The Milan Multi-Apartment buildings use a ground to water heat pump and thermal solar panels for heating purposes and also for the production of domestic hot water. A condensing gas boiler is also used as a backup during the cold winter months. Figure 2 shows the scheme for the hot water system in the pilot site. The buildings are not equipped with any active cooling system, instead cooling is achieved using natural ventilation strategies.

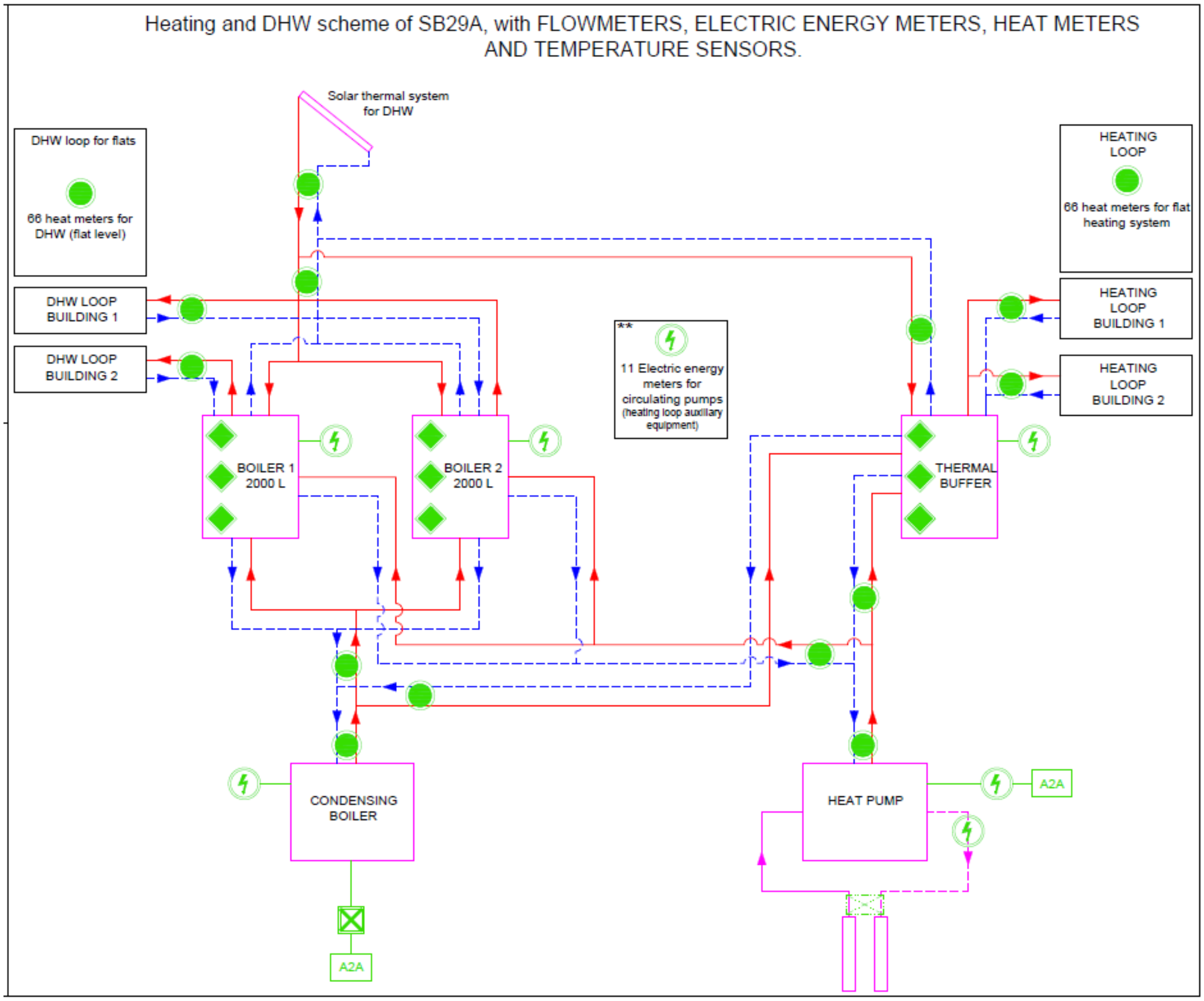

Figure 2 – Scheme of heating system in Milan Multi-apartment pilot.

The buildings are equipped with a centralized ventilation system with heat recovery during winter and a bypass to enable free cooling during the summer.

Energy production and storage is also available in these building, having a photovoltaic system with 127 m^2 of panels and a solar thermal system with 20 m^2 of panels, producing around 20 MWh and 9 MWh_{th} every year. The existing storage system enables to store up to 20 kWh of electrical energy.

2.1.3. Monitoring and control

The Milan Multi-apartment pilot site is connected to the Siemens DEOP platform[1] which logs and displays all the data collected through the monitoring system.

Electrical energy is monitored for each apartment through the utility smart meters, although this data is anonymized for privacy reasons. The buildings' common parts are also monitored as shown in Figure 3.

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[1] https://new.siemens.com/my/en/products/energy/energy-automation-and-smart-grid/grid-applications/energyip/deop.html

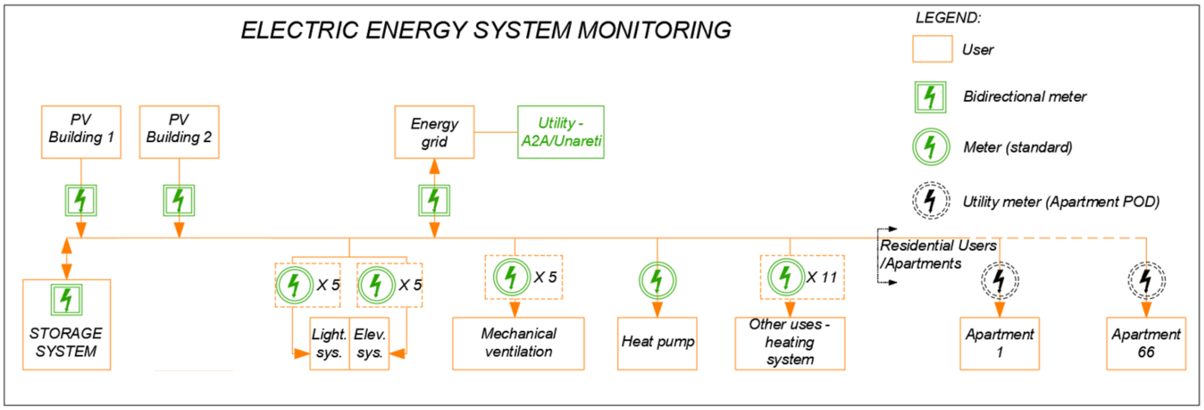

Figure 3 – Map of electrical energy meters in Milan Multi-apartment pilot.

As Figure 3 shows, independent meters are used to assess each individual system. Bidirectional meters are used for the photovoltaic and storage systems, as well as to assess the energy consumed and injected in the public grid. Standard meters are used for the common systems such as the centralized ventilation, heat pump, lighting, elevator, and others. This data is sent via Modbus to the Siemens DEOP platform.

In this pilot there is also monitoring for the thermal energy used by each apartment, collected on an hourly basis. Inlet and outlet temperatures of the hot water are measured, as well as the flow, enabling to calculate the thermal energy consumed in each apartment.

Besides the energy monitoring, several parameters of indoor environment quality (IEQ) are measured. Indoor air temperature and relative humidity are measured every 10 minutes, while CO_2 concentration levels are measured hourly. All parameters are measured using a Capetti WineCap WSD00TH5CO IEQ sensor[2].

2.2. Milan Single Apartment Residential Pilot

2.2.1. General description

Milan Single Apartment Residential Pilot (Figure 4) is a studio type apartment located on the top floor of an apartment building in Milan, Italy.

The studio was retrofitted in 2020/2021 and has a net floor area of 50 m^2. There are only two people living in this studio. As the retrofit was concluded recently, it is still not clear what will be the energy consumption of the house.

The partner responsible for this pilot site is Politecnico de Milano.

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[2] http://www.capetti.it/uploads/docs/WA0292-WSD00TH5CO_Manuale_Utente_R02.pdf

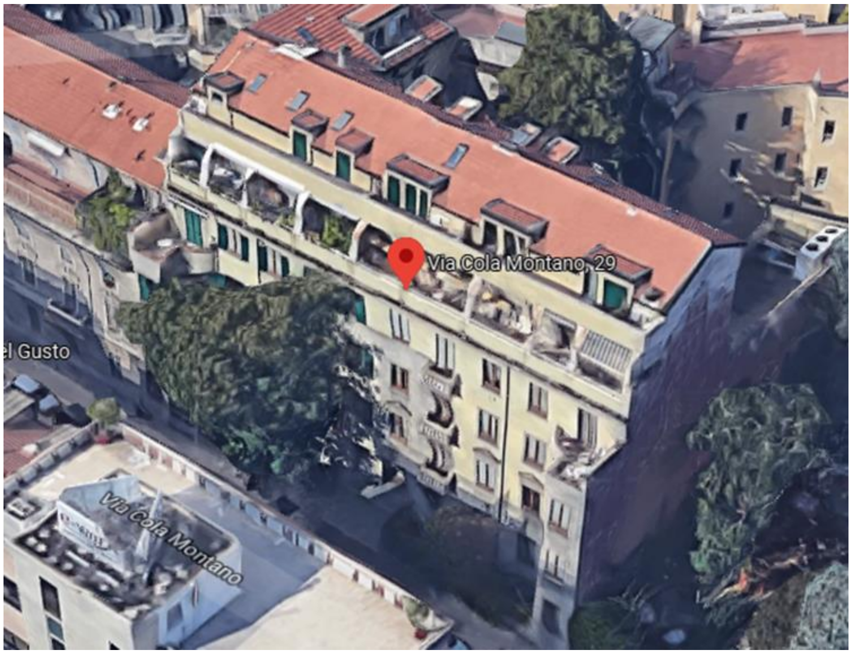

Figure 4 – Aerial view of Milan Single Apartment pilot.

