WP7 – Pilots Deployment, Operation and Socioeconomic Evaluation

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D7.1 First feedback from the Proof-of-Concept deployment and Introduction to the other pilots

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Abstract:

This document describes the Proof of Concept carried out in Project PHOENIX. The document covers the actions and measures that were implemented in terms of hardware, with the solutions that were adopted as well as the implementations in terms of software. In implementing the Phoenix platform at the PoC pilot, it became evident that the intermediate components between the sensors/gateways and the services are of great importance and that those layers are the basis of interoperability. This aspect is therefore highlighted in this document. The lessons learnt from the PoC are many, but in general, we have seen that (i) each building has specific characteristics that need to be assessed and (ii) the person-hours of specialized personnel is expensive and difficult to find whereas hardware solutions can be more cost effective and easier to implement. In addition, we have seen that integrating the BMSs is key for the proliferation of smart buildings.

Keywords:

Smartness; Integration; Legacy equipment; Communication; Middleware; Pilot; Use Case; Services.

Revision History

The following table describes the main changes done in the document since created.

Revision	Date	Description	Author (Organization)
0.1	08/06/2021	Preparation of the skeleton of the document	UMU
0.2	12/06/2021	Integration of the synthetic	UMU
0.3	15/06/2021	Integration of KaMa pilot introduction	KaMa
0.4	15/06/2021	Integration of Miwenergia pilot introduction	Miwenergia
0.5	21/06/2021	Integration of Arden pilot introduction	Arden
1.0	23/06/2021	Merging of developments on services	UMU
2.0	23/06/2021	General overview	UMU
2.1	24/06/2021	Review of the document	VERD
3.0	30/06/2021	Proof reading	ARDEN/UMU

Executive Summary

This document is a description of the Proof of Concept (PoC) that was developed as part of project PHOENIX. This PoC consisted on evaluating at a small scale the technologies that will enable the services which will be implemented on the European Project PHOENIX, a circa 5M€ project with the aim of investigating ways of upgrading the smartness of existing buildings thanks to an “adapt & play” philosophy.

The PoC has been successful, as it has been capable of proving technologies at every level of the PHOENIX solutions. This includes: sensors and actuators, gateways that send the data of the sensors to the PHOENIX platform, Internet of Things (IoT) agents that are capable of translating the data to standardised data models in JSON format, algorithms that produce higher level information with semantic data, and services offered to the final users that could be occupants, building managers, grid operators, or the administration.

The result of this document is a comprehensive body of knowledge that has been generated over the circa nine months during which the team was designing and evaluating options and implementing and testing the solutions of the PoC. In this document the reader can find guidance, best practices and the difficulties that one may overcome to carry out an endeavour such as the one described here.

Disclaimer

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1. Introduction

1.1. Scope of the Document

This document covers the learnings about the Proof of Concept of project PHOENIX. The Proof of Concept has been a global effort coordinated by the University of Murcia (UMU) that makes a transversal testing of all the components that will be found on the final solution set of the PHOENIX project. This includes legacy hardware adapted with modern gateways, modern smart hardware installed with the purpose to gain connectivity, IoT agents that serve as the bridge for the PHOENIX platform, security components, data models, and services.

Here, the different components are explained; the sections cover the different components that make the PoC functional and that enabled the testing a series of scenarios producing extensive and valuable lessons.

It is worth noting that the PoC also included a synthetic testing framework. The reason for this, has been to thoroughly evaluate possibilities of making tests on the grid as if Distribution System Operators (DSOs) or Transmission System Operators (TSOs) were testing services (Which in practice would be very complicated and unrealistic for the PHOENIX project). Instead, at this point, the PoC has developed a testing framework, with realistic consumption profiles, and that has all components that will be of interest on a real testing framework. This will also be connected to the PHOENIX platform as if a real neighbourhood was fully connected with appliances and occupants reporting their statuses, usage and preferences in real time.

The document also covers the plans for the upgrading of the main PHOENIX. These plans have been developed after incorporating all lessons learned from the PoC and taking into account all specificities of each pilot, checking what technologies are most desirable for upgrading smartness and evaluating the best options available.

The document closes with conclusions and further work. For this specific document, the lessons learnt are rather important as the rest of the pilots will look into the experience of the PoC for integrating the systems on their pilots. It has been challenging to include all the learning that the PoC has provided, but the last sections summarise the most important ones in the view of the authors.

1.2. Relevance to other deliverables

This deliverable has a direct connection with deliverable 3.1. Although Del 3.1's scope is much more extensive, in the sense that it covers different levels of the PHOENIX solution, the PoC has been possible thanks to the integrations that have been developed in detail on deliverable 3.1. In the case of this document much more is said about the other components and the peripheral systems and studies that have made the PoC a valuable tool (the synthetic framework, the data models the *Smart Readiness Indicator* [SRI] evaluation…). In the case of Del 7.1, preliminary services are integrated. It should be noted that the services do not use complex Artificial Intelligence algorithms or techniques. Instead, the services used for the PoC are a proof that the lower layers of the envisaged solutions are reporting their data appropriately and that the data goes all the way up to the higher levels with the right format to make possible the services.

1.3. Structure of the document

The document starts with this introductory section. This is followed by three sections that describe, without replication with other deliverables, mostly the hardware side of the PoC. These are the site description in Section 2. The integration of the equipment (in Section 3) and a description of the installation manuals that were presented more in detail on deliverable 3.1, in section 4). The following four sections cover mainly the software part of the developments, including the design of integration agents on Section 5, the description of the data models in Section 6, the impact on the SRI of the interventions in Section 7, with a thorough description that allows a full understanding of this really crucial aspect of the intervention, and Sections 8 and 9 that describe the synthetic PoC for the grid integration testing, as well as the new data in the PoC and the PoC services on 10. Section 11 closes the document with conclusions and further work. The document includes a section of bibliography and an annex with a new class developed for the ontology developed on the PoC.

2. Description of the PoC

The PoC has been deployed in a sub-set of buildings of the University of Murcia, in the Campus of Espinardo. There are several buildings where a number of devices are already operational. Among them, some are already integrated in an existing BMS while others are essentially isolated and unable to communicate with any platform. One of the goals of this PoC is to add connectivity to these isolated devices.

In addition to having all the devices connected, another goal of this PoC is to have a single platform where all the different equipment can speak the same language to simplify the maintenance tasks of each system.

2.1. Legacy equipment and systems

As part of the PoC, the legacy equipment involved was:

- Solar domestic hot water.
- Electric vehicle chargers.
- HVAC of Pleiades building.
- PV Installation adjacent to the Campus' swimming pool.
- Air Quality monitoring.
- WiFi Smart Sockets.
- Building Management System

In addition, there are other legacy devices/systems yet to be integrated, which are planned to be considered for integration during the following month in which the UMU Pilot will be deployed:

- Smart electric vehicle charging points. There are some (at least one for now) charging points in the Campus compatible with OCPP (Open Charging Point Protocol).
- In the Pleiades building there is a Building Management System (BMS) that's managing a number of devices. It has direct control over individual air conditioning units, temperature, humidity, lighting, Infra Red (IR) presence sensors, etc.
- The same building has 2 external backup petrol generators.

The plot area delimited for the construction of the building is practically a square of 10,982.77 m2. It consists of 5 floors in addition to the ground floor, spread over 4 buildings. Building 1 has 5 floors, building 2 has 3 floors and building 3 has 3 floors. The fourth building will be a library with 2 floors. Horizontally the building is organized around a large corridor axis that separates the research areas of the library area, which extension would allow connecting in the future with other extensions. The orientation of the building is 20º with respect to the North axis, having latitude of 38º. The laboratories included at the PoC are located on the first level of building 2. The three laboratories of similar size will be referred to as laboratories 14, 15 and 16 and the largest as 17. The latter also has an attached server room. Figure 1.

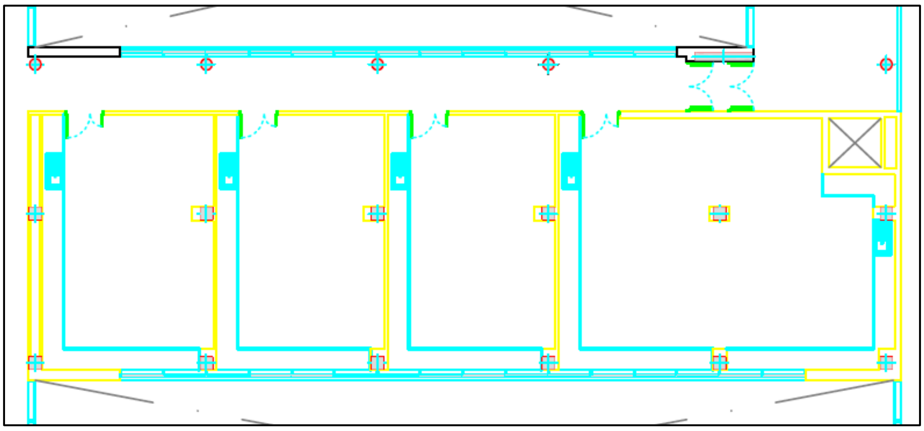

Figure 1. Blueprints of offices on PoC pilot, and a server room shown as an X.

The offices are equipped with indoor units that get their cooling or heating from exterior units on the roof forming a Variable Refrigerant Flow system. The diagram of this equipment has been shown on Figure 3. The internal units are Toshiba units with product code: MMU-MAP0362H.

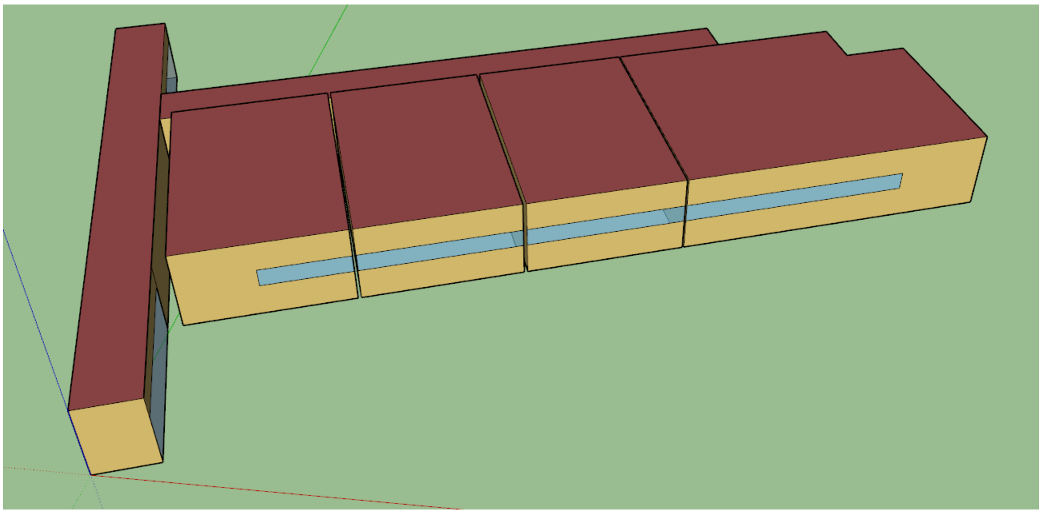

Figure 2. 3D model of the site where the PoC will be carried out.

In order to comprehensively analyse the influential aspects that affect the comfort of the building, it is important to consider the location of the rooms and the conditioning equipment.

- Location: latitude of 38.0245º, a length of -1.1732º. Time slot +1 GTM and with an altitude of 60m above sea level.
- Equipment following the scheme of Figure 3. Central unit MMY-AP3014HT8 and units in rooms MMU-MAP0362H.

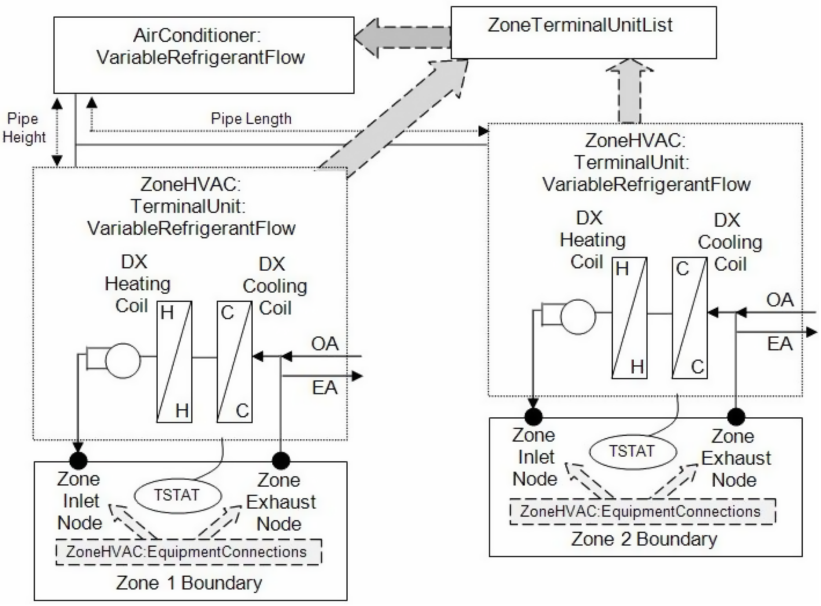

Figure 3. Schema of the conditioning equipment (using EnergyPlus software).

3. Integrations of legacy equipment and systems in the PoC

The PoC has a range of devices that have a significant relevance for the smartness of the building and for its energy consumption, but that were not monitored or connected by any means. It was important therefore to adapt that equipment to enable their monitoring and control through the PHOENIX platform. The situation of the equipment before the intervention and after the intervention, is summarised in Table 1 with a detailed description in the following subsections.

Table 1. Situation of Legacy equipment before and during PoC.

System	Situation prior PoC	Situation on PoC
Solar Domestic Hot Water	No connection	Generation of Power by the Solar panels monitored. Flow of water in the secondary circuit monitored. Temperature of operation IN/OUT monitored
Electric Vehicles Charing Points	No connection	Monitoring of the energy consumed at the charging points. Possible actuation for charging scheduling
Conditioning system + AHU	No connection	Monitoring of consumption on

		conditioning and AHU[1]. Monitoring of temperatures in relevant points of the system
Indoor environment sensing	Local SCADA communication	Integration into PHOENIX platform
Sockets Loads	No connection	Monitoring of loads and potential actuation
PV plant yield	Logging into local (isolated) server	Secured connection to PHOENIX platform

Figure 4. Pictorial view of the PLEIADES building where the PoC is taking place.

