

Integrated Demand REsponse SOLution Towards Energy POsitive NeighbourhooDs

WP 2: Use case deployment and follow-up

T 2.1: System architecture design

D2.1 RESPOND system reference architecture

The RESPOND Consortium 2018



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EXECUTIVE SUMMARY

This deliverable presents the architecture defined for the RESPOND project. It is part of the *WP2: Use Case Deployment and follow-up* and a direct output of *T2.1: System architecture design* which started in month 1 and ends in month 12.

The RESPOND system architecture is a key part of the whole system's operation and it gathers the requirements defined in *WP1: Pilot Site Characterization*. Furthermore, it has a key role in the *T2.4: Early deployment at pilot sites* as well as in *WP4: ICT enabled cooperative Demand Response model* and *WP5: System integration and interoperability*.

The information gathered in this deliverable aims at providing a clear view of the features of the RESPOND architecture, as well as the role of the different components that contribute to an adequate operation of the overall system.

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ABBREVIATIONS AND ACRONYMS

AIOTI	Alliance for Internet of Things Innovation
ADR	Automated Demand Response
B2B	Business-to-business
CIM	Common Information Model
DEXCell EM	DEXCell Energy Manager
DMTF	Distributed Management Task Force
DR	Demand Response
EMS	Energy Management System
FERC	Federal Energy Regulatory Commission
FI	Future Internet
FP7	Seventh Framework Programme
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
LAN	Local Area Network
M2M	Machine to machine
PdM	Predictive Maintenance
PM	Preventive Maintenance
RDBS	Relational Database System
REST	Representational State Transfer
SOA	Service Oriented Architecture

1. INTRODUCTION

The purpose of this document is to define and design the system architecture model based on the requirements gathered in the WP1.

The purpose of this document is to define and design the system architecture model based on the requirements gathered in the WP1.

In order to undertake the task of designing the RESPOND system architecture, the draft proposed in the RESPOND Project proposal has been used as a starting point. First of all, a review of the main architecture trends was done. In this review, reference bodies, energy-related projects and main commercial actors have been taken into consideration.

The requirements specified in *T1.1: Operation scenarios and technical characterization of pilot sites*, *T1.2 Demand Response programmes* and *T1.3: Interoperability issues at pilot level* have been considered in the adaptation process.

Throughout the process of polishing this architecture design, experience from partners in previous successful projects such as Energy Warden or EPIC-HUB. The architectures defined in these projects inspired the architecture presented in the Project proposal. Likewise, the proposed architecture is the base for the final architecture.

The central component of the RESPOND architecture is the middleware that acquires all the incoming messages from different sources and distributes them correctly. After analyzing the existing devices and their communication interfaces described in *D1.3 Respond strategy to support interoperability*, and devices to be installed in *D2.3 Initial deployment plan*, the necessity of an energy gateway was demonstrated.

After studying different options and considering the devices to be integrated in pilot sites, finally a MQTT Broker was chosen as the foundation of the middleware. This matter is further explained in section 3.2.1.

Another agreement reached in this process was the addition of the Time Series Platform (also known as the TICK Stack) to the RESPOND architecture. The TICK Stack provides services and functionalities to accumulate, analyze, and act on time series data, which are envisioned as a big part in the RESPOND project. This platform is covered in section 3.2.2.

The incorporation of the stack of analytic services was also decided during the architecture polishing process. Since each service makes use of data in a given format, it was decided that each of them would count on their own data repository, based on the Time Series DB storing historical data. Furthermore, the need of a semantic repository was anticipated for linking data from different modules and systems. At the same time, the definition of the CDM (Canonical Data Model) for the data integration has been performed.

Summing up, the final RESPOND system architecture presented in this document has been the result of the agreement reached between the different partners involved.

The rest of the document is structured as follows. Section 2 describes the process of definition of the RESPOND architecture: from the initial proposal, until the final agreement. Section 3 analyses on the one hand reference architecture proposed by different standardization bodies, on the other, European projects are related to RESPOND, and lastly, commercial product. Section 4 presents the RESPOND reference architecture, detailing some of its main components. Finally, the conclusions of this document are shown in Section 5.

Furthermore, it is complemented with the *D2.2 Integration of RESPOND technology tiers*, where the integration between the different system components is defined. The rest of the document is structured as follows. Section 2 describes the process of definition of the RESPOND architecture: from the initial proposal, until the final agreement. Section 3 analyses on the one hand reference architecture proposed by different standardization bodies, on the other, European projects are related to RESPOND, and lastly, commercial product. Section 4 presents the RESPOND reference architecture, detailing some of its main components. Finally, the conclusions of this document are shown in Section 5.

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2. ARCHITECTURE ANALYSIS

2.1 STANDARDIZATION BODIES REFERENCE ARCHITECTURES

In this section, reference architectures proposed by different standardization bodies are presented. In particular, the architectures are listed and described considering the relevance for RESPOND project.

2.1.1 OASIS

OASIS is a non-profit consortium that drives the development, convergence and adoption of open standards for the global information society. OASIS open standards offer the potential to lower cost, stimulate innovation, grow global markets, and protect the right of free choice of technology [1]. The Energy interoperation describes an information model and a communication model to enable collaborative and transactive use of energy, service definitions consistent with the OASIS SOA (Service Oriented Architecture) Reference Model (see Figure 1), and XML vocabularies for the interoperable and standard exchange of:

- Dynamic price signals
- Reliability signals
- Emergency signals
- Communication of market participation information such as bids
- Load predictability and generation information

This work facilitates enterprise interaction with energy markets, which:

- Allows effective response to emergency and reliability events
- Allows taking advantage of lower energy costs by deferring or accelerating usage
- Enables trading of curtailment and generation
- Supports symmetry of interaction between providers and consumers of energy
- Provides for aggregation of provision, curtailment, and use

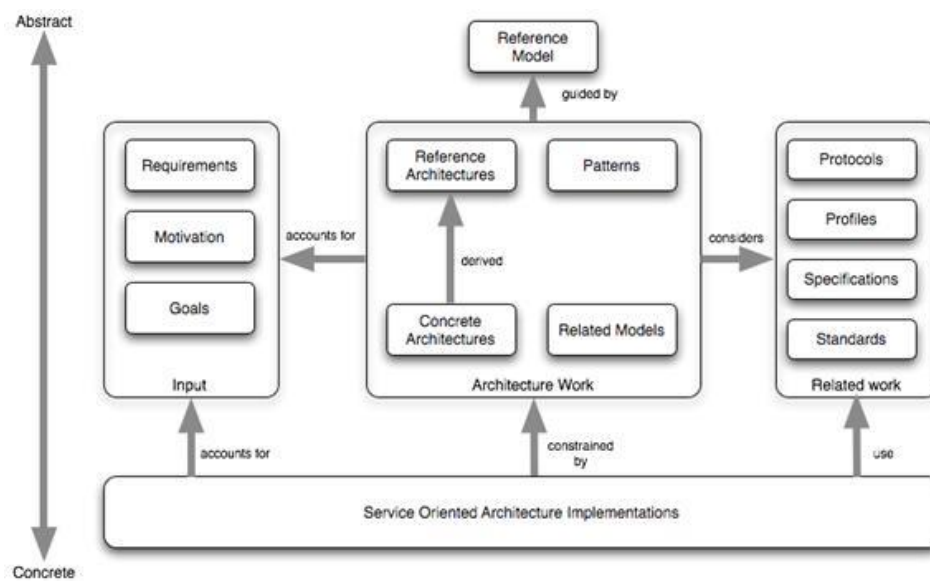


Figure 1: OASIS Reference Model relation to other work

2.1.2 AIOTI

The Alliance for Internet of Things Innovation (AIOTI) was initiated by the European Commission in 2015, with the aim to strengthen the dialogue and interaction among Internet of Things (IoT) players in Europe, and to contribute to the creation of a dynamic European IoT ecosystem to speed up the take up of IoT. Other objectives of the Alliance include: fostering experimentation, replication, and deployment of IoT and supporting convergence and interoperability of IoT standards; gathering evidence on market obstacles for IoT deployment; and mapping and bridging global, EU, and member states' IoT innovation activities [2]. AIOTI WG03 has developed a High-Level Architecture (HLA) for IoT that should be applicable to AIOTI Large Scale Pilots [3]. The HLA takes into account existing SDOs and alliances architecture specifications and the Domain Model is shown in Figure 2.

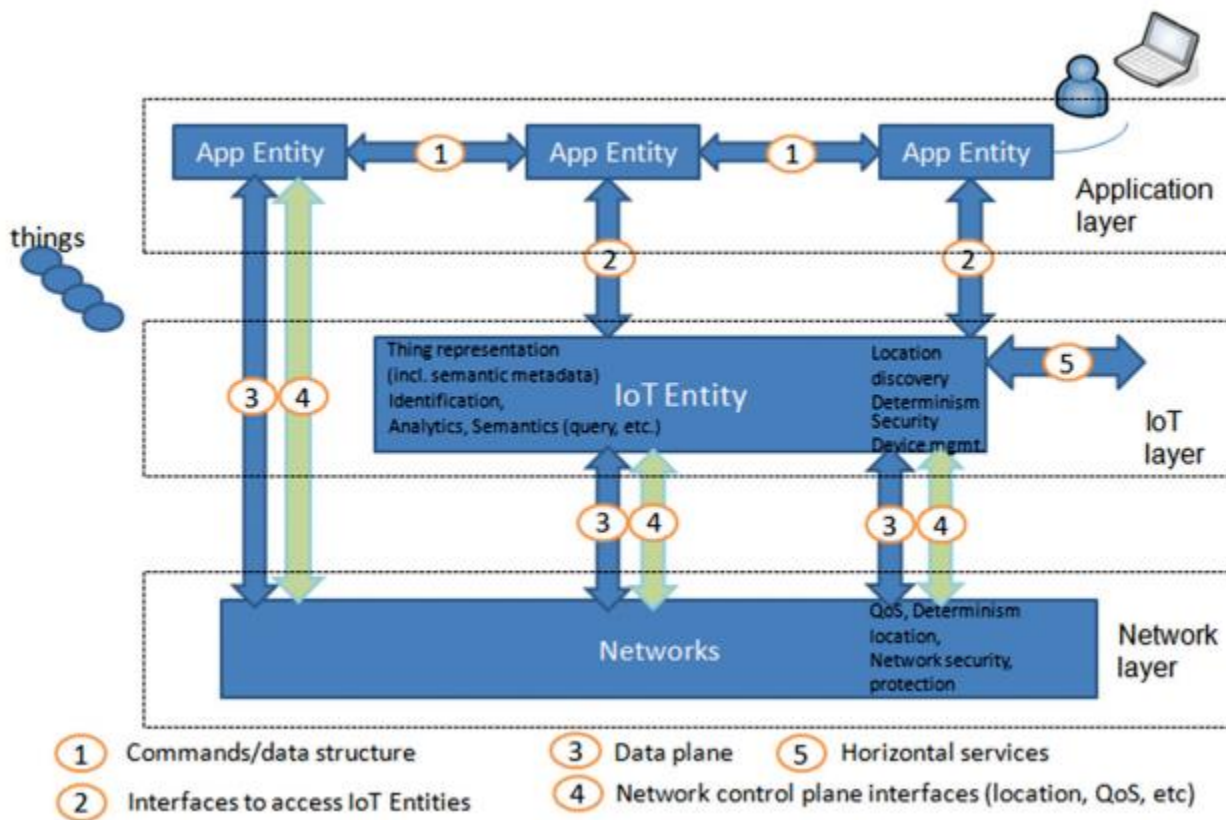


Figure 2: AIOTI HLA Functional Model

2.1.3 CIM

The DMTF's (Distributed Management Task Force) Common Information Model (CIM) provides a common definition of management information for systems, networks, applications and services, and allows for vendor extensions.

The CIM Schema provides the actual model descriptions. Management schemas are the building-blocks for management platforms and management applications, such as device configuration, performance management, and change management. CIM structures the managed environment as a collection of interrelated systems, each composed of discrete elements. Supplying a set of classes with properties and associations that provide a well-understood conceptual framework, CIM organizes information about the managed environment [4]. Figure 3 shows an overview of the CIM schema.

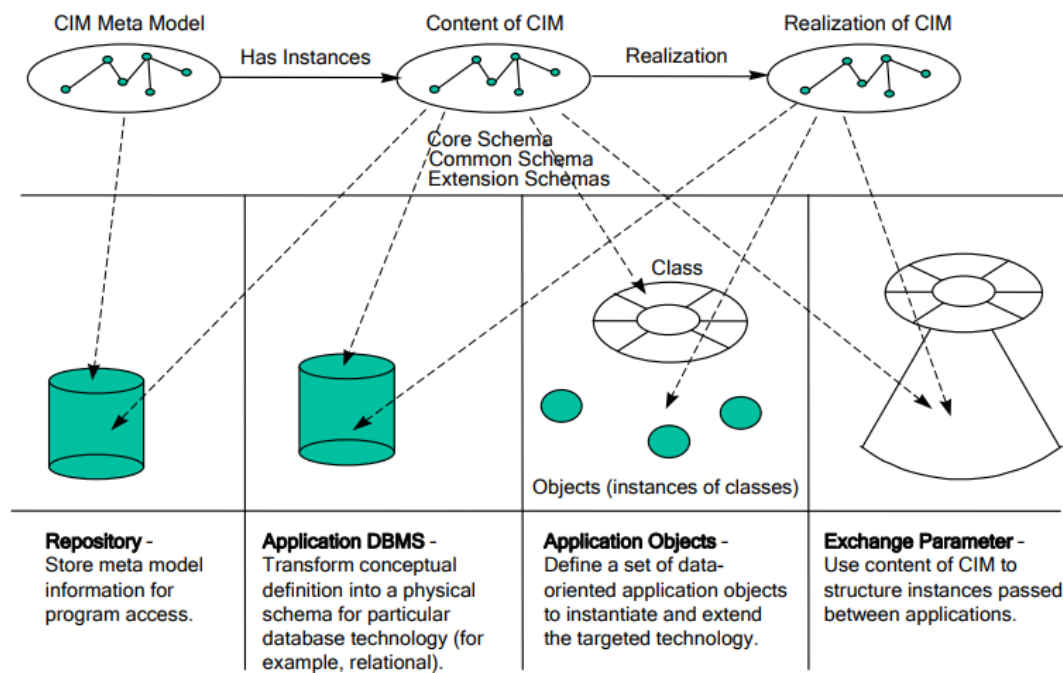


Figure 3: CIM Schema

2.1.4 OPENADR

Automated Demand Response or ADR helps system operators reduce the operating costs of DR programs while increasing DR resource reliability. Successful implementation of ADR requires standardization allowing wholesale producers to communicate with utilities and aggregators, who in turn communicate with their customers, who can then reduce demand during peak periods. Without an ADR standard, automated DR would be difficult and costly to implement.

Open Automated Demand Response (OpenADR) is an open and standardized way for electricity providers and system operators to communicate DR signals with each other and with their customers using a common language over any existing IP-based communications network, such as the Internet. As the most comprehensive standard for Automated Demand Response, OpenADR has achieved widespread support throughout the industry. The OpenADR Alliance was formed by industry stakeholders to foster the development, adoption and compliance of the Open Automated Demand Response (OpenADR) Smart Grid standard utilizing existing standards from OASIS, UCA and NAESB [5].

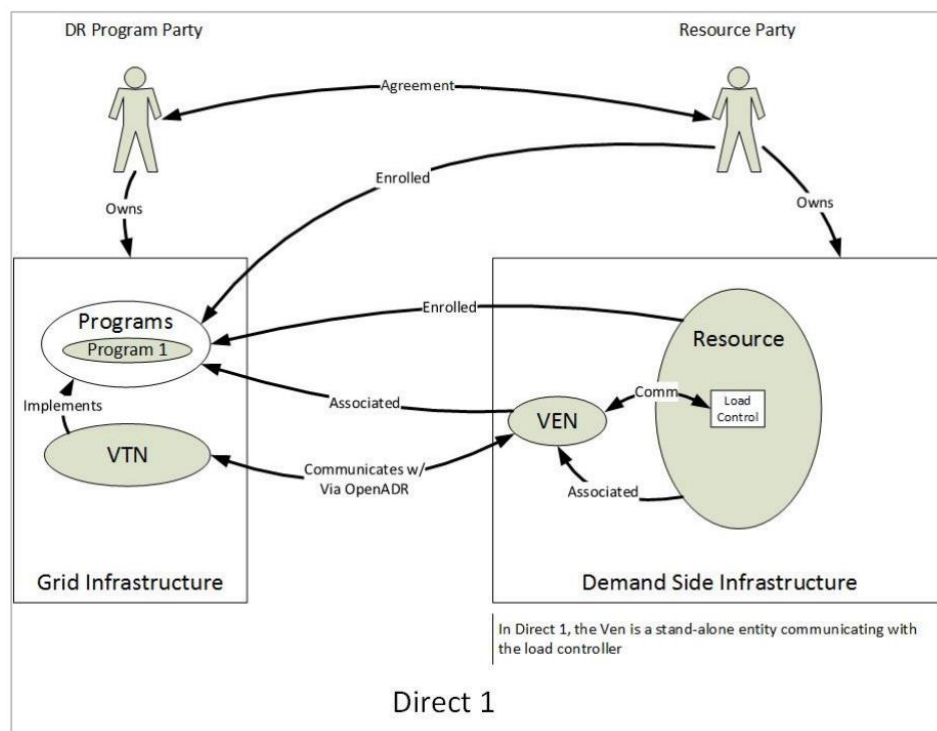


Figure 4: OpenADR

2.1.5 ONEM2M

The purpose and goal of oneM2M is to develop technical specifications which address the need for a common M2M Service Layer that can be readily embedded within various hardware and software, and relied upon to connect the myriad of devices in the field with M2M application servers worldwide [6]. In the oneM2M functional architecture two basic types of entities are defined. One is an AE (short for Application Entity) and the other is a CSE (short for Common Services Entity). In this use case, the lights and smartphone each host an AE. Also an IN-CSE (short for Infrastructure Node CSE) is hosted in the cloud by the oneM2M Service Provider and a MN-CSE (short for Middle Node CSE) is hosted on the Home Gateway. Figure 5 depicts the oneM2M architecture.

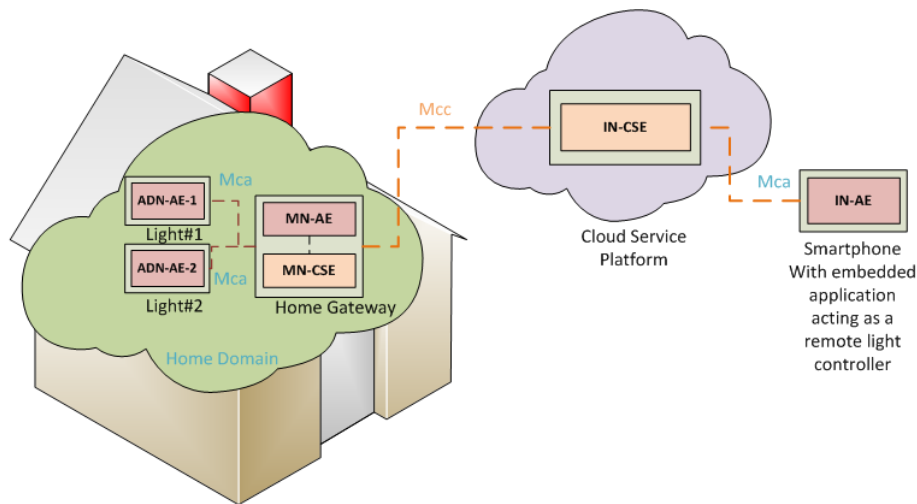


Figure 5: oneM2M architecture

2.1.6 EEBus

The EEBus Initiative e.V. is an independent association with over 60 members: which predominantly includes leading European manufacturers in the fields of smart home, connected home automation, electro mobility and energy. The Internet of Things and Smart Grids can only be successful when devices are able to communicate seamlessly with another one. EEBUS is opposing the confusing array of protocols with a global language for energy – the basis for genuine market progress [7]. The ultimate aim of EEBUS is to develop a standard that is universally applicable. For that reason, the data model is designed to be compatible with a broad range of protocols and transmission channels. Figure 6 represents the EEBus Data Model.