2.2.2. Building equipment

The apartment is equipped with a heat pump that is used for space cooling and heating, and also provides heat for the production of domestic hot water. The building is also equipped with photovoltaic panels. Natural ventilation will be promoted to provide cooling. The single apartment has an oven, fridge, dishwasher and washing machine that will be potentially monitored during the project.

2.2.3. Monitoring and control

Currently the Milan Single Apartment Pilot does not have any monitoring device installed, however, in the next couple of months, a KNX[3] monitoring and control system will be installed, covering electric and thermal energy measurements, as well as indoor air temperature, relative humidity and CO_2 concentration levels. A control system for the HVAC will also be installed.

The electrical energy monitoring will include the monitoring of selected appliances, the heat pump, the mechanical ventilation, the energy production from the photovoltaics system and the total energy demand of the whole apartment. The thermal energy monitoring will include the inlet and supply temperatures of the heat pump, and the water flow for the heating and the domestic hot water in order to calculate the enthalpy.

Other sensors installed in this pilot include thermocouples in walls and roof to assess temperature distribution, pyroelectric infrared motion sensors, illuminance sensors and window opening sensors.

To promote natural ventilation, a control system is already in place for the automatic opening and closing of the Velux[4] windows installed in the studio.

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[3] https://www.knx.org/knx-en/for-professionals/index.php

[4] https://www.velux.com/

Other controls available in the pilot include shading control and lighting control systems.

2.3. Aalborg Residential Pilot

2.3.1. General description

The Aalborg Residential Pilot is a building located in the Town of Frederikshavn in the north of Denmark, with a net floor area of 2160 m^2. The building was built between 1949/1950 and was retrofitted in 2012. There is a total of 24 apartments distributed over 3 floors, varying in typology from 1 to 3 bedrooms with areas of 74 m^2, 92 m^2 and 102 m^2. The 24 apartments house around 50 people.

Regarding energy consumption, the building has a total electrical energy consumption *circa* 40 MWh per year and a total thermal energy consumption *circa* 70 MWh$_{th}$ per year for the heating, cooling and domestic hot water necessities.

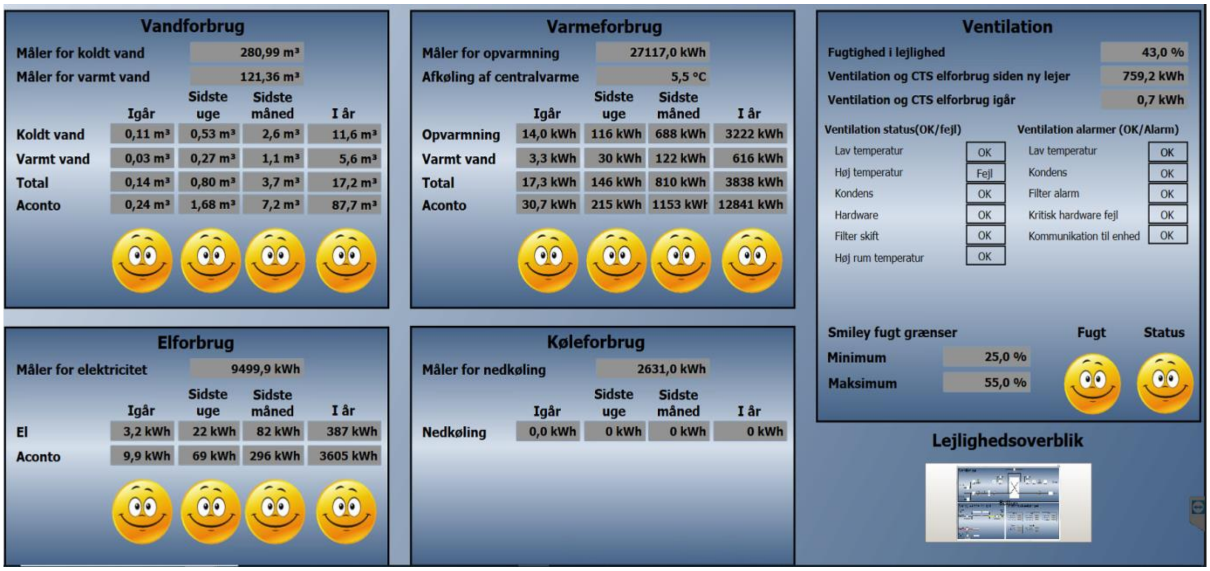
The HVAC system works at building-level and is used for every apartment. Hence forward, the HVAC system and all equipment working at building-level is called 'common equipment'.

The building owner is Frederikshavn Boligforening, which will also be the responsible partner for the pilot site, accompanied by Aalborg University. Figure 5 shows an aerial view of the Aalborg Residential Pilot site.

Figure 5 – Aerial view of Aalborg residential pilot.

2.3.2. Building equipment

The Frederikshavn building has a building management system (BMS) developed by Soft&Teknik[5] that displays all monitoring points of common equipment and per apartment, giving users the ability to oversee their setpoints and consumptions using a friendly interface that also indicates the level of performance of each users with the objective to trigger a more energy efficient behaviour. Figure 6 shows the users interface of the BMS.



Vandforbrug

Måler for koldt vand	280,99 m³
Måler for varmt vand	121,36 m³

	Igår	Sidste uge	Sidste måned	I år
Koldt vand	0,11 m³	0,53 m³	2,6 m³	11,6 m³
Varmt vand	0,03 m³	0,27 m³	1,1 m³	5,6 m³
Total	0,14 m³	0,80 m³	3,7 m³	17,2 m³
Aconto	0,24 m³	1,68 m³	7,2 m³	87,7 m³

Varmeforbrug

Måler for opvarmning	27117,0 kWh
Afkøling af centralvarme	5,5 °C

	Igår	Sidste uge	Sidste måned	I år
Opvarmning	14,0 kWh	116 kWh	688 kWh	3222 kWh
Varmt vand	3,3 kWh	30 kWh	122 kWh	616 kWh
Total	17,3 kWh	146 kWh	810 kWh	3838 kWh
Aconto	30,7 kWh	215 kWh	1153 kWh	12841 kWh

Ventilation

Fugtighed i lejlighed	43,0 %
Ventilation og CTS elforbrug siden ny lejer	759,2 kWh
Ventilation og CTS elforbrug igår	0,7 kWh

Ventilation status(OK/fejl)	
Lav temperatur	OK
Høj temperatur	Fejl
Kondens	OK
Hardware	OK
Filter skift	OK
Høj rum temperatur	OK

Ventilation alarmer (OK/Alarm)	
Lav temperatur	OK
Kondens	OK
Filter alarm	OK
Kritisk hardware fejl	OK
Kommunikation til enhed	OK

Smiley fugt grænser	
Minimum	25,0 %
Maksimum	55,0 %

Fugt

Status

Elforbrug

Måler for elektricitet	9499,9 kWh

	Igår	Sidste uge	Sidste måned	I år
El	3,2 kWh	22 kWh	82 kWh	387 kWh
Aconto	9,9 kWh	69 kWh	296 kWh	3605 kWh

Køleforbrug

Måler for nedkøling	2631,0 kWh

	Igår	Sidste uge	Sidste måned	I år
Nedkøling	0,0 kWh	0 kWh	0 kWh	0 kWh

Lejlighedsoverblik

Figure 6 – Photo of the BMS user interface of Aalborg residential pilot

The heating used in the building comes from ground source heat pumps, that are located near each entrance of the building. The total consumption of energy for heating is about 70 MWh per year. For all apartments, the heat is distributed over radiant floor.

Since the ground-source heat pumps are not reversible, cooling is achieved by circulating water in the boreholes, taking advantage of the cooler ground temperature. The cooled water is then distributed over the radiant floor and account for an energy consumption *circa* 7 MWh per year.

The domestic hot water system takes advantage of the same ground-source heat pumps as the heating system, contributing with an additional energy consumption of *circa* 22 MWh per year.

For ventilation, there is a decentralized balanced mechanical ventilation system, with one unit per apartment for supply and return supplying up to 90 m^3/h of air. Additional, kitchens are equipped with a kitchen range hood with an extraction capacity of 240 m^3/h. It is estimated that ventilation accounts for an energy consumption of 5 MWh each year.

The Danish residential pilot site is also equipped with a photovoltaic system, covering about one third of the roof top, 339 m^2, with a capacity of 49 kW$_p$ and a generation of around 55 MWh/year.

At the moment, appliances are not being considered for detailed monitoring in the Aalborg Residential Pilot.

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[5] http://softogteknik.dk/

2.3.3. Monitoring and control

The Frederikshavn pilot building has a modern monitoring infrastructure, meaning that there is already in place a built-in system that monitors electric energy, thermal energy, indoor air temperature and relative humidity. The connection to the BMS system is wired and uses M-Bus communication protocol. The frequency of measurement is 10 minutes for every parameter. The same system also handles the control of heating, cooling, and ventilation systems.

The electrical energy consumption is monitored using metering points at the building-level, entrance-level, and apartment-level. Other systems are constantly monitored, including: the technical room, heat pumps, domestic hot water system, the BMS and others.

The thermal energy is monitored for all apartments through the flow and inlet/outlet temperatures. The heat use is also assessed for the whole building, for the production of domestic hot water and for each heat pump.