4. Manuals for the integration of hardware and software

As part of the effort of the PoC the creation of integration methodologies for the legacy equipment that was found there was needed. The methodologies for integration can be found on Deliverable

[1] *Air Handling Unit*

3.1 in the form of annexes. The findings shown in this document have been achievable thanks to that integration.

5. Design of agents to integrate on the broker

As explained in Deliverable 3.1 in more detail, in order to communicate with the legacy devices and build systems which are going to be integrated in the different pilots, there are a number of agents to be configured and tested. Depending on the technology used by each device, it will be necessary to select the type of middleware or gateway.

For the PoC a set of agents have been integrated that allow communication with TCP/RTU connected devices, with Modbus devices, with devices using a Z-WAVE adaptor gateway and with the SCADA of the building using a middleware designed for that purpose. This is shown Figure 5.

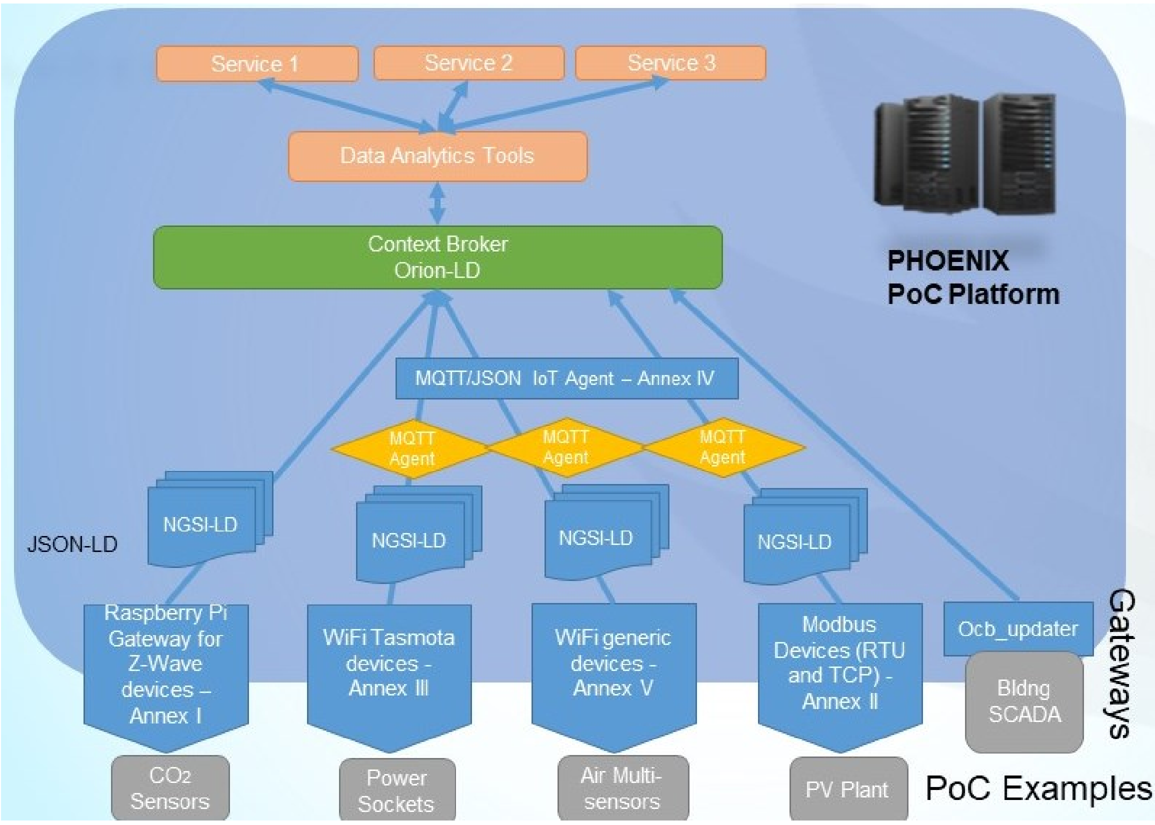

Figure 5. Representation of the platform used for the PoC with an emphasis on the connection mechanisms of the legacy equipment.

6. FIWARE Smart Data Model

The PoC has carried out the task of defining a data model for the transfer of information based on accepted schemes. With this it was intended to standardise the data formats and to provide value to the higher layers of the platform within the information that is sent. For the purpose of modelling, the smart-data-models of FIWARE was used.

Smart Data Model is a unified approach to data models along with contributions from international organizations such as FIWARE, GSMA and TMForum and IUDX. These data models have been harmonized to enable data portability for different applications including Smart Cities/Buildings, Smart Agrifood, Smart Environment, Smart Sensoring, Smart Energy, Smart Water and other domains. They are intended to be used in any field but compliance with FIWARE NGSI version 2 and NGSI-LD is necessary.

These data models are available in the following repository https://github.com/smart-data-models. The lower level repository is a Subject (i.e. Alert, Streetlighting, etc). Every subject repository is aggregated into domain repositories. Domain repositories compile several subjects. At the same time, a subject could appear in several domains (i.e. Weather appear in Smart Buildings/ Cities).

For the PHOENIX data model, the entities of the Building scheme, and entities on the smart cities schemes were used. Also and to complete the definition of the data, a new class was created that was given the name of *Zone* this new class was defined to be contained within a building, and the device was configured to be located within it.

To make sure that the data streams had enough information relevant for the data analytics part, the QoI schema was used, and the classes *Stream* and *StreamObservation* selected to be considered as the final entity that is updated as the data is produced live by the sensors. The classes used can be seen in Figure 6.

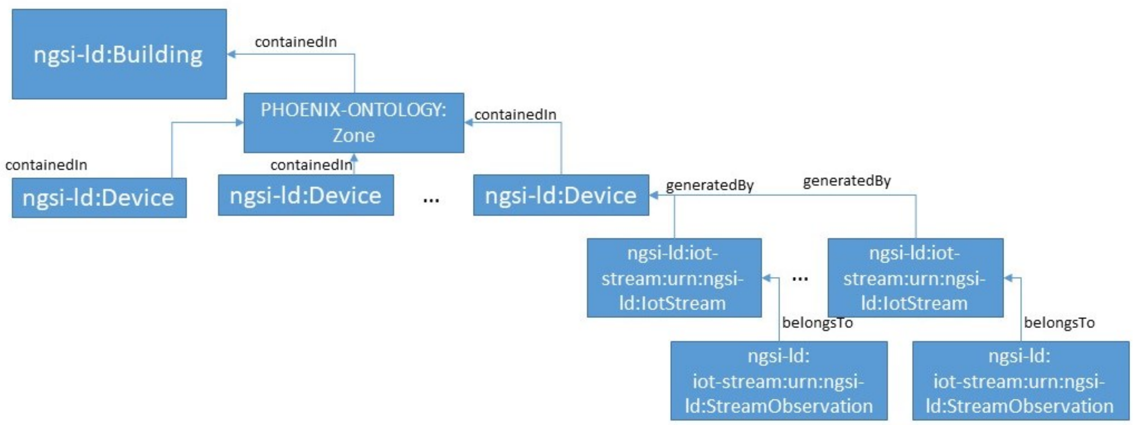

Figure 6. Example of hierarchies in the data model used for the data collected for the PoC.

6.1. Buildings

Three buildings have been included within the PoC to facilitate the testing of the co-existence of several buildings on a semantic environment, and to evaluate the way in which the sensors will be handled depending on their location. The buildings were PLEIADES, the main building of the PoC, and two peripheral buildings that have served for the testing of other technologies, the Estates building and the university pool.

Table 2. Buildings as described by the NSGI-LD modelling.

Building	NGSI-LD Identifier	Use	PHOENIX interest	Comments
PLEIADES	urn:ngsi-ld:Building:UMU-Pleiades	Offices and Laboratories	Main intervention performed in this building	All interventions performed at the PoC except for solar energy systems and EV charging have been done in this building
Estates	urn:ngsi-ld:Building:UMU-MaintenanceUnit	Department of Estates	The electric cars used by the estates are charged in this building	This building is located outside the PLEIADES Building, but its high relevance for the project has made us select it for the PoC.

Swimming Pool	urn:ngsi-ld:Building:UMU-Pool	Swimming pool sports facility	The roof of the swimming pool sports facility has a PV installation with	It is a photovoltaic solar installation with thin layer modules (cadmium tellurium technology) connected to the grid

Figure 7. PV thin film installation of the swimming pool. The efficiency of this technology (thin film) will be monitored and reported within the PHOENIX platform.

6.2. Zones

Although the ontology used by PHOENIX has been almost-fully based on the smart-data-models ontology of FIWARE, the mapping of the components relevant for the project showed that the FIWARE ontology lacks the definition of a *zone* as a living space such as room, office, lab, hall, or dining room. This class was important for the project as many services are run for a given room, and in that case personalised feedback could not be produced if the recommendation was agnostic to room level.

This was something learnt from the implementation of the PoC and helped on the development of the ontology for the full pilots. In this regard, a *zone* class was created that allows the integration of the location of the sensors within the specific of the zone. Annex I of this document describes this new zone class that was used on the PoC and in the following pilots.

6.3. Sensors

Within the PoC, a series of sensors have been integrated and modelled with the ontology adopted in the project. These sensors include CO_2, Temperature, presence and light levels. The following table shows information about the sensors integrated.

Table 3. Examples of sensors already integrated as NSGI entities in the Context Broker of the PHOENIX platform.

Sensor	NSGI-LD example	Variable	Comments
CO_2	urn:ngsi-ld:Device:UMU-Pleiades-BlockB-B1.1.014-CO2	Carbon Dioxide proportion in air [ppm]	These sensors are located at sitting height to measure the levels breathable for occupants.
Luminosity	urn:ngsi-ld:Device:UMU-Pleiades-BlockB-B1.1.014-Light1	Light Levels	The light levels are not proportional to illuminance but are a good proxy of the level of light existing in the zone.
Presence/occupation	urn:ngsi-ld:Device:UMU-Pleiades-BlockB-B1.1.014-Motion	Movement within the zone	These sensors send a 1 one motion id captured within the zone.

6.4. Power meters

The power meters are key sensors for the PoC and for the whole project. With power meters not only it will be possible to measure the energy use of appliances but also of whole areas and whole buildings. But also, the power meters will facilitate obtaining behavioural patterns as well as efficiency of certain elements.


```
{
    "id": "urn:ngsi-ld:Device:UMU-Pleiades-B1.1.014-LightingCircuit-PowerMeter",
    "type": "Device",
```

```
    "category": {
      "type": "Property",
      "value": [
        "meter"
      ]
    },
    "description": {
      "type": "Property",
      "value": "Power Meter Pleiades Block B / B1.1.014 lighting circuit"
    },
    "containedIn": {
      "type": "Relationship",
      "object": "urn:PhoenixOntology:Zone:UMU-Pleiades-BlockB-B1.1.014"
    },
[…]
```

Figure 8. Example of Power meter of the PoC for a given block of the building.

6.5. Inverters

The devices reporting the generation of the PV plant among other variables related to the export of electricity to the electric grid are provided by the inverters. These inverters were reporting the variables to a local server. PHOENIX has developed a secured middle-ware capable of reading that data and send it in quasi-real time to the PHOENIX platform.

6.6. HVAC

The HVAC system of the PoC consist on a Variable Refrigerant Flow system with independent consoles operating in different zones. The compressors operating in the roof, and in charge of generating the refrigerant and the heating flow, are metered. Also the consoles in the zones are connected via Modbus connection to a BMS of the building. Within PHOENIX, the *ocb_updater* has been created to serve as a conduit and provide connection between the BMS and PHOENIX. The consoles offer a great deal of connectivity, reporting temperatures and operation modes to the platform, but also offering the possibility of changing their operation remotely. The header of one of this consoles data modelled with the PHOENIX ontology can be seen it he following.

```
  {
    "id": "urn:ngsi-ld:Device:UMU-Pleiades-BlockB-B1.1.014-HVAC",
    "type": "Device",
    "category": {
      "type": "Property",
      "value": [
        "hvac"
      ]
    },
    "description": {
      "type": "Property",
      "value": "HVAC unit for room B1.1.014"
```

```
    },
    "containedIn": {
      "type": "Relationship",
      "object": "urn:PhoenixOntology:Zone:UMU-Pleiades-BlockB-B1.1.014"
    },
            "location": {
                "type": "GeoProperty",
                "value": {
                    "type": "Point",
                    "coordinates": [
                        38.02418,
                        -1.17311,
                        630
                    ]
                }
            },
```


7. Impact of the interventions on the PoC on the SRI

This section describes the improvements in terms of smartness achieved for the PoC, a sub/set of buildings of the University of Murcia. The interventions involved in particular the overall connectivity between the devices of the building and the PHOENIX platform. The strategies have been evaluated in terms of upgrading the Smart Readiness Indicator (SRI) score, throughout its several domains.

A preliminary study was conducted in order to evaluate the potential improvement in the SRI framework, and several strategies were considered and are reflected in more detail on Deliverable 3.1. Table 4 summarises these interventions and the effect on the SRI.

Table 4. Evaluation of all potential interventions that could be done in the PoC, from D3.1.

Domain SRI code	Hardware	Location	SRI points gained (acc)	PHOENIX interest
Electric Vehicle	Meter and Actuator on UT charging line	UT location	10	5/5
Electric Vehicle	Connection to Circutor chargers	Faculty of CS	10	5/5
DHW	Heat meter for solar DHW installation	Ground floor shed near parking	9	5/5
Electricity	Smart sockets in all appliances	Scattered over the rooms	9	3/5
Controlled ventilation	Air quality sensors (CO2)	Scattered over the building	8	5/5
Controlled ventilation	Actuation over MVHR	PLEIADES Rooftop	7	5/5
Electricity	Petrol generator monitoring	Ground floor shed near parking	7	5/5
Electricity: Renewable & storage	Meters and actuators security shed	Security at University entrance	5	5/5
Heating	VRF power meter	PLEIADES roof top	3	5/5

DHW	Smart sockets on 30 domestic water tanks	Scattered over the building	3	3/5
Cooling	VRF power meter	PLEIADES roof top	3	5/5
Lights	Remote ON/OFF of lights	Central switch at entrance	3	3/5
Monitoring and Control	Occupancy control (IR sensors)	Scattered over the rooms	2	2/5
Heating	Presence control	Each room	1	1/5
Cooling	Presence control	Each room	1	1/5

In this document, the intervention chosen are presented, and a comparison between the SRI score prior and subsequent to them is discussed.