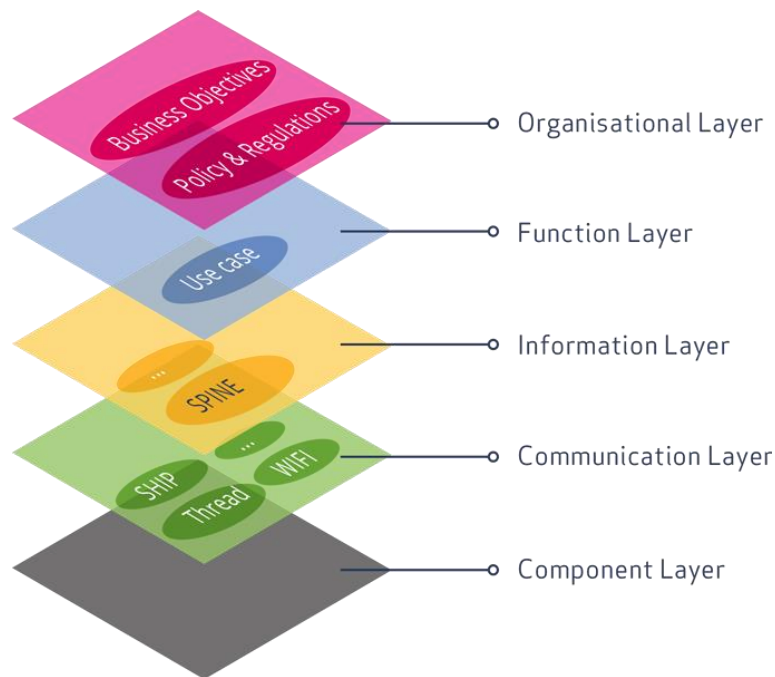


Figure 6: EEBus Data Model

2.2 EUROPEAN PROJECTS

Next, a number of preceding and current European project are shown. These projects have inspired to a greater or lesser extent the proposed RESPOND system architecture, therefore, they are worth introducing them.

2.2.1 FIWARE

The FIWARE Community is an independent Open Community with the mission of building an open sustainable ecosystem around public, royalty-free and implementation-driven software platform standards that will ease the development of new Smart Applications in multiple sectors [8]. The FIWARE platform offers a modular design providing relevant enablers for each application needs, from device integration to complex event processing. This flexibility enables a huge set of use cases and provides great adaptability without requiring any customization. The architecture is shown in Figure 7.

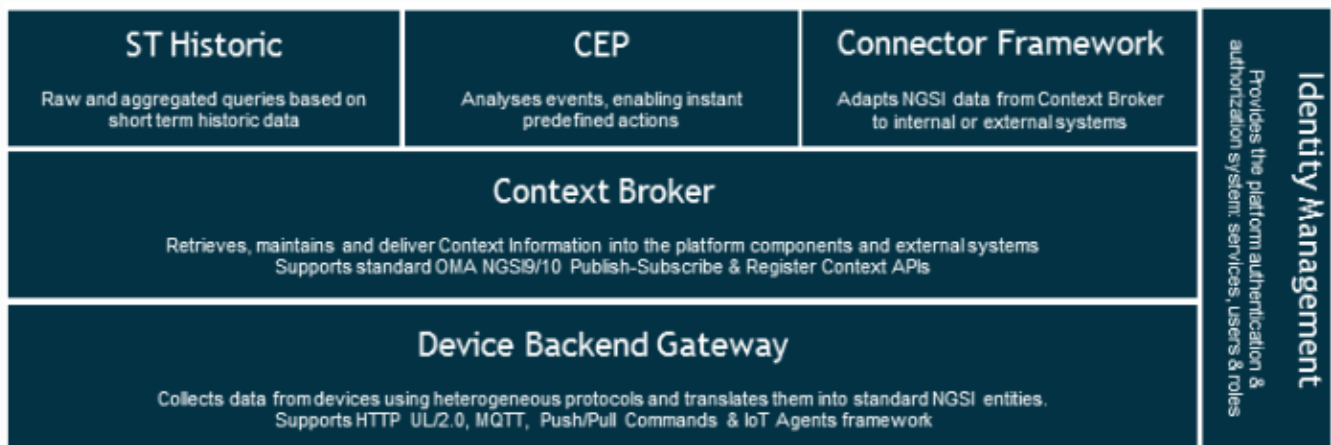


Figure 7: FIWARE architecture

2.2.2 ENERGY WARDEN

The ENERGY WARDEN (EW) FP7 project (2010-2013) addressed the optimisation of renewable energy technology (RET) deployment in the building domain [9]. EW developed and marketed the following products:

- **SIMULATOR (EW-S):** A simulator and modelling tool, including dynamic models for energy producing, storing and using units that may provide decision aid when designing or retrofitting energy infrastructures at the building domain. Important to highlight is that the simulator will be run in a short and a long-term time frame; that of 1-4 days and that of a year. The first time-frame will be driven by meteorological forecast data, which have a large level of confidence for this time-frame. The first-time frame delivers set points to the EW Controller, whereas the more long term one is more suitable for assessing RET investment scenario.
- **CONTROLLER (EW-C):** The controller is based on an expert system/ neural network approach and will provide real time control of the RET infrastructure. The real time controller manages how energy is allocated between uses, stores, and possibilities to be fed back to the energy network. The EW-C also unveils energy use trends, particularly useful for the simulator. In this way, the EW-S and the EW-C form a closed loop. The EW-C will include a data collection module, low cost hardware including sensors and data loggers/ transmitters, which will be deployed at the building over a period of time and facilitate the collection of data. It is emphasized that emerging wireless protocols are a key aspect of this data collection, as such systems are particularly important in the case of energy retrofit action, where wired sensors may be impossible or costly to install.
- **POLICY (EW-P):** A higher level functionality supports policy conformance and emission trading, allowing to monitor the building performance, old and new, against existing policies or standards, including the EU directive on building energy as well as supporting the capability for use in emission trading calculations.

EW was expected to be an open, standard compliant, system, able to support many new, upcoming, supply/ store/ use options that are constantly entering the market. Figure 8 shows an overview of the Energy Warden architecture.

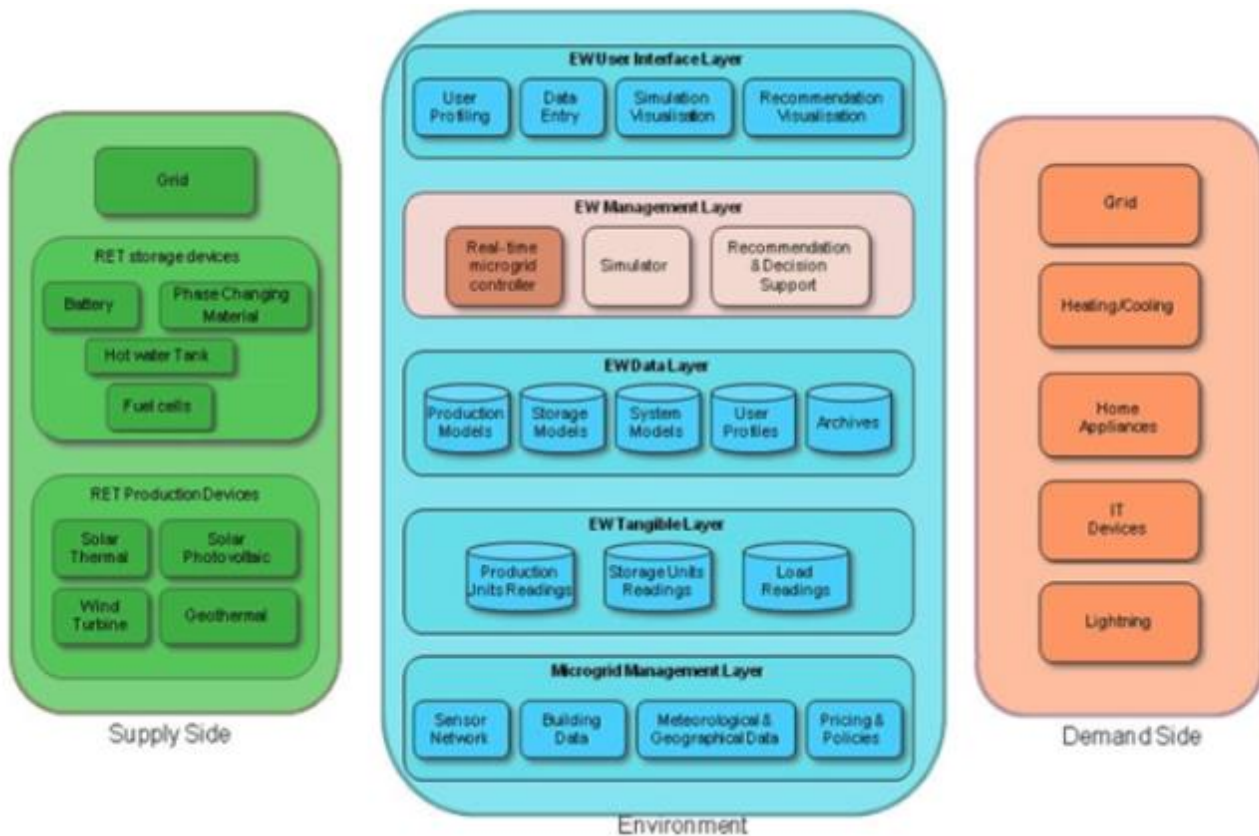


Figure 8: Energy Warden system architecture

2.2.3 OPENIoT

The Internet-of-Things (IoT) will be an integral component of the Future Internet (FI) and therefore should be smoothly integrated within FI service delivery models and the emerging utility based cloud computing paradigms [10]. To-date several researchers have described the benefits of a pervasive (sensor-based) distributed computing infrastructure without however providing a systematic and structured solution to the formulation and management of utility based IoT environments.

The OpenIoT (Open Source blueprint for large scale self-organizing cloud environments for IoT applications) FP7 project (2011-2015) is perceived as a natural extension to cloud computing implementations, which will allow access to additional and increasingly important IoT based resources and capabilities. OpenIoT is pertinent to a wide range of interrelated scientific and technological areas spanning: (a) Middleware for sensors and sensor networks, (b) Ontologies, semantic models and annotations for representing internet-connected objects, along with semantic open-linked data techniques (c) Cloud/Utility computing, including utility based security and privacy schemes.

OpenIoT creates an open source middleware for getting information from sensor clouds, without having to worry about what exact sensors are used. Furthermore, OpenIoT explores efficient ways to use and

manage cloud environments for IoT “entities” and resources (such as sensors, actuators and smart devices) and offering utility-based (i.e. pay-as-you-go) IoT services. Lastly, OpenIoT will also provide instantiations of cloud-based and utility-based sensing services enabling the concept of “Sensing-as-a-Service”, via an adaptive middleware framework for deploying and providing services in cloud environments. The OpenIoT architecture is shown in Figure 9.

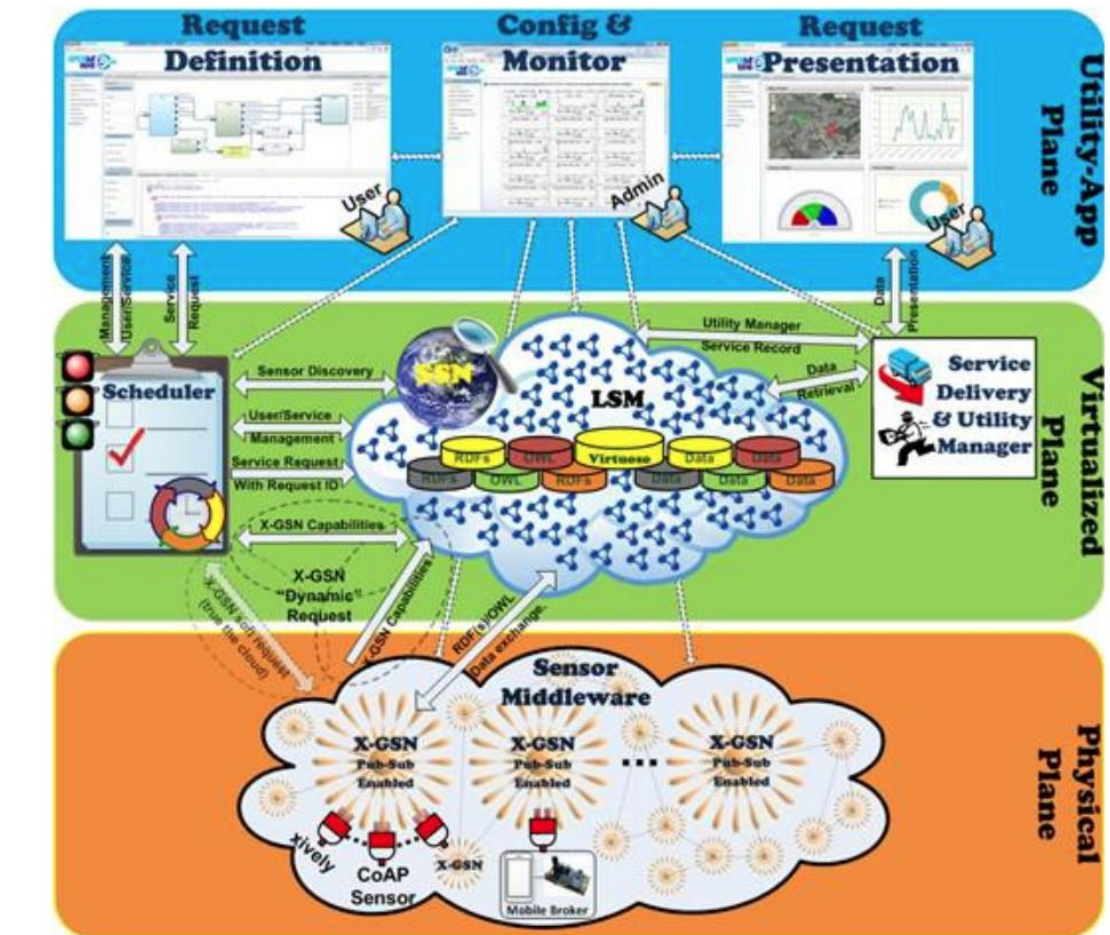


Figure 9: OpenIoT architecture

2.2.4 EPIC-HUB

The goal of EPIC-HUB (Energy Positive Neighbourhoods Infrastructure Middleware based on Energy-Hub Concept; 2012-2016) was to develop a new methodology, an extended architecture and services able to provide improved Energy Performances to Neighbourhoods (NBH). By combining powerful Energy-Hub-based Energy Optimization capabilities with seamless integration of pre-existing and new ICT systems, EPIC-HUB contributed to achieve the global objective of the Energy-positive Neighbourhood. EPIC-HUB covered all the aspects directly or indirectly connected to efficient Energy-based Management, Control and Decision-Support at neighbourhood-level, and defined a Fully-Interoperable Middleware solution able to provide integration and a structured vision of the overall infrastructure, friendly usable by all the involved stakeholders (e.g. the energy managers and utilities). By exploiting the concept of Energy Hub, EPIC-HUB Middleware focused on energy usage optimization at neighbourhood level: EPIC-HUB defined

a "neighbourhood-aware" energy trading platform aiming at improving Energy Efficiency and reduce the energy cost, taking into account Renewable Energy Sources as well as the Electricity Distribution Grid. The adaptability of the EPIC-HUB approach was demonstrated by the implementation of different pilots with highly motivated communities. The Genoa Port (Italy), Belgrade Airport (Serbia) and Bilbao Exhibition/Fair Centre (Spain) hosted very challenging pilots, involving their respective neighbourhood use-cases, and demonstrating how critical infrastructures can benefit from innovative Energy Management. The involvement of the neighbourhoods' operators, the Energy utilities and the local Public Authorities allowed EPIC-HUB to effectively tackle the development of innovative Business Models, with a clear validation of the project results including impacts on economic and business development, as well as carbon reduction [11]. The EPIC-HUB reference architecture is shown in Figure 10.

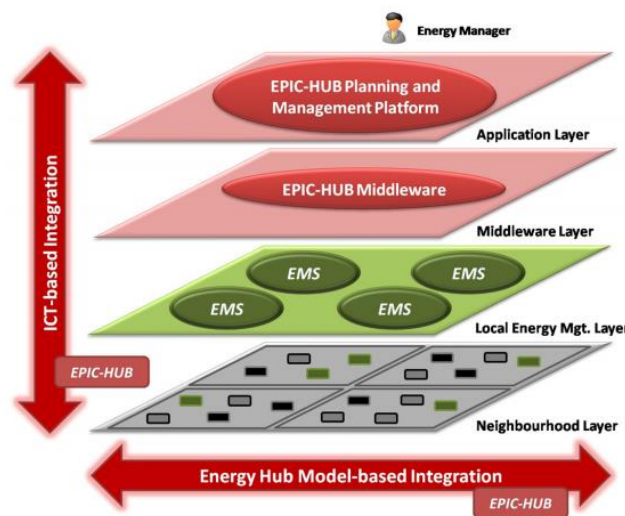


Figure 10: EPIC-HUB architecture

2.2.5 SEMIAH

The consortium behind the SEMIAH (Scalable Energy Management Infrastructure for Aggregation of Households) FP7 project (2014-2017) aimed to pursue a major technological, scientific and commercial breakthrough by developing a novel Information and Communication Technology (ICT) infrastructure for the implementation of DR in households [12]. This infrastructure enables the shifting of energy consumption from high energy-consuming loads to off-peak periods with high generation of electricity from Renewable Energy Sources (RES). The project's innovative approach is based on the development of an open ICT framework that will promote an environment for the deployment and innovation of smart grid services in households. A centralised system for DR service provisioning based on aggregation, forecasting and scheduling of electricity consumption will be developed. Furthermore, the project delivers a DR solution for control of electrical loads at a competitive price. The solution consists of a number of smart plugs that can be controlled over a home area network through a gateway connected to a wide area network. The consortium will integrate security and privacy functions to ensure that the system cannot be compromised. Finally, the consortium will develop new business

models for electricity players and residential customers to quantify costs and benefits for players in the value chain. SEMIAH will provide benefits to residential customers, energy utilities and the society in general, through lower electricity bills, improved integration of RES and higher stability of the electricity grid. Hereby, the project will enable savings in CO₂ emissions and fuel costs and reduce investments in electricity network expansions and electricity peak generation plants.