Indoor environmental quality parameters, namely indoor air temperature and relative humidity, are measured for all rooms in each apartment (kitchen/living room, bedrooms and bathrooms). The setpoints used on the heating/cooling system for each room are also logged in the system.

During the project pilot activities, indoor CO_2 concentration levels will also be monitored for a sample of 6 apartments (all rooms). Between 25 and 30 sensors are expected to be deployed, sampling CO_2 levels every minute directly to the SATO platform via Wi-Fi. Additionally, window opening sensors will be installed in the same apartments, to monitor the period when windows are open or closed.

Regarding the control system, besides the control of the setpoints for the HVAC, the activation of the cooling mode is made automatically by the system when it detects 36 consecutive hours with an outdoor air temperature above 17°C.

2.4. Seixal Residential Pilot

2.4.1. General description

Seixal Residential Pilot is composed of 50 single family houses and apartments in the municipality of Seixal, which is located 5 km south of Lisbon (Portugal) on the south bank of Tagus river. Seixal building stock can be divided in two groups, the houses built before and after the year 2000. The houses or apartment blocks built in the XX century have typically a very low energy efficiency, characterized by having no wall insolation and no heating or cooling systems. In the XXI century there is a notable improvement on the building stock, specifically for building built on 2014 or after, since that was the year that the energy certificate was introduced. The newer buildings already have wall insolation, heating and cooling systems, renewable energy solutions and an overall high energy efficiency.

The building to be selected for the pilot site will incorporate both newer and older buildings, with high and low energy efficiency ratings. There will also be a mix between detached houses and apartments.

Another thing to take into consideration is the existence of photovoltaic systems and air conditioning units in some of the houses, since one of the goals for this pilot it to monitor such systems.

To identify these buildings, people that participated in previous sustainability projects in the municipality will be contacted, namely people that participated in "Eco-Familias" and "Selo Verde – Edifício amigo do ambiente" which are two projects that supported families to reduce their energy consumption and attributed prizes to the most efficient houses. Besides that, to broaden the type of buildings selected, a campaigned will be launched in the municipality to gather interest on the project.

The responsible partners for this pilot site are EDP CNET and AMES. Figure 7 shows a photo of Seixal old town.

Figure 7 – View of Seixal old town.

2.4.2. Building equipment

Based on the criteria selected to choose the buildings for this pilot site, between the several buildings there will be photovoltaic systems, air conditions split units, electric water heaters, freezers, dishwashers, washing machines and other appliances. An individual list per building will be made when all buildings are selected, before the start of the pilot activities.

2.4.3. Monitoring and control

Monitoring and control equipment is already accounted for all 50 houses or apartments. The EDP re:dy[6] monitoring and control system will be deployed on all 50 houses or apartments, allowing to control AC split units and to turn on/off the selected appliances. The EDP re:dy system also will collect 1 minute data for the whole electrical energy consumption of the house/apartment and the electrical energy consumption of 3 selected appliances and an extra 2 systems if the electric boards allows for separated metering.

Additionally, all 50 houses or apartments will have 1 minute data monitoring, in 3 rooms, for indoor air temperature, relative humidity, and CO_2 concentration levels.

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[6] https://www.edp.pt/particulares/servicos/redy/

2.5. Aspern C4 Technology Centre Pilot

2.5.1. General description

Aspern C4 Technology Centre is an office building, divided into 29 different spaces with different sizes and types of usage across a net floor area of 6314 m^2. The building is located in Aspern, a neighbourhood in the north-east of Vienna, Austria, home to one of Europe's largest urban development projects [1].

The Technology Centre is a modern infrastructure built on 2018 and owned by Wirtschaftsagentur Wien that aims to provide a future-oriented space for companies to work, research and develop their businesses. The C4 building has 4 floors and a total eletrical energy consumption of 23.7 kWh/m^2 per year and a thermal energy consumption of 7.4 kWh/m^2 per year. Note that these consumptions were measured during the COVID-19 pandamic period, which may have impacted the building's energy consumption.

The responsible partner for this pilot site is Siemens Austria. Figure 8 shows two photos of the Aspern C4 Technology Centre Building.

Figure 8 – View of Aspern C4 Technology Centre Building.

2.5.2. Building equipment

The Austrian pilot site has a building management system (BMS) from Siemens. This system allows building managers to promote energy savings by keeping the whole building under constant monitoring. Complementary, the BMS used in this building is also integrated with wall panels that are installed in all rooms, allowing users to interact with the building and benefit from adequate indoor conditions while maintaining high levels of energy efficiency.

Cooling and heating needs of the building are handled by a ground source heat pump with heat recovery consuming a total of 204 kWh for heating and 151 kWh for cooling per year. The ventilation system consumes about 43 kWh per year. All these values were registered during the COVID-19 pandemic.

Besides the mechanical ventilation system, the building uses natural ventilation strategies to provide cooling. Others features of the building are its highly insulated façade and the sun protection elements in it.

This building is also equipped with a photovoltaic system with a peak power of 131 kW, producing around 80 kWh every year.

2.5.3. Monitoring and control

The Aspern C4 Technology Centre is a highly monitored building, having several meters for different types of energy and indoor environment quality parameters. Also, the HVAC system is able to be controlled locally through the definition of individual setpoints for each room. The monitoring system collects all data with 1 minute frequency.

Dedicated energy meters collect data for the heat pump, allowing to separate this consumption from the whole building energy consumption. Also, thermal energy is also measured in the air handling units, which is a key parameter to measure the efficiency of the HVAC system.

Further, indoor environment quality sensors constantly measure the indoor air temperature, relative humidity, and CO_2 concentration. These sensors are used to perceive and set the comfort conditions for the building occupants.

2.6. Aalborg University Office Pilot

2.6.1. General description

The Aalborg University Office Pilot is a building owned by the Aalborg University, located in Aalborg, northern Denmark. The building is part of the university campus and has several types of rooms, including laboratories to conduct classes and research, lecture rooms for classes, student rooms, offices for staff and a large atrium in the middle of the building. Between employees and students, it is estimated that the total number of building occupants is around 750.

The building was built in accordance with the Danish Energy regulation from 2015, has a total of 4 floors and a net floor area of 9000 m^2. The estimated electrical energy of the building is about 56.3 kWh/m^2 per year and all heating needs are supplied through the district heating.

The responsible partner for this pilot site is Aalborg University, and a photo of the exterior and of an office room is shown in Figure 9.

Figure 9 – External view and office view of Aalborg University Office building.

2.6.2. Building equipment

The Aalborg University Office pilot is equipped with a Building Management System from Schneider, that oversees the HVAC system and the overall building energy consumption and generation.

The building's ventilation system has 14 air handling units with heat recovery and allows for the implementation of free cooling strategies when the outdoor air temperature allows its implementation.

The district heating system is used for all heating needs of the building. For space heating, a system of radiators is used to distribute the heat from the district heating system throughout the building, being separated into 9 different control units that enable to have different types of control strategies in different parts of the building. District heating is also used for the production of domestic hot water using 9 heat exchangers. On a yearly average, there is a consumption of 21 kWh_{th}/m^2 and 7.2 kWh_{th}/m^2 for room heating and domestic hot water production, respectively.

This pilot site is also equipped with a photovoltaic system for energy production with an installed capacity of 6 kW_p.

2.6.3. Monitoring and control

The monitoring system implemented in this building tracks the total electric energy consumption of the building on an hourly basis, as well as 6 different monitoring points in the 1st, 2nd and 3rd floor each, on a minute basis.

The thermal energy used in the building is also monitored every minute, and there is historical data with 1 hour sampling. The thermal energy corresponds to the total energy deliverable by the district heating system. Regarding the specific heating circuits, there is real-time data available for each individual room, and also real-time data for position of the radiator valve. The main heating circuit is also monitored, with the same frequency as the whole system meter, and has two monitoring points covering the east and the west sides of the building. The thermal energy is assessed based on the supply and return temperature in each point and the water flow.

Besides the direct monitoring of thermal energy in the building, there is also data for the current heating or cooling setpoints defined by building users, and the damper position on the ventilation system.

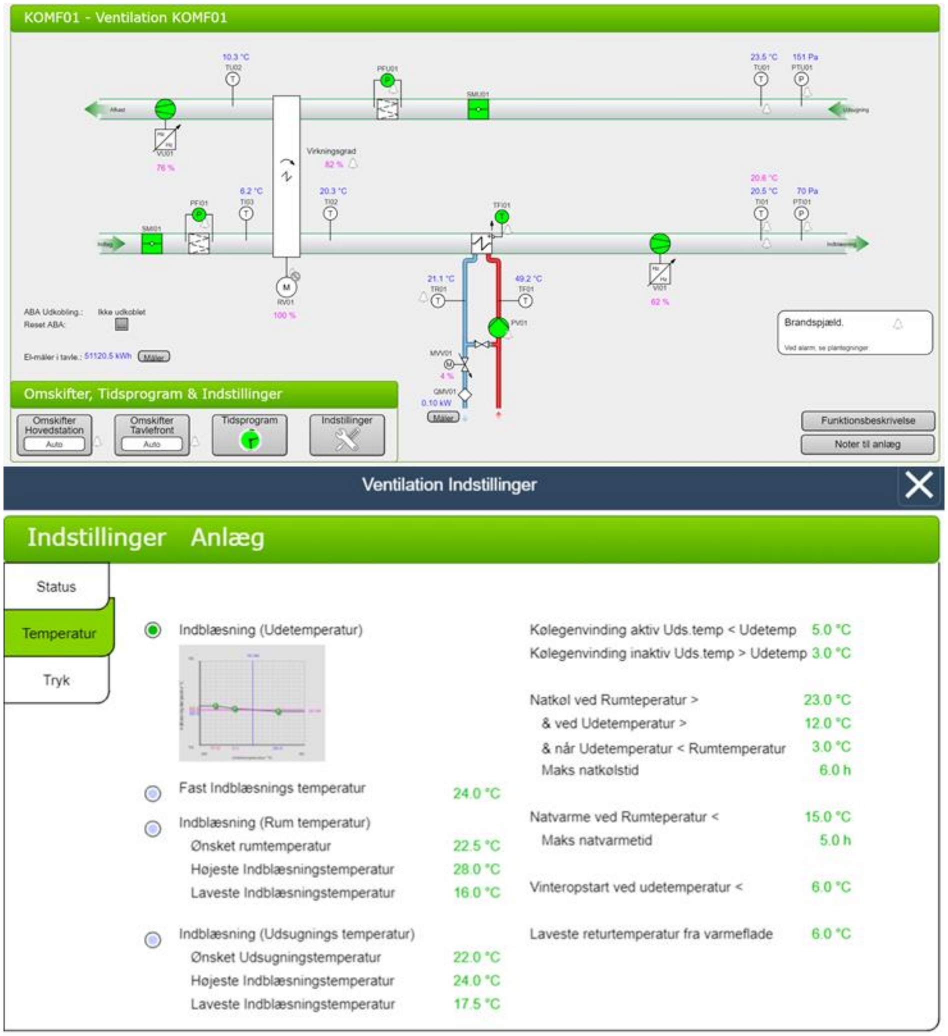
Indoor environment quality parameters such as indoor air temperature or CO_2 concentration levels are also assessed on a minute basis. In the case of indoor air temperature, the measurement is made in every room/office in the building. However, CO_2 concentration is only measured on the larger rooms/offices (occupation higher than two people).