Heating

The heating system of the building consists of a Variable Refrigerant Flow (VRF) with a heat pump. The VRF includes several consoles (indoor units) in each room that have thermostats which assures an individual control on the heat emission at zone level. Hence, the corresponding functionality level for the service ‘Heat emission control’ Heating-1a code is level 2. To reach a higher level, communication between controllers is needed. With respect to the heat pumps, the heat generator capacity has a multi-stage control that depends on the inverter frequency control, meaning that a level 2 is reached in the service ‘Heat generation control (for heat pumps)’ Heating-2b code. In fact, the Toshiba VRF system installed is a modular multi system with an infinitely variable control that adjusts compressor rotation speed in near-seamless 0.1 Hz steps (Figure 1).

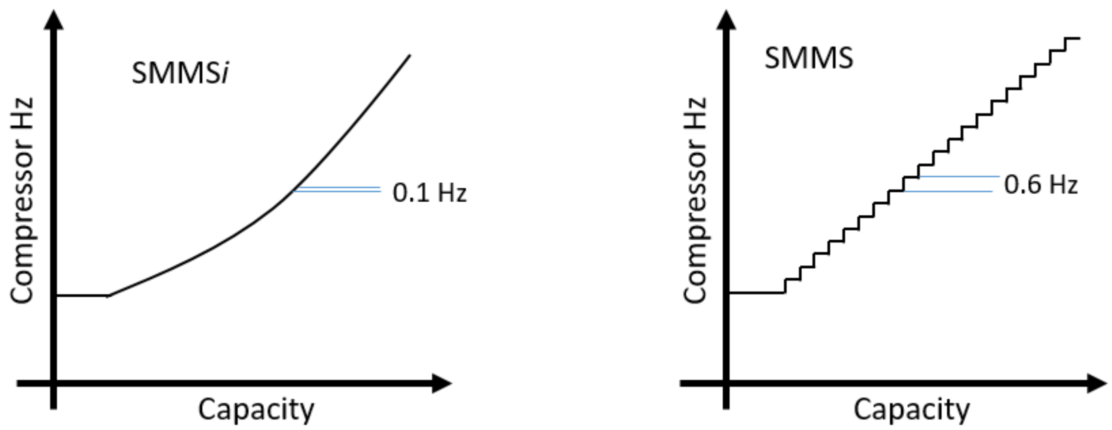

Figure 9. Variable control of the modular multi system installed (adapted from: ‘Product overview Toshiba’).

Other services do not apply to this specific case: control for TABS, Thermal Energy Storage, heat generation control (except heat pumps) and sequencing in case of different heat generators are not applicable with the typology of the system, so a level 0 is applied. Other services scored level 0 as well since there was no automatic control for fluid temperature, distribution pumps in the networks, the reporting of performance and the grid interaction.

The heating domain was improved through the installation of VRF power meters that report the energy consumption of the outdoor unit. This together with the operation of the consoles can provide a proxy of the performance. In addition, external data sources of weather are integrated into the platform, so it is possible to report the performance including forecasting. The platform also allowed also inclusion of predictive management and fault detection thanks to the monitoring of several variables that may show up estrange behaviour, so level 4 is reached in the service 'Report information regarding heating system performance', code Heating-3. Furthermore, the interventions allowed the communications among the controllers and the BACS, so level 3 is reached in the service Heating-1a. Because of the connection to the grid, the heat generator capacity will depend also on the external signals from the grid. In fact, such improvement would allow, through the consoles connected to the platform, modification of the heating generation according to the condition of the grid, so that level 3 is reached in service Heating-2b. Finally, the connection with the grid allowed also the development of Demand Side Management (DSM), which can lead to flexible control of the heating system; a step forward that can be done in the PoC would be adding a predictive control model based on local predictions. In this scenario, level 4 would be reached in the service 'Flexibility and grid interaction', code Heating-4. The sum of the SRI point gained with the actuation for this domain is 24.

Domestic Hot Water (DHW)

The DHW system consists of a dual tank system (SOLAR + DHW). For the solar tank, a heat exchanger is used, and there is a secondary tank with an auxiliary electric resistance heater. Before the intervention, there was no monitoring or automatized control of the storage charging nor the performance of the system. Hence, the domestic hot water domain of the pilot scored level 0 in all five services. The changes implemented consisted of monitoring of the generation of power by the solar panels.

Temperature reading points at the entrance and the exit of the solar circuit together with the flow meter allowed reaching a level 2 in the service 'Report Information regarding domestic hot water performance', code DHW-3. Once in the platform, the information can be processed in order to include forecasting, predictive management and fault detection, so level 4 is reached. The cumulative sum gained is equal to 7 SRI points.

Cooling

As explained for the heating domain, the building has a VRF system that allows the occupants of every room to have control over the heating, but also over the cooling. Therefore, to the corresponding service of ‘Cooling emission control’ Cooling-1a, a level 2 (individual room control, e.g. thermostatic valves, or electronic controller) was assigned. In addition, the cooling production capacity is controlled at a multi-stage level, so that a level 2 was reached in the correspondent service, ‘Generator control for cooling’, code Cooling-2a.

The cooling domain was improved through the insertion of VRF power meters that report power data, with which a proxy of the performance can be calculated. Through the processing of the data in the platform, a level 4 in the service ‘Report information regarding cooling system performance’, code Cooling-3 is achieved. For the service Cooling-1a, the cooling emission control was improved through the communication between the controllers and the BACS (level3). As explained in the Heating section, one of the main improvements falls within the flexibility of the system through the connection to the grid. Hence, level 4 is reached for both service Cooling-4 (‘Flexibility and grid interaction’) and service Cooling-2a (‘Generator control for cooling’). The sum of the SRI point gained with the actuation for this domain is 26.

Ventilation

The ventilation system of the building included an air handling unit (AHU) with heat recovery. Supply airflow was clock-controlled but it was not monitored how much power was used for it. That is why, in the domain of controlled ventilation, the only service with a level not equal to zero was the ‘supply airflow control at the room level’ service Ventilation-1a, which scored a level 1 due to the clock control. This service was improved by the insertion of CO_2 sensors at the rooms, connected to the PHOENIX platform through a Raspberry-Pi gateway (Z-Wave), reaching a level 3 (Central Demand Control based on air quality) possible. To reach level 4, dampers are required, and that has not been implemented. The air quality sensors also improved the service ‘Reporting information regarding IAQ’, code Ventilation-6, which reached level 2, i.e. Air quality sensors and historical information of IAQ available to occupants.

Despite power metering added to the AHU circuit, no changes are reported in the services concerning air pressure control, prevention of overheating and air temperature control.

The changes in the ventilation system had an impact in particular on Wellbeing and health and on Maintenance & fault prediction, gaining a cumulative score of 13 SRI points.

Lighting

Lighting is monitored in the building through sensors, but no automatic control has been established. For this reason, the functionality levels of the lighting service group were both set to zero. An intervention was not considered cost-effective, for the large investment necessary.

Dynamic Building Envelope

The building is not equipped with an automatic window control system, neither overhangs nor other DE system. Hence, a level 0 was assigned in the three services of the DE domain. An intervention of this magnitude was not considered cost-effective, for the large investment necessary.

Electricity

The monitoring system of the building, prior to the intervention, consisted of power meters that reported the general consumption for the whole building. Hence, the service 'Reporting information regarding electricity consumption', code electricity-12, had a functionality level 1 (reporting on current electricity consumption on building level).

The main interventions for the electricity domain consisted, on the one hand of the connection to the existing local electricity generation system (PV panels), and on the other hand the monitoring of consumption behaviour. Power smart sockets were plugged into several devices of the building. Consequently, the service electricity-12 about electricity consumption was upgraded to level 2 (real-time feedback or benchmarking on building level). Besides, the processing of data allowed to report information about forecasting, predictive management and fault detection, so that level 4 is reached in the service electricity-2. A cumulative score of 9 SRI points is gained.

Electric Vehicles charging

On campus, low-weight electric vehicles are used by the estates department and a charging point circuit already existed at the department of estates. Hence, the service 'EV Charging Capacity', code EV-15 had a functionality level 2, i.e. 0-9% of the parking spaces has recharging points. Notwithstanding that, the charging was no controlled, which means a negative score was assigned in the evaluation of the flexibility of the service group. This is a significant fact, since this is one of the few negative scores in the whole SRI evaluation. Measuring and actuation capacities and connectivity were improved: a second electric control panel with a controller was added to the initial installation, meters and controllers were installed and connected to the platform. After the intervention, time for charging can be restricted to convenient ranges, e.g. time in which electricity is greener or cheaper.

As a consequence, the service 'EV Charging Grid balancing', code EV-16, reached level 1, i.e. 1-way controlled charging (e.g. including desired departures time and grid signals for optimization), and the service 'EV charging information and connectivity', code EV-17, reached level 1 as well (i.e. Reporting information on EV charging status to occupant). In the EV domain, 8 SRI points were gained.

Monitoring and control

The Monitoring and Control (MC) domain involves services such as run-time management of HVAC, fault detection, connected services, reporting of performance and information. Before the intervention, the monitoring and control in the building were managed through a single platform that allowed manual control of the TBS. That scored a level 1 in the correspondent service, MC-30.

The communication through the platform and the connection to the grid, that allowed to enable the DSM, have led to improvements on several services. MC-3 ('Run time management of HVAC system'), which worked just with manual setting, will be controlled by both building loads and grid signal, in order to enhance the flexibility of the HVAC system, so level 3 is reached. MC-25, ('Smart Grid Integration'), was upgraded to level 1 because of the connection between the grid and some individual TBS. The service about the reporting information for DSM performance, MC-28, was also increased because of the communication to the platform, which will allow reporting information on both current and historical DSM statuses. DSM control can be overridden by the building user if their comfort is affected, so the service MC-29 reached level 2; schedules override and reactivation, necessary to further increase the level of this service, have not been implemented. Finally, the existing platform that controlled the multiple TBS (the aforementioned service MC-30) was implemented through the connection to the grid and the communication to the platform, hence level 4 (single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signals) is reached. cumulative score of 15 SRI points is gained.

Final remarks

The pilot building was used to carry out a Proof-of-Concept of the project, in which a series of devices were integrated. Among them, there was a legacy BMS already in place, and other systems that had to be integrated. The SRI evaluation prior to the actuations showed a lack of connectivity that could be improved (and has been improved) in some domains. A deeper study of the SRI parameters allowed planning of an effective intervention to increase the smartness of the pilot building in several domains considered. The major improvements concerned the impact on flexibility, possible through the connection to the grid.

In terms of summation of SRI points, a difference of 132 points is registered. Considering the different impacts, as well as the weighting due to the climate zone, the results are the following (in brackets, the improvement due to the intervention):

- Energy savings on site → 3.58% (+2.25%)

- Flexibility for the grid and storage → 14.66% (+13.74%)
- Comfort → 2.11% (+1.13%)
- Convenience → 2.65% (+1.87%)
- Health & Wellbeing → 3.11% (+1.59%)
- Maintenance & fault prediction → 10.36% (+10.06%)
- Information to occupants → 4.74% (+4.63%)

The final indicator obtained is **41.22%**, which is a significant improvement compared to the 5.94% that the building scored prior to the changes.

8. Synthetic environment for services and algorithms testing

The PoC has not only consisted on the testing of the equipment and the services on the real world. The PoC has also included the creation of a virtual environment that mimics a neighborhood with a variety of domestic buildings in which realistic profiles of use have been represented.

This virtual environment is a simulator of the buildings and the occupants of them, that use the appliances and demand heating and cooling according to real data.

8.1. Geographical disposition of the pro/consumers

The simulator has a given number of nodes that can be located in realistic positions to simulate micro girds. This was important as the location of the nodes can determine overloading of certain sections of the grid.

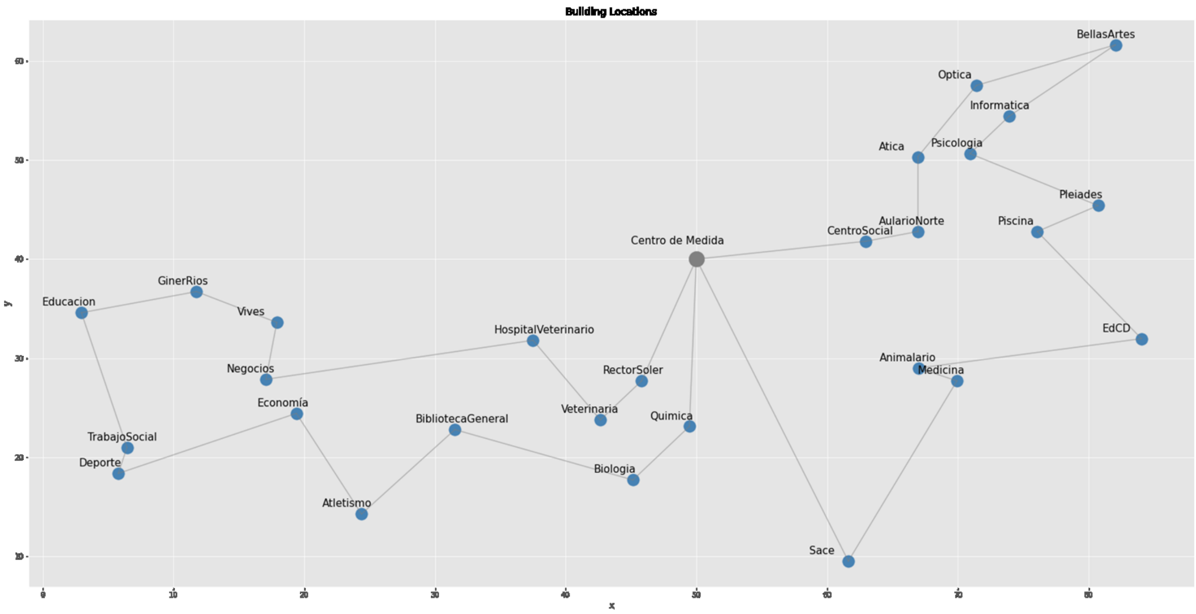

Figure 10. Map view of the neighborhood with a series of nodes. To have a realistic electrical network, the medium voltage grid of the University of Murcia has been used.