The system consists of the elements shown in Figure 11. On the one hand, a back-end system, consisting of a central server which manages and controls information from the households connected to the system network, and which provides intelligent services for energy management of the household. On the other, a Home Energy Management Gateway to control customers' loads based on OGEMA framework. Last but not least, it also has a user interface (smartphone application and consumer web portal) that allows the user to configure the settings of household equipment and add/remove equipment to/from the system.

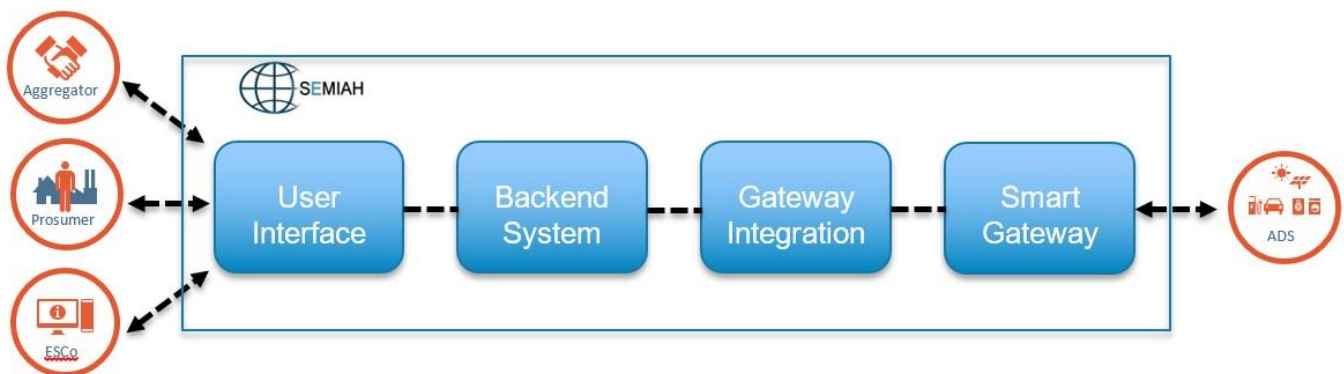


Figure 11: SEMIAH platform

2.2.6 HIT2GAP

HIT2GAP (Highly Innovative building control Tools Tackling the energy performance GAP) is an H2020 four-year project which began in September 2015 and will run to September 2019 [13]. Its aim is to reduce the gap between the theoretical energy performance of buildings and the actual consumption in use, by focusing on what happens, and on what could be done, while a building is in operation.

A typical office building will use much more energy than the design team and client expected at the design and construction phases. An innovative project, called 'HIT2GAP' is now seeking to solve this problem, in order to help to reduce the gap between the anticipated energy use of a building and what actually happens once the building is occupied. The reasons for 'the gap' relate to the fact that the design and construction of a building involves compromises, construction issues and unforeseen behaviours, some of which will have an energy impact.

For example, the difference between the theory of putting together the building and the complexity of doing this on a building site means that construction defects can arise as the building is assembled. Once the building has been constructed, the commissioning of heating, cooling and ventilation introduce further inefficiencies in the overall performance of the building. Finally, the people who

occupy buildings introduce unpredictable needs and behaviours, some of which will lead to higher energy consumption.

All of these factors can contribute to the energy consumption of the building being higher than had originally been anticipated. Furthermore, renewable energy devices and other building services do not always work well with each other, and this can reduce the overall savings from devices designed to save energy.

HIT2GAP cannot solve all of these problems, and while the project is focused specifically on eliminating some of the wastage of energy in buildings in use, it can also help identify other contributory factors such as construction defects. The Figure 12 shows an overview of the Hit2GAP platform.

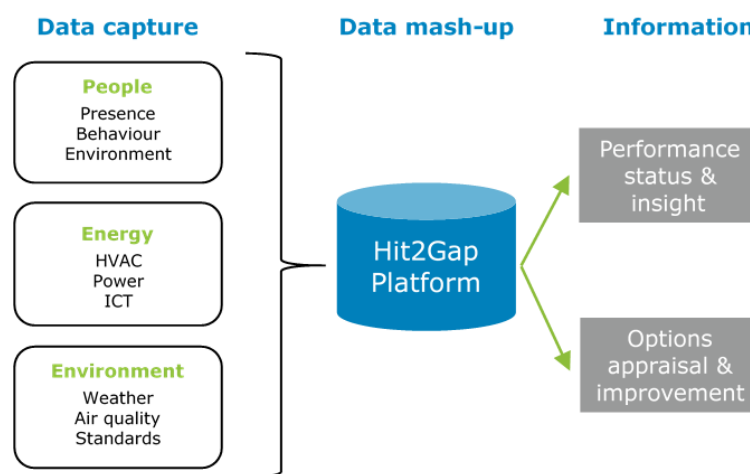


Figure 12: Overview of the Hit2GAP platform

2.2.7 SYMBIOTe

In a world of smart networked devices, wearables, sensors and actuators, transparent and secure access to the available resources across various IoT domains is crucial to satisfy the needs of an increasingly connected society [14]. The current IoT ecosystem is however fragmented: a series of vertical solutions exist today which, on the one hand, integrate connected objects within local environments using purpose-specific implementations and, on the other hand, connect smart spaces with a back-end cloud hosting dedicated often proprietary software components.

The symbloTe (symbiosis of smart objects across IoT environments) H2020 project (2016-2018) comes to remedy this fragmented environment by providing an abstraction layer for a “unified view” on various platforms and their resources so that platform resources are transparent to application designers and developers. In addition, symbloTe also chooses a challenging task to implement IoT platform federations so that they can securely interoperate, collaborate and share resources for the mutual benefit, and what is more, support the migration of smart objects between various IoT domains and platforms, i.e., “smart object roaming”. symbloTe will achieve all of the above by designing and implementing an Open Source mediation prototype. In light of the above, symbloTe opens up the potential for innovative business models that are incrementally deployable. This is especially important

for SMEs who are symbloTe's primary target group. Moreover, symbloTe removes the strict separation between IoT islands to create an environment which i) has significant impact on the market since it bridges individual efforts and investments, ii) is attractive for a heterogeneous user group, iii) matches the dynamicity of modern life due to ease of use and iv) is helpful for various business, home and public infrastructure use cases. The overview of the symbloTe architecture is shown in Figure 13.

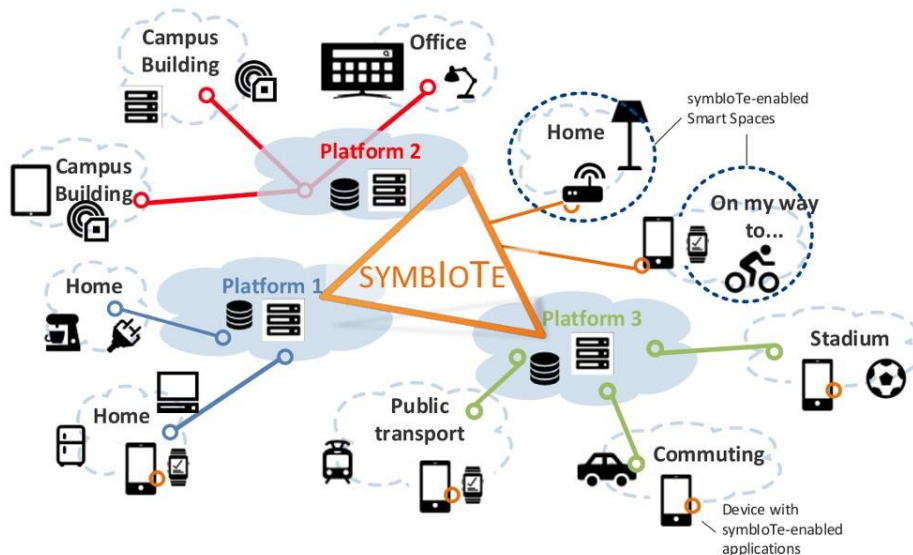


Figure 13: SymbloTe architecture

2.3 COMMERCIAL PRODUCTS

In this section, a set of related commercial products that have been analysed are shown.

2.3.1 METASYS

Metasys Building Automation System is aimed to be the foundation of modern building energy management efficiency. This system connects commercial HVAC, lighting, security and protection systems – enabling them to communicate on a single platform to deliver the needed information, allowing a better decision-making while enhancing occupants' comfort, safety and productivity [15]. Figure 14 shows the features and advantages of Metasys.



Figure 14: Features of Metasys system

2.3.2 NIAGARA

From office towers to manufacturing plants, hospitals to hotels, airports to convenience stores, in single buildings or multi-building campuses—Tridium's Niagara Framework is a global leader in the complex challenges of building integration and enterprise connectivity [16]. With Niagara, conventional facilities can be transformed into dynamic, flexible and intelligent buildings with higher efficiencies, lower costs and greater returns. Furthermore, Niagara enables monitoring and management of nearly every aspect of facilities, ranging from security to HVAC or lighting as shown in the example of Figure 15. Niagara solutions also allows:

- Preserve existing investments and integrate them with new technologies
- Access and control all diverse systems through any standard web browser
- Combine information from different systems to support better overall facility management
- Specify interoperable systems and applications from multiple vendors—eliminating vendor lock
- Generate return on investment, reduce energy costs, increase tenant satisfaction, improve security and gain greater control of your buildings

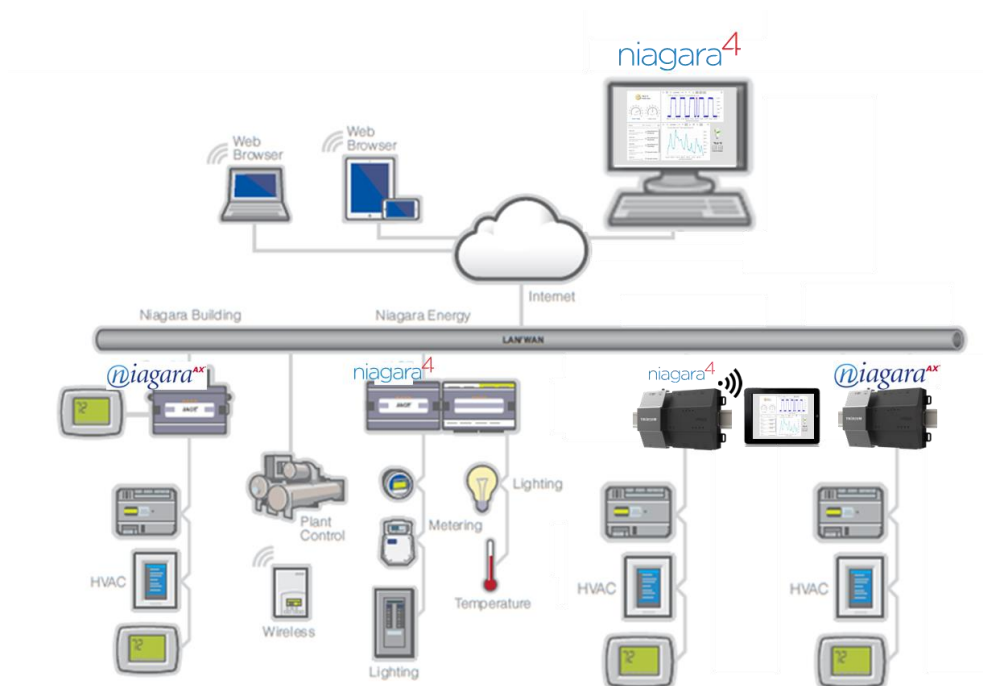


Figure 15: Example of the Niagara framework implementation

2.3.3 WSO2

The quantity and diversity of endpoints, protocols and data formats is increasing [17]. Yet integration projects are slowed by their complex, disaggregated, hybrid nature. Iterative approaches and low-code integration just don't work. While most development has shifted to agile, the same can't be said for Integration. WSO2 offers the technologies and methodology that digitally driven organizations need to become integration agile, as shown in Figure 16.

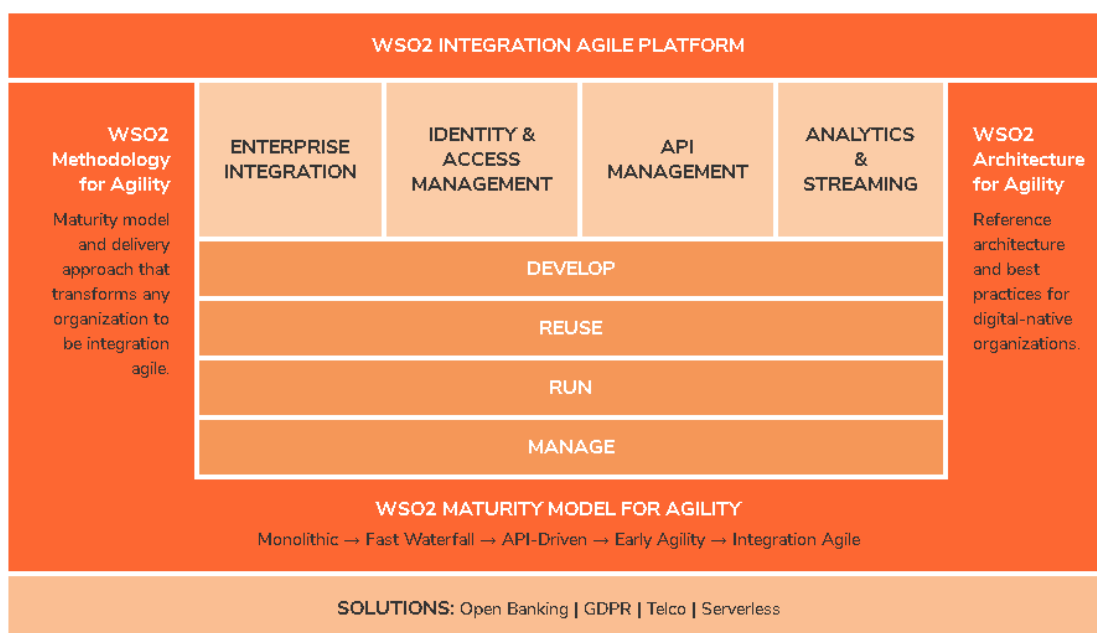


Figure 16: WSO2 Integration agile platform

3. RESPOND REFERENCE ARCHITECTURE TECHNICAL DESCRIPTION

3.1 OVERVIEW

Figure 17 shows the final RESPOND reference architecture, which is an addition of different components. The architecture comprises already existing components (in green) such as the field level devices and the EMS platform, and components that need to be developed throughout the RESPOND project (in blue), such as visualization components (in purple). The cornerstone of the architecture is the middleware based on a MQTT Broker (in red).

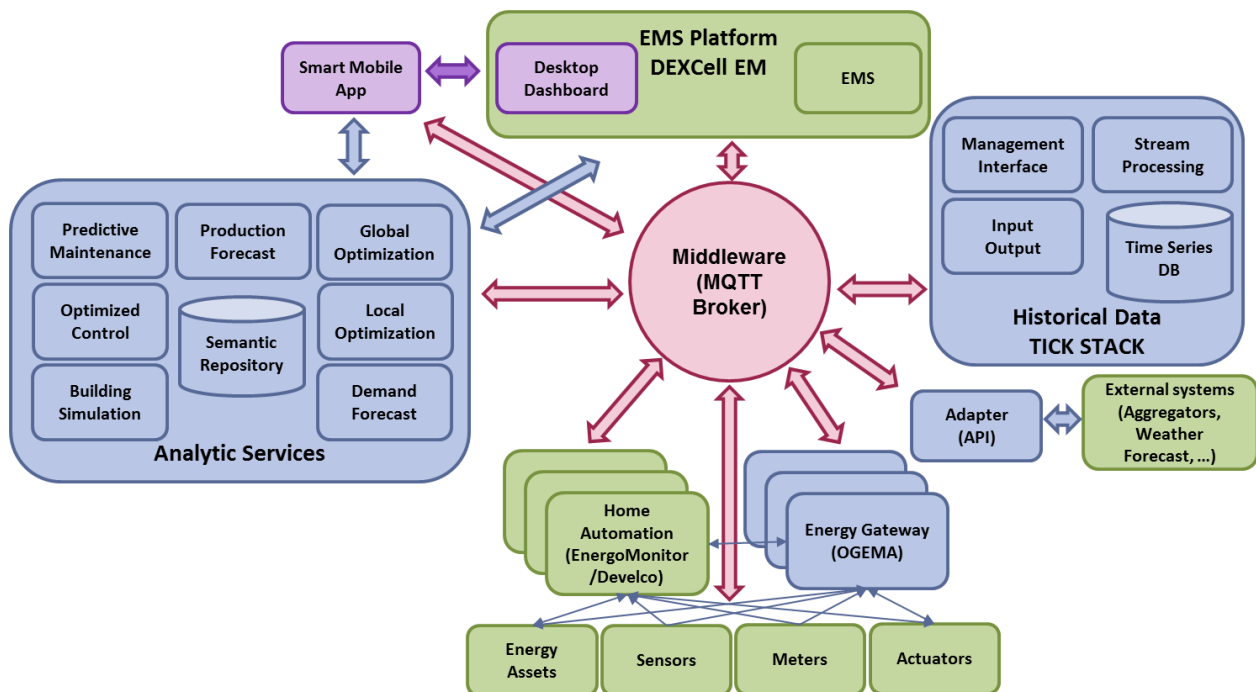


Figure 17: RESPOND reference architecture

The middleware, which is based on an MQTT Broker, is the central part of the RESPOND architecture. This component allows the integration of information coming from different sources, as well as the communication between different components. The communication with the middleware is done via the publish/subscription method, which decouples the client that sends the message (the publisher) from the client or clients that receive the messages (the subscribers). Furthermore, message adapters are envisioned to be necessary for enabling the communication with the middleware.

The field level of the architecture consists in the already existing devices and systems. Energy assets, sensors, meters and actuators from different manufacturers are deployed in the pilot sites and the data they generate needs to be integrated. Home automation systems developed by Develco and Energomonitor are in charge of managing that information and transmitting it to the middleware. In

case the aforementioned devices and systems cannot communicate with the middleware with the existing home automation systems, an energy gateway should be implemented.

External services such as aggregators or weather forecasting services provide relevant information that can be valuable for other components, such as the Analytic Services. In order to integrate data provided by these services, it is necessary to develop an adapter.

All the information gathered by from the different devices and systems needs to be stored somewhere. This is why, a Historical Data module needs to be implemented. This module will be based on the TICK Stack which provides services and functionalities to accumulate, analyse, and act on time series data.

Since historical data may not be enough at times, a set of analytical services in charge of generating advanced analytics will add intelligence to the architecture and therefore, it will be an added value to the system. This module is composed of a set of analytic services that transform historical data into valuable information that contributes to an optimal decision making. Among the components of this module, there will be a semantic repository to store metadata based on an ontology.

Finally, the visualization services such as the EMS Platform Desktop Dashboard or the Mobile app are the way users have to interact with the data. User engagement is an added value of the project so, efforts in visualization must be oriented towards this goal.

