RESPOND

DEMAND RESPONSE FOR ALL

Integrated Demand Response Solution Towards Energy Positive Neighbourhoods

WP6 Validation and replication of project results

T6.2 Validation analysis and reporting

D6.2 Validation analysis of operation scenarios

The RESPOND Consortium
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EXECUTIVE SUMMARY

Task 6.2: This task is targeted to collect and analyse all the data produced in the pilot tasks and by operation scenarios. The quantitative and qualitative information provided by the devices, installers, energy managers and end consumers was treated in order to produce this demonstration and validation report that details the on-site results achieved by the RESPOND project.

Validation analysis has been carried out by monitoring the performance of installed and integrated RESPOND solution for baseline and reporting periods of 12 months. It has included the system evaluation through a set of unit and software tests performed under controlled conditions and during operation scenarios at project pilots. The validation compared also the performance of households in and out of the DR programs tested in the project. Performed analysis has been leveraged upon the methodology devised in Task 6.1, and exploit IPMVP (ISO/DIS 17741) and eeMeasure ICT PSP validation methodology and roadmap. One of the outcomes of this task has been the documentation of the best practices that has been further exchanged through the identified dissemination means and reported for exploitation channels in WP7.

Purpose: This report presents a validation analysis of the RESPOND project. The document is divided in three parts: The first one describes the scenarios updates after the final installation, data sources for the validation process and a description of the demand response events defined for each pilot. The Second part shows the validation process of the RESPOND project, including the analysis of the KPIs related to the Use Cases quantitative analysis. The third and last part of the document shows the project results, a discussion about the results and conclusion.

The inputs from previous RESPOND deliverables are described below:

- ➔ WP 01 - Deliverables 1.1 [1] - 1.4 [2]
- ➔ WP 02 - Deliverable 2.1 [3] - 2.5 [4]
- ➔ WP 04 – Deliverable 4.4 [5] - 4.5 [6]
- ➔ WP 05 - Deliverable 5.3 [7]
- ➔ WP 06 - Deliverable 6.1 [8] – 6.3 [9] - 6.5 [10]

Key findings and Conclusion:

USE CASE 01 - IMPACT OF THE RESPOND APP TO THE USER
The energy consumption and CO_2 emissions increased by 6.8% in the Madrid pilot. Aarhus and Aran Islands pilots presented a reduction of 4.7% and 20.2%, respectively. The air quality for Aran and Madrid presented enhancements, staying in the category III of prEN15251.

USE CASE 02 - IRELAND - MAXIMIZE AUTO CONSUMPTION CONTROL SWITCHES FOR APPLIANCES
The energy consumption and CO_2 emissions decreased by 17.8% over the use case period. Regarding renewable consumption, on average 72.7% of the PV production was consumed in test case 01, and 79.6% in test case 02. Rescheduled demand had the best results in test case 01, with a 30% demand increase during the event hours. Compared to the baseline, 20% less energy from the grid was necessary to perform the actions.

USE CASE 03 - IRELAND - PV PANEL – OPTIMAL PROFILE OF USE FOR HEAT PUMPS
The energy consumption and CO_2 emissions decreased by 29.7% over the test case. The rescheduled demand shows that the optimized model presented 54% more load activity in the event period, with renewable energy consumption 39.1% higher compared to the baseline.

USE CASE 04 - IRELAND - PEAK SHAVING USE CASE

The energy consumption and CO_2 emissions decreased by 14.73% over the use case period, which may be related to the COVID-19 (people staying home due to the restrictions). Rescheduled demand and peak load remained steady.

USE CASE 05 - DENMARK - LOAD SHIFTING DISTRICT HEATING SYSTEM

The energy consumption and CO_2 emissions decreased by 14.36% on average in the participant houses over the use case period. The test case performed in the last two weeks of the use case achieved even more savings, reaching 27.46%. Peak load reduction of up to 50% was achieved in some of the week periods.