8.2. Real world environmental data

The synthetic environment takes the data from the weather station located at the university of Murcia and from the weather station located at a nearby location in the specific case of the solar radiation. This allows realistic demands of heating, cooling and ventilation from the synthetic set-up in real time and using real data to be obtained. Also, the generation of photovoltaic electricity can be made realistic thanks to the irradiance metering at the station, and the external dry-bulb temperature that affects the performance of the cells.

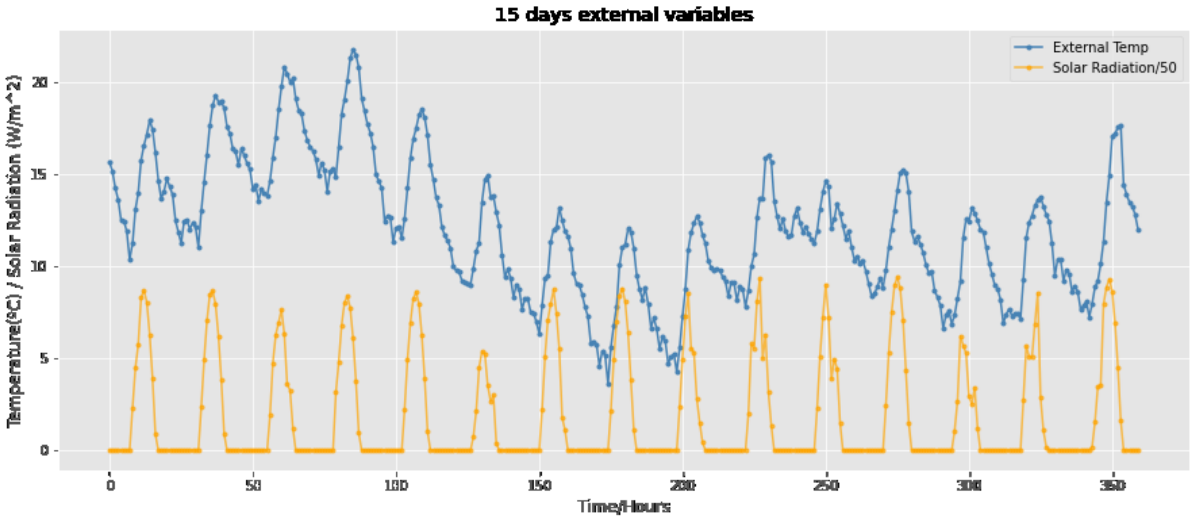

Figure 11. 15 days of external data (temperature and solar radiation) from weather stations integrated on the synthetic framework.

8.3. Realistic occupation patterns

Each one of the consumers have been equipped with a parameter that represents the number of occupants living in the building. With this and a Markov Chain implemented based on the literature[2], it was possible to have realistic occupation profiles that can govern the use of the rest of the appliances, and the responses to a given feedback.

8.4. Realistic appliances profiles

A key element of the synthetic testing framework to be valid in the context of PHOENIX services, was to have realistic electricity profiles. For that, the framework includes realistic profiles of appliances as a time series that depends on the given device. This was taken from realistic data published in the work of Issi et al.[3]

8.5. Thermodynamic modelling of buildings

The testing framework includes a thermodynamic model of each building, this will enable testing of the effect of demand response events, and the effect of rescheduling heating and cooling demands. Also, the peaks produced for heat waves or cold snaps will be representatives when

[2] *Ian Richardson, Murray Thomson, David Infield, A high-resolution domestic building occupancy model for energy demand simulations, Energy and Buildings, Volume 40, Issue 8,2008, Pages 1560-1566.*

[3] *Issi F, Kaplan O. The Determination of Load Profiles and Power Consumptions of Home Appliances.* Energies. *2018; 11(3):607. https://doi.org/10.3390/en11030607*

observing the electricity consumption and the energy required for heating and cooling. The thermal model is based on Lumped Parameter Models, and it the one created by Ramallo-González et al 2015[4]. The thermal characteristics of the buildings have been introduced using real data from real buildings. However, these parameters can be changed to represent the thermodynamics of other buildings including heavy weight constructions and light weight constructions.

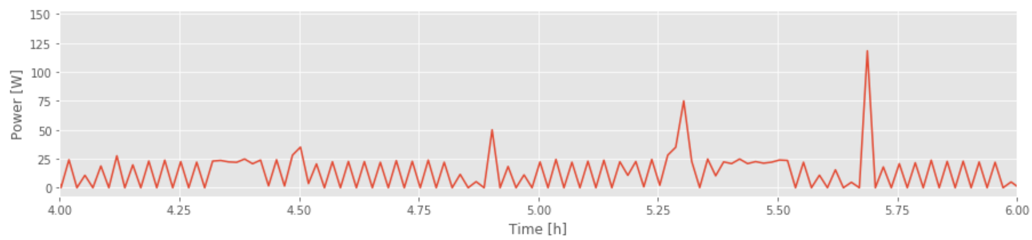

Figure 12. Time series of the electric use of a fridge. To be used in the testing framework.

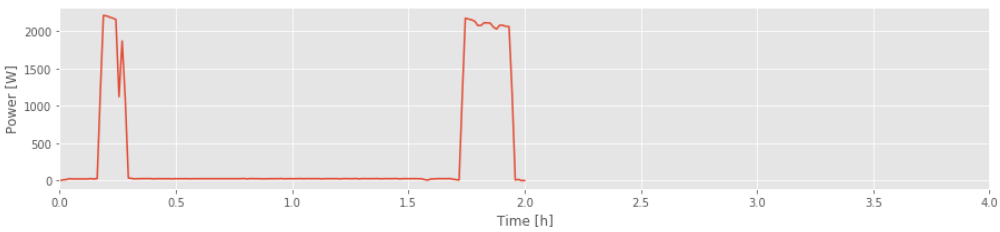

Figure 13. Time series of the dishwasher. To be used in the testing framework.

[4] *Ramallo-González, A.P., Eames, M.E., Natarajan, S., Fosas-de-Pando, D., Coley, D. A., An analytical heat wave definition based on the impact on buildings and occupants, Energy and Buildings, Volume 216, 2020. JCR Q1.*

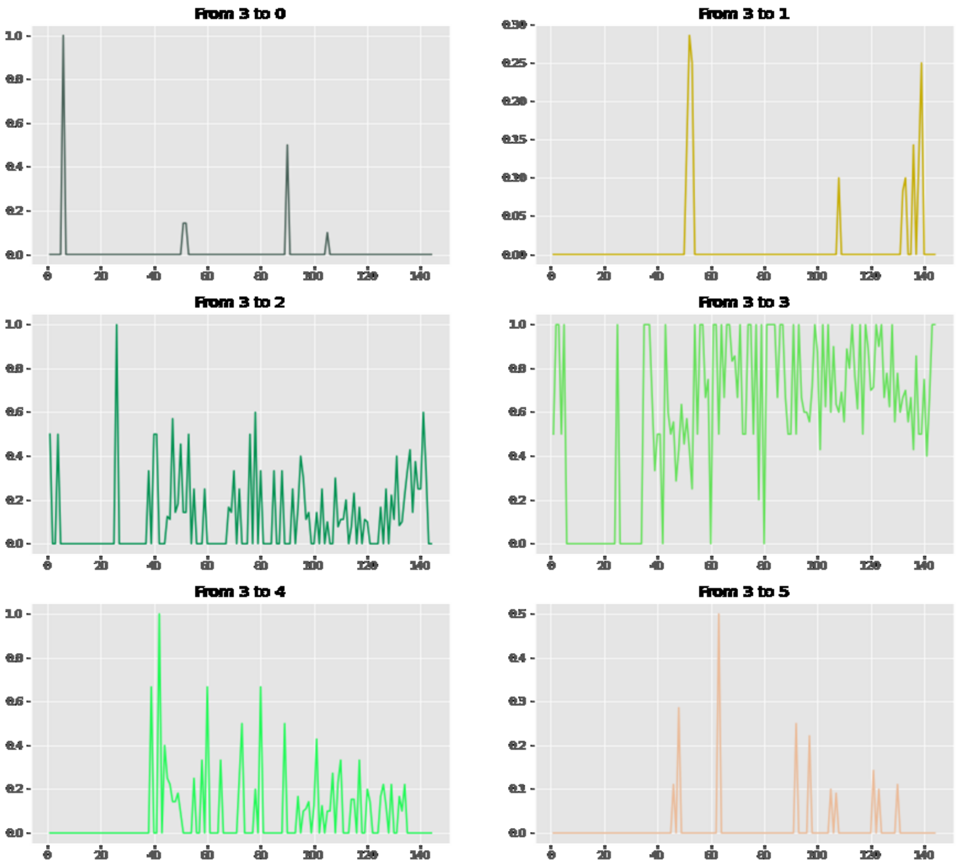

Figure 14. Example of occupancy profiles based on published literature and using Markov Chains. The y axis represent occupancy ratios and the x axis represent time steps.

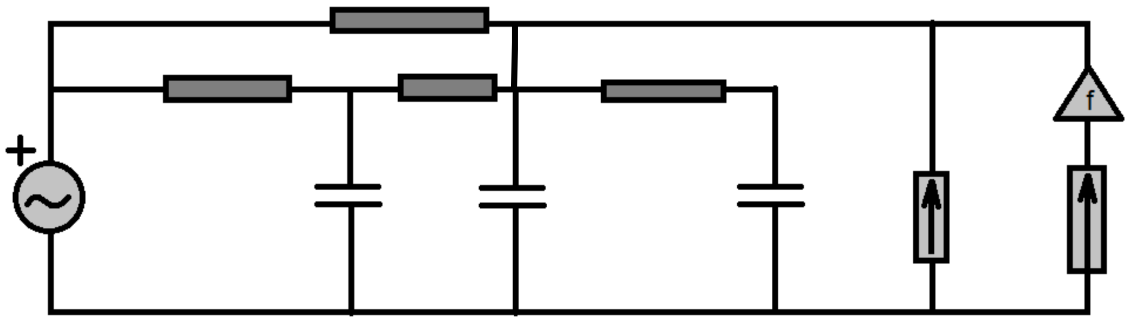

Figure 15. Thermodynamic model a Lumped Parameter Model of the buildings in the synthetic testing framework

In addition to the sensor data, the meters, the weather information, and the framework for the synthetic simulation of the grid. The services for grid integration will have the connectivity with the API of *Red Eléctrica Española* (REE). REE is the Transmission System Operator (TSO), of Spain, although it operates on other countries.

The API of REE offers the possibility of consulting in real time the mix of production for that given moment what opens the door to use AI to optimise not only the scheduling for reducing peaks in kilowatts, but also on reducing peaks in CO_2 emissions. An example of the output that one can get from the API of REE can be found on Figure 16.

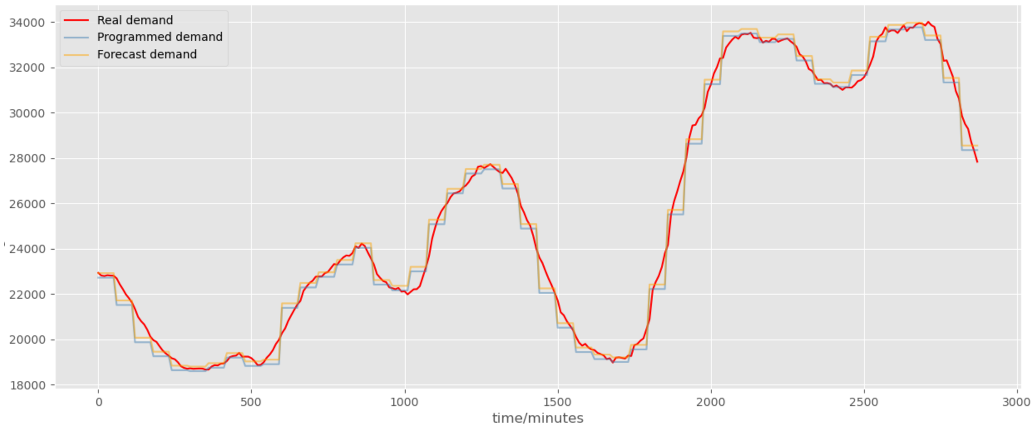

Figure 16. Integration de PHOENIX with Red Eléctrica Española. The y axis represent power in kW.

9. Data coming from the new devices installed

For the PoC new components have been installed. At the same time that these systems were being configured, some of their data was collected. With this, we allowed ourselves to have some records of data, that although not being introduced in the context broker, were valuable to identify weaknesses and strengths of (1) the integration methods and (2) the data.

The following table shows the devices that were sending data at variable reporting periods and the data in which they were given entities in the context broker; following figures and graphs represent these data.

Table 5. List of devices that have reported data on local logs before integrating them on the Context Broker.