For the ventilation system, many parameters are monitored in real-time, namely the status/mode of ventilation for each room, and the different temperatures and pressures on both the air and water (cooling) systems.

Window opening is also monitored in this pilot site, meaning that there is data on a minute basis for every window on its current status (opened or closed).

Other data measured in the Aalborg University Office pilot is illuminance in each room, PIR motion sensors in each room for light control, and domestic hot/cold water deliverable. All this data is measured with a frequency of 1 minute.

Regarding control, both the ventilation and heating system are controllable. The heating system is indirectly controlled through the setpoints defined for each room, while the ventilation is not controlled locally but can be influenced by changing the setpoints. Both systems can be controlled at BMS level. Besides these systems, the lighting and façade shading system can also be controlled at BMS level. Figure 10 shows the user interface of the BMS.



● Indblæsning (Udetemperatur)

○ Fast Indblæsnings temperatur 24.0 °C

○ Indblæsning (Rum temperatur)
Ønsket rumtemperatur 22.5 °C
Højeste Indblæsningstemperatur 28.0 °C
Laveste Indblæsningstemperatur 16.0 °C

○ Indblæsning (Udsugnings temperatur)
Ønsket Udsugningstemperatur 22.0 °C
Højeste Indblæsningstemperatur 24.0 °C
Laveste Indblæsningstemperatur 17.5 °C

Kølegenvinding aktiv Uds.temp < Udetemp 5.0 °C
Kølegenvinding inaktiv Uds.temp > Udetemp 3.0 °C

Natkøl ved Rumteperatur > 23.0 °C
& ved Udetemperatur > 12.0 °C
& når Udetemperatur < Rumtemperatur 3.0 °C
Maks natkølstid 6.0 h

Natvarme ved Rumteperatur < 15.0 °C
Maks natvarmetid 5.0 h

Vinteropstart ved udetemperatur < 6.0 °C

Laveste returtemperatur fra varmeflade 6.0 °C

Figure 10 – Photo of the BMS and user interface of Aalborg Office pilot.

2.7. Seixal Municipality Office pilot

2.7.1. General description

The Seixal Municipality Office pilot site is located in Seixal, a municipality southeast of Lisbon, across the Tagus River. The building is the main office of the mayor of Seixal and it is where all municipality administrative services are located.

The pilot site is composed by one building, built in 2009, that is divided into a main atrium, open office spaces, meeting rooms and individual offices. There is a total of 3 floors and a basement, and the net floor area of the building is 15 000 m^2, distributed in four blocks that are connected by the central atrium. The two largest blocks, named North and South buildings, have three levels of office spaces. Each floor is divided in a large open space (facing the outdoor facade) and small offices (facing the atrium). Below the ground floor sits a partially underground area composed of small offices, storage spaces and a garage. At the eastern edge of the atrium, there is a small building with two floors for storage and cafeteria. The fourth block sits in the north-western edge and houses a small auditorium that is used only in special events.

It is estimated that between visitors and municipality employees there are around 700 people in the building each day. The electrical energy consumption of the building is around 1 616 MWh yearly and the thermal energy consumption is around 72.8 MWh$_{th}$ yearly.

The owner of the building is Seixal Municipality and the responsible partners for this pilot site are Agência Municipal de Energia do Seixal (AMES) and FC.ID. An exterior and interior view (atrium) of the building is shown in Figure 11.

Figure 11 – Exterior and Interior view (Atrium) of Seixal Municipal Office building.

2.7.2. Building equipment

The pilot site is equipped with a BMS from Sauter that provides capacity to control and log data from the heating, cooling, ventilation, domestic hot water, and lighting systems.

The ventilation system consists of 7 air handling units from Wesper, with heat recovery and free-cooling. There is also a humidity control unit from Munters. The central atrium also has an automatic natural ventilation system, using automated windows to trigger it when feasible.

The heating and cooling system consists of 3 Wesper heat pumps of 250 kW and an additional unit of 510 kW. The heat/cool is distributed through a radiant floor network. Additionally, there is one specialized cooling machine for the Data Centre room, with a capacity of 102 kW.

The domestic hot water is produced using a natural gas boiler from ROCA, with a capacity of 83 kW, and there are 12 solar thermal collectors from ROCA, that occupy a total of 24 m^2 in the roof of the building.

2.7.3. Monitoring and control

The Seixal Municipality Office will mostly focus on the monitoring of HVAC related parameters. As such the pilot will monitor enthalpy from the heat pumps and heating/cooling distribution system in order to estimate the thermal energy used in the building.

Indoor environment quality parameters are also measured in the pilot, including indoor air temperature and relative humidity, and CO_2 concentration levels. All these three parameters are measured in all rooms of the building.

Regarding controls, besides the automatic atrium windows that enable natural ventilation, the BMS can control the radiant floor heating/cooling distribution, and the lighting system on the atrium and the open-space offices.

2.8. Lisbon Services Building Pilot

2.8.1. General description

The Lisbon Service Building Pilot is a library building located in the campus of the Faculty of Sciences of the University of Lisbon, in Portugal. The building was built in 1990 and then retrofitted 2010, mostly for the implementation of a large-scale photovoltaic system on the rooftop.

The pilot building has a large reading room in the centre, then there are several study rooms, offices, meeting rooms and book storage areas. There is a total of 3 floors in this building for a net floor area of 3 745 m^2.

It is estimated that there are around 200 users per day, most of them being visitors. The building's electrical energy consumption is estimated around 430 MWh per year.

The building owner is the Faculty of Sciences of the University of Lisbon and the responsible partner for the pilot is FC.ID. Figure 12 show the exterior and interior views of the building.

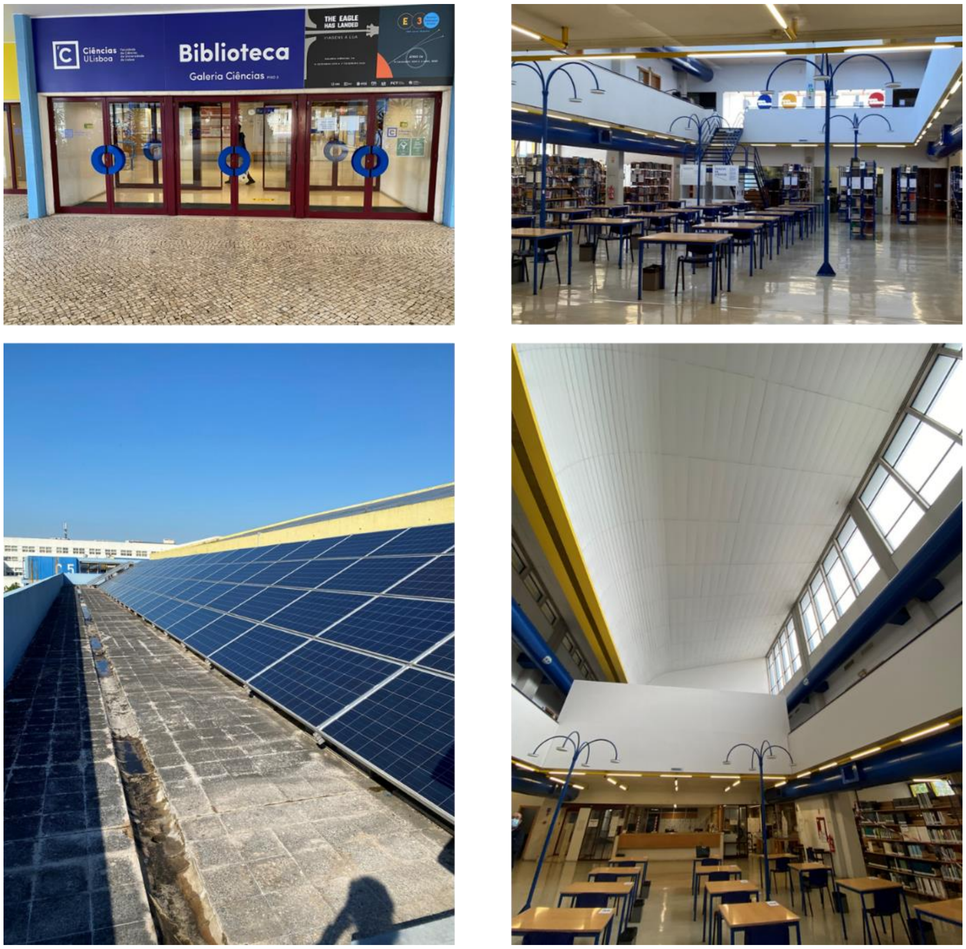


Figure 12 – Exterior and interior views of the Lisbon Service Building.