3.2 MIDDLEWARE

In this section, RESPOND architecture's middleware is described, whose main responsibility is to integrate RESPOND analytic services with the corresponding field level devices (monitoring and control layer), external services and visualisation application. This middleware layer enables the seamless connection of sensing and actuating devices with the rest of the RESPOND system, as well as the collection, storage and processing of data obtained from the field level devices and other related system components. As it can be seen in Figure 18, the RESPOND middleware consists of the following components:

- Message broker (MQTT) – it enables the exchange of messages among different system components in a lightweight manner by employing publish/subscribe messaging pattern
- TICK stack – it is comprised of different standalone modules that enable the collection, storage and processing of collected data

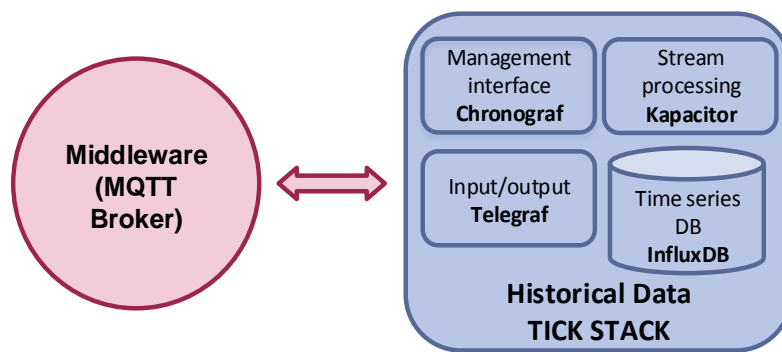


Figure 18: RESPOND system middleware

3.2.1 MQTT BROKER

MQTT is a client-server messaging transport protocol that employs publish/subscribe messaging pattern. The main goal of this messaging pattern is to decouple the sending (Publisher) and receiving (Subscriber) party and at the same time bringing many benefits:

- It is not necessary that Publishers and Subscribers are aware of each other.
- Implementation of the publisher and subscriber parties independently from each other.
- One Publisher could send messages to many different Subscribers
- One Subscriber could receive messages from many different Publishers

These characteristics make it ideal for use in many situations, including constrained environments such as Internet of Things deployments where small code footprint and network bandwidth are usually the limiting factors for implementation.

The publish/subscribe (also known as pub/sub) pattern is taken as an alternative to the classical client-server architecture, where a client communicates directly with a server (endpoint). In the pub/sub model, the publishers and subscribers never communicate to each other directly. Instead, the connection between them is handled by a so called messaging broker (e.g. Mosquitto MQTT broker), whose main function is to filter all the messages received by different publishers and distribute them correctly to the subscribers. In such a way, publishers and subscribers are decoupled so that they only need to know the hostname/IP of the broker and do not have to be online at the same time. Besides, most of the MQTT client libraries are based on callbacks or a similar model that does not require tasks to be blocked while waiting for or publishing a message.

MQTT employs a so called subject-based message filtering. Every MQTT message contains a topic (subject), that the broker uses to send the message to the client that has been previously subscribed to that topic. A topic consists of one or more topic levels where each topic level is separated by a forward slash (e.g. home/2ndfloor/livingroom/humidity). It is important to note that there is no need for a client to create the desired topic before publishing and subscribing to it since a broker accepts each topic without prior initialization.

An instance of a Mosquitto MQTT broker will be deployed as a part of the RESPOND cloud platform. MQTT broker will be used as a central data collection module where all the field level gateways will publish messages that convey measurements obtained by various sensors and smart meters deployed in the households. Besides, MQTT broker will be also used to send the control actions from the RESPOND cloud platform towards the actuators (e.g. smart plugs and smart relays). Finally it will be used for message exchange among different services deployed as a part of RESPOND platform in cases where pub/sub communication pattern suits their needs.

3.2.2 TICK STACK

InfluxData TICK stack [18] is a scalable open source platform aimed to collect, store and process IoT time series data. The scalability and reliability of TICK stack makes it particularly suitable for RESPOND cloud platform development where possibly large number of devices will be deployed. TICK stack core consists of separate modules that can be used individually or collectively: Telegraf, InfluxDB, Chronograf, and Kapacitor.

Telegraf

Telegraf is a metric collection daemon that can collect metrics from different inputs and write them into a wide array of outputs. It is plugin-driven for both collection and output of data so it is easily configurable and extendable. It is written in Go and a compiled into standalone binary that can be executed on any system with no need for external dependencies. Telegraf's flexibility supports different architectures allowing execution on embedded devices as well as cloud systems. It can parse the input data into various metrics, including: InfluxDB Line Protocol, JSON, Graphite, Value, Nagios, and Collectd.

For configuration of its input and output plugins, a configuration file is provided where developer can add the information related to input and output plugins (e.g. MQTT broker address and topics subscription, InfluxDB URL and data format), as can be seen in the following listing:

```
[[outputs.influxdb]]
  urls = ["http://127.0.0.1:8086"]
  database = "telegraf"
  retention_policy = ""
  ## HTTP Basic Auth
  username = "telegraf"
  password = "metricsmetricsmetricsmetrics"

[[inputs.mqtt_consumer]]
  servers = ["tcp://localhost:1883"]
  persistent_session = true
  qos = 2
  connection_timeout = "30s"
  topics = [
    "+/update/zb/dev/+/ldev/smartplug/data/demand",
  ]
  name_override = "demand"
  client_id = "telegraf"
  username = "respond1"
```



```
password = "asdf1234"  
data_format = "json"
```

InfluxDB

InfluxDB is a time series database designed to handle high write and query loads as well as down sampling and expiring old data. It is meant to be used as a backing store for any use case involving large amounts of time stamped data, including DevOps monitoring, application metrics, IoT sensor data, and real-time analytics. It employs a SQL-like language for interacting with data, called InfluxQL allowing a large volume of time-series to be analyzed in real-time. InfluxDb schema can be described as follows:

- Database – represents a logical container for different time-series data, users, retention policies, and continuous queries
- Series – represent the collection of data that share common measurement, tag set and retention policy
- Measurement – stands for the data stored in the associated fields
- Tag keys and values – used to store metadata. Tag keys are indexed so that queries that are performed on tag keys are faster.
- Field keys and values – used to store metadata and the actual measurements and can be of different types: integer, float, string and boolean. Fields are not indexed and each field value is always associated with a timestamp. Queries on field values scan all points that match the specified time range and, as a result, are not performant.
- Retention policy – describes for how long the data will be kept in the database. By default it is set to be infinite (no data are removed)
- Continuous query – an InfluxQL query that runs automatically and periodically within a database. It can be used to aggregate older data in order to save persistent storage.

In InfluxDB, a timestamp identifies a single point in any given data series. This is like an SQL database table where the primary key is pre-set by the system and is always time. InfluxDB also allows that the schema preferences change over time. In InfluxDB it is not necessary to define schemas up front. Data points can have one of the fields on a measurement, all of the fields on a measurement, or any number in-between. New fields can be easily added to a measurement by simply writing a point for that new field.

Chronograf

Chronograf is an open source web application. It can be used with the other components of the TICK stack to manage databases, visualize the collected data and easily create alerting and automation rules. Besides, by using Chronograf it is possible to monitor not only data collected from external data sources, but also the performance metrics of the server where the TICK stack is installed. It supports multi user configuration with different access levels. An example of Chronograf dashboard is shown in Figure 19.

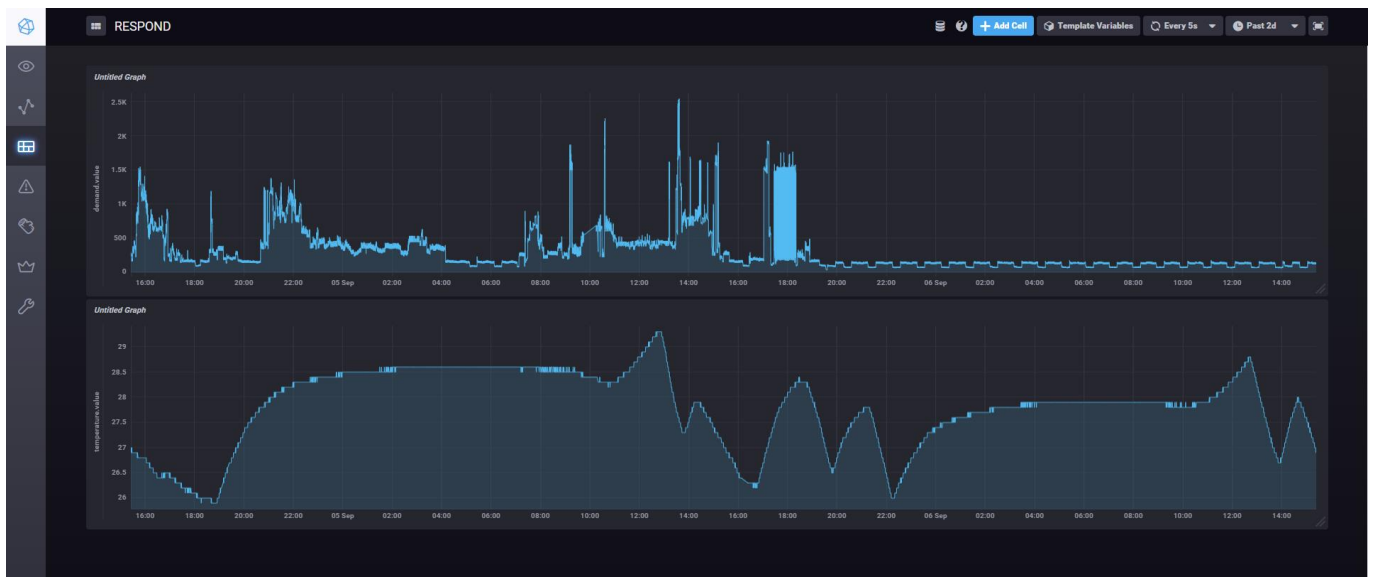


Figure 19: Chronograf dashboard

Kapacitor

Kapacitor is an open source data processing module that can be used for real-time data processing and creating alerts when anomalies in data are detected. It can be used to process both streaming data as well as recorded one. Moreover, it can perform any transformation that is currently possible in InfluxQL and store transformed data back to InfluxDb. In addition to the embedded data processing functions, custom user defined functions can be added. Kapacitor allows scripting to be done using lambda expressions (TICKscript) in order to define data transformations as well as to define logic conditions that can be used to filter data. An example of TICK script is given in the following listing:

```
stream
  |from()
    .measurement('cpu')
  // create a new field called 'used' which inverts the idle cpu.
  |eval(lambda: 100.0 - "usage_idle")
    .as('used')
  |groupBy('service', 'datacenter')
  |window()
    .period(1m)
    .every(1m)
  // calculate the 95th percentile of the used cpu.
  |percentile('used', 95.0)
  |eval(lambda: sigma("percentile"))
    .as('sigma')
    .keep('percentile', 'sigma')
  |alert()
    .id('{{ .Name }}/{{ index .Tags "service" }}/{{ index .Tags "datacenter" }}')
    .message('{{ .ID }} is {{ .Level }} cpu-95th:{{ index .Fields "percentile" }}')
  })

  // Compare values to running mean and standard deviation
  .warn(lambda: "sigma" > 2.5)
  .crit(lambda: "sigma" > 3.0)
  .log('/tmp/alerts.log')
```

All the data messages that have been published to the MQTT broker by field-level devices (via corresponding Develco gateways and Energomonitor bridge service) will be further transferred into Influx database for persistent storage. The connection between MQTT broker and InfluxDB will be implemented by using the Telegraf component of the TICK stack. In particular, its input plugin called MQTT_consumer will be configured to ingest all the messages published to the topic (+/data), where + represents a wildcard for any gateway id. On the other side, its output plugin will be configured to pass the measurement data to the InfluxDB.

3.3 FIELD LEVEL

RESPOND aims to integrate different home automation devices and legacy systems that may already be present in pilot locations. The goal is to use the common interface towards all these systems and integrate them in a unified manner. This will in turn ease the deployment, debugging and future system maintenance (see Figure 20). Since there are differences in hardware and software implementations of devices produced by different vendors, a Canonical Data Model (CDM) is designed to work along with the MQTT message exchange protocol.

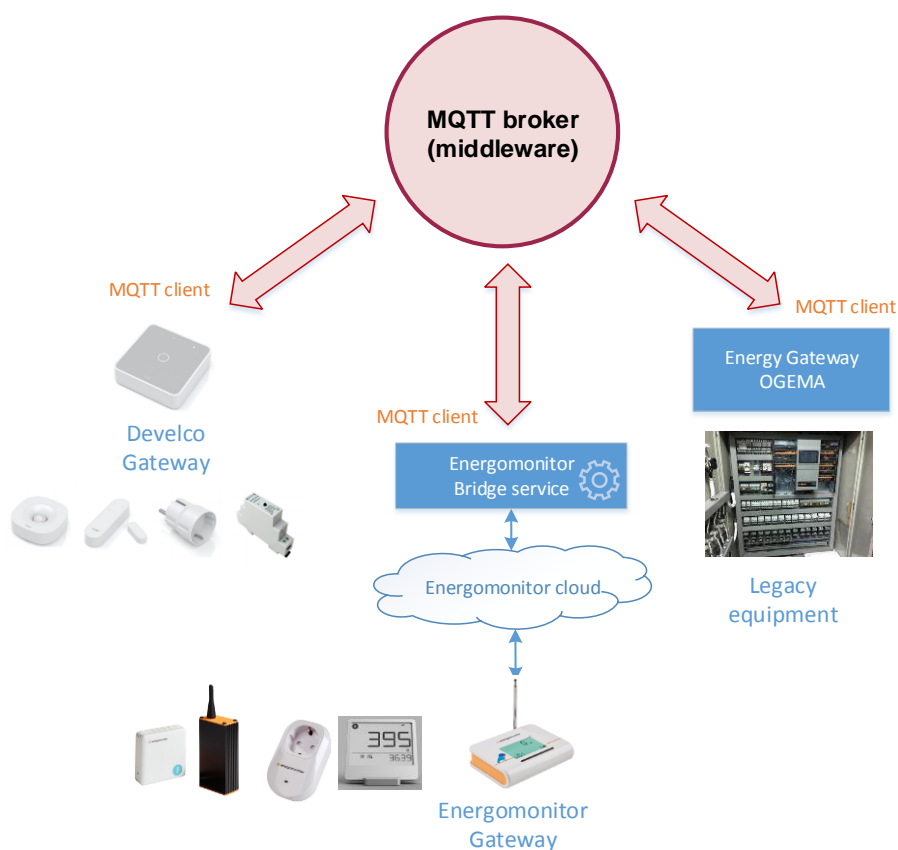


Figure 20: Integration of field level devices

3.3.1 HOME AUTOMATION

Develco Products is a B2B (business-to-business) company providing white label products within the fields of smart home, energy management, home security, and assisted living. The main data collecting unit is the Squid.link gateway. On the one side, it integrates multiple communication protocol interfaces (Zigbee, Zigwave, M-Bus, Bluetooth) that are used to provide a low-power connection to sensors (e.g. door/window, humidity, temperature and smoke sensor), smart meters and actuators (smart plugs and relays). On the other side, the gateway is connected via Wireless LAN or Ethernet connection to the MQTT broker that is part of RESPOND cloud platform. The Develco gateway supports the MQTT protocol that is used to either send the measurements from the gateway to the cloud platform, or to receive the control actions from the cloud platform (e.g. a control action to turn on/off the switch in the smart plug or smart relay). However, the original MQTT message payload format is proprietary, thus requiring of a translation into the CDM used by the rest of the RESPOND platform to ensure interoperability among different system components. The translation from the proprietary data format into the CDM will be performed on the gateways themselves, after an appropriate gateway software customization.

Energomonitor provides a cloud platform for storage and visualisation of the collected data. Furthermore, it provides hardware components for monitoring and control purposes, as Develco does. The Energomonitor sensors and actuators employ a proprietary low-power communication protocol (Chirp) to communicate with the corresponding gateway. The gateway is connected via wired LAN connection to the MQTT broker deployed as a part of Energomonitor's proprietary cloud platform. The data received by Energomonitor's MQTT broker is stored and offered to the end user via a proprietary web portal. In order to integrate Energomonitor's devices in the same manner as the ones provided by Develco, a so called "Bridge service" will be developed (see Figure 20). The bridge service will be implemented as a continuously running server software that collects the data obtained by the Energomonitor cloud platform and sends it to the RESPOND cloud platform by using MQTT protocol. The MQTT messages payload will be structured according to the same CDM data format employed by Develco. In such a way, from the point of view of RESPOND MQTT broker, both Develco gateways and Energomonitor systems will act in the same manner, resulting in a more stable and maintainable system.

3.3.1.1 MEASUREMENTS COLLECTION

In the sequel, the data format that shall be used for messages sent from sensors and smart meters to the RESPOND cloud platform is specified. This message exchange is done using the MQTT protocol.

MQTT payload format

MQTT messages shall be in JSON format with the message fields and descriptions provided in Table 1.

Table 1: MQTT message payload fields for Measurements

Field name	Field type	Additional description
timestamp	integer	UNIX time in milliseconds

value	float	Value of measurement without the unit (e.g. 24.0)
measurementIndex	integer	An index of the measurement (set to 1 for scalar value; 1,2,3 for e.g. 3-phase measurement)
deviceId	string	Unique ID of a particular sensor or smart meter. A vendor specific prefix (e.g. DEV-xxxxxxxx or ENE-xxxxxxxx) is proposed. Develco's sensors shall add DEV prefix and Energomonitor's sensors shall add ENE prefix to their proprietary hexadecimal serial number. (e.g. DEV-4567ACF79454AF6548 or DEV-4567789454AF6548)
measurementID	string	<p>a string identifying the measurement type provided by the given sensor:</p> <ul style="list-style-type: none"> • demand – power consumption in W • acfrequency – ac frequency in Hz • voltage – ac voltage in V • current – ac current in A • onoff – true if door/window is open, false if door/window is closed • occupancy – true if occupancy sensor detects presence, false is occupancy sensor doesn't detect presence • alarm – alarm true if door/window is open or if occupancy detects presence and false vice versa • illuminance – light illuminance in Lux • temperature – air temperature in degrees Celsius • humidity – relative humidity in % • battery – battery voltage in V • networklinkstrength – network link strength 0-100. Applicable to Develco devices • rssi - RSSI (signal strength) in dB. Applicable to Energomonitor devices

MQTT topics structure

GATEWAY_ID/data

Where GATEWAY_ID is a unique ID of a gateway device composed of the manufacturer's prefix and the gateway's serial number (e.g. DEV-4567789454AF6548).

All the messages are published with QoS = 0.

3.3.1.2 CONTROL ACTIONS

In this sequel, protocol and message format for control actions that will be sent from RESPOND platform towards the actuators deployed in the field (smart plugs, smart cables and smart relays) are described.

MQTT payload format

MQTT messages shall be in JSON format with the message fields and descriptions provided in Table 2.