Device	Variable	Log start	Device generating	Format
Flow meter	Flow meter DHW use	09/04/2021	IoT-Connector Pleiades / DHW	Integrated in Context Broker on 16/06/2021
Temperature probe	Temperature secondary circuit -> SOLAR	09/04/2021		
Temperature probe	**Temperature SOLAR -> Secondary circuit**	**09/04/2021**		
Temperature probe	Temperature SOLAR -> DHW	09/04/2021		
Temperature probe	Temperature DHW -> Building	09/04/2021		
Power Meter Mechanical Ventilation Pleiades / Bloque B	Active power phase 1	09/04/2021	IoT-Connector Pleiades / Roof Bloque B	Integrated in Context Broker on 17/06/2021
	Active power phase 2	09/04/2021		
	Active power phase 3	09/04/2021		
	Active Energy	**09/04/2021**		
Power Meter Conditioning 1 Pleiades / Bloque B	Active power phase 1	09/04/2021		
	Active power phase 2	09/04/2021		
	Active power phase 3	09/04/2021		
	Active Energy	**09/04/2021**		
Power Meter Conditioning 2 Pleiades / Bloque B	Active power phase 1	09/04/2021		
	Active power phase 2	09/04/2021		
	Active power phase 3	09/04/2021		
	Active Energy	**09/04/2021**		
Temperature probe	**Mechanical Ventilation / Supply**	**09/04/2021**		
Temperature probe	**Mechanical Ventilation / Return**	**09/04/2021**		
Temperature probe	**Exterior**	**09/04/2021**		
Humidity sensor	Mechanical Ventilation / Supply	09/04/2021		
Humidity sensor	Mechanical Ventilation / Return	09/04/2021		
Humidity sensor	Exterior	09/04/2021		
Pressure sensor	Mechanical Ventilation / Supply	09/04/2021		
Pressure sensor	Mechanical Ventilation / Return	09/04/2021		
Power Meter Electric Vehicles Estates	Active power phase 1	09/04/2021	IoT-Connector Estates / Car park	Integrated in Context Broker on 16/06/2021
	Active power phase 2	09/04/2021		
	Active power phase 3	09/04/2021		
	Active Energy	**09/04/2021**		
PV inverters Swimming pool	**Generated Energy**	**03/11/2020**	**Script consumer from FTP**	**Integrated**

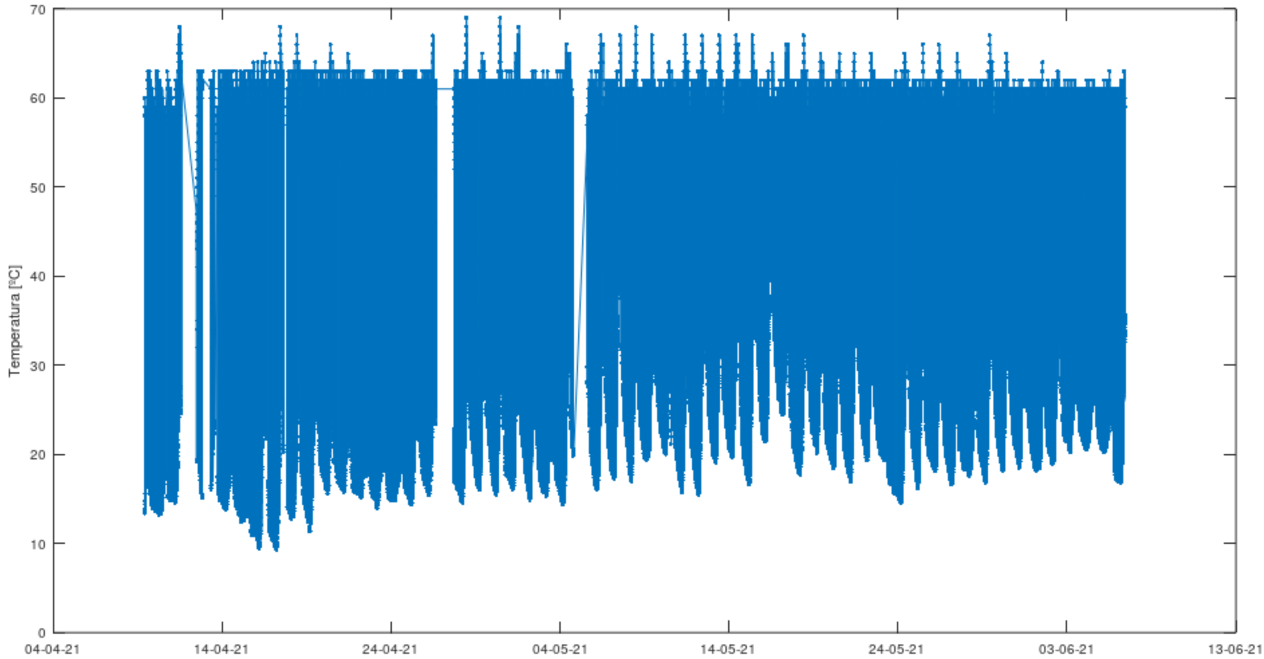

Figure 17. Recording of the temperature sensor of the Solar DHW circuit obtained from the sensor log.

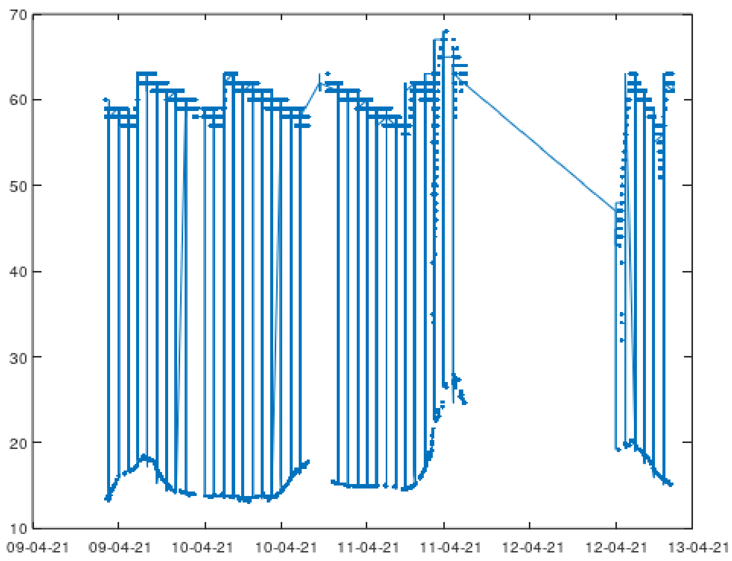

Figure 18. Zoom in of the data shown in the previous picture (the y axis represent temperature in degree Celsius).

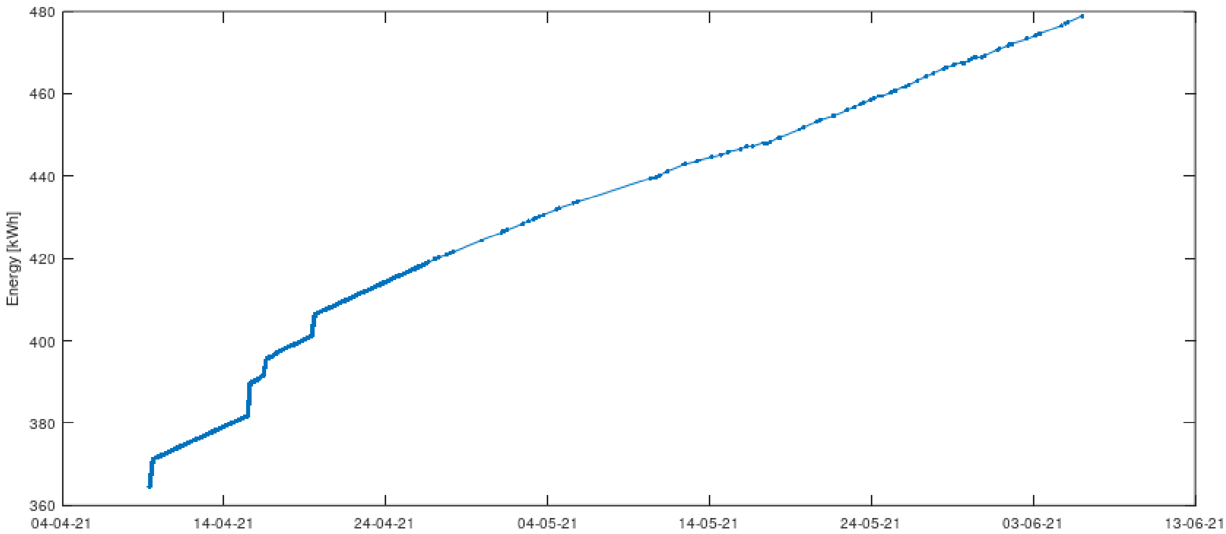

Figure 19. Data from logs of the energy consumption of the conditioning machines at the Roof of the PoC building.

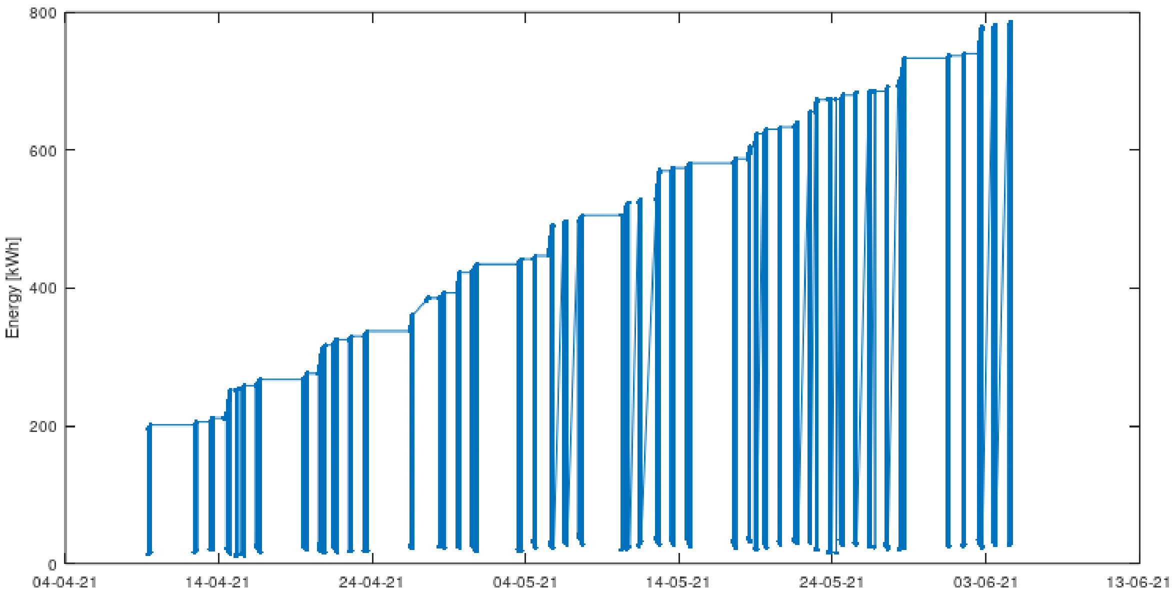

Figure 20. Readings of the meter installed on the EV charger at the Estates department.

10. PoC services

A series of services were implemented in the PoC to make sure that the integration mechanisms used were functioning correctly. This facilitated the evaluation of the efficiency of the Context Broker and made easier creating the recommendations for the full pilots. In the following the implementation of the services in the PoC is described.

10.1. Data extraction.

In the first place, to perform any service it is necessary to get the data, which can be obtained using the PHOENIX Context Broker API, from which a time series is obtained that will be used to obtain information and predictions. In this URL the table or sensor has to be specified, the start and end date and the time interval for downloading the data. The context broker then understand it is being asked for a historical set, and search the given data. The following figures show examples of time series of the three variables that will be used in this report: temperature, CO_2 and active energy. The reason why these three magnitudes were selected was that they demonstrate the gateways used for the integration of the devices work and the data is available.

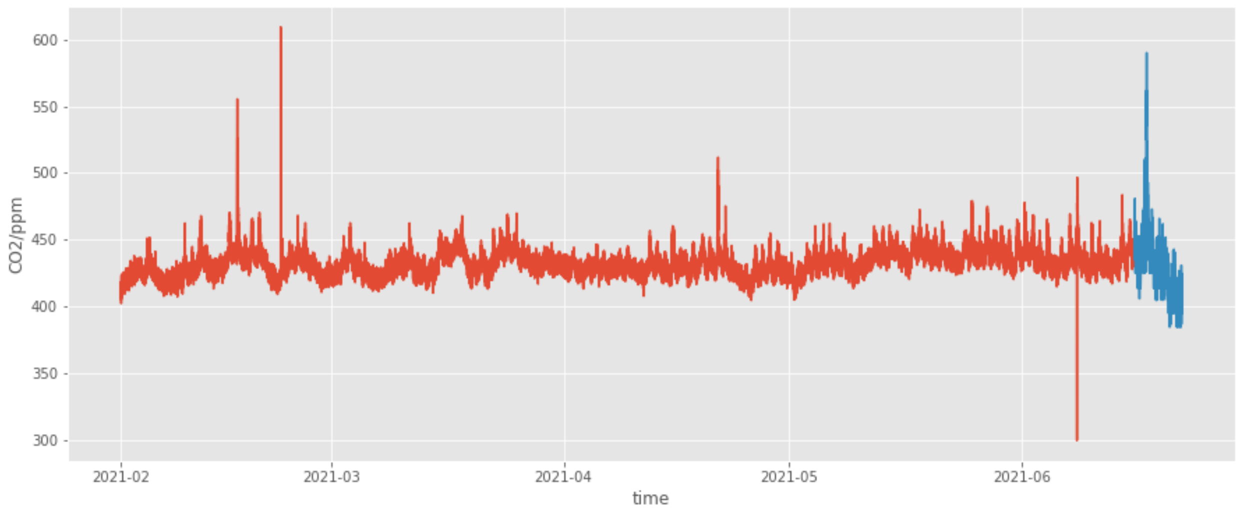

Figure 21. Graph with CO2 readings for the PoC. The red are historical data and the blue represents the data coming from the new devices using the Z-wave gateway.

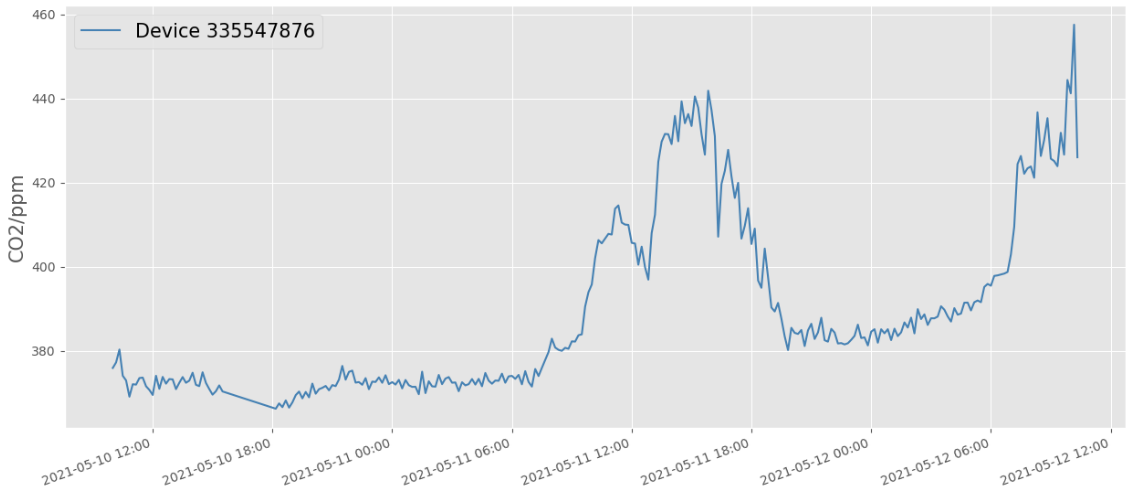

Figure 22. Time series of CO_2 making a zoom on the 11th of May.