2.8.2. Building equipment

The Lisbon Services Building pilot has a BMS that uses BACnet over IP as communication protocol allowing building automation and control systems for the different building applications.

The HVAC system has one air handling unit and one heat pump with a capacity of 22 kW_{th}. Also, the building design allows that the main area of the library can take advantage of natural ventilation strategies, reducing the necessity of HVAC use of some periods. On the rooftop there is a photovoltaics system with an installed capacity of 93 kW_p. Also, the building is equipped with two electric vehicle charging units, at street level. No domestic hot water is used in this building.

2.8.3. Monitoring and control

The library pilot site does not currently have the capacity for monitoring or control of any parameter. However, there is a plan to install some metering and control during the project. The current plan is to install electrical energy meters to assess the electrical energy consumption of the whole building and its different systems. CO_2 concentration levels and indoor air temperature will also be assessed using specific sensors that will be installed during the project. Additionally, and to make the most of the natural ventilation potential in the building, some sensors/controls will be installed on the windows to trigger natural ventilation whenever feasible.

2.9. Seixal Retail Store Pilot

2.9.1. General description

The Seixal Retail Store pilot is a store inside of the RioSul Shopping, in Seixal, Portugal. This store was last retrofitted in 2015 and it is a two stories store. The store is divided in three areas: the sales areas, the warehouse area, the social area, with a net floor area of 2 233 m^2, 304 m^2 and 174 m^2, respectively.

It is estimated that the store has around 2000 visitors on a daily average and its energy consumption is approximately 600 MWh yearly. The partner responsible for this pilot site is Worten. The interior of the retail store can be seen in Figure 13.

Figure 13 – Interior views of the Seixal Retail Store Building

2.9.2. Building equipment

The pilot site has a centralized management system that covers the HVAC and lighting systems. The lighting system is 100 % LED and accounts for 26 kWh for the yearly energy consumption.

The HVAC system consists of 3 rooftop units from Lennox, 4 split units from LG, 1 split unit from McQuay and 1 split unit from Daikin. Overall, the total power of the HVAC system is over 100 kW.

2.9.3. Monitoring and control

No monitoring or control device has yet been defined for this pilot site.

2.10. Torres Novas Retail Store Pilot

2.10.1. General description

The Torres Novas Retail Store pilot is a store inside of the Retail City Park, in Torres Novas, Portugal. This store was last retrofitted in 2001 and it is divided in three areas: the sales areas, the warehouse area, the social area, with a net floor area of 1 190 m^2, 102 m^2 and 34 m^2, respectively.

It is estimated that the store has around 500 visitors on a daily average and its energy consumption is approximately 260 MWh yearly. The partner responsible for this pilot site is Worten. The exterior of the retail store is shown in Figure 14.

Figure 14 – Exterior view of the Torres Novas Retail Store Building

2.10.2. Building equipment

The pilot site has a centralized management system that covers the HVAC and lighting systems. The lighting system is 100% LED with a total power of 5.5 kW.

The HVAC system consists of 2 rooftop units from Lennox and 3 split unit from Daikin. Overall, the total power of the HVAC system is over 65 kW.

2.10.3. Monitoring and control

No monitoring or control device has yet been defined for this pilot site.

2.11. Loures Retail Store Pilot

2.11.1. General description

The Loures Retail Store pilot is a store on a shopping centre in Loures, Portugal. This store was last retrofitted in 2008 and it is divided in three areas: the sales areas, the warehouse area, the social area, with a net floor area of 1 925 m^2, 170 m^2 and 72 m^2, respectively.

The energy consumption is approximately 335 MWh yearly. The partner responsible for this pilot site is Worten. Figure 15 shows the entrance of the Loures retail store.

Figure 15 – Entrance of the Loures Retail Store Building

2.11.2. Building equipment

The pilot site has a centralized management system that covers the HVAC and lighting systems. The lighting system is 100% LED. The HVAC system consists of 2 rooftop units from Lennox.

2.11.3. Monitoring and control

No monitoring or control device has yet been defined for this pilot site.

2.12. San Sebastian de los Reyes Retail Store Pilot

2.12.1. General description

The San Bastian de los Reyes Retail Store pilot is a store in San Bastian de los Reyes, Madrid, Spain. This store was last retrofitted in 2017 and it is divided in three areas: the sales areas, the warehouse area, the social area, with a net floor area of 1 367 m^2, 611 m^2 and 318 m^2, respectively.

The partner responsible for this pilot site is Worten, and an external view can be seen in Figure 16.

Figure 16 – Exterior view of the San Sebastian de los Reyes Retail Store Building

2.12.2. Building equipment

The pilot site has a centralized management system that covers the HVAC and lighting systems. The lighting system is 100% LED with a total power of 20 kW. The HVAC system consists of 1 rooftop units from Lennox with free-cooling and a power of 42 kW.

2.12.3. Monitoring and control

The retail store has electrical and thermal energy monitoring for the Lennox rooftop unit, being able to monitor the energy consumption used for heating and cooling, as well as the machine efficiency. The pilot is also equipped with indoor air temperature sensors to monitor thermal comfort conditions.

The centralized technical management system allows to control the setpoints for the HVAC system.

3. Relation between KPIs and project pilot sites

This section aims to map all the project pilot sites, and respective applicable use cases, with the project KPI's so that future developments in SATO project can be evaluated individually, based on its own type of application, installed monitoring equipment, metering points and frequency.

3.1. Mapping of sensors per pilot site and applicable KPIs

The identification of KPIs per pilot site was firstly started on SATO task 1.2, with the broad definition of KPI that could be applicable in SATO's pilot site. This broad definition culminated in the deliverable 1.2, with specific formulas and description of KPIs identified at the time.

In task 1.4, this work was continued with the identification of the project Use Cases, an essential step to carry out and organize the pilot activities that will occur in the scope of work package 6 and run until the end of the project. The identification of Use Cases allowed to match each pilot site with several goals of the project and solutions being developed, leading to the identification of the previously described KPIs with the pilots.

In task 1.5, SATO aims to provide a comprehensive list of performance indicators that must be monitored in order to evaluate all solutions developed. This list is shown in table 1 and will be described further bellow. Note that this list does not include all KPIs identified in task 1.2, mainly due to the evaluation framework described in the next chapter, but also to enable to focus on the most relevant indicators, making it easier to apply in an evaluation framework and also to ensure an easier replicability.

Table 1 - List of KPI that must be monitored in order to evaluate all solutions developed.

Pilot / KPIs	Building performance			Building2grid		Cost performance		Environment	
	Total specific energy use	Specific electrical energy use	Specific thermal energy use	Electric load shifting ability	Thermal load shifting ability	Specific electricity cost	Specific district heating/cooling cost	Total CO_{2e} emissions	Specific CO_{2e} emissions
Milan multi-apartment	a, d	a	d	c, f, g, h, i	d, f, h, i	i	-	a, d	a, d
Milan single-apartment	a, b	a	b	c, f, g, h, i	d, f, h, i	i	-	a, b	a, b
Aalborg residential	a, b	a	b	c, f, g, h, i	d, f, h, i	i	-	a, b	a, b
Seixal residential	a	a	-	c, f, g, h, i	-	i	-	a	a
Aspern C4 Technology Centre	a, b	a	b	c, f, g, h, i	d, f, h, i	i	-	a, b	a, b
Aalborg university office	a, b	a	b	c, f, g, h, i	d, f, h, i	i	i	a, b	a, b
Seixal municipality office	a, b	a	b	c, f, g, h, i	d, f, h, i	i	-	a, b	a, b
Lisbon services building	a	a	-	c, f, g, h, i	-	i	-	a	a
Lisbon and Madrid retail stores	a	a	-	TBD	-	i	-	a	a

Pilot / KPIs	Systems and components					
	Specific local energy production	Renewable load factor	Specific ventilation energy use	Cooling/heating recovery rate	Specific energy use (i) system	Operating hours (i) system
Milan multi-apartment	c	a, c	c	-	c (Lighting)	c (Lighting)
Milan single-apartment	c	a, c	c	-	e (*)	e (*)
Aalborg residential	c	a, c	-	TBD	c (DHW)	c (DHW)
Seixal residential	c	a, c	-	-	e (**)	e (**)
Aspern C4 Technology Centre	-	-	c	TBD	-	-
Aalborg university office	c	a, c	c	d, f, h	c (***)	c (***)
Seixal municipality office	d	d, b	c	TBD	c (Lighting, DHW)	c (Lighting, DHW)
Lisbon services building	c	a, c	TBD	TBD	-	-
Lisbon and Madrid retail stores	-	-	TBD	-	TBD	TBD

a) Building-level electrical energy meter, b) Building-level thermal energy meter, c) System-level electrical energy use, d) System-level thermal energy use, e) Appliance-level energy use, f) Indoor air temperature and relative humidity, g) CO2 concentration, h) Weather parameters, i) Audit

*Fridge, dishwasher, washing machine, oven

**Freezer, dishwasher, washing machine, electric water heater, air conditioning split unit

***Lighting, DHW, shading

Table 1 - Continued.