USE CASE 06 - DENMARK - MAXIMIZE AUTO-CONSUMPTION FROM GRID CONNECTED PV PANELS

Total renewable energy consumption achieved up to 12.18% of increase over the use case period. The rescheduled demand analysis showed a 16.33% of more load activity in the event hours.

USE CASE 07 - MADRID - PRICE BASED DR FOR ELECTRICAL ENERGY CONSUMPTION

The energy consumption and CO_2 emissions were steady over the use case period, compared to the baseline. A peak reduction of 36.5% on average was achieved across the different test cases.

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INTRODUCTION

Deliverable 6.2 is a report created by NUIG in collaboration with ARAN for Ireland AURA, ALBOA and AAU for Denmark and FEN and TEK for Spain for describing the data collection and validation process for RESPOND project. As many projects have ambiguous outcomes or do not directly lower an energy bill [11], the validation process for RESPOND project uses concepts of IPMVP options C and D. Option C as a before-after comparison, were regression analyses with real data can be applied and D during the calibrated simulations.

The IPMVP was designed explicitly for projects in the industrial sector, those with annual consumption levels of over 1,000,000 kWh. Some parameters such as demand response and avoided CO_2 emissions are not considered in the IPMVP protocol and this is where extensions are required. [12] This way, the ICT-PSP methodology for energy saving measurement - ee-measure residential methodology is also referenced for guarantee that all the project aspects are covered.

KPIs, in general, measure the effectiveness of a project towards the achievement of specific key objectives. In general, indicators should express as precisely as possible to what extent an aim, a goal or a standard has been reached or even surpassed. [13] In RESPOND project, the KPIs are related to the project use cases and objectives. This way, after the use cases application, KPIs will be analysed guaranteeing the achievement of project goals.

Report structure:

<u>Section I</u> – Demonstrated solution

The main objective of the section I is to describe the final status of each pilot. Describing topics such as final layout of service integration, architecture of the system, monitoring points updates, final number of households, data sources, description of the demand response events, characteristics of the use cases realization for each pilot and baseline. The aim is to show the final attributes of the pilots when the project validation was applied.

<u>Section II</u> – Validation

Section II is going to show how the validation process was applied. Describing points such data analysis in each pilot (data sources, system and obstacles) and the KPIs calculation for each use case. The main objective is to describe all the validation process in a way that can be replied in other demand response projects in the future.

<u>Section III</u> – Conclusion

The results are going to be shown in section III. With some comments about the achievements of each use case, the conclusion brings final thoughts regarding statistical analysis and KPI results.

1. DEMONSTRATED SOLUTION

The RESPOND project architecture was designed to be scalable and replicable in other future similar demand response projects. This section presents information about the main components involved in the demonstrated solution, including the device lists, the direct and indirect services, and the KPIs applied for each of the pre-defined use cases. Since the project has evolved and some characteristics may have changed since the first deployment, this section shows the final architecture and user's appliances found in the pilot sites, as can be seen summarized in Table 1. Moreover, a description of the characteristics of each use case in the pilots with an explanation regarding the demand response events and test period is provided. Finally, the section provides a data collection description and the KPI calculation methodology, following the criteria defined on deliverable 6.1 [8].

Table 1 - Number of dwellings and Measurements points per pilot

	Dwellings	Devices[1]
Ireland – Aran Islands	9 houses	• Dishwasher • Electricity Meter • EV Charger • Heat Pump • PV Panel • Sensor CO_2 • Sensor humidity • Sensor temperature • Tumble Dryer • Washing Machine
Denmark - Aarhus	20 houses	• Heat Meter • Electricity Meter • Dishwasher • Washing Machine • Thermostat • Tumble Dryer • Lamp • Printer • IT • Sensor temperature • Sensor humidity
Spain - Madrid	11 houses	• Electricity Meter • Air Conditioner • Stove Oven • Sensor CO_2 • Washing Machine • Dishwasher • TV • Water Meter

[1] Not all the devices are available for all houses

1.1 PILOT DESCRIPTIONS

The final list of sensors in the houses changed over the three years of the project, aiming to best meet users' needs or tackle technical challenges. The next subsections present a brief description of the pilot sites and the list of sensors installed in each of their respective houses, which were used in the validation process.