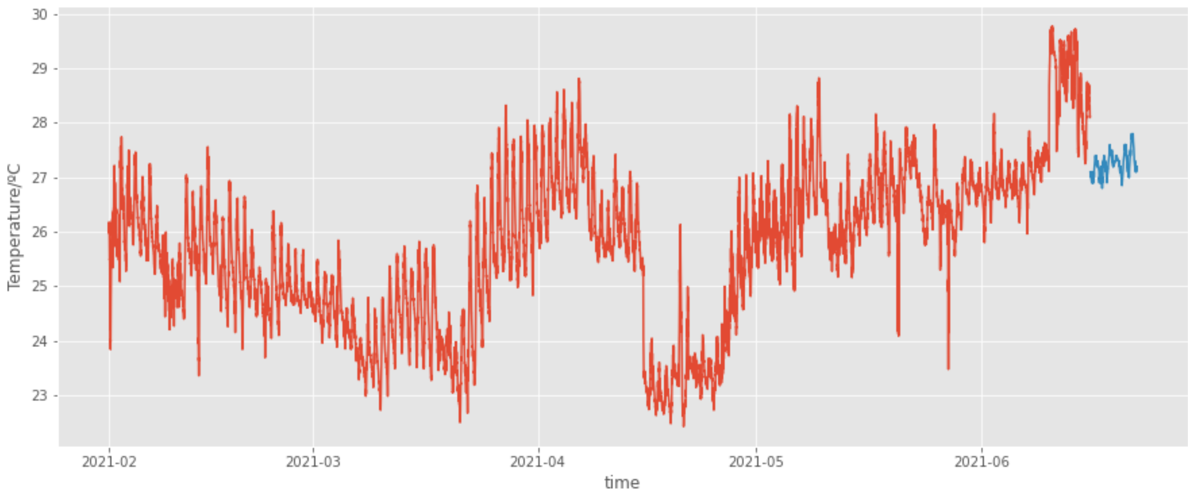

Figure 23. Graph with temperature readings for the PoC. The red are historical data and the blue represents the data coming from the new devices using the Z-wave gateway.

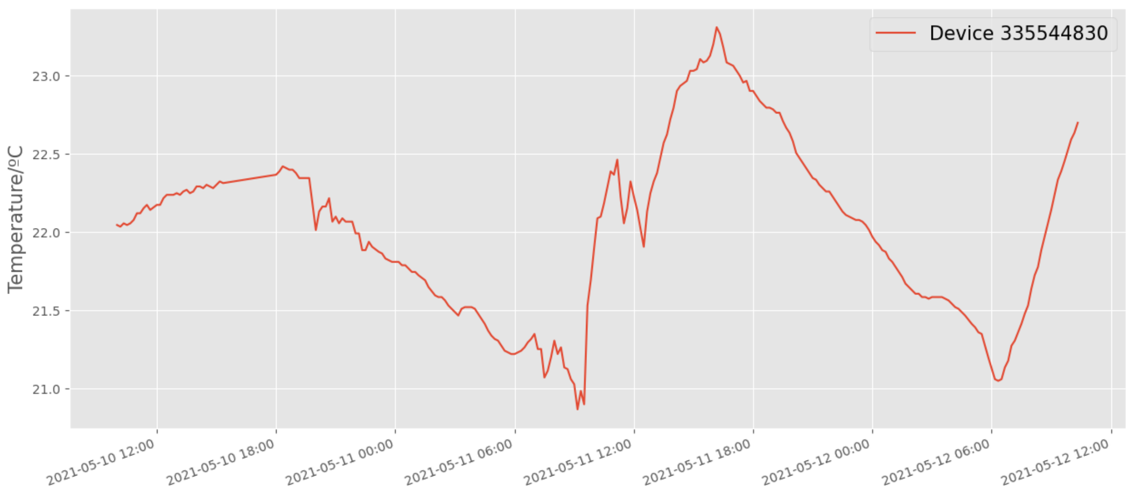

Figure 24. Temperature time series making a zoom on the 11th of May.

10.2. Energy consumption

With the measurement of the active energy sensors at the building level (meters) it is possible to aggregate by time (in the case of the one-hour graph) and thus obtain the energy consumed in the building. The graph shows the sum of the energy of all sensors hour by hour for two whole days.

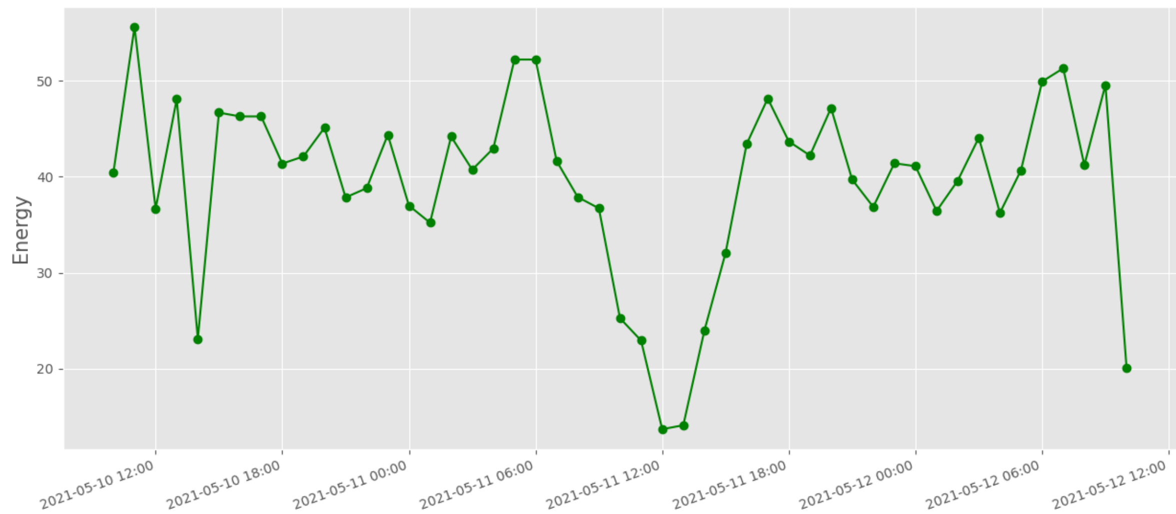

Figure 25. Example of Power time-series. (y axis on kWh)

10.3. Occupancy estimation.

The CO_2 sensors have been used as an indicator of the occupation of a room. The following graph shows an example of two time-series, corresponding to this variable.

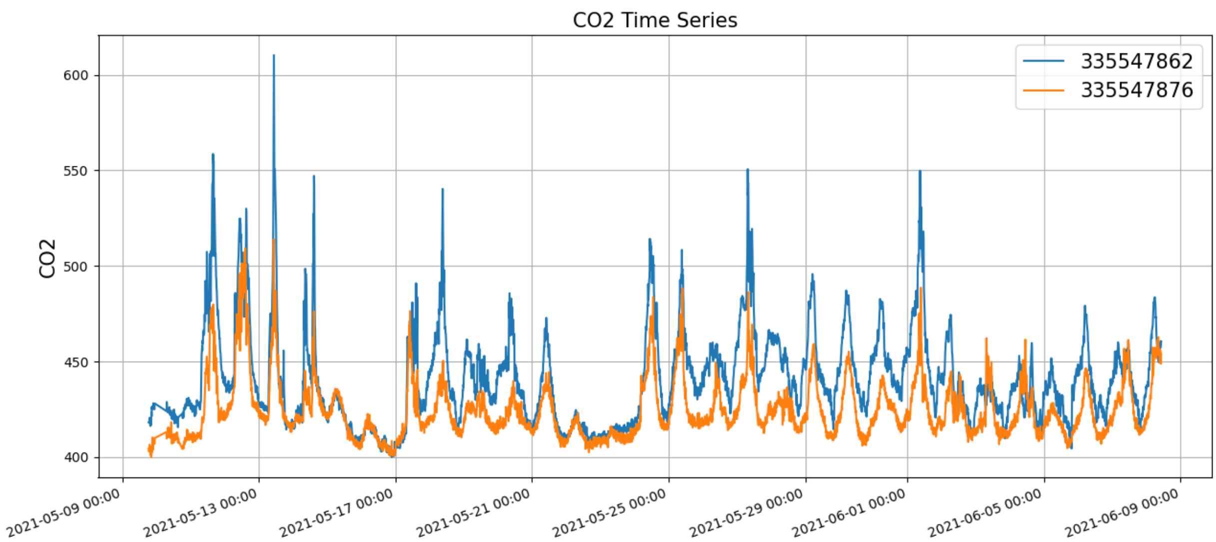

Figure 26. Time series of Carbon Dioxide content on air. (y axis on ppm)

The algorithm that obtains this information is rather simple, since when the CO_2 values exceed a certain threshold, then the room will be considered to be occupied. The following graph shows the previous time series including occupation:

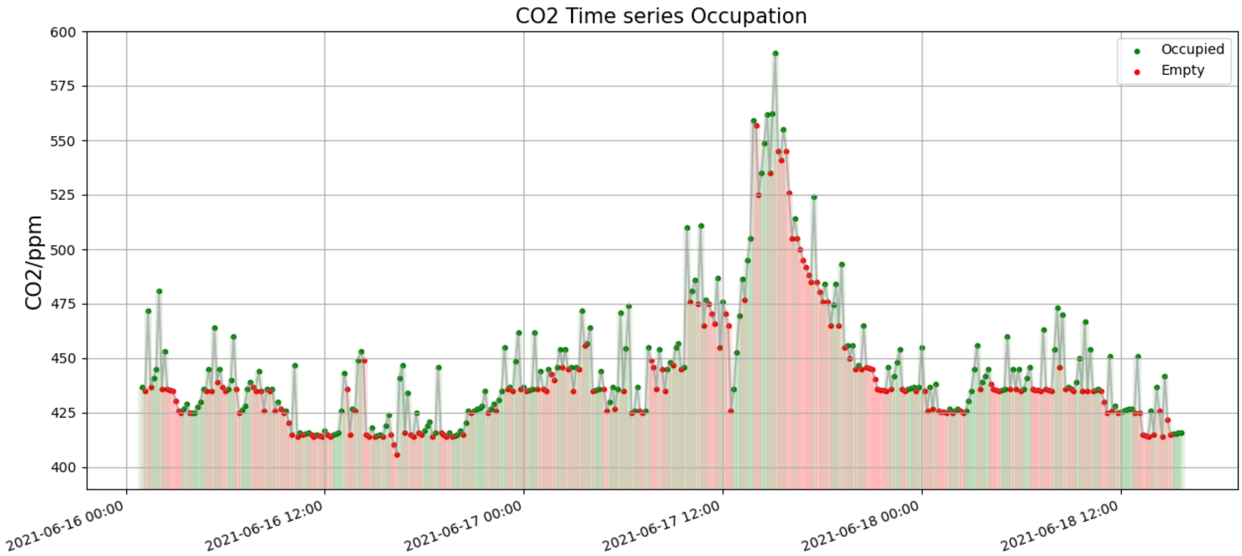

Figure 27. Estimation of occupation using CO2 as a service.

10.4. User Comfort Estimation

Having the simple occupation model, the thermal comfort of the user can be estimated in a simple way by observing the temperature values of the room when it is occupied, in such a way that in the case in which a space is occupied and its temperature is find acceptable values (in this simple model between 21 and 24) it will be said that the space will be comfortable, when the space is unoccupied, this information will be irrelevant. Thus, in the graph, three types of points are shown: the green ones are those in which the space is occupied and the users are comfortable, the red ones correspond to the occupied spaces with uncomfortable conditions and the grey ones correspond to data of spaces not occupied.

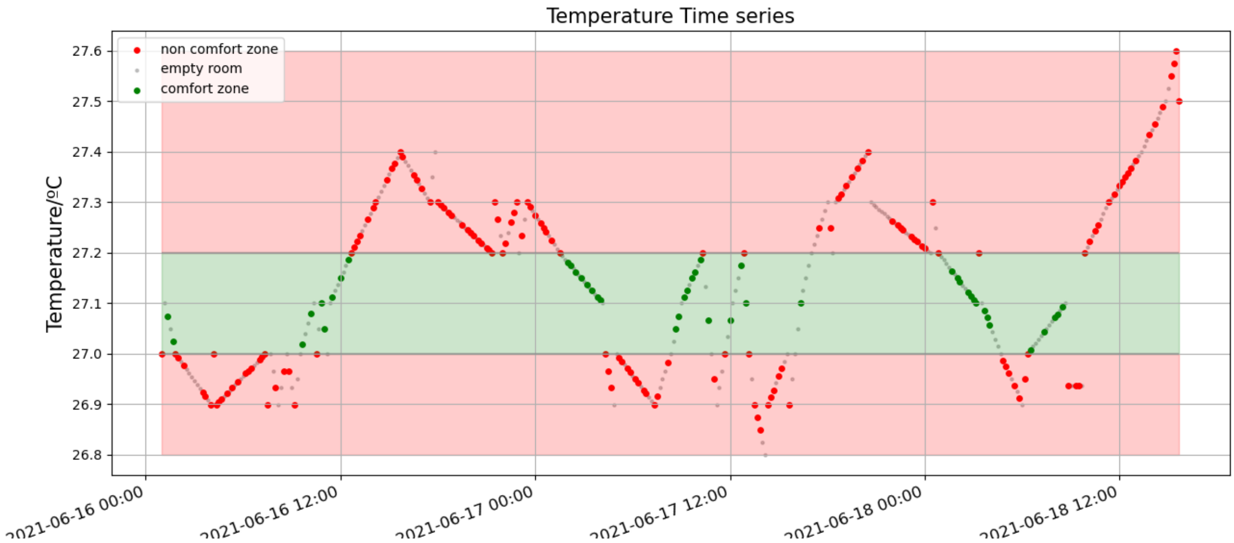

Figure 28. Service on the PoC that evaluates if the occupants are in their comfort zone using temperature and CO_2 sensing.

10.5. Forecasting

Finally, a forecasting service has been implemented that trains an ARIMA model with the data provided by the framework and tries to predict future values. The ARIMA model is a simple fitting method that uses previous values to predict future values assuming there is a certain auto-correlation between data-points. The graph shows an example of energy prediction of a device; the red line corresponds to the prediction while the blue line to the actual data.