Table 2: MQTT message payload fields for control action

Field name	Field type	Additional description
deviceId	string	A unique ID of an actuator device that the service will send the command to. Develco's device shall add DEV prefix and Energomonitor's sensor shall add ENE prefix to their proprietary hexadecimal serial number. (e.g. DEV-4567789454AF6548 or ENE-6A5F000054876542)
requestID	string	A unique identifier which will be used to identify the response for the given request (explained below). It is composed of two parts (e.g. OPT-156): <ul style="list-style-type: none"> • Requester prefix, e.g. OPT for optimizer • An increasing integer 1, 2, 3....
value	boolean	<ul style="list-style-type: none"> • true if smart plug is to be turned ON • false if smart plug is to be turned OFF • null if a service just needs to read a status of a smart plug without changing its state

MQTT control protocol

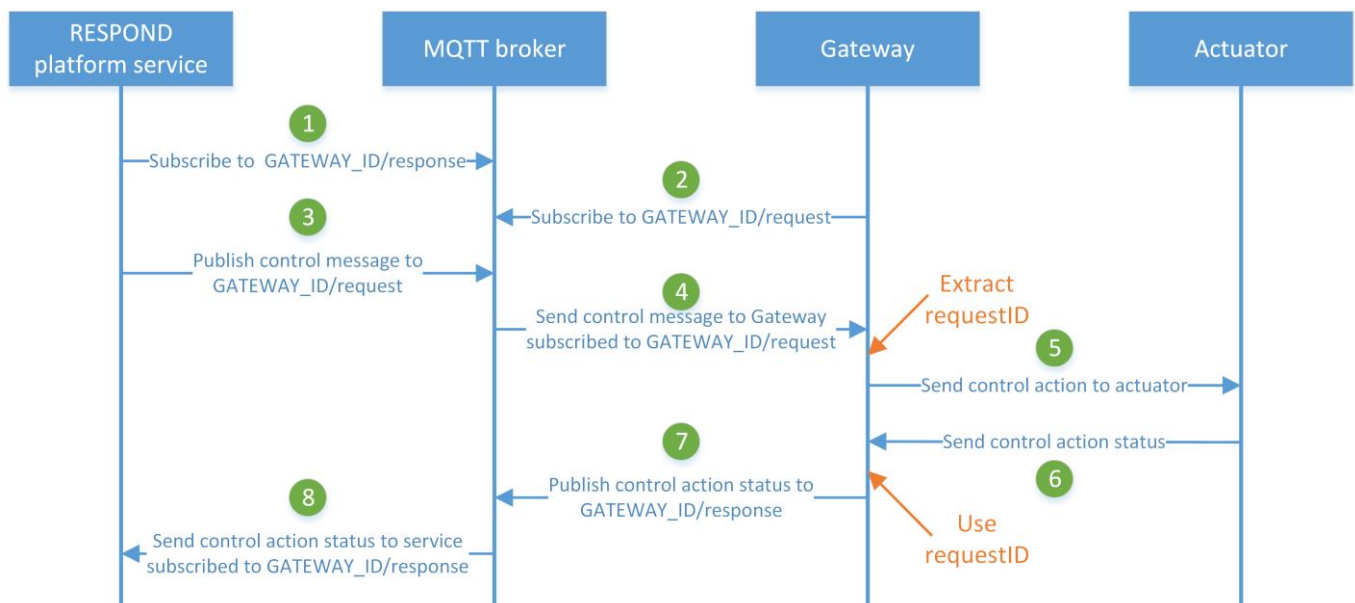


Figure 21: MQTT based protocol for actuator control

The MQTT based protocol used to perform control actions on actuators can be described as follows (see Figure 21):

1. The service (e.g. RESPOND service such as Optimization) subscribes to the topic: GATEWAY_ID/response where GATEWAY_ID is a unique ID of a gateway where specific actuator is connected to. Manufacturer's prefix + 16HEX serial number (e.g. DEV-4567789454AF6548)
2. The gateway (Physical device from DEV) subscribes to the topic: GATEWAY_ID/request where GATEWAY_ID is a unique ID of a specific gateway, with the corresponding manufacturer's prefix as described in the previous step. This topic structure is necessary so that the gateway can receive requests to turn on/off the actuator devices (smart plug, smart cable).
3. The service publishes the MQTT message for control action to the topic GATEWAY_ID/request with the payload structured according to the specification provided above in Table 2.
4. The gateway receives the control message from the MQTT broker since it has already been subscribed to the topic GATEWAY_ID/request in Step 2 and extracts the requestId field from the message payload.
5. The gateway sends the control action to the actuator according to the value field set in the payload of the MQTT message.
6. The actuator sends the control action status to the gateway.
7. The gateway uses the previously extracted requestId field and publishes the response in the MQTT message to the topic GATEWAY_ID/response, where the published message shall have the format according to specification provided in Table 3:
8. The MQTT broker sends the control action status to the service since the service has already been subscribed to the topic GATEWAY_ID/response in Step 1.

Table 3: MQTT message payload fields for control action status

Field name	Field type	Additional description
timestamp	integer	UNIX time in milliseconds
value	boolean	Set to the current value (new value if it is changed by control action) <ul style="list-style-type: none"> • true is smart plug is turned ON • false if it is turned OFF • null if no action has been performed due to an error.
status	integer	Set to one of the following codes: <ul style="list-style-type: none"> • 0 – action performed correctly • 1 – invalid request - invalid JSON, missing field, invalid field value, etc. • 2 – gateway unreachable

		<ul style="list-style-type: none"> • 3 – actuator device (e.g. smart plug) is not reachable by gateway • 4 – actuator device is not paired with the gateway
deviceId	string	A unique ID of a particular actuator device with the corresponding manufacturers prefix (DEV for Develco)
requestID	string	The same field that has been extracted from the received message payload in Step 4.

Both control action request and control action response messages are published with QoS=0.

Once the data reaches the RESPOND MQTT broker, it is parsed by the Telegraf component of the TICK Stack and stored in Influx database. There will also exist Chronograf and Kapacitor components that will be used for configuration and real-time processing of measurements collected by both Develco and Energomonitor devices deployed in pilot sites.

3.3.2 ENERGY GATEWAY

In order to ensure the interoperability with legacy hardware and software systems, OGEMA (Open Gateway Energy Management) will be deployed. OGEMA is an open source software platform that supports standardized building automation and energy management applications. The software is designed to be installed on a gateway computer between the customer and the smart grid. Since the platform is manufacturer and hardware independent, OGEMA allows energy flows within customer premises to be optimized with high degree of modularity. OGEMA is designed to be easily extendable by means of plugins (i.e. communication drivers) which support different communication protocols and enable translation from and to proprietary data formats (Zigbee, Z-Wave, Modbus, BACnet, KNX).

Applications installed in OGEMA can obtain access to consumer devices, user displays, smart meters as well as data provided by external services such as energy pricing information and grid parameters. OGEMA is designed to act as an operating system that enables applications to access different types of connected hardware and external services without having to deal with the physical aspects of the connection.

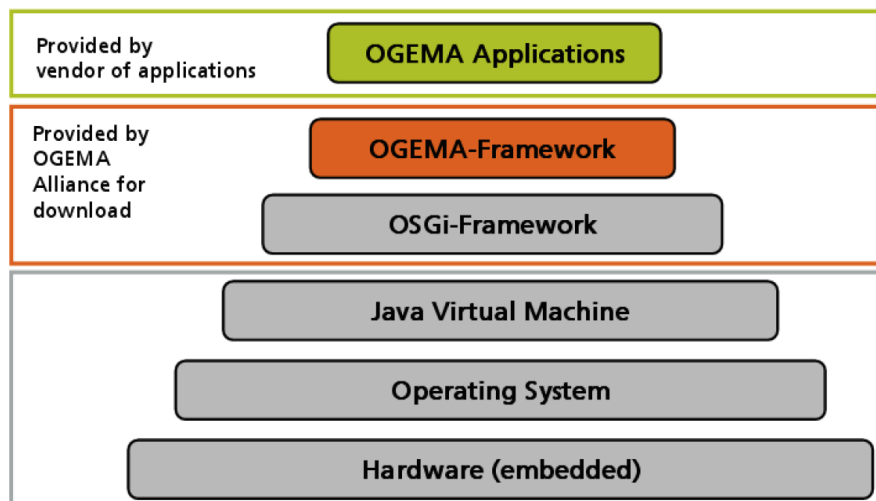


Figure 22: OGEMA technology stack

OGEMA implementations are able to run on a variety of devices including PCs, and embedded computers with low energy requirements (e.g. Raspberry Pi 3). The framework is Java based and requires a Java Virtual Machine to be installed on the targeted platform, as can be seen in Figure 22, where OGEMA technology stack is presented.

In the context of the project, an OGEMA application will be developed in order to translate the data read from the different plugins to CDM payload. Then, this data will be sent using the MQTT protocol to the broker. Furthermore, the application will be able to receive control actions subscribing to MQTT topics and to execute the corresponding command in the devices via protocol plugins.

The KNX plugin will be used in the Madrid pilot site to enable the communication with the thermosolar panels system.

3.4 ANALYTIC SERVICES

RESPOND platform represents a highly flexible and interoperable, cloud-based IoT platform which integrates energy monitoring and automation devices with environment sensing and innovative energy services. The proposed platform aims to enable application of demand response measures as well as tailored energy conservation recommendations, decision support and guided actions. In other words, it will provide relevant energy and cost saving measures that are relevant to a specific end user and his operating context, who is then able to act upon them without compromising personal comfort and convenience. Moreover, the platform's objective is to enable the application of advance energy analytics services so as to provide end users with better insight about their consumption, detect wasteful energy practices as well as energy and cost saving opportunities (through specific incentives according to their preferences and limitations) and, finally, to engage users through both automatic (remote) and manual control of the most important energy assets.

The aim of this section, is to provide an insight about RESPOND's analytical services through a brief overview of their functionalities and main functioning principles which will be featured in the three

platform use cases, validated by the project demo sites. Before delving into further details about the concrete analytical services, one should first be aware of the overall RESPOND's "measure-forecast-optimize-control" approach depicted in the Figure 23. The figure shows the main system components and the critical data/information workflow that enables delivery of the RESPOND services.

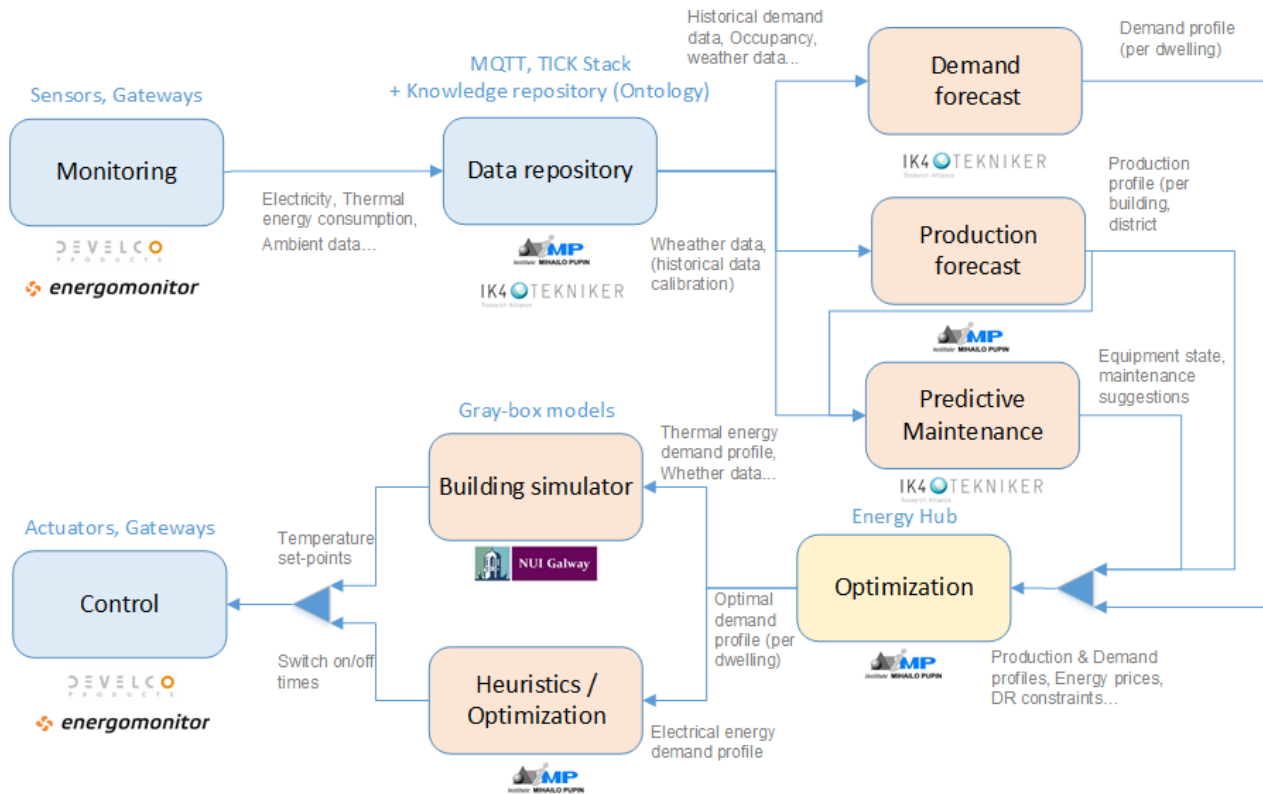


Figure 23: RESPOND's measure-forecast-optimize-control iterative approach

The initial, "measure" stage entails a comprehensive monitoring platform, able to collect measurements from different sensors through their dedicated gateways. Owing to the developed RESPOND's CDM, used as a common messaging format inside the platform, flexible vendor-independent integration of various sensors and data/information providers is enabled. Each gateway is responsible for performing the translation of the proprietary field level equipment protocols to the common CDM and, thus, a standardized and uniform format is used by the rest of the platform. The collected data and information (such as electricity, thermal energy consumption, ambient data...) are routed via messaging bus (MQTT broker) and cloud platform (TICK stack) to be stored within the RESPOND's data and knowledge repository (based on a developed ontology). Before the collected data/information is collected, they are properly processed, which includes data cleaning, normalization and interpolation if needed.

The following "forecast" stage entails a set of forecaster components, which can be generally divided into two major groups, the production forecast and the demand forecast tools. The production forecaster aims to deliver energy production profiles of different Distributed Energy Resources (DER) and Renewable Energy Sources (RES) using primarily historical measurements comprising both weather data and previous corresponding generation data. Likewise, the demand forecast also uses historical values related to historical demand and building occupancy (also applicable weather data) to deliver demand profiles for different demand types, namely the electricity, heating and cooling.

The main consumer of the acquired measurements data and derived forecasts is the “optimization” stage, which aims to deliver optimal control and scheduling of available energy assets. In other words, by using different measurements and forecasts (production and demand profiles etc.), contextual energy related information (energy prices, import/export regulation etc.) and both user and utility requirements (DR constraints, flexibility of demand etc.), the optimization stage delivers optimal energy dispatching in a multi-carrier energy environment. To “translate” the outputs of the optimization stage into applicable control actions, applied over existing energy assets, both building simulation and common heuristic approaches will be employed. The former will mainly be based on the gray-box models whereas the latter will employ suitable rule-based algorithms.

Finally, the “control” stage entails automatic, remote, control actions performed by the RESPOND platform based on the derived decisions from the previous stages. By complementing manual and semi-automatic controls also supported by the platform, the automatic controls will be transferred to the field actuating devices by leveraging the same gateways used for the data acquisition as well as the message routing bus (MQTT broker). Moreover, the developed CDM was also designed so as to accommodate provision of control functionalities.

To facilitate better understanding of the split of the development responsibility in the RESPOND consortium, the Figure 23 also features partners involved in each stage of the RESPOND’s workflow.

The previous workflow will be employed by the platform’s three use cases, featured by the three demo sites, which highlight the different aspects in which the RESPOND platform may contribute to reaching an improved energy and cost efficiency. The flexibility and applicability of the proposed RESPOND workflow and developed analytics services will be validated at the three demo sites which have completely different energy related contexts, geographical and meteorological areas, available energy assets and renewable energy harvesting potential. Table 4 briefly summarizes the main features of the three demo sites and highlights their specific features. These are further detailed in *D1.1: Pilot technical characterization and operation scenarios*.

Table 4: RESPOND’s demo sites properties

Demo site	Ireland	Denmark	Spain
Available energy carriers	Power grid Solar energy	Power grid Solar energy District heating	Power grid Solar energy Gas Boiler
Primary energy demand	Electricity, heating and domestic hot water	Electricity, heating and domestic hot water	Electricity, heating, cooling and domestic hot water
Energy assets	Photovoltaic panels Electricity storages Air source heat pumps (heating) Electric heaters Electrical appliances* EVs	Photovoltaic panels Electrical appliances* Controllable radiators (set-point control)	Solar thermal collectors Electric appliances* Common boiler
Energy and cost	Integration and	Optimisation of thermal	Exploitation of variable

saving objective	optimization of supply and electrical control	electricity pricing and optimization of thermal control
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**electrical appliances: washing machine, dishwasher, tumble dryers (+ refrigerators, freezers, electric oven/stove for manual control)*

3.4.1 PRODUCTION FORECAST

This service will be responsible for delivering energy production forecast from the RES available at the demo sites, which will be further consumed by the optimization service in order to determine optimal dispatch of the produced energy between satisfaction of immediate loads, energy storage or export to the power grid. Although local generation may also come from dispatchable sources, such as diesel generators, combined heat and power plant (CHP) etc., their production is controllable and can be pre-scheduled. Moreover, the output of the energy production forecast from renewables can be a valuable input for DR programs. For example, if a peak of energy production is anticipated, the demand should be rescheduled to match this peak.

In the context of the RESPOND project and its demonstration sites, the two main types of energy generation devices are the photovoltaic (PV) panels, enabling production of electricity from solar energy, and the solar thermal collectors (STC) which also harness solar energy but for production of thermal energy. The PV panels are available at the demonstration buildings in Aarhus (Denmark) and Aran Islands (Ireland), while the STC is available at the buildings in Madrid (Spain). It should be emphasized that the RESPOND approach is not limited to these energy generation units and that its flexible modelling and optimization environment can easily incorporate other types of DER and RES.

Forecasting the operation of any RES is heavily dependent on the weather forecast. However, given the complexity of weather forecast problem and the availability of a wide range of open and reliable forecast services, weather forecast will not be developed but instead included as an external service, providing the necessary predictions about weather parameters. It should be highlighted, though, that the imported forecast has to be location specific and with sufficient sampling resolution, typically having one-hour granularity. In case when there is no available weather forecast for a specific location and the local weather exhibit some systematic bias with the regional weather, some sort of localization techniques will be considered (e.g. wind velocity has logarithmic dependency on altitude etc.). Also, the operating conditions and status of the energy generation equipment have a significant influence to the energy production and, therefore, the Predictive Maintenance service (explained in Section 4.4.5) will also be considered to properly evaluate and account for its impact.

For the implementation purposes, both deterministic and stochastic approaches will be considered. The first will leverage acknowledged deterministic mathematical models of renewable energy sources to estimate their operation behaviour based on given meteorological conditions and technical characteristics provided by the corresponding vendors/manufactures. It can be applied to any energy source, as long as the critical technical information about the device itself is available, i.e. various parameters such as rated power, efficiency dependence etc. The second approach represents

employment of a data-driven technique, e.g. machine learning, which leverages its training process only on measurements from historical energy production of specific source recorded together with applicable meteorological conditions. Once the model is trained, it is then simply supplied with forecast of meteorological conditions to estimate future energy production.

3.4.2 DEMAND FORECAST

In order to fully maximize the potential of DR programs, another aspect to take into consideration is the energy demand. This is why, this demand forecast service will play a key role in the RESPOND project. The goal of this service is to estimate the energy demand (both electric and thermal energy) that will occur in a house or at a neighbourhood level in a given time in the future.