1.1.1 IRELAND

The location of the first pilot site is on Inishmore, the largest of the three Aran Islands in the mouth of Galway Bay. With a population of approximately 800 people, the island itself is very exposed to the weather elements, particularly during the winter months as it has very little shelter. The islands, which are very popular with tourists, especially in the summer season, are very isolated and have little in the line of services that one might see in some of the other pilot areas [1].

The islands are connected to the mainland through a subsea cable. In 2017, Aran alone imported from the mainland 1,855 MWh of electricity. In 2016, a fault in the sub-sea cable resulted in a power outage on two Aran islands lasting for four days and affecting nearly 400 residents. Islanders had to rely on local diesel-powered generators. The blackout demonstrated the negatives of islands' dependency and resumed a conversation about carbon-neutrality and renewable energy generation [14].

With this in mind, four use cases were applied in the Irish pilot, in which three of them were specifically designed to fit the Aran Islands requirements and also to provide information about the effect of demand response on the participants. The final topology of the project in the islands contains 9 houses and 114 sensors. These sensors are divided into the sections described in Table 2:

Table 2 – Aran Islands - Description of measurement points per House

	Dishwasher	ElectricityMeter	EVCharger	HeatPump	PVPanel	TumbleDryer	WashingMachine	sensor_temperature	sensor_humidity	sensor_co2	Grand Total
Aran_01	1	1		1	1	1	1	3	2	1	12
Aran_02		1		1	1	1	1	5	5	1	16
Aran_03	1	1		1	1	1	1	5	2	1	14
Aran_04		1		1	1	1	1	4	1		10
Aran_05		1		1	1	1	1	5	2	1	13
Aran_06		1		1			1	5	2	1	11
Aran_08	1	1	1	1		1	1	5	2	1	14
Aran_10	1	1		1				5	2	1	11
Aran_12		1		1	1	1	1	5	2	1	13
Grand Total	**4**	**9**	**1**	**9**	**6**	**7**	**8**	**42**	**20**	**8**	**114**

1.1.2 DENMARK

The danish pilot site is located in Aarhus. It is the second-largest city in Denmark with 315.00 citizens. At present, the population is growing with approx. 5000 new citizens every year. It's a city with a large building activity. Aarhus is an innovative city, characterized with a lot of students and the largest container port in Denmark. Aarhus University is placed in the city and has more than 40.000 students. In 2017, Aarhus was the European Capital of Culture [1]. The final topology in the pilot consists of 20 houses and 394 sensors. The number of sensors per house is described in Table 3.

Table 3 - Aarhus - Description of measurement points per House

	Dishwasher	ElectricityMeter	HeatMeter	IT	Lamp	other	Printer	Thermostat	TumbleDryer	WashingMachine	sensor_temperature	sensor_humidity	Grand Total
Aarhus_01	1	1	1			2		11		1	4	4	25
Aarhus_02	1	1	1			2		11		1	4	4	25
Aarhus_03	1	1	1		2			12	1	1	4	4	27
Aarhus_04	1	1	1			2		11	1	1	4	4	26
Aarhus_05	1	1	1			2		11	1	1	4	4	26
Aarhus_06		1	1		1	1		12		1	4	4	25
Aarhus_07	1	1	1			2				1	4	4	14
Aarhus_08	1	1	1			2		12		1	4	4	26
Aarhus_09	1	1	1			2		11	1	1	4	4	26
Aarhus_10	1	1	1			2			1	1	4	4	15
Aarhus_11	1	1	1			1		11			4	4	23
Aarhus_12	1	1	1			1	1			1	4	4	14
Aarhus_13	1	1	1			2				1	4	4	14
Aarhus_14	1	1	1			2				1	4	4	14
Aarhus_15	1	1	1			2		11		1	4	4	25
Aarhus_16	1	1	1			2				1	4	4	14
Aarhus_17	1	1	1	1		1				1	4	4	14
Aarhus_18	1	1	1			2					4	4	13
Aarhus_19	1	1	1			2			1	1	4	4	15
Aarhus_20	1	1	1		1					1	4	4	13
Grand Total	**19**	**20**	**20**	**1**	**4**	**32**	**1**	**113**	**6**	**18**	**80**	**80**	**394**