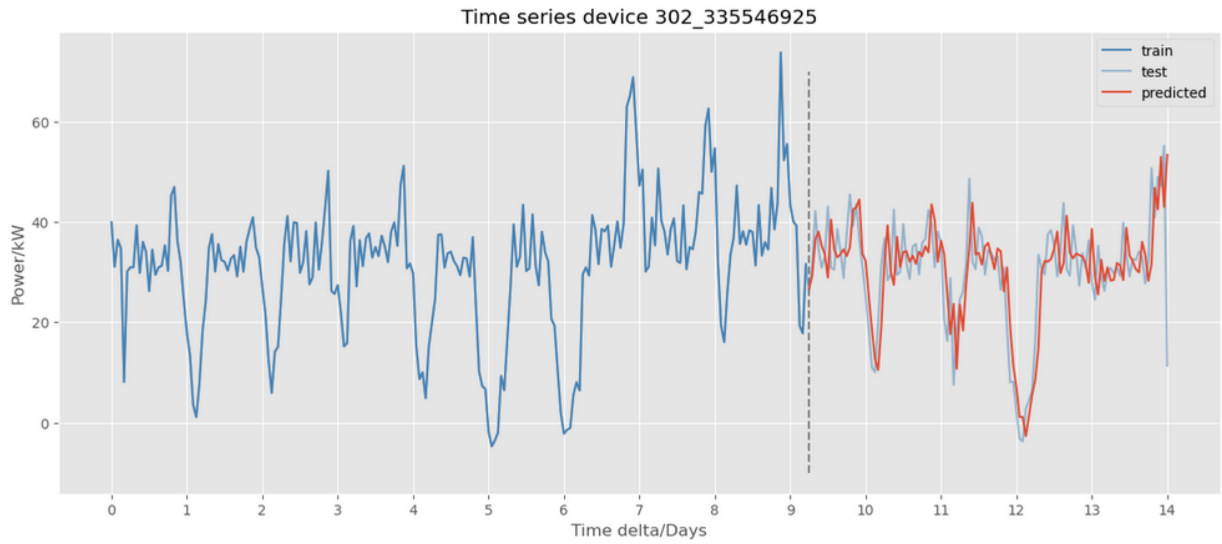

Figure 29. Time series used for forecasting.

11.Introductory Feedback to pilots

The learnings from the PoC and the study of the situation in each one of the PHOENIX pilots have served to create a plan for the different necessary integrations. This was done after a series of meetings between the PoC leaders (UMU), the Pilots Manager (OdinS), the Pilots coordinator (VERD) and each one of the Pilot-site managers where their situation was evaluated and implementation plans agreed.
One of the lessons learnt on this respect have been that the buildings normally present a given configuration in which one method / type of device has been used, and the adaptation/integration needs to be done therefore with a given solution. In the following we illustrate with diagrams the plan of action for the different pilots.

11.1. UMU

The UMU pilot needs to be considered as a special case as the connectivity effort comes inherited from the PoC. The effort on the UMU pilot will be on increasing the number of devices that have been tried in the PoC, and to enhance the feasibility of the implementation of services at a larger scale, and to transfer the knowledge of the integration to the other partners.

11.2. Miwenergía

In the case of Miwenergía, the legacy equipment is limited and not connected to the internet. This requires the installation of new hardware that has been selected to be easily connected to the PHOENIX platform using the Z-Wave configuration.

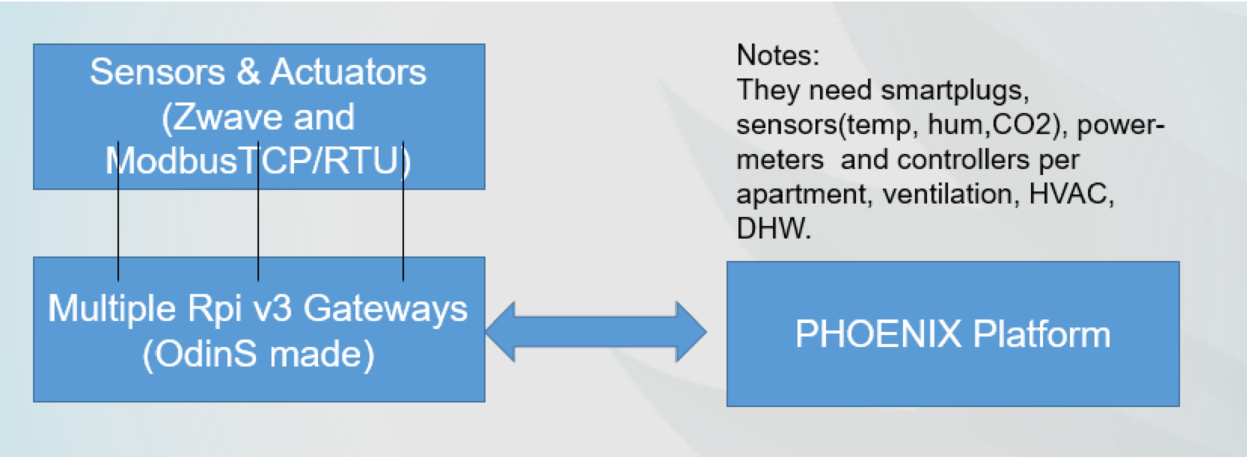

Figure 30. Overall integration plan of the Miwenergía equipment.

MIWenergia´s pilot site is located at Region de Murcia and includes two different types of building, an office building and a residential building.

The demonstration activities for the office building will take place at CEEIC in Cartagena. This business incubator building focus on start-up and early-stage innovative companies. 20 spaces between company's offices and lecture rooms will participate in PHOENIX project.

The residential building selected is located at the city centre of Murcia. Four apartments will be involved in the pilot site. Each apartment is approximately 125 square meters and they are equipped with common domestic appliances.

The devices/systems to be integrated to upgrade the smartness of the legacy equipment are:

- Raspberry Pi gateways to gather data from the different smart devices and connect the local system with PHOENIX platform.

- Z-Wave smart meters: they will measure the consumption of each individual office/dwelling and the HVAC consumption.
- Z-Wave sensors (CO2, temperature, humidity, illuminance) which will collect information about comfort parameters for decision making.
- Modbus devices to control the individual HVAC units in the office building.
- Z-Wave smart plugs for telematic controlling of small appliances.

11.3. KaMa

The situation in KaMa is rather similar to the case of Miwenergía. In the KaMa pilot, the only smart devices already installed are smart thermostats that control the refrigerant flow that serve the fan coils to perform the conditioning of the apartments. After study of those devices, it was seen that the integration of them would have required a large amount of resources. As there are easier options to implement to the PHOENIX platform, it was decided to replace the devices with ones that are controllable by gateways as performed on the PoC, and then carry out a configuration effort to establish communication with the PHOENIX platform.

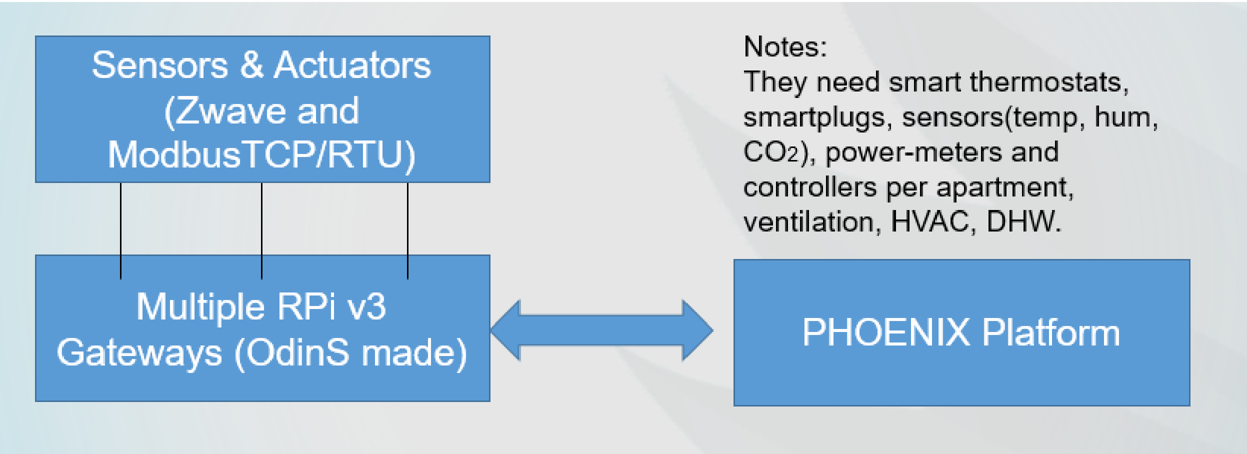

Figure 31. Overall integration plan of the KaMa equipment.

The rest of the domains of KaMa pilot are going to be upgraded accordingly:

- **Monitoring devices (energy consumption):** Modbus RTU Smart Meters for energy consumption measurements of home appliances of each apartment (kitchen, washing machine and fan coil), of the electric vehicle charger and of the building.
- **Monitoring devices (air quality):** WiFi/MQTT CO_2 Sensor for the building's air quality monitoring.
- **Domestic hot water:** Modbus RTU Differential Thermostats for the operation of the solar thermal boilers of DHW of each apartment.

- **IoT devices:** WiFi/MQTT Smart Plugs for one or two devices in each apartment; at the moment there are no smart devices present in the apartments.
- **Lighting:** One Z-wave LED Lamp in each apartment that can be remotely controlled by the residents.
- **Dynamic envelop:** Z-wave Luminance Meter and Z-wave Relays for the building's shading system automation.
- **Renewable energy:** Two Modbus TCP inverters as part of the flat roof installation of the building, composed of 60 PV panels of 19.8 kW total capacity
- **Energy storage:** A battery of 5,1 kWh is available on site and will be accessible via the one of the two inverters.

All these sensors that will be integrated in the KaMa pilot, will communicate with the gateway and the PHOENIX Platform and will allow controlling and monitoring various everyday activities that take place in the building.

11.4. LTU

The LTU pilot site is located in Skellefteå, a city in northern Sweden. The climate conditions in this zone are characterized by a cold winter with snow and a mild summer. The pilot site includes a building which is both residential and commercial. It has 12 apartments and a commercial space at the front of the building on the ground floor. The total area including the commercial space is 1920 square meters of heated area and 1278 square meters of living area. The building has big apartments with 4-5 rooms each. In addition to the apartments there is a community laundry and a common room for socializing. There are 4 outdoor parking places on the street with electric points for heating the cars and 10 indoor garages for cars. The building was built in 1966 and is made of concrete with 3 pane glass windows. It has an FX system for ventilation with two fans for supply and exhaust air with a rotating heat exchanger where 80% of the energy is sent back into the building. The occupant age group ranges between 20-76 years with average age of 50 years approximately. All apartments are equipped with appliances owned by the owners. Approximately, 50% have their own washing machines as well however the rest use communal washing machine in the common laundry room.

The sensors and actuators at the LTU pilot site will be connected to a platform managed by LTU. The platform is based on FIWARE and this will connect to the Phoenix platform to share the data. Since both platforms use the same language this will facilitate data exchange between the two platforms. The LTU platform will run on a server at LTU.

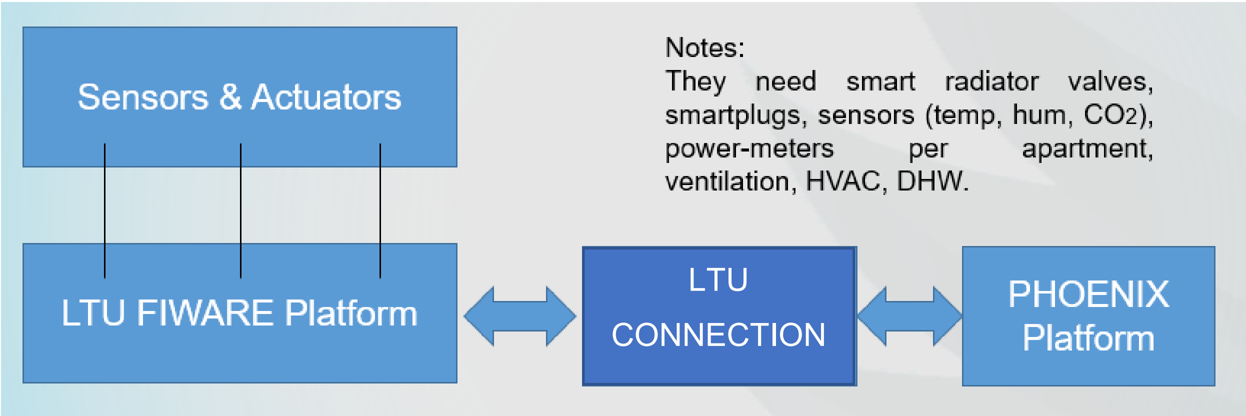

Figure 32. Overall integration plan of the LTU equipment.

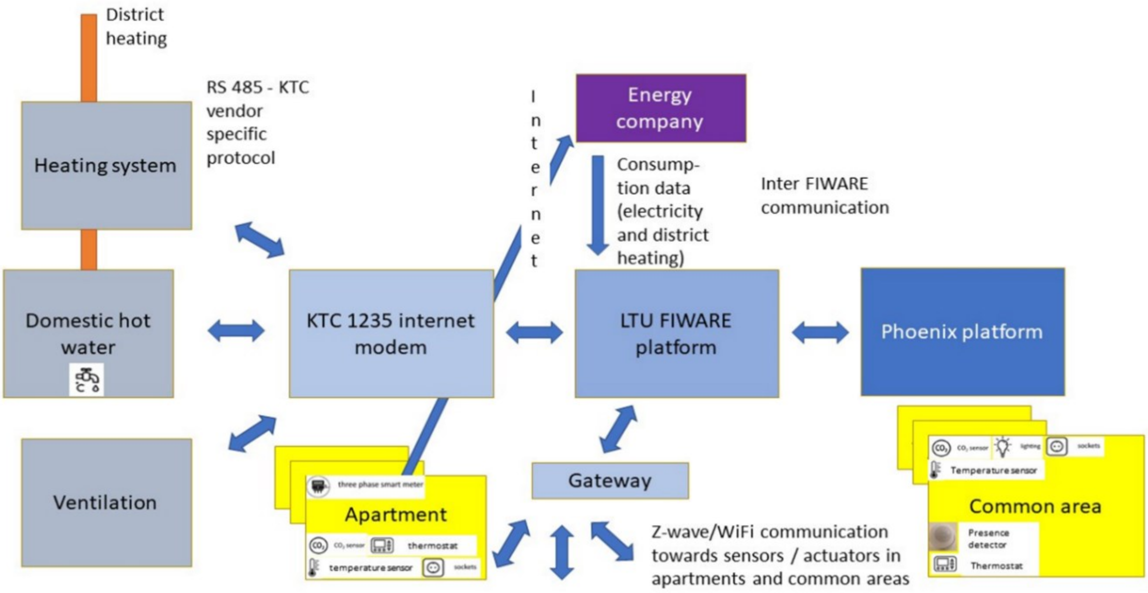

Figure 33. Overall integration plan of the LTU equipment.