The energy demand is strongly influenced by dwellers' habits. Likewise, dwellers' habits are affected by the culture, the income of the house and the location of the building to name a few. This means that, even though two houses are next to each other, their energy demands may vary considerably. Therefore, it is necessary to forecast the energy demand forecast for each dwell. The demand forecast service will receive inputs coming from different sources to produce as accurate predictions as possible. Among the relevant input there are weather forecast (e.g. cloud cover, external temperature), the date, the time, the season of the year, the consumption (thermal or electric, depending on what forecast is aimed), the indoor conditions and whether it is a laboral day or not.

With this forecast, it is possible to estimate ahead of time how to deal with the demand, trying to apply the adequate DR programs to avoid peak demands, incentive dwellers to reallocate the demand and to fully optimize the energy produced from renewable sources. This energy forecasting service should ideally work together with other services such as the building simulation or optimized control, in order to further increase its benefits.

3.4.3 BUILDING SIMULATION

Today's buildings move toward low-energy standards but the buildings' renewal rate is very low. Therefore, it is essential to propose solutions to reduce consumption on medium to high-energy buildings. Potentially, significant consumption reduction can be reached by using smart control strategies of heating and cooling systems. Therefore, in order to improve building control and to anticipate high price periods, precise and robust predictive models are needed.

Building simulation models can be classified into three approaches, white-box, black-box and grey-box models. White-box-modelling is based on a very detailed physical description of a building. They are efficient, but they need very detailed data on the building characteristics. For this reason, this type of simulation is time consuming to parameterize and not used in the monitoring phases. Black-box-models are developed based on an analysis of measured time series. They do not require any specific knowledge about the system's physical structure and are therefore coupled with very low development costs. However, their ability to predict building behaviour in the case of new control strategies is not demonstrated.

Grey-box models combine both approaches. A very simple physical model is used and its parameters are identified with measured data. Despite their reduced-order structure, grey-box models provide relatively accurate energy performance predictions once trained with monitored data [19]. Compared to black box models, grey-box models better predict the building thermal behaviour in the case of new control strategies.

In this regard, RESPOND will deploy the Building Simulation service that will provide the modelling of building energy parameters and the estimation of influences caused by control actions to be performed.

Modelica is used to develop the Building Energy Simulator and that specifically is a grey-box model based on the model proposed by [20]. A statistical tool has been created to estimate the main building energy parameters. The information needed to populate the tools has been taken from available technical information, surveys and interviews. The remaining uncertain parameters are evaluated based on specific values, and then adjusted throughout the calibration process.

Once the building simulation model is calibrated, it will be ready for translating optimization scenarios into thermal control actions. For instance, the building simulation will use as inputs the optimal energy demand profile coming from the RESPOND optimization component, the current operational conditions inside the dwelling and the weather forecast to simulate the effect of an operational indoor climate control action (i.e. lowering the indoor temperature set point for the next two hours). As a result, it will provide the effectiveness of the control action in terms of energy consumption and indoor thermal comfort level, in order to understand the feasibility of the optimization scenario proposed by the RESPOND platform.

3.4.4 OPTIMIZED CONTROL

The optimization stage represents one of the key features of the RESPOND platform, which sits at the very heart of its workflow. To fulfil the overarching objective of the platform, i.e. to provide optimized operation of existing energy assets, and allow for their improved energy and cost performance, the optimization module leverages all available data/information collected by the platform to provide decision support in terms of suggested control actions. In other words, it employs data measurements from the field equipment, semantically enriched information from the RESPOND knowledge base, outputs from the analytical services devoted to production and demand forecasting and, finally, information from external sources (e.g. day ahead or real-time energy prices) to facilitate optimal operation of energy related infrastructure and appropriate Demand Response (DR) actions.

In particular, the optimization module will consider both supply flexibility, yielded by the existing multi-carrier energy supply portfolio, as well as demand flexibility coming from the daily activities of end users as well as acceptable compromise in their thermal comfort. Hence, the output from the optimization module will consider optimal energy supply and load profile, for each available energy carrier, as well as concrete DR actions related to significant electricity consumption appliances. The DR actions will typically entail recommendations for re-scheduling operation of those appliances. On the other hand, optimal load profiles related to the thermal loads (namely heating and cooling) need to be “translated” to actual DR actions, i.e. control actions for the actual heating/cooling equipment (e.g. set-points). This

will be performed by the Building Energy Simulator, described in the previous section, which provides comprehensive modelling framework for building energy parameters and estimation of impact caused by potential control actions. In this way, the output from the optimization module will be used, together with operational and comfort constraints, to determine actual control actions applicable for the end users.

The following is a brief overview of the conceptual and modelling framework adopted by the RESPOND's optimization module, which leverages the acknowledged energy hub concept [21] with necessary modifications so as to account for project's specific needs and requirements. In particular, this considers modelling of DR actions and corresponding constraints.

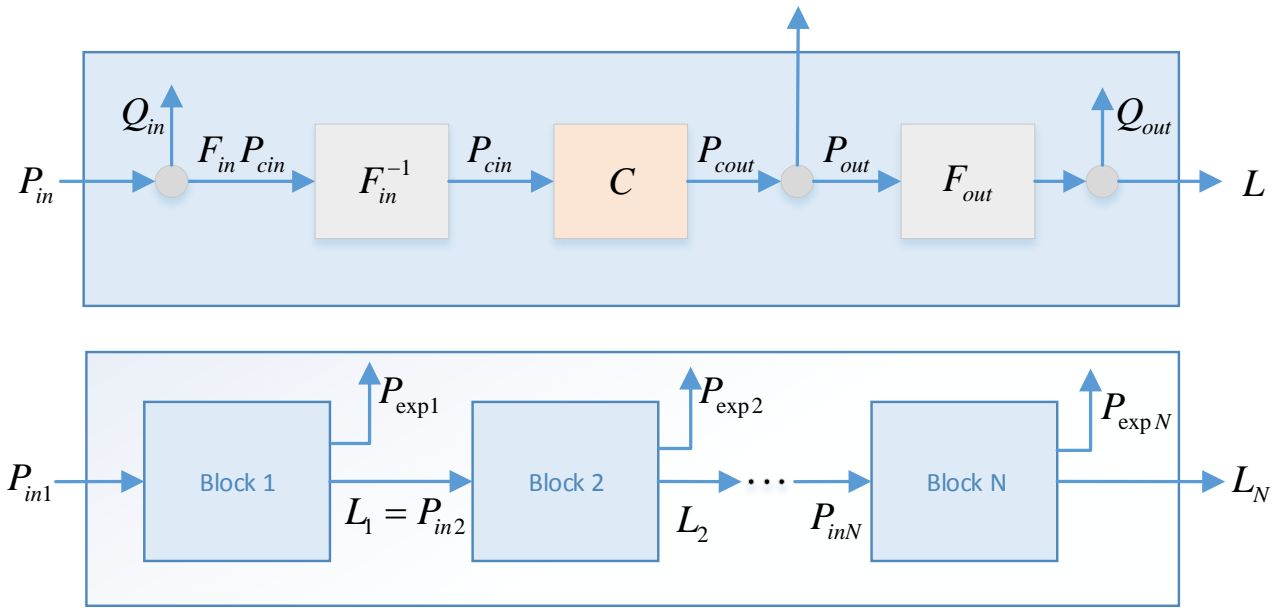


Figure 24: Block schematic of energy hub and multi-block schematic of energy hub

3.4.4.1 OPTIMIZATION MODULE FOR SINGLE FLAT/HOME OPTIMIZATION

As stated, the framework for modelling of energy infrastructure is based on the concept of energy hub, which represents a flexible and scalable form suitable for the formulation and solution of generic optimization problems related to energy management. Given its holistic approach, it accounts for available energy supply carriers, energy conversion options and existing storage units. The chosen approach was adapted from [22] and can be schematized as depicted in Figure 24.

The basic modelling block features energy input, sequentially followed by conversion and output stages. Once the energy flows enter the hub (P_{in}) they can be either stored immediately at input stage (Q_{in}), if storage facilities are available, or dispatched through the dispatch element (F_{cin}) to the converter stage (C) as P_{cin} . Once the energy conversion is performed the output (P_{cout}) can then be exported (P_{exp}) and the net remaining output (P_{out}) is forwarded (via the dispatch element F_{out}) to the output stage where it is either stored (Q_{out}) or immediately employed to satisfy the load demand (L). This modelling framework allows for integrated optimization of energy supply flows and demand side flexibility thus offering a holistic energy management paradigm. Although the energy hub concept was initially intended to reduce energy related operation costs by optimizing energy imports and dispatching of

conversion and storage assets, its use was further extended by facilitating implementation of DR schemes. From the mathematical modelling perspective, this extension entails change of the nature of load demand (L) from being a model parameter to being model variable (i.e. variable to be optimized). This however requires definition of a set of additional constraints, ranging from physical constraints of regular facility operation to end user comfort level requirements.

3.4.4.2 OPTIMIZATION MODULE FOR AGGREGATION OF FLATS IN A BUILDING

Although the previously described energy hub approach is suitable for definition on a single entity level (e.g. a flat or a detached house), the RESPOND concept aims to deliver advance energy management services to a broader scope of multi-flat building or district/neighbourhood. Therefore, it is necessary to further extend the modelling and optimisation framework so as to account for an integrated optimisation of multiple entities and possibly their common energy assets (e.g. boiler, CHP plant, battery storage or else). There are, however, several challenges that hinder application of an energy management of interconnected entities. The first one lies in the physical limitation of energy interconnections between different entities. Even if they are found in the vicinity of each other, they normally do not share a common energy infrastructure except from the existing electricity or hot water distribution network. However, even these are owned by corresponding authorities and may not be freely used to dispatch energy from one entity to another. The second major obstacle in establishing the aggregated energy management is in fact related to the consensus of all beneficiaries around an acceptable business model. Since it is a common situation that different entities act as separate legal subjects (e.g. each flat is owned by a different family), each of them has the objective of achieving the best running performance, including the energy related costs. However, district/neighbourhood optimization approaches typically aim at operation optimality of neighbourhood as a whole, while the operation of each entity is subjected to the neighbourhood guidelines which, expectedly, are not always the best option for the corresponding entity. As a consequence, there is very little motivation for separate entities to participate in the neighbourhood scheme unless the overall benefits are shared among the stakeholders in a fair manner. This however is not an easy task due to the very nature of the predictive energy management problem. First, entities must accept sub-optimal operation at certain times (for the sake of neighbourhood) in order to gain some benefits in the future. However, since the overall optimization scheme is highly dependent on the forecast of various parameters, such as weather conditions (implying generation from renewables) or consumption profile (depending on weather, number of people, operational requirements etc.), the expected future benefits carry a significant amount of uncertainty. Hence, entities are required to accept the participation in the neighbourhood scheme without being certain of the actual benefits they will receive at the end of contracted period, which may vary from one to an arbitrary number of days or even months. Therefore, RESPOND's aggregated energy management solution will propose a novel aggregated optimization scenario, leveraged upon the developed architecture and related technological tiers. The overall concept is depicted in Figure 25 briefly outlined in the following.

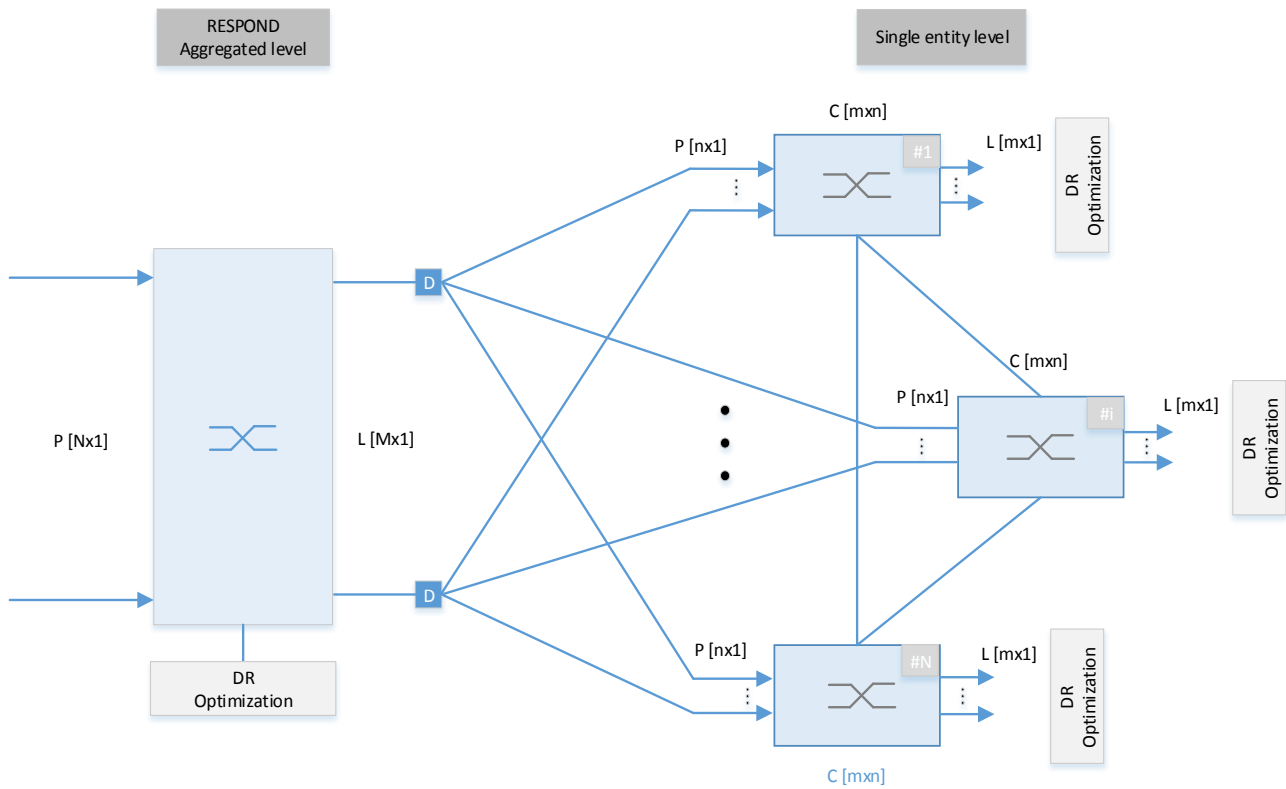


Figure 25: Neighbourhood deployment scenario

Starting from a set of separate physical entities, each one is represented with an energy hub (numbered with #i), which may be formulated in the form of single or multi block hub, a so-called district/neighbourhood is formed on voluntarily basis. A neighbourhood may be represented by either a logical and/or physical entity at which a aggregated energy management optimization is performed. Picking one option over the other should be governed by the availability of some common energy assets and/or infrastructure, e.g. a CHP plant or a common storage facility.

The entire optimization process is divided into two major steps. The first step refers to the “upwards” direction, going from the separate hubs towards the neighbourhood authority. It starts with the request for energy supply or available storage space from each hub ($P[nx1]$), based on demand ($L[mx1]$), which is derived as an output from the energy hub optimization associated with “local” DR strategies. These supply vectors are summed accordingly and transferred to the demand side of the neighbourhood ($L[Mx1]$) where another round of energy hub and DR optimization is applied while taking into account also the energy assets available at neighbourhood level. A necessary neighbourhood supply ($P[Nx1]$) is found as the output, revealing the net energy import from the external grid. However, as a lateral consequence of the neighbourhood optimization the demand of neighbourhood is also altered (due to DR), yielding a slightly changed profile ($L'[Mx1]$). This has a direct impact on the supply of local entities and, consequently, fulfilment of their energy demand.

At this point, the second step starts, now going from neighbourhood level “downwards” to local entities. The main objective of this “reverse” optimization is to modify the supply of each local entity ($P'[nx1]$) while offering them a quantifiable benefit (financial, environmental etc.) which is calculated for a time span for which optimization is performed. Each local entity is offered with the option to follow the

recommendation of the neighbourhood authority or to disregard it, thus relying solely on its own optimization and assets. In the extreme situation, when all local entities decide not to follow the recommendations, there is still one degree of freedom for the neighbourhood optimization, i.e. to optimally operate common energy assets located at the neighbourhood level, completely independent from the local entities. Another issue in this process is how to distribute available energy coming from the neighbourhood (L' [Mx1]) and even more how to split the benefits among local entities which participated in the neighbourhood scheme. Different heuristics may be applied for this purpose. For instance, the available energy (L') may be proportionally distributed among the local entities according to the share of their prior energy request in the total energy demand. On the other hand, the split of potential revenues should be tied with the effort of each local entity, i.e. proportional with the share of deviation in their energy supply. After complying with recommendations coming from the neighbourhood level, each local entity follows their proprietary optimization objectives (e.g. operational costs, environmental impact etc.) based on which an actual dispatch of energy is performed.

3.4.5 PREDICTIVE MAINTENANCE

Preventive maintenance (PM) and predictive maintenance (PdM) are methods to extend the life of assets, prevent unexpected breakdowns and save organizations money. Both methods are already popular in manufacturing, machine, and energy companies and can be used in conjunction with mobile workforce management software.

PM is performed while equipment operates normally to avoid unexpected breakdowns and the associated downtime and costs. Downtime is scheduled based on calendar dates or usage. Performing this maintenance can mean extending the life of assets, increasing productivity, improving overall efficiency and reducing maintenance costs. PM is based on the theoretical rate of failure and does not account for actual equipment performance. Every organization is different and daily operations impact equipment functionality, so using this strategy may result in performing unnecessary maintenance. On the other hand, PdM directly monitors equipment performance during normal operation to anticipate failure and allows organizations to take proactive, cost-effective actions [23].

In the RESPOND system architecture, there is a service in charge of predicting the performance of the energy producing equipment (such as PV panels) as well as the monitoring devices in order to allow cost-effective decision-making.

This service will be built based on the monitoring of devices throughout 2 years due to the short time available. The data monitored during the first year will be used as the baseline, and the second one as the verification period, with views to detecting the fault causes that may occur in the aforementioned devices. For an efficient predictive maintenance service, real failures are needed, as well as the historical maintenance operations performed. Furthermore, having historical performance data will result in the improvement of the PdM service.

The first step consists in setting a “normal performance” of devices. In the case of Figure 26, the normal performance would be the blue line, which is drawn between the top red and the bottom green lines. A

device with such a performance would be considered as a device that is functioning optimally and that does not need any maintenance work.

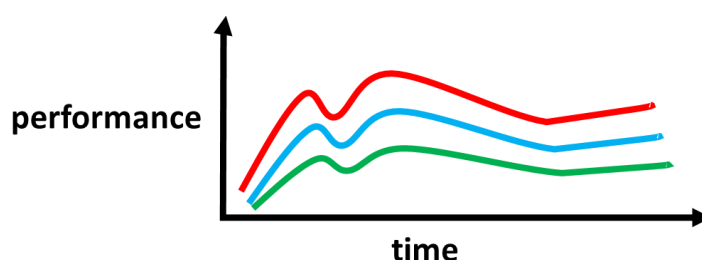


Figure 26: The normal performance curve of a device

In case the performance of the device is out of the ranges considered as “normal”, indicates that an anomaly is produced such as in Figure 27. Therefore, an immediate alarm is triggered, meaning that the device is not performing as expected and it needs maintenance work.