Pilot / KPIs	SRI	Indoor environment		
	Impact smart readiness score	Thermal comfort	Average CO_2 concentration	Average relative humidity level
Milan multi-apartment	ALL	f	g	f
Milan single-apartment	ALL	f	g	f
Aalborg residential	ALL	f	g	f
Seixal residential	ALL	f	g	f
Aspern C4 Technology Centre	ALL	f	g	f
Aalborg university office	ALL	f	g	f
Seixal municipality office	ALL	f	g	f
Lisbon services building	ALL	f	g	-
Lisbon and Madrid retail stores	ALL	f	g	f

a) Building-level electrical energy meter, b) Building-level thermal energy meter, c) System-level electrical energy use, d) System-level thermal energy use, e) Appliance-level energy use, f) Indoor air temperature and relative humidity, g) CO2 concentration, h) Weather parameters, i) Audit

The indicators identified in Table 1 are highlighted in this deliverable as the most relevant indicators to provide an evaluation to SATO solutions. Despite this, the evaluation framework is flexible to incorporate additional indicators if necessary, as is shown in Evaluation Framework for SATO (Section 4). In short, the methodology takes into consideration the importance of each indicator for a specific building, using a weighting system that is defined by SATO experts and other stakeholders, in accordance with the specific conditions of the building and SATO solutions and use cases applied.

The 19 different indicators identified can be detailed as follows:

- **Total specific energy use** – Described in D1.2 as "Measure of amount of specific energy during a year", this indicator evaluates the impact of SATO solutions in the total energy use. Due to the different sizes of buildings, the indicator uses the specific energy use per square meter (kWh/m^2). While in some buildings the number of occupants and occupied period have large impact on energy use, the indicator is simplified to be easily applicable in all buildings. Other indicators can be given a larger weight if occupancy is seen as a differentiation factor in a certain building, e.g. a building with very high or very low occupancy per square meter.
- **Specific electrical energy use** – Similar to the previous indicator but focused on the electrical energy only, either supplied from the local grid or generated on-site.
- **Specific thermal energy use** – Similar to the first indicator but focused only on the thermal energy, that can be generated used electric energy (e.g. heat pump), fuels (e.g. gas boiler), renewable sources (e.g. solar thermal collectors) or supplied from district heating/cooling.
- **Available flexibility capacity** – The flexibility capacity is the ability of reducing or increasing the energy consumption for a certain duration of time without impacting comfort. The indicator evaluates the available power that can be used at each time to provide flexibility.
- **Flexibility operated** – Similar to the indicator above, the yearly flexibility operated is based on the energy flexibility that can be used to shift a load to a different time period. This indicator evaluates the total energy flexibility that was operated during a period of time.
- **Specific electricity cost** – Specific electricity cost evaluates the tariff at which electricity is being bought. Since no investment in self-generation is taken into account, all self-generation will greatly improve this indicator, meaning that it will reflect the self-consumption ability, as well as the ability to use SATO solutions to reduce energy consumption and take advantage of cheaper energy tariffs.
- **Specific district heating/cooling cost** – Similar to the previous indicator but focusing on the cost of buying heat/cold through a district distribution system.
- **Total CO_{2e} emissions** – As the name indicates, it evaluates total yearly CO_{2e} emissions associated to the buildings' energy consumption. CO_{2e} emissions are measured in tonnes of CO_{2e}.
- **Specific CO_{2e} emissions** – Similar to the previous indicator but it evaluates as a function of the total specific energy use in the same building.
- **Specific local energy production** – Evaluates the amount of locally produced energy in relation to the building net floor area.
- **Renewable load factor** – Evaluates the percentage of energy that is produced locally from renewable energy sources as a function of the total final energy consumption.

- **Specific ventilation energy use** - The combined amount of electric energy consumed by all the fans in the air distribution system divided by the design extraction airflow rate of the building.
- **Coefficient of performance** - COP is defined as the relationship between the power (kW) that is drawn out of the heat pump as cooling or heat, and the power (kW) that is supplied to the compressor.
- **Specific energy use (i) system** – Unlike other indicators, this one can be calculated multiple time for a single building since it addresses all suitable systems. For example, it can address the lighting system or the domestic hot water production, but also the relevant appliances may also be considered here. The energy consumption of such system is evaluated as a function of a specific parameter related to the output objective of that system, for example, in the case of a washing machine, the specific parameter should be the average number cycle used for that time period.
- **Operating hours (i) system** – Similar to the previous indicator but it tracks the number of hours that the system under evaluation works.
- **Impact smart readiness score** – The smart readiness score of a building expresses how close the building is to maximal smart readiness. Based on the seven impact criteria evaluated, a score is aggregated and compared to the best-case scenario that could be verified in the same building. Further explanation on the Smart Readiness Indicators and its calculation can be found on D2.1.
- **Thermal comfort** – Evaluates the yearly percentage of hours inside of thermal comfort conditions in accordance with the setpoints defined by building occupants.
- **CO_2 concentration** – Evaluates the number of hours that the CO_2 concentration levels are above the recommended values for healthy indoor air quality.
- **Relative humidity level** - Evaluates the number of hours that the indoor relative humidity levels concentration levels are outside the recommended values for healthy indoor air quality.

The formulas for the calculation of the KPI’s can be found in the calculation spreadsheet prepared in the scope of T1.2.

In order to facilitate the correspondence of Table 1 with the Use Cases defined in task 1.5, the preliminary distribution of Use Cases per pilot site can be found in Table 2. Note that in accordance with the implementation, or not, of certain Use Cases, some of the indicators mentioned in Table 1 may not be as relevant, as such they can be classified as low importance by experts and other stakeholders. This will be reflected in the weight scale used on the Evaluation Framework, meaning that SATO solutions or related business models will not be penalised for using the same set of KPI’s.

Table 2 – Match between the SATO Use Cases and the SATO pilots

UCs / Pilot	Milan multi-apartment	Milan single-apartment	Aalborg residential	Seixal residential	Aspern C4 Technology Centre	Aalborg university office	Seixal municipality office	Lisbon services building	Lisbon and Madrid retail stores
Data collecting, self-assessment and forecasting (UC1, UC2 and UC3)	X	X	X	X	X	X	X	X	X
Benchmarking building performance (UC4)	X	X	X	X	X	X	X	X	X
Benchmarking appliance performance (UC5)		X	X	X					
Integration of sensors layer into BIM project for visualization and location optimization (UC6)					X	X	X	X	X
Visualization of the main KPIs and energy flows using web or mobile interface (UC7)	X	X	X	X	X	X	X	X	X
Optimize energy efficiency and improve indoor environment quality (UC8 and UC9)	X	X	X	X	X	X	X	X	X
Provide grid flexibility services to an energy aggregator (UC10)								X	X
Load-shifting as na energy cost reduction strategy (UC11)			X			X		X	X
Using thermal mass for BaB energy storage (UC12)	X	X	X	X		X	X	X	
Exploitation of natural ventilation as a cost-effective indoor comfort strategy (UC13)		X					X	X	
Holistic optmial control and cloud management (UC14 and UC15)	X	X	X	X	X	X	X	X	X

Table 2 shows that not all pilots will apply all solutions developed within SATO. This preliminary list may be further modified in Work Package 6, when more details about the pilots are known. Based on this table it is possible to see that the business scenarios identified in task 1.7 need to be flexible, adding or removing features when appropriate and adapting to the reality of different pilot buildings. The Evaluation Framework detailed in the task is flexible enough to support the necessity of having high replicable business cases.

3.2. Monitoring frequency

Besides addressing the different monitoring points, the frequency of sampling for each sensor and pilot site is also an important topic to address. Since some models can only be applied successfully with large quantities of data, the monitoring frequency might be a key aspect to consider when thinking about what solutions can be deployed in each pilot. Table 3 summarizes the monitoring frequency for each sensor, as known before their integration with SATO platform.

Further decisions on the impact of applicable solutions on pilots based on the available amount of data will be made in Work Package 4, when all models are defined.

Table 3 - Monitoring frequency of the sensors installed or to be installed in the different pilot buildings

Pilot / Sensors	Building-level electrical energy meter	Building-level thermal energy meter	System-level electrical energy use	System-level thermal energy use	Appliance-level energy use	Indoor air temperature and relative humidity	CO_2 concentration	Weather parameters
Milan multi-apartment	(15 min)	(1 hour)	(15 min)	(1 hour)	-	(10 min)	(1 hour)	(1 min)
Milan single-apartment	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Aalborg residential	(10 min)	(10 min)	(10 min)	(10 min)	-	(10 min)	(1 min)	(1 min)
Seixal residential	(1 min)	-	(1 min)	-	(1 min)	(1 min)	(1 min)	(1 min)
Aspern C4 Technology Centre	(1 min)	(1 min)	(1 min)	(1 min)	-	(1 min)	(1 min)	(1 min)
Aalborg university office	(1 min)	(1 min)	(1 min)	(1 min)	-	(1 min)	(1 min)	(1 min)
Seixal municipality office	TBD	TBD	TBD	TBD	-	TBD	TBD	TBD
Lisbon services building	TBD	-	TBD	-	-	TBD	TBD	TBD
Lisbon and Madrid retail stores	TBD	-	TBD	-	-	TBD	TBD	TBD

4. Evaluation framework for SATO

The evaluation of SATO solutions and associated business models aims to provide a clear view of the potential of such solutions and business models in a competitive market to all stakeholders. Using a qualitative evaluation method developed from quantitative metrics, SATO will be able to provide an evaluation framework that can be used to benchmark SATO results from different pilots.

This section defines an evaluation framework to support decision-making for business strategy enabling a global evaluation that takes into account the various dimensions of interest (e.g. thermal comfort, systems efficiency, etc). This framework will support the decision-making process for business strategy since it provides an evaluation based on real-time data with potential impact on energy consumption and environmental related issues.