1.1.3 SPAIN

The third pilot site is located in an urban area near to Madrid city centre. This city of 3.2 million inhabitants in the centre area and more than 6 million including the metropolitan area enjoys a mainland Mediterranean weather with soft winters and few rainfalls. As the country's capital, it is a modern and dynamic city with a strong presence of services and industries. The final topology of the site contains 11 houses, three meter-rooms and one boiler-room, totalizing 264 measurement points that are described in Table 4. Madrid_00 to Madrid_13 represent the apartments, while the other designations belong to meters in the common areas.

Table 4 - Madrid - Description of measurement points per House

	AirConditioner	Dishwasher	ElectricityMeter	StoveOven	TV	WashingMachine	WaterMeter	sensor_temperature	sensor_humidity	sensor_co2	Grand Total
Madrid_00	1	1	1	1	3	1		5	4	3	20
Madrid_01	1	1				1		2	1		6
Madrid_02	1	1				1		3	2	1	9
Madrid_03	1	1				1		3	2	1	9
Madrid_04	1	1				1		3	2	1	9
Madrid_05	1	1				1		3	2	1	9
Madrid_06	1	1				1		3	2	1	9
Madrid_07	1	1				1		3	2	1	9
Madrid_10	1	1				1		3	2	1	9
Madrid_12	1	1				1		3	2	1	9
Madrid_13	1	1				1		3	2	1	9
BoilerRoom_CostaRica_17							138				138
MeterRoom_CostaRica_17			8								8
MeterRoom_CostaRica_19			7								7
MeterRoom_CostaRica_21			4								4
Grand Total	**11**	**11**	**20**	**1**	**3**	**11**	**138**	**34**	**23**	**12**	**264**

1.2 DATA COLLECTION

The data collection is divided in two main topics, the qualitative and the quantitative evaluation. Both approaches are described in the following sections.

1.2.1 QUALITATIVE DATA COLLECTION

The qualitative data collection was realized by the pilot's representatives and the results analysed by AAU. The main idea of the qualitative data collection was to understand the user's experiences of the use cases based on interviews, focusing on gathering the most important aspects to improve the RESPOND platform. The initial approach was to have focus groups with in-site visits for collecting feedback from the participants. However, due to the coronavirus crisis, the approach changed and data were collected remotely via online/ phone call interviews.

- **Aran Islands**: The interviews were realized by ARAN by phone.
- **Aarhus**: The interviews were realized by AAU using online platforms.
- **Madrid**: FEN realized the interviews with the participants by phone.

The information about the qualitative analysis present in this document aims to give a context about this part of the validation process. The related assessment and results, including the complete methodology, can be found in RESPOND Deliverable 6.3 [9]. Additionally, topics about lessons learned and recommended improvements from information collected in the interviews can be found on Deliverable 6.5 [10].

1.2.2 QUANTITATIVE DATA COLLECTION

The quantitative data collection was used in the validation process to ensure that RESPOND project objectives have been achieved, through the calculation of the project KPIs defined on Deliverable 6.1 [8]. Due to its architecture, there are different ways to analyse data from the sensors in the RESPOND project. The data collection architecture is described on previous project deliverables, and a technical description can be found on section 03 of Deliverable 2.1 [3]. Figure 1 shows the interaction of the main components within this architecture.