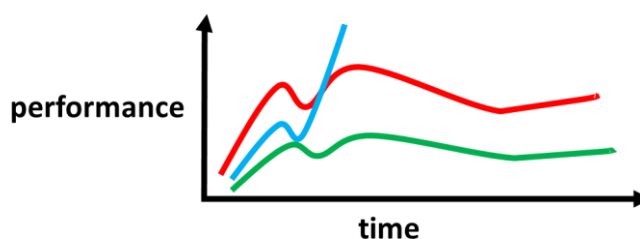


Figure 27: An anomalous performance curve of a device

There is also a third case where the performance of the device is not out of the “normal performance” range, but instead it does not follow the expected trend. In those cases (see Figure 28), even though the device is not malfunctioning, it can be considered to happen a degradation. Therefore, an alert is triggered.

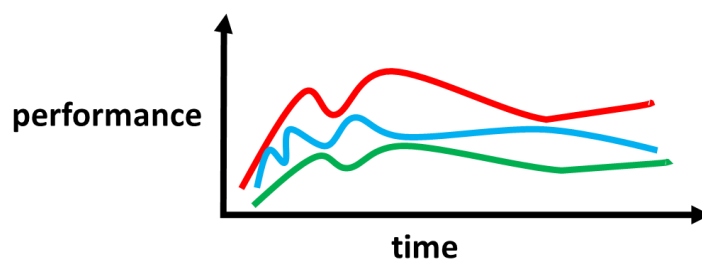


Figure 28: A performance not following the expected curve of a normal device

All in all, the goal of this service is to allow the early detection of anomalies in devices based on the statistical normal asset performance.

3.5 SEMANTIC REPOSITORY

The semantic repository will be in charge of storing all the metadata regarding the pilot sites, the test houses, the devices deployed and their capabilities among others. This information will be stored in a RDF Store, which is a data storage solution that makes data available for the future use. It is typical for an RDF data store to be accompanied by a parser and a serializer to populate the store and publish information from the store, respectively. Just as in the case for conventional (e.g., RDBS) data stores, an RDF store may also include a query engine to provide access to an RDF Store, much as an SQL engine provides access to a relational database. Just as in the case of conventional data stores, RDF stores are differentiated based on a variety of performance features, including the volume of data that can be stored, the speed with which data can be accessed or updated, and the variety of query languages supported by the query engine [24].

RDF store implementations range from custom programmed database solutions to fully supported off-the-shelf product from specialty vendors. In order to evaluate the performance of RDF stores, there are some RDF Benchmarks such as [25]:

- Berlin SPARQL Benchmark (BSBM) [26], provides for comparing the performance of RDF and Named Graph stores as well as RDF-mapped relational databases and other systems that expose SPARQL endpoints. Designed along an e-commerce use case. SPARQL and SQL version available.
- The SP2Bench SPARQL Performance Benchmark SP2B [27]: provides a scalable RDF data generator and a set of benchmark queries, designed to test typical SPARQL operator constellations and RDF data access patterns.
- Lehigh University Benchmark LUBM [28]: developed to facilitate the evaluation of Semantic Web repositories in a standard and systematic way. The benchmark is intended to evaluate the performance of those repositories with respect to extensional queries over a large data set that commits to a single realistic ontology.

After analyzing different RDF Store capabilities, finally the Stardog RDF Store was chosen. The rationale behind this decision is further detailed in *D4.1: Semantic information Model*.

3.6 EMS SYSTEMS

DEXCell Energy Manager is a cloud-based EMS (Energy Management System) developed by DEXMA, already installed in a huge data base of commercial buildings from approximately 37 countries throughout a network of more than 250 partners (mainly Building & Energy Managers). DEXMA's current market solution provides energy audits and efficiency recommendations together with analytics, reports and alarms to Energy Managers and Building Managers that handle mid-sized and large enterprises in various industrial and service sectors.

DEXCell already has an open API [29] that is based on REST architecture and that uses HTTP requests & JSON formatting. The API is secured using token authentication & authorization.

Its fitting within RESPOND architecture is clear, it will act as the central node integrating all the key technology tiers of the RESPOND platform. Its functionalities and capabilities will be integrated and used as much as possible, it will do the following:

1. Gather real time and import historical (field level) data of the 3 pilot sites from the MQTT broker by means of a subscription.
2. Display analytic services outcomes such as Demand and Production forecast, predictive maintenance, optimized control etc. that could be retrieved using DEXMA's API.
3. Feed the mobile app with the information that it requires to show the user via DEXMA's API:
 - a. Social ranking
 - b. User profiles
 - c. Energy conservation opportunities

3.7 VISUALIZATION

The RESPOND architecture needs to develop some components to visualize the gathered information. Next, they are described.

3.7.1 DESKTOP DASHBOARD

Based on DEXCell's current features and new ones that will be developed, DEXCell Energy Manager (from now on, referred to as DEXCell EM) will be the tool used within the RESPOND framework to provide advanced visualisation capabilities of the system to deliver relevant information to the building managers and building inhabitants in real time. This information will be delivered to the end user in an intuitive, understandable and personalized way as shown in Figure 29.

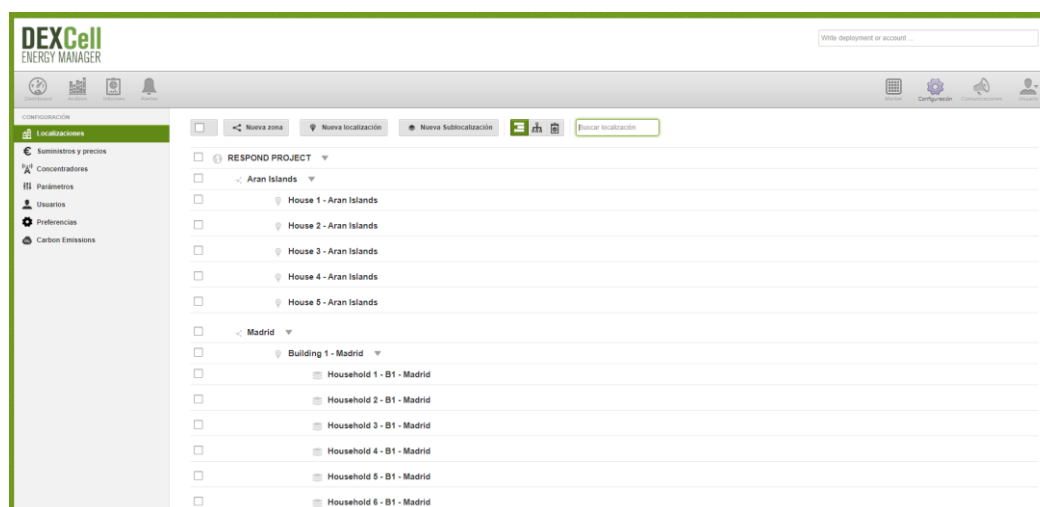


Figure 29: Hierarchy of the different buildings show to the user in DEXCell EM for Respond project

Moreover, DEXCell EM would provide inputs to the performance of the buildings such as number of occupants, weather data, insights into the past, current, and forecasted energy demand. This might help into the performance in terms of energy /cost savings achieved by DR programs.

Next, a more detailed view of the display of these functionalities will be shown:

- Figure 30 shows an example of how weather data (Temperature) is displayed for a building in Madrid.

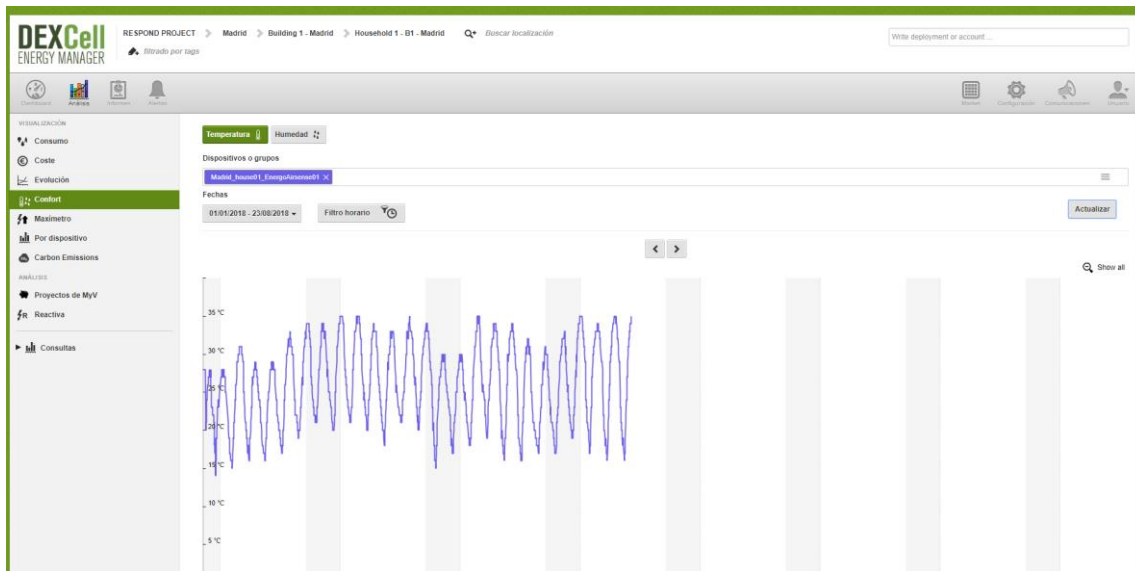


Figure 30: Example of how weather data is displayed in DEXCell EM for a house in Madrid's pilot currently (Respond project)

- Figure 31 shows the monitoring data for a building/neighbourhood within a new user interface. The end user will be able to select the dates, the frequency and the devices whose data wants to be checked. This interface will also allow to apply some ratios to normalize the energy consumption such as surface, heating degree days, cooling degree days, occupancy etc.

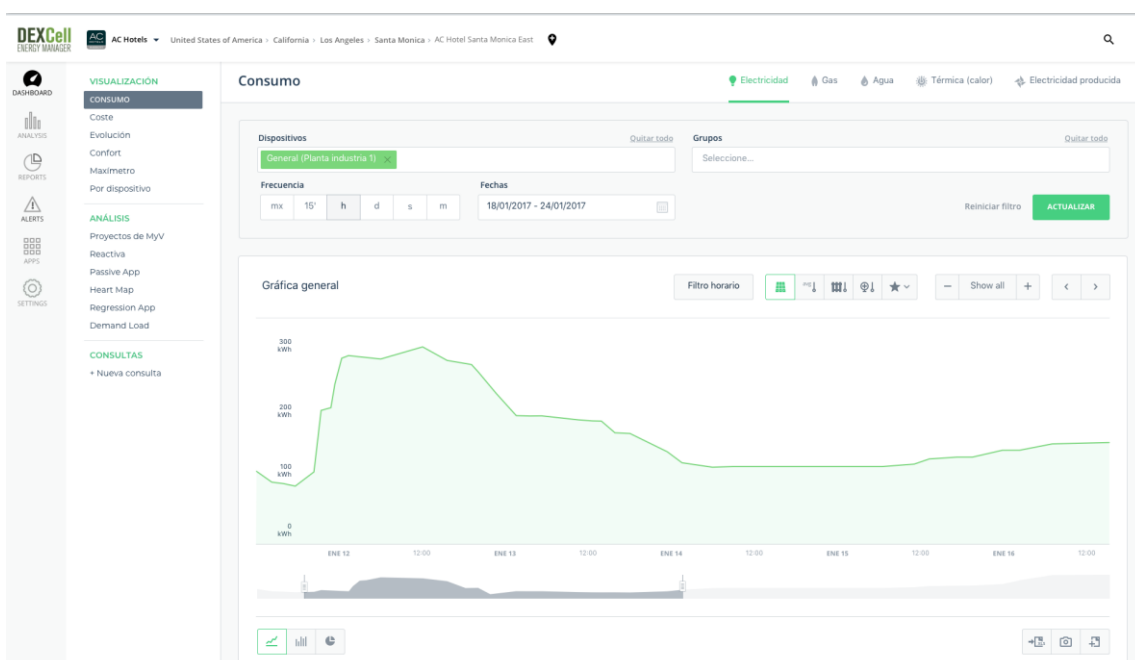


Figure 31: Mock-up of how energy demand will be shown in Respond solution

- The performance history will be shown by means of Measure and Verification projects (Figure 32). This functionality will allow the user to verify and validate the savings obtained thanks to an energy efficiency improvement, that could be recommended by RESPOND solution (analytical service such as predictive maintenance, production & demand forecast etc.) to improve the performance of the buildings under DR programs.

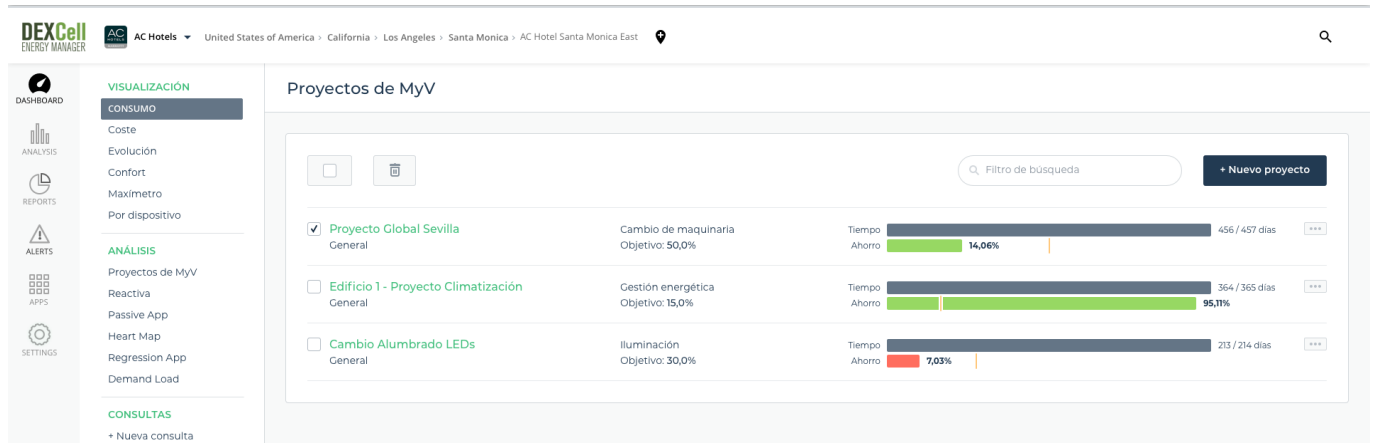


Figure 32: Mock-up of how performance history of a building will be show.

- Another functionality of the DEXCell EM will be to provide a global overview of the whole portfolio of buildings that are managed by a facility manager. To do so, DEXCell EM will provide a functionality of dashboards that will allow the user to check on a quick way several variables that will be vital for RESPOND's project, for example:
 - Energy consumption
 - Energy production
 - Weather data
 - Energy cost
 - Comparison between buildings and their average/best performance.

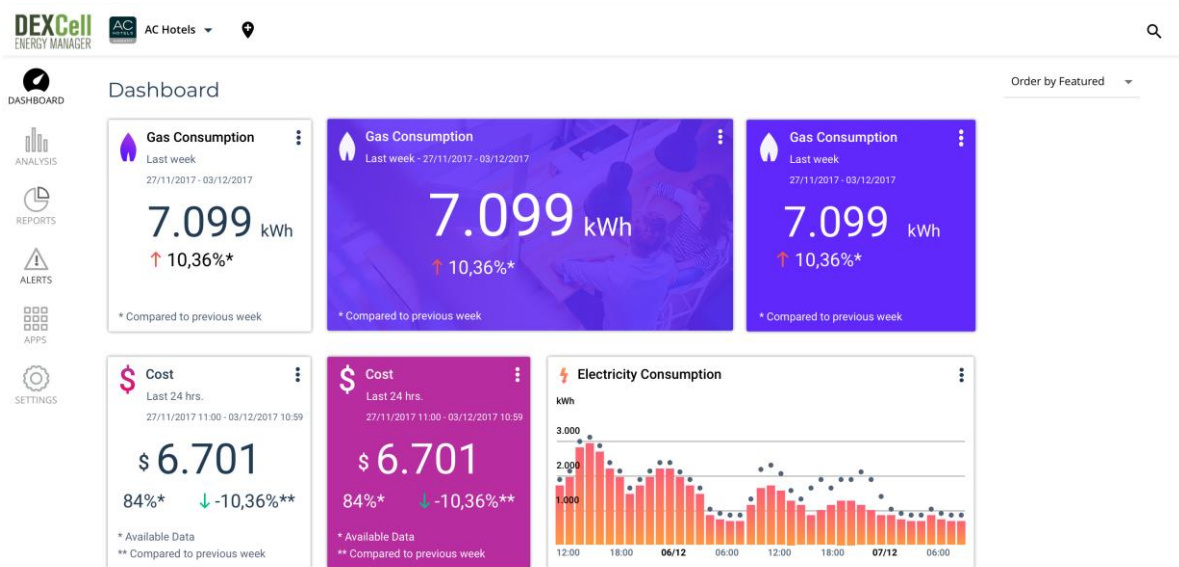


Figure 33: Mock-up of how dashboard functionalities will be display to the facility manager.

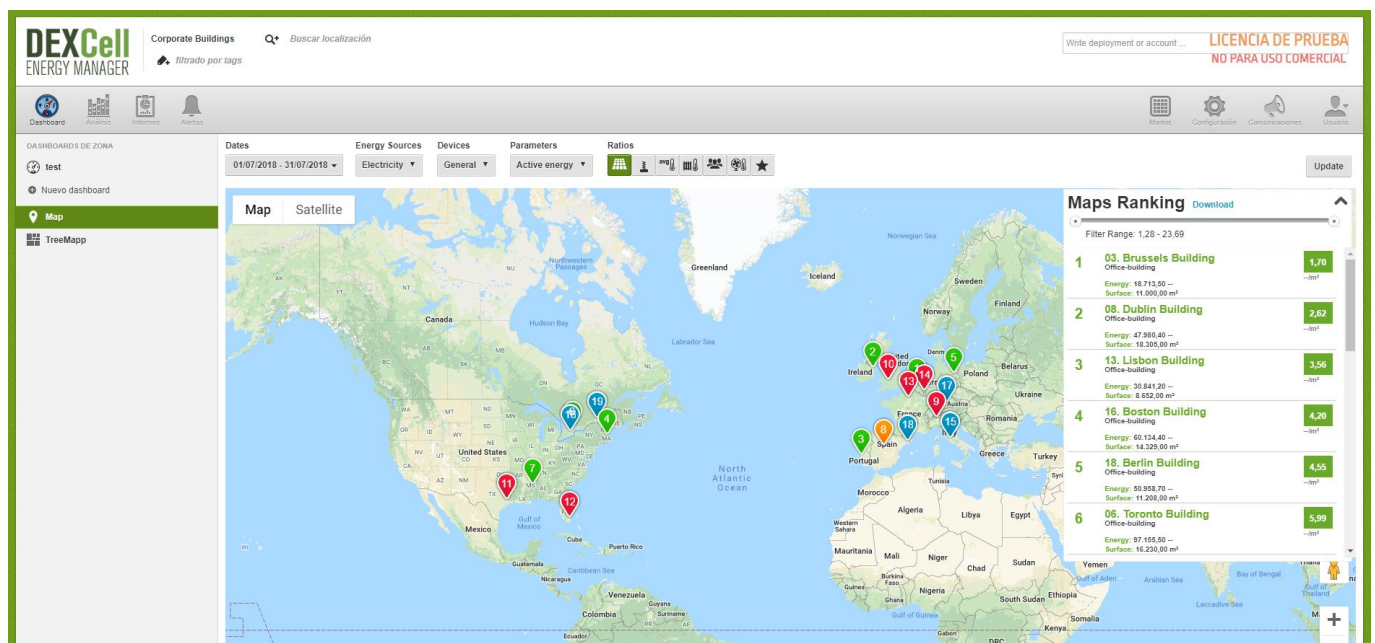


Figure 34: Mock-up of how comparison among buildings will be display to the facility manager.