The LTU FIWARE platform will be connected to existing legacy equipment in the pilot building i.e. heating system, (district heating), domestic hot water and ventilation. Currently, these are connected via a KTC modem which is operated by Riksbyggen, the company that manages the building infrastructure. The KTC modem can be accessed via Automate BMS to collect data. The KTC modem (version 1235) is a legacy system which does not allow data access without the Automate software. However, for the PHOENIX platform to receive real-time data this cannot be used. The current plan is to use KTC's IMC (Integration and Master Communicator) (https://www.ktc.se/wp-content/uploads/2018/10/Produkdatablad_IMCv3_revA.pdf) to gather data via the existing KTC modem. This integration is planned in August 2021 with help from KTC developer team. The parameters that can/will be collected for each of the legacy system are:

1. Heating: outside temperature, supply temperature, returning heat from the radiators, supply hot water temperature, return hot water temperature.
2. Ventilation: supplier temperature, outside temperature, efficiency of the heat exchanger, freeze guard temperature, pressure sensor, flow pressure, static pressure inside the duct for supply air and exhaust air

New sensors will also be installed in apartments and common areas and will be connected to the LTU's FIWARE platform. At first one apartment will be equipped with sensors to test all components before ordering equipment for the rest of the building to see it can be connected. Some of these sensors may vary based on individual living conditions of each of the residents.

11.5. ARDEN

The ARDEN pilot is formed by commercial and residential buildings, having a large wealth of data which is locked at the moment on closed systems that need to be integrated.

The commercial pilot building is the National Centre for the Circular Economy in Ireland, the Rediscovery Centre. The building is a repurposed boiler house and includes solar PV, CHP, heat pump and solar thermal. The sensors and actuators are connected to a Building Management System that allows control of services It is an ideal demonstration site for optimisation in a building with a BEMS and a range of energy using and conversion technologies.

For the connection of this BMS to the PHOENIX platform, ARDEN is going to implement a middleware that is capable to connect the Delta Controls BMS to the PHOENIX platform, with this, it will be possible to connect to the sensors and actuators already existing on the commercial building. Equipment and sensors connected to the BMS which will then integrate with the Phoenix platform includes:

- Solar PV
- Cogeneration (CHP) plant
- Heat pump
- Environmental (temperature and humidity) sensors

The BMS also accesses weather data which may be used to integrate with the Phoenix platform.

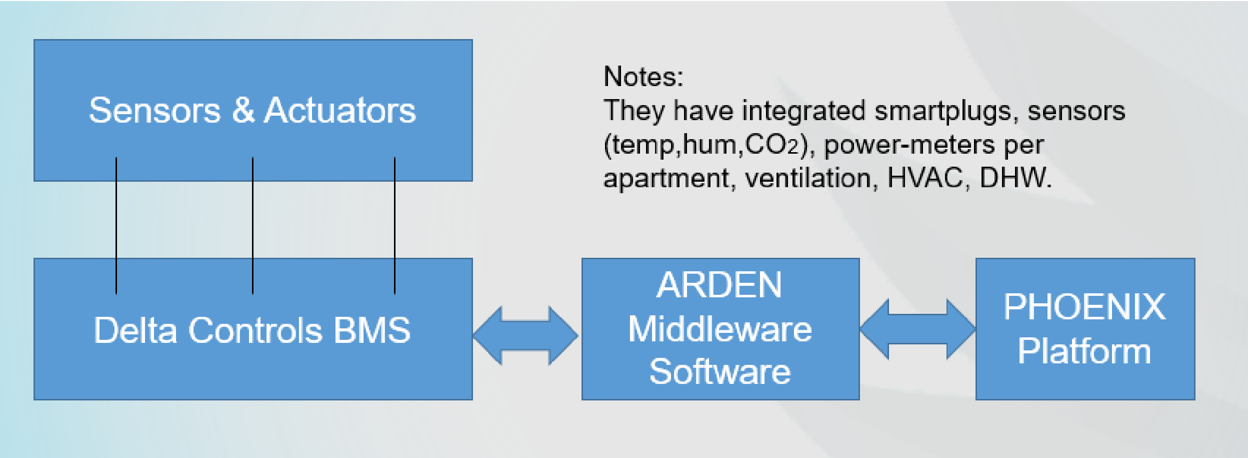

Figure 34. Overall integration plan of the ARDEN equipment on the commercial building.

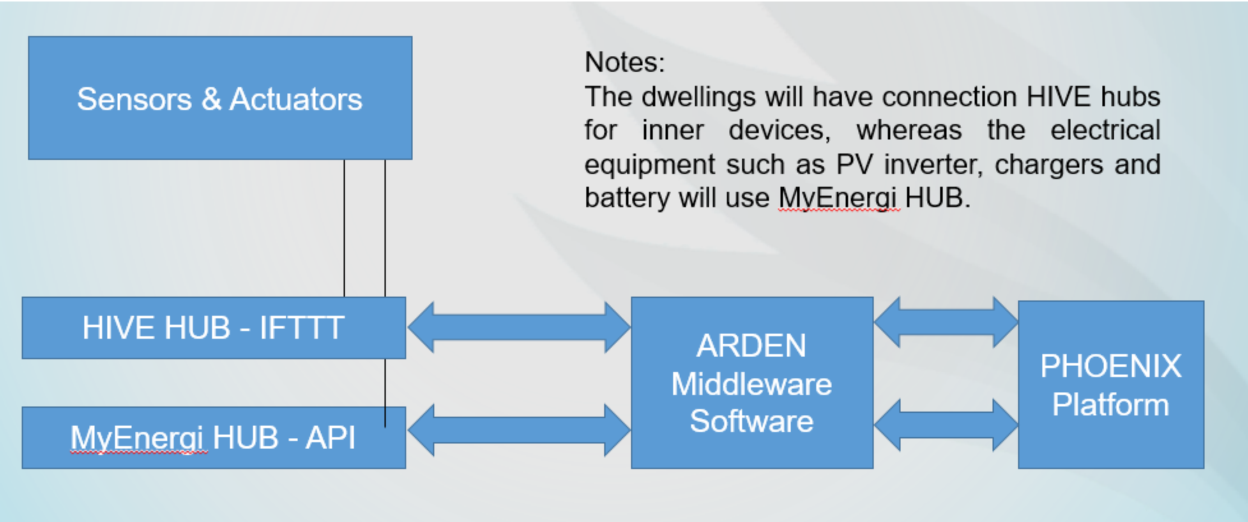

Figure 35. Overall integration plan of the ARDEN equipment on the domestic building.

Two privately owned residential buildings located within a Sustainable Energy Community located to the south east of Dublin City have been chosen as good exemplars of smart upgrades for energy and related services. In the residential buildings, the ARDEN pilot will install new hardware that has been selected with the purpose of easing the connectivity to the PHOENIX platform. The MyEnergi home portal solution will be used at both sites (one site already has a MyEnergi hub and one will be installed at the other site) and their manufacturers have been contacted to verify if they offer connectivity options. An API has been provided by the manufacturer to enable the connection of the hubs with the PHOENIX platform via middleware being developed to run on the cloud and to send data to the PHOENIX platform using a MQTT interface.

The equipment integrated at the domestic sites via the MyEnergi hub includes:

- Solar PV
- EV Charging
- Electric water heater
- Plug loads
- Environmental (temperature and humidity) sensors

Both the domestic and commercial pilot sites will avail of smart billing and time of use pricing services determined by day ahead electricity prices which will be integrated with the Phoenix hub, again via middleware connecting the market data API to the phoenix hub via MQTT. Also, the availability of weather data from the implementation performed at the PoC will be considered.

12.Conclusions and further work

The work presented in this document is the first practical development of PHOENIX project. Here the proof of concept is described, and the different components that were needed for its integration commented.

The document should be read taking into consideration the efforts of integration that were done for the PoC that, although summarised here, are described more in detail in Deliverable 3.1. Also Deliverable 4.1 should be read together with this document so the first steps to create the so called "PHOENIX Smartness Hub" are described, and within it the PoC was capable of making their first creation of knowledge.

It should be taken into consideration that the effort of the PoC was more focused on the transversal testing of all the components than on creating ready to use business-relevant services. Instead, the services developed on the PoC are indeed a Proof of Concept, and they demonstrate that the principles of design of the PHOENIX platform are such that the solution will succeed.

Along the process of the PoC a great deal of lessons learnt were highlighted. They have been grouped in different categories following, so the reader can get them on an organised manner.

Hardware The integration of hardware in the PoC will increase the smartness of the pilot, and that was quantified in two different ways. Firstly, in achieving PHOENIX Pilot's KPIs and the increase of the SRI of the pilot. This led to a table of preferences that showed that in some cases, a given software can significantly increase the smartness of a building, as it "scores" points on several aspects of the SRI. A clear example of this on our PoC was the installation of energy meters, particularly those that can differentiate between energy consumed, energy produced, and energy used on EV charging. This scored points on electricity, on monitoring, on EVs, and on heating and cooling effectiveness as the conditioning on the PoC is done using heat pumps. The *most desirable* devices need to be taken into consideration, as the budget for making a building smart is always limited and the hardware that produce the best results has to be considered.

Another lesson learnt from the hardware installation of the PoC is that a great variety of devices are commercially available. Furthermore, the prices are rather low. This, when considered together with the fact that person-hours cost of blue-collar professionals on home automation are expensive (something really relevant for this project too), one sees that the best devices are usually the ones that will require the less hours of integration. In our case, Z-Wave devices were seen to be desirable in this aspect, as the gateway solution developed at this stage of the project for this communication protocol is rather versatile and thanks to the configuration modes of the Node-red solution (spaghetti-like configuration) is accessible for many.

Software/Middleware: With respect to software, there have been many learnings on the PoC and lessons learnt that will be useful for the pilots of PHOENIX, hence many of them have already designed their strategies according to this learning. First of all, it has been seen how the necessary step in all pilot's intervention is the integration of the BMSs to the given platform (PHOENIX for our case). The BMS is a great solution as starting point, but it lacks important components to enable the building to really develop the services that will be used in the future smart buildings paradigm. Connections to the grid or to the markets/tariffs are crucial to develop, for example, services that deploy demand response events. The integration of BMSs to IoT platform offer this possibility making them a much stronger tool. The integration of the BMS highly depends on the kind of solution in place, the developer of the BMS and the access to IT professionals that can make the integration. We have seen that the concepts have to be very clear to make this integration function correctly.

In addition to the BMS integration to the PHOENIX platform we have seen a crucial component of the PoC, the definition of the correct data formats. This will be given a specific paragraph.

Data models Integration and interoperability will be key for the new paradigm of smart buildings. We have seen that smart buildings are not fully realised and the data models to represent the data that come from the variety of sensors and actuators that are installed within them are far from being complete. For the PoC we have done a substantial effort to enrich the existing data models to the extent of creating a new class and relating three different ontologies. Only with that, could the need of semantic models be covered adequately. The ontology suggested has been seen to work well and, to our understanding so far, covers the needs for the requirements of a smart building.

In conclusion, the work here presented has been a preliminary effort to assess if the developments on PHEONIX, and particularly, the pilots are in the right path. We have seen that the path does indeed seem appropriate, and although some efforts were greater than expected at first (such as the data modelling, the SRI understanding, or the BMS integration) the PoC has served to find ways that will result less tortuous in the real pilots. Also, the fact that we have a smaller version of the whole PHOENIX solution, has been seen to facilitate the movement towards more complex implementations.

Annex I – Description of the Class *Zone* for the PHOENIX ontology

<table>
<tr><td>Zone{</td><td></td></tr>
<tr><td>description:</td><td>Information on a zone of a building</td></tr>
<tr><td>id*</td><td>Property
anyOf: List [OrderedMap { "description": "Property. Identifier format of any NGSI entity", "maxLength": 256, "minLength": 1, "pattern": "^[\\w\\-\\.\\{\\}\\$\\+*\\[\\]`|~^@!,:\\\\]+$", "type": "string" }, OrderedMap { "description": "Property. Identifier format of any NGSI entity", "format": "uri", "type": "string" }]

Unique identifier of the entity</td></tr>
<tr><td>alternateName</td><td>Property

An alternative name for this item</td></tr>
<tr><td>areaServed</td><td>Property

The geographic area where a service or offered item is provided</td></tr>
<tr><td>category*</td><td>Property
items: OrderedMap { "enum": List ["apartments", "bakehouse", "barn", "bridge", "bungalow", "bunker", "cathedral", "cabin", "carport", "chapel", "church", "civic", "commercial", "conservatory", "construction", "cowshed", "detached", "digester", "dormitory", "farm", "farm_auxiliary", "garage", "garages", "garbage_shed",</td></tr>
</table>

	"grandstand", "greenhouse", "hangar", "hospital", "hotel", "house", "houseboat", "hut", "industrial", "kindergarten", "kiosk", "mosque", "office", "parking", "pavilion", "public", "residential", "retail", "riding_hall", "roof", "ruins", "school", "service", "shed", "shrine", "stable", "stadium", "static_caravan", "sty", "synagogue", "temple", "terrace", "train_station", "transformer_tower", "transportation", "university", "warehouse", "water_tower"], "type": "string" }
dataProvider	Property A sequence of characters identifying the provider of the harmonised data entity.
containedInPlace	Relationship https://smart-data-models.github.io/dataModel.Building
dateCreated	Property($date-time) Entity creation timestamp. This will usually be allocated by the storage platform.
dateModified	Property($date-time) Timestamp of the last modification of the entity. This will

	usually be allocated by the storage platform.
description	Property A description of this item
floorsAboveGround	Property Floors above the ground level
floorsBelowGround	Property Floors below the ground level
glazingArea	Property Area of openings in m2 of the zone
location	GeoJSON Geometry{...}
name	Property The name of this item.
occupier	Relationship Person or entity using the zone
orientation	Property

	"North", "South, "East", "West"
peopleCapacity	Property *minimum: 0* Allowed people present at the zone
peopleOccupancy	Property *minimum: 0* People present at the zone
source	Property A sequence of characters giving the original source of the entity data as a URL. Recommended to be the fully qualified domain name of the source provider, or the URL to the source object.
type*	Property NGSI Entity type