Since the SATO project will develop innovative solutions for building management it is expected that some of these solutions will be more market-ready than others. The evaluation procedure should help to define the more mature solutions so that the consortium can focus on such solutions for the development of business models. In deliverable 1.7 – Business Case, Business Model and Financing - these business models will be described in detail and the evaluation framework developed in this deliverable will be applied to achieve a concrete score for each of the business models developed.

4.1 Evaluation framework of SATO solutions

Decisions involving energy, economic, environmental, and social related topics, usually include difficult trade-offs between divergent criteria due to the high amount of complex and contrasting data. Analysing the data and structuring complex issues through normalised and aggregated/composite indexes of performance and comparable scales lead to more informed and sustainable decisions.

A direct analysis of different KPI's values identified in section 3 allows to benchmark the results against similar buildings and/or compared them to threshold limits identified in literature. However, KPI's do not provide a clear score that can be easily identified by non-technical stakeholders, since they are usually expressed in different units or the analyses is not so straightforward. To evaluate the SATO solutions, the proposed framework considers an analysis focusing on the KPI's defined in section 3 which were identified in deliverable 1.2 – *Requirement of the Self-Assessment Framework*, and later in deliverable 1.5 – *Description of the Use Cases and Test Experiments*.

4.1.1. Unit and scale normalization

When analysing large quantities of data related to building energy performance and occupant's comfort, it is important to ensure that the selected KPI's are expressed in a relevant and comparable unit and scale of performance, particularly when considering KPI's that are expressed in absolute values (e.g. number of discomfort hours or consumed energy). The main issue behind any normalisation is usually the same, the variables or KPI's are measured at different units and scales and do not contribute in a similar way to the model's evaluation or model's learned function and may culminate in biased models or conclusions. To overcome this challenge, all KPI's to be included in the SATO Evaluation Framework need to be normalised into the same Functional Unit (FU), based on the concept of FU defined in ISO14040:2006 [2] on life cycle assessment – "a unit that enables comparability and benchmarking of the different performance indicators". The FU quantifies the overall performance using a reference unit to which all the KPI's data are normalised into.

Another important step when considering composite or aggregated performance indexes, besides the unit normalisation, is the development of a uniform scale to consolidate the different data. In literature, there are many methods for data normalization that allows the aggregation of different variables or KPI's, for example: min-max, z-score normalisation, percentage of monthly/annual variations over consecutive months/years, distance to a reference, and categorical scale [3].

The z-score normalization, also known as standardization, uses a common scale that the mean value is 0 and a standard deviation of 1, in which the indicators are converted. The downside of this method is the fact that indicators with extreme values have a higher impact on the composite indicator [3].

The percentage of monthly/annual/etc. differences over consecutive months/years/etc. considers the percentage variation relative to the previous timestep. This method requires the existence of a baseline scenario to calculate the variation between the different timesteps.

Distance to a reference considers the relative distance between a reference and the indicator. The reference scenario can be given multiple numbers depending on the objective. For example, the reference could be the average of all values, thus indicators above average receive values higher than 1, and indicators below average receive values lower than 1. The maximum value could also be used as the reference, receiving the value of 1, and all the other indicator values would be lower than 1. Again, this method considers extreme values, which may attribute a high value to outliers [3].

The categorical scale method attributes a numerical or qualitative score to each indicator. The indicators are usually based on percentiles of the distribution, assigning different values to each defined percentile. Although this method allows changes in the definition of the indicator without impacting the transformed indicator (the percentile transformation remains the same throughout time), it has several limitations: it is difficult to analyse increases over time; when the data remains almost without variations the percentile variation forces categorisation without considering the underlying distribution; and large quantities of information regarding the variation of the transformed indicators are excluded by the categorical scales [3].

The min-max normalisation method, also known as linear scaling, performs a linear transformation on the original data where the minimum or "worst" and the maximum or "optimum" measure values get transformed into the new desired lower and upper limit values (usually 0 and 1), respectively. For example, if the minimum or "worst" value of a KPI was 10, and the maximum or "optimum" value was 30 and the normalisation procedure considered a range scale of [-5;5], then 10 would be transformed to -5, 30 to 5, and a middle value such as 20 would be transformed to zero. Dıáz-Balteiro & Romero [4] proposes the following equations when the indicators are of the type "higher values are better" (Equation 1) or "lower values are better" (Equation 2), respectively:

$$\boldsymbol{\bar{R}_{ij} = 1 - \frac{R_j^* - R_{ij}}{R_j^* - R_{*j}}}, \forall \boldsymbol{i, j} \qquad (1)$$

$$\bar{R}_{ij} = 1 - \frac{R_{ij} - R_j^*}{R_{*j} - R_j^*}, \forall i, j \qquad (2)$$

where

R_{ij}: measured value of the i^{th} variable when is evaluated according to the j^{th} KPI;

R_j^*: maximum or “optimum” value of the j^{th} indicator of performance;

R_{*j}: minimum or “worst “value achieved by the j^{th} indicator of performance (anti-ideal value).

While being one of the most common used methods for data normalization, the min-max method presents one significant disadvantage: outliers and extreme values can distort the indicator [3]. However, this method may increase the range of indicators that lie within a small interval, increasing the impact of the specific KPIs on a higher scale than the z-score method.

For SATO, the min-max method seems to be the most appropriate method because it fit the great majority of the KPI identified. The specific range of the min-max method could be adapted for each KPI, but [0;5] seems a suitable interval for most of the KPIs understudy. However, the use of other normalization methods is encouraged for specific KPI or situations, since the min-max method is not a fit for all situations (e.g. for qualitative data, the categorical scale method may be more suitable).

4.1.2. Weighting methods

While the unit and scale normalization allow to have more comprehensible KPI’s, that can be evaluated by non-technical people, to build an Evaluation Framework it is necessary to establish a single value that can represent the overall potential of the solution. The simplest solution to achieve that would be to average all considered KPI’s if the scale was the same for all of them. However, considering that all KPI’s have the same important in all scenarios fails to recognize the different realities and the differences between the several SATO solutions and Business Models.

The proposed Framework incorporates a weighting method, enabling to adapt the relevant of each KPI to the specific scenario. According to the literature there are several different types of weighting methods such as the data envelopment analysis, the benefit of doubt approach, the unobserved components model, the budget allocation process, public opinion, the analytic hierarchy process, the conjoint analysis, and others.

Analysing the several methods available, the Budget Allocation Process (BAP) is highlighted due to its short time of execution as well as the ability to balance correlated indicators. The BAP defined the weight for each indicator based on expert opinion on the topic, distributing the total percentual points over the selected number of indicators.

Unlike other of the mentioned methods, the BAP has the advantage that experts acknowledge the correlation between the several indicators, while methods using linear models or similar cannot provide balanced weights when there is high correlation between indicators, which is the case for the SATO KPI’s. Another advantage is that some models require large baseline datasets, while expert opinion is based on similar experiences and the data does not need to be fed into the system.

One of the disadvantages pointed out for the BAP is that the expert opinion may be based on current policy for a specific region. This will not be a disadvantage for SATO as the goal is to use the BAP in the different regions to value the most important indicators in each geography.

To ensure that the BAP is successfully applied it is essential that the panel of experts selected represent a wide spectrum of knowledge and experience, and that the experts are considered experts in the topic and not only experts in one of the indicators categories. SATO partners will be the main panel of experts for this weighting methods, supported by some project stakeholders.

After collecting all expert opinions, the weights will be the average of the weight proposed by each expert, forming the final weights. The product between the final weights and the normalised KPI's will result in the final single score of the Evaluation Framework.

4.1.3. Application example

This subchapter covers one example of application of the Evaluation Framework described in this deliverable to make it easier to replicate and apply during SATO project.

To simplify, let's assume that there are 3 KPI's – specific energy consumption, specific peak power, renewable load factor.

The KPI's are calculated as follows:

- Specific energy consumption – Total yearly energy consumption of a building as a function of its net floor area;
- Specific peak power – Average daily peak power registered for a building as a function of its total yearly energy consumption;
- Renewable load factor – Percentage of renewable energy used in the total yearly energy consumption.

Based on this description, for building X, located in Y, the following values were calculated:

- Specific energy consumption – 330 kWh/m^2;
- Specific peak power – 30 W/MWh;
- Renewable load factor – 20%.

The unit normalization is based on the following references:

- Specific energy consumption – Optimal: 50 kWh/m^2, Worse: 500 kWh/m^2;
- Specific peak power – Optimal: 5 W/MWh, Worse: 100 W/MWh;
- Renewable load factor – Optimal: 100%, Worse: 0%.

Note that the reference values are estimations made for the purpose of the example.

Normalizing the three KPI's to a scale from 0 to 5:

- Specific energy consumption – 1.3;
- Specific peak power – 3.4;
- Renewable load factor – 1;

The weights were determined as follows for the three KPI's:

- Specific energy consumption – 0.5;
- Specific peak power – 0.1;

- Renewable load factor – 0.4;

Note that the weights are examples used for the purpose of the example.

Based on the weights identified, the final score obtained for the building analysed was:

- Final score = $1.3 * 0.5 + 3.4 * 0.1 + 1 * 0.4 = \mathbf{1.4}$

To analyse the specific SATO solutions, the KPI's used should focus on the areas where the solutions will have an impact. It is suggested that the Evaluation Framework is used in the beginning of pilot activities to get a baseline scenario to which the SATO consortium will be able to track the progress that is being achieved in each pilot.