3.7.2 MOBILE APPLICATION

The mobile app will be the instrument RESPOND users will account on to visualize all the relevant data regarding their appliances or consumptions. The mobile app uses HTTP requests to retrieve the necessary information from each service.

The DEXCell EM platform, which contains information about efficiency recommendations, analytics or reports, counts on a REST API for communicating. In order to visualize building topology information, the mobile application needs to retrieve that information from the semantic repository. As mentioned before, the Semantic Repository will be based on Stardog. Stardog offers an HTTP API [30] that will be used to make SPARQL queries through HTTP requests. The results of those SPARQL queries will be adequately parsed in order to provide users with results that are easy to understand. As for when the mobile app needs to visualize advanced information, the analytic services stack will be leveraged. Depending on what data is needed, the corresponding analytic service will be accessed. Each one of them will enable HTTP requests via web services. Furthermore, analytic services generate notifications which are sent to the mobile app via push messages.

The mobile application design and implementation details are further extended in *D3.4: Personal energy performance assistant design*.

3.8 EXTERNAL INTERFACES

RESPOND platform will be connected to external providers such as DR aggregators or third-party services by means of an open Application Programming Interface (API). This connection will be the extension of third party business processes and their further integration into smart grid products and services. Allowing an open API for integration makes RESPOND solution scalable, thus attracting future customers and improving market's penetration.

3.8.1 SMART GRID

The architecture model will describe and enable the service integration through the internal and external physical and functional interfaces, the development of the application services, and the user interfaces. With regards to Smart Grid external interfaces, in order to ensure long-term interoperability, RESPOND will take leverage of open interoperability standards. Main contribution of RESPOND in this regard, can be summarised as follows:

- Ensured interoperability through the concept of Open API which will enable exploitation of external services (such as energy pricing, weather data, etc.), but also put core RESPOND features at disposal to third party services.
- Open API concept will be deployed in a web-service manner providing interface for bidirectional communication with smart grid services.
- Long-term connectivity with smart grids based on open (interoperability) standards and specifications.

In the following sections, preliminary findings about these concepts will be described. The technical developments of this concepts will be carried out during *T5.2: Smart grid connectivity*.

3.8.1.1 ENSURED INTEROPERABILITY THROUGH THE CONCEPT OF OPEN API

With regards to the Open API, RESPOND's architecture will enable the integration of well-known external resources to provide key parameters for smart grid operation such as weather data and energy pricing. While traditional business partnerships and product integrations are often time-consuming and expensive to create and maintain, the open API model will be designed for nearly effortless, asymmetric scaling in many simultaneous new directions. It will attract government, industry, energy providers and consumers, but most of all, it will help RESPOND gaining advantage and achieving momentum in market penetration.

As for the research carried out during the first months of the project and the previous experience provided by RESPOND partners in the smart grid field (such as DEXMA, TEK and IMP), the following data providers have been selected in a first attempt. This preliminary subset of data providers will be extended during the implementation of T5.2 following an agile development approach. The development process will include the creation of the Open API functionality taking into consideration the technical requirements imposed by these third-party data providers, as well as the ongoing standardization processes taking place in the European market.

3.8.1.2 ENERGY PRICE DATA

Energy price data external services such as ESIOS [31] for Spain, will allow users to import wholesale market prices into the RESPOND project based on the formula they have contracted with their supplier/aggregator. By means of this external source, RESPOND users will be able to know what represents its consumption/generation in Euros, importing real time pricing information directly from Red Eléctrica Española (Spanish TSO, so valid for the Spanish and for testing purposes in Irish and Danish pilots).

The preliminary design of this external service envisages the following functionalities:

- Prices start to be calculated at 22h of the previous day.
- Prices are being consolidated as soon as Red Eléctrica Española updates its prices.
- Prices based on the information available in Red Eléctrica de España.
- Once the prices are imported, RESPOND users will be able to use them in the different analytic and operation services enabled in the platform.

Figure 35 shows the available information in the ESIOS platform, which is also available through an open interface for system integration purposes. During the implementation of T5.2, similar data sources will be taken into consideration for Irish and Danish pilots. Namely, for the Denmark Pilot site, Nord Pool service will be used. Nord Pool runs the leading power market in Europe, and offers day-ahead and intraday markets [32] as shown in Figure 36. As for the Irish electricity market price, it is provided by SMO (Single Energy Market Operator) [33] as shown in Figure 37.

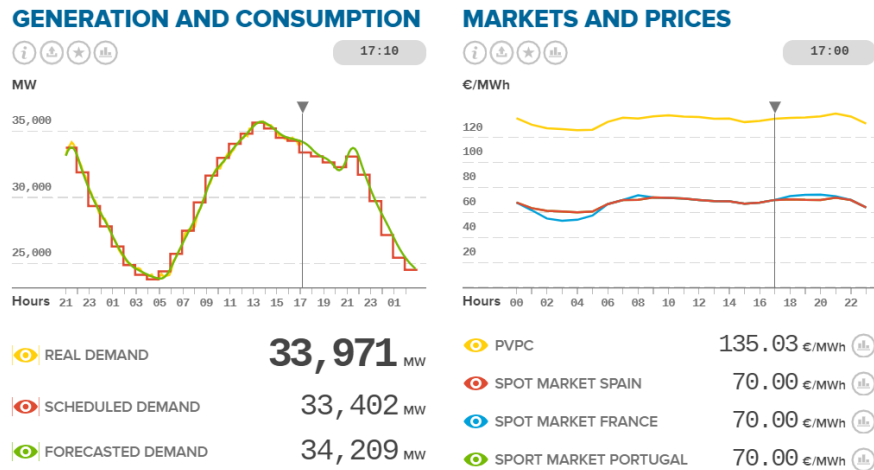


Figure 35: Spanish daily electricity market information

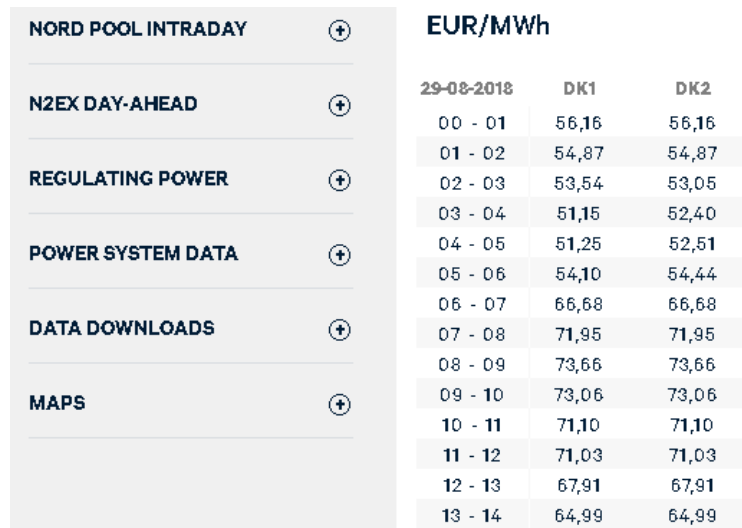


Figure 36: Danish daily electricity market information

The Single Electricity Market Overview 28th August 2018

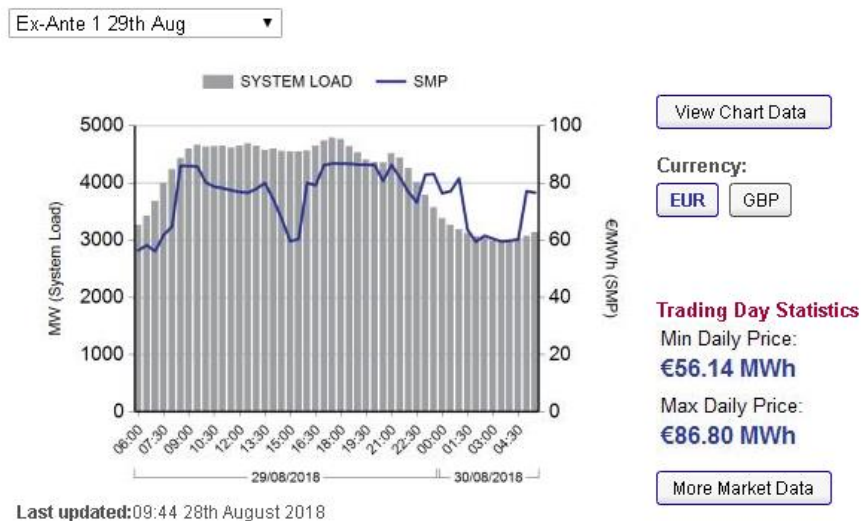


Figure 37: Irish daily electricity market information

3.8.1.3 BIDIRECTIONAL COMMUNICATION WITH SMART GRID SERVICES

The Aggregator has a central role in the RESPOND architecture. It gathers available flexibility information from RESPOND platform to provide flexibility services to third party electricity market players such as (BRPs, TSOs and DSOs). To offer flexibility, first the Aggregator must sign a contract with the Prosumer (respond user) to have access to its flexibility.

Within this context, the identification of the proper communication channels between aggregators and RESPOND users is of utmost importance. During the implementation of the architecture, a set of expert interviews were carried out, and has been complemented with the previous know-how of RESPOND project key technical partners. As a result of this process, OpenADR [34] has come up as the most suitable model to cover this need.

OpenADR stands for Open Automated Demand Response. It is an open and interoperable information exchange model and emerge Smart Grid standard developed by the OpenADR Alliance. This alliance was created to foster the development, adoption, and compliance of the proposed standard. The solutions based on OpenADR will standardize, automate, and simplify the use of Demand Response worldwide. It makes Demand Response a more reliable and cost-effective resource to help electric market actors coping with growing demand for energy, and giving Prosumers greater control over their energy.

One of the key advantages of OpenADR Alliance is its collaboration with the USEF Foundation (Universal Smart Energy Framework) [35], key player of demand response in Europe. USEF delivers the integrated market structure, the tools and rules for commoditization and trading of flexible energy use, as well as a universal framework to accommodate and monetize demand response. Both, OpenADR and USEF have been collaborating since November 2015. Together they have developed and added a USEF deployment scenario (shown in Figure 38) and three new Demand Response program templates to standardize the use of OpenADR within the USEF framework.

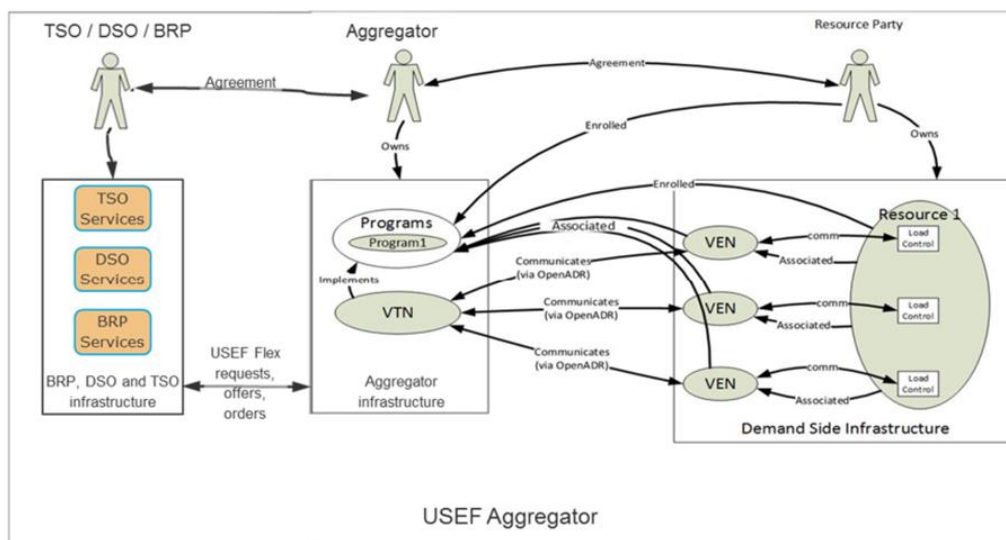


Figure 38: OpenADR and USEF deployment scenario

Nonetheless, as for the result of the market and technical assessment carried out, the field implementation of these models is still in a very early stage in Europe. Some players are taking it into consideration when doing DR pilots and developing commercial solutions, but there is still a lack of end-to-end standardization when dealing with DR interoperability. Therefore, the OpenADR-USEF framework will be taken into consideration when further developing the smart grid connectivity in T5.2, but RESPOND consortia will remain flexible in order to be able to make any required “customisation” for the project pilots and the interested stakeholders of the demand response sector (mainly aggregators, TSOs and retailers).

With regards to the technical implementation, after discussing it with some DR actors as well as with internal technology experts of the RESPOND project, MQTT messaging transport protocol has been selected as a first option. As described in previous sections, MQTT is the client server publish/subscribe messaging transport protocol in which the RESPOND architecture will rely on. It is light weight, open, simple and designed so as to be easy to implement. These characteristics make it ideal for use in many situations, including constrained environments such as for communication in Machine to Machine (M2M) and Internet of Things contexts where a small code footprint is required and/or network. These characteristics have turned MQTT protocol as one of the most interesting technologies to be used in the smart grid environment, and consequently is being widely adopted by some of the key demand response players in Europe. OpenADR-USEF principles will be used to define the interoperability between RESPOND and external demand response players, integrating its parameters and processes into the MQTT payloads and topics.

3.8.2 OPEN DATA

According to the Open Data Handbook [36], Open data is data that can be freely used, re-used and redistributed by anyone - subject only, at most, to the requirement to attribute and share alike. The full Open Definition gives precise details as to what this means [37]. To summarize the most important:

- **Availability and Access:** the data must be available as a whole and at no more than a reasonable reproduction cost, preferably by downloading over the internet. The data must also be available in a convenient and modifiable form.
- **Re-use and Redistribution:** the data must be provided under terms that permit re-use and redistribution including the intermixing with other datasets.
- **Universal Participation:** everyone must be able to use, re-use and redistribute - there should be no discrimination against fields of endeavour or against persons or groups. For example, ‘non-commercial’ restrictions that would prevent ‘commercial’ use, or restrictions of use for certain purposes (e.g. only in education), are not allowed.

In the RESPOND project context, Open Data has a big relevance. It is considered as a key external source of information that may enrich data received from assets and enable the development of applications and services. Open Data comes in heterogeneous data formats and following different schemas and models that are mainly defined by the data providers. Therefore, before exploiting that

Open Data information, it may be necessary to preprocess it and transform it to a predefined ad-hoc data model.

3.8.2.1 WEATHER DATA

Open Data is envisioned to be useful to get weather forecasts which has been proven to be crucial for the aforementioned Production Forecast and Demand Forecast services. The integration of this information will cover the need for some of the energy efficiency and DR projects that in the future will be managed by means of RESPOND platform to compare and forecast the facility consumption according to the external temperature (among other key weather parameters). In order to avoid hardware installation (temperature probes, weather stations, etc.) RESPOND is considering to offer the integration with WeatherBit [38] service where, just configuring the location post code, RESPOND integration will provide a list of the closest weather stations available. Later, the user will get data from these weather stations every 15 minutes, for temperature, humidity, and/or other parameters required for its day by day energy operation.

These meteorological datapoints will be available for one or more energy projects within RESPOND. From a technical perspective, WeatherBit's scalability and simplicity of implementation are one of its main advantages, together with its notable accuracy – checked by DEXMA through comparisons made within real measurements and other well-known on-line weather data resources such as SolarGis [39]. WeatherBit service will be able to include, among others, the following information for RESPOND users:

- Historical data from their network of 38.000 weather stations reporting hourly weather data. This is hourly historical data, and a request will return data from the nearest reporting station.
- 48 h Forecast data in one-hour interval from any point in the planet.

Figure 39 shows some of the data that can be retrieved in both WeatherBit calls (historical and forecast). This represents highly relevant data for the RESPOND platform, such as solar irradiation, temperature and wind speed.

- `lat`: Latitude (Degrees).
- `lon`: Longitude (Degrees).
- `timezone`: Local IANA Timezone.
- `city_name`: City name.
- `country_code`: Country abbreviation.
- `state_code`: State abbreviation/code.
- `data`: [
 - `datetime`: Date UTC (YYYY-MM-DD:HH).
 - `ts`: Timestamp (Unix Timestamp).
 - `pres`: Pressure (mb).
 - `slp`: Sea level pressure (mb).
 - `wind_spd`: Wind speed (Default m/s).
 - `wind_dir`: Wind direction (degrees).
 - `wind_cdir`: Abbreviated wind direction.
 - `wind_cdir_full`: Verbal wind direction.
 - `temp`: Temperature (default Celcius).
 - `app_temp`: Apparent/"Feels Like" temperature (default Celcius).
 - `rh`: Relative humidity (%).
 - `dewpt`: Dew point (default Celcius).
 - `clouds`: Cloud coverage (%).
 - `pod`: Part of the day (d = day / n = night).
 - `weather`: {
 - `icon`: [Weather icon code](#).
 - `code`: [Weather code](#).
 - `description`: Text weather description.
- `...]`

Figure 39: List of parameters provided by WeatherBit cloud provider

Besides, from a business point of view, the cost of WeatherBit to the end customer is very low, which makes it even a more advantageous solution to be taken into consideration in RESPOND project.

4. CONCLUSIONS

In this document, RESPOND system's final architecture is described. This architecture is the cornerstone of the RESPOND system, as it ensures the correct communication of the different components and therefore, the correct functioning of the whole system.

After a period of conversations between the different partners, the design of a distributed architecture has been agreed, in which each of the involved partners' expertise in different areas is reflected.

The analysis of existing standards has been crucial to agree the design of an architecture with views to ensuring component interoperability and integration. The MQTT broker component and the energy gateway, have contributed to provide the RESPOND system with capabilities of adaptation to standard systems, as well as to proprietary ones. Furthermore, the architecture is also designed as an extendable one, where additional external sources can be incorporated to the system, and new services or functionalities can be generated and added.

The incorporation of the semantic repository is another added value of the architecture. Being based on well-known ontologies, the semantically annotated data with a common vocabulary, opens a whole range of possibilities for data analysis and linkage with other existing Linked Open Data repositories.

The brain of the system is located in the analytical services. This set of services will combine several technologies to generate useful information for decision support and for automatizing actions that will help to the occupants or facility managers to adequate their demand to the generation. The interactions between these modules are complex and they will be extended and refined in WP4 to achieve the ICT enabled cooperative demand response model.

Last but not least, thanks to having a decoupled the back-end and front-end, the generation of new user interfaces is facilitated. These interfaces should ideally be adjustable to multiple device, and adaptable to the role of DR participants.

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D2.2: Integration of key RESPOND technology tiers

D3.4: Personal energy performance assistant design

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