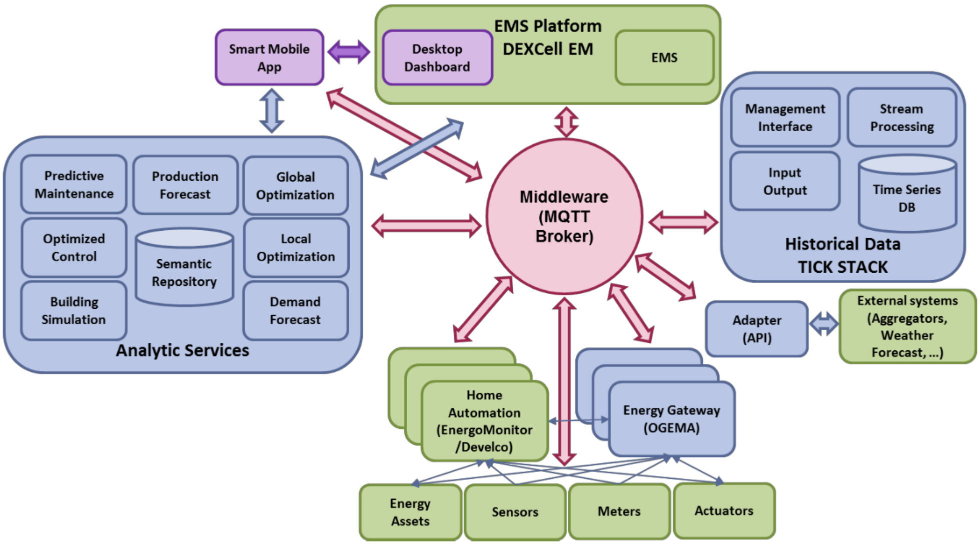


Figure 1 - RESPOND project architecture [3]

For assessment purposes, information from all repository platforms has been used. The detailed data collection is described on the respective use case topic on Section 2 – Validation process. The baseline definition was done based on the characteristics of each pilot and each use case. The variables/devices collected are all described in deliverable 1.1 [1] and a summary can be also found on Table 1.

1.3 USE CASES DESCRIPTIONS

The RESPOND project has 8 different use cases that started to be realized in November 2019 and finished in August 2020. The demand response events were created considering the specific characteristics of each pilot. For more information about the demand response actions and the validation analysis for each pilot site, please refer to table 1 of Deliverable 1.4 [2], where the validation approach for each scenario can be found. Also, the detailed information about use cases can be seen on deliverable 6.1 [8].

Table 5 summarizes the main aspects of each use case, such as start and finishing dates, houses participants, objectives and operation. Furthermore, the main components directly and indirectly involved over the validation process are presented, following three major categories:

- Devices: related to installed equipment (sensors, meters, actuators) described on deliverable 1.4 [2].
- Core Services: related to the RESPOND services described in deliverable 4.5 [6].
- KPIs: related to the validation KPIs described in deliverable 6.1 [8].

Use Case Description

UC 01 - IMPACT OF THE RESPOND APP TO THE USER

Objective: To verify if customers change their energy usage behaviour after having access to the data in the RESPONSE app.

Operation: The scenario is based on which modifications the customers made in their routine after having access to the data and app dashboards.

DR description: Energy consumption reduction.
DR type: Implicit.

Pilot: Spain, Denmark and Ireland.
Participating houses: All houses.

Event start: 13/04/2020
Event ends: 31/05/2020

Precondition: The participant has access to the RESPOND app.

Components:

Devices (D1.4)	Core services (D4.5)	KPIs (D6.1)
- CO_2 Sensor (ENE) - Humidity Sensor (ENE) - Smart plugs (DEV/ENE) - External Meter Interface (DEV/ENE) - Gateway (DEV/ENE)	- RESPOND APP (TEK) - Monitoring (DEV/ENE) - Production Forecast (IMP) - Optimization (IMP) - Data Repository (TEK/IMP) - User Adapter (TEK)	- Energy Savings - Reduction of greenhouse gas emissions - Communication performance - Indoor air quality

UC 02 - MAXIMIZE AUTO CONSUMPTION CONTROL SWITCHES FOR APPLIANCES

Objective: Increase the energy usage in days with high PV production.

Operation: The customer receives a message asking for using more energy during a certain period.

DR description: Maximize PV self-consumption (House level).
DR type: Implicit.

Pilot: Ireland
Houses participating: Houses: 01, 02, 03, 04, 05 and 12 (all with PV production).