As shown in this example the Evaluation Framework is divided in the following steps:

- **Identification of relevant KPI's** – The KPI's identified in Chapter 2 should be prioritized but other relevant KPI's may be added to the framework;
- **Calculate the KPI's** – Use the available data to calculate each KPI identified;
- **Identify the reference values for each KPI** – Search relevant literature to suggest and justify the references used for the scenario under analysis;
- **KPI normalization** – Use the reference values to normalize the KPI's to a simple scale;
- **Budget allocation process** – Use the budget allocation process to identify the weights that will be attributed to each KPI for the scenario under analysis;
- **Final score** – Calculate the final score using the normalized KPI's and the determined weights.

Every application of the Evaluation Framework proposed in this deliverable must always use this **6-step procedure.**

4.2 Evaluation framework of SATO business models

While the Evaluation Framework described in the previous subchapter is flexible and easily applicable for the evaluation of SATO solutions, SATO business cases are more complex in the sense that there are important parameters for the success of a business model that are not covered by the project KPI's. Besides that, the business cases may address more than one SATO solution, which means that evaluating each solution independently will not result in an evaluation of the business model.

It is evident that the current Evaluation Framework is missing two topics to be able to address SATO business models more accurately, one being to establish specific criteria for evaluating business models, and the other being to address how the Evaluation Framework would work on multiple solutions.

Reviews of literature show that there is not a widely used methodology for the evaluation of business models. Some authors suggested the definition of a criteria (e.g., Fit, Evolution, Uniqueness, Profit Potential, Comprehensiveness, Imitability, Robustness and Sustainability) that is fundamental to have a successful business model [5, 6]. These criteria evaluate the following aspects of the business model:

- Fit – Consistency between the components of the business models, and the external environment conditions.

- Evolution – The ability for the business to evolve over time and articulate with different market rules or regulations.
- Uniqueness – The unique features of the business model and how it differs from the competition.
- Comprehensiveness – The limited or broad scope of the business model and how that affects marketability.
- Imitability – The capacity for the business model not to be copied by competition.
- Robustness – The ability to withstand changes in internal or external conditions.
- Sustainability – The ability of maintaining profits and expenses at a certain rate.

While all these criteria make sense to assess and are tied with the success of a business model, these criteria are hard to measure, especially with the consistency required for SATO. The reason is that the business models will be applied by different partners and on different geographies, so it is important that different stakeholders can reach the same or very similar scores when evaluating similar scenarios. To have this consistency, a mathematical based method needs to be introduced.

Since the business model canvas will be introduced in task 1.6, the solution proposed by Díaz-Díaz et al. [7], for the Evaluation of business models for Smart Cities, may be easily applicable in SATO and will address the two points mentioned, provide criteria to support the evaluation and enables to evaluate a business model that is based on more than one SATO solutions. Above all, the method presented will be more consistent since it is based on the business model canvas and uses specific questions with specific scores attributed according to the answer.

The method takes into account four sections of the business model canvas and two additional sections on social and environmental impact: cost structure, revenue streams, social and environmental costs, social and environmental benefits, value proposition and customer segments.

Upon achieving a score for each of the six sections above, Díaz-Díaz et al. [7] proposes the concept of Value of Business Model (VBM), which is a single value to classify a business model, similar to the one proposed on the Evaluation Framework for SATO solutions. This value is calculated as follows:

$$VBM = (CE + RE - SEC + SEB + VP) * CS$$

Where:

- CE is the Cost structure score;
- RE is the revenue streams score;
- SEC is the social and environmental costs score;
- SEB is the social and environmental benefits score;
- VP is the value proposition score;
- CS is the customers segment score.

The cost structure, revenue streams, and customers segments scores vary between -5 and 5. The social and environmental benefits, and the value proposition scores vary between 0 and 5. The social and environmental costs score varies between -5 and 0.

Looking at the VBM formula and knowing the variation between each of the scores it is possible to understand that the method proposed by Díaz-Díaz et al. [7] highly values the customer segment part of the business models. While this approach is highly disputable as there are high value niche markets, it is at the same time a valid approach due to the importance of that section. Due to the possible dispute over this approach, SATO will again use the budget allocation process to define the weights of each of the 6 scores by collecting expert opinion on the importance of each section, leading to the creation of the SATO Value of Business Model (SATO VBM).

The calculation of each individual score is based on a series of questions, related with the sections that have some predefined rules to attribute scores.

The **cost structure score** is given by the following questions:

1. Related to the service provided with the traditional system, the cost offered with smart technologies is higher or lower?
2. Related to the service provided with the traditional system, the sources of costs are less, equal, or more diversified?

For the first question, there score will be between -4 and 4. +4 will be attributed if cost is more than 50% lower, +3 if up to 50% lower, +2 if up to 20% lower, +1 if up to 5% lower, 0 if the cost is the same. The negative values follow the same thresholds but for a cost higher than the traditional solution.

The second question has a score between -1 to 1. +1 is attributed if the sources of costs are more diversified, 0 is attributed if the sources of costs are equal, and -1 is attributed if the sources of costs are less diversified.

The **revenue streams score** is given by the following questions:

1. Related to the service provided with the traditional system, the amount of revenue that this product/service will generate more or less revenues?
2. Related to the service provided with the traditional system, the sources of revenues are less, equal, or more diversified?

The first question is evaluated in the exact same way as the first question from the cost structure score.

The second question is evaluated in the exact same way as the second question from the cost structure score.

As the questions for the **social and environmental costs score** and **social and environmental benefits score** presented are more adapted to non-profit scenarios, these two sections were aggregated into the **social and environmental impact score**, and the questions were adapted as follows:

1. Does the product/service contribute to the European targets set in the Energy Performance in Buildings Directive?
2. Does the product/service contribute positively to the local or family economy?
3. Does the product/service contribute towards the Sustainable Development Goals?

4. Does the product/service contribute positively to the well-being and health of citizens?
5. Does the product/service contribute positively to energy poverty, social cohesion and discrimination?

All questions have scores of -1, 0 or 1. -1 is attributed if the business model negatively impacts the strategic objective. 0 is attributed if the business model has no impact on the strategic objective. +1 is attributed if the business model positively impacts the strategic objective.

The **value proposition score** is given by the following questions:

1. The product/service meets a need of the occupants?
2. Are the occupants interested in adopting this product / service?
3. Is this product/service a plausible improvement in the quality of life of occupants?
4. Is the product/service of better quality than current alternatives?
5. Is the product/service's price better price than current alternatives?

The **customer segment score** is given by the following questions:

1. What percentage of buildings can adopt the product/service?
2. Is the product/service beneficial to all citizens?

Unlike the previous sections, the first question is evaluated based on a percentage. If the percentage is higher than 80% the score attributed will be +4. Else if the percentage is higher than 50% the score obtained will be +3. Else if the percentage is higher than 30% the score obtained will be +2. Else if the percentage is higher than 10% the score obtained will be +1. If the percentage is below 10% the score obtained will be 0.

The second question scores either 1 or 0. +1 is attributed if the product/service is evaluated as beneficial to all citizens, while 0 is attributed if the product/service is beneficial just for some citizens.

It is important to note that all answers to the questions above must be justified in order to have a VBM that is transparent and considered valid by other peers. For the questions that directly address the building occupants, inquiries must be made to understand their position.

The threshold percentages were slightly adapted from Díaz-Díaz et al. [7] to simply the description. As these questions were specifically prepared for the evaluation of Smart Cities business models, SATO slightly adapted the questions so as to fit better within the topic of smart building and will use this method and the respective questions to evaluate its innovative business models.

Overall, this methodology will provide a consistent way of evaluating SATO business models despite the differences on its application, being a good to benchmark the performance against other SATO business models, but also against the traditional business models.

5. Relation to other tasks

This deliverable provides the Evaluation Framework for SATO solutions and business models. The deliverable takes into consideration many details of previous deliverable under Work Package 1 and will provide an evaluation method that will be especially useful for Work Package 6. All relations with other tasks are shown in table 4.

Table 4: Task contribution and uptake to other tasks of the project.

Tasks	Contribution or uptake level	Main contribution
Analysis of Self-assessment Framework & Requirements (1.2)	Medium	KPI's defined were used as base KPI's for Evaluation Framework
Definition of the Pilots Demonstration Framework and KPIs to evaluate SATO SA&O services and Business Models (1.5)	Medium	Definition of solutions to be implemented per pilot supported the definition of a flexible Evaluation Framework
Residential multi-apartment pilots (Aalborg, Milan, Seixal): SA&O operational experiments and monitoring (6.2)	Medium	Evaluation Framework will be used to track potential of solutions
Office building pilots (Aalborg, Aspern, Seixal, Lisboa): SA&O operational experiments and monitoring (6.3)	Medium	Evaluation Framework will be used to track potential of solutions
Appliance retail store pilots (Lisboa, Madrid): SA&O operational experiments and monitoring (6.4)	Medium	Evaluation Framework will be used to track potential of solutions

6. Conclusions

This deliverable proposes an Evaluation Framework that can be used to evaluate the potential of different solutions applicable to buildings under different conditions. The work developed will support the claims of the solutions developed within SATO, as well providing an easily readable measure for non-technical people to understand the potential of such solutions. Furthermore, the detailed pilot description will also support many other tasks throughout the project, providing key information for the development of solutions to be tested in the pilots.

The Evaluation Framework detailed in this deliverable has a 6-step application, with the two more complex steps being the normalization of the KPI's and the BAP weighting method. The normalization of the KPI's consists on using a method that enables to convert KPI's into a simple scale, that can used to communicate a qualitative representation of the KPI value, for example bad, normal, or good. The BAP weighting method is a method of collecting expert opinions on the relevance of each KPI to form weights that will make so that some KPI's will account for a larger percentage towards the final score.

By using the final score as qualitative representation of SATO solutions value against similar solutions already on the market it will be possible to understand the added value from these solutions.

Overall, the result of this document is methodology for the evaluation of the SATO solutions and business models that will be tested in Work Packages 6.

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