Event start: 31/05/2020
Event ends: 31/08/2020

Precondition:
Case 01: 01/06/2020 → 30/06/2020
- PV production forecast for at least 900Wh for all houses.
- During the test 01 period, the message was sent with the information about the hours that the production was supposed to be above the pre-defined threshold.

Case 02: 18/07/2020 → 31/08/2020
- 600 W for Aran01, Aran03, Aran04, Aran05, Aran12 and 1100W for Aran02 for summer period.
- During the test 02 period, the message was sent when a minimum threshold was achieved during the day. The hours defined on the message was one hour before and one hour after the maximum point of forecasted production curve during the day.

Components:

Devices (D1.4)	Core services (D4.5)	KPIs (D6.1)
- Smart plugs (ENE) - External Meter Interface (ENE) - Electricity wire for PV (ENE) - Gateway (ENE)	- RESPOND APP (TEK) - Monitoring (ENE) - Production Forecast (IMP) - Demand Forecast (TEK) - Data Repository (TEK/IMP) - User Adapter (TEK)	- Renewable total energy consumption - Reduction of greenhouse gas emissions - Rescheduled demand - Analytical services accuracy - Economic savings during the DR event - Coefficient of performance - Communication performance - DR campaign penetration

UC 03 - OPTIMAL PROFILE OF USE FOR HEAT PUMPS

Objective: Increase the energy usage by using the heat pump during the period of high PV production.

Operation: In the days of the month that the PV production prediction achieved at least 600 W, a remote command should be sent to the heat pumps to activate them. Due to coronavirus restrictions, the remote control was not installed in the Aran Islands. Instead, a simulation using the Building Simulator and real data was performed to estimate the results for this use case.

DR description: Increase the use of the heat pump during the period of PV production peak.
DR type: Explicit/Implicit.

Event start: 01/08/2020
Event ends: 31/08/2020

Pilot: Ireland.
Houses participating: House 04.

Precondition: The PV production prediction should achieve at least 600 W in the day.

Components:

Devices (D1.4)	Core services (D4.5)	KPIs (D6.1)
- External Meter Interface (ENE) - Electricity wire for PV (ENE) - Electricity wire for Heat Pump (ENE) - Gateway (ENE)	- RESPOND APP (TEK) - Monitoring (ENE) - Production Forecast (IMP) - Data Repository (TEK/IMP) - Building Simulator (NUIG) - User Adapter (TEK)	- Renewable total energy consumption - Energy reduction - Reduction of greenhouse gas emissions - Rescheduled demand - Economic savings during the DR event - Communication performance - DR campaign penetration

UC 04 - PEAK SHAVING USE CASE

Objective: To verify if customers changed their behaviour of energy usage after a message asking for not using energy to decrease carbon emissions.

Operation: A message was sent manually to the customer RESPOND app asking for decreasing energy usage during one hour on the day of the event. The hour was selected based on energy prediction usage in Ireland provided by EirGrid [15].

DR description: Decrease consumption with the objective of decrease CO_2 emissions.
DR type: Implicit.

Event start: 23/07/2020
Event ends: 11/08/2020

Pilot: Ireland.
Houses participating: All houses.

Precondition: No other event happening in the pilot during the day.

Components:

Devices (D1.4)	Core services (D4.5)	KPIs (D6.1)
- Smart plugs (ENE) - External Meter Interface (ENE) - Electricity wire for Heat Pump (ENE) - Gateway (ENE)	- RESPOND APP (TEK) - Monitoring (ENE) - Data Repository (TEK/IMP) - Building Simulator (NUIG) - User Adapter (TEK)	- Energy Savings - Reduction of Greenhouse gas emissions - Peak load reduction - Rescheduled demand - Analytical services accuracy - Economic savings during the DR event - Communication performance - DR campaign penetration

UC 05 - LOAD SHIFTING DISTRICT HEATING SYSTEM

Objective: Peak load shifting of the district heating system by changing the set-point temperatures of thermostats remotely in peak hours, and without losing the comfort conditions.

Operation: Automated control during the event period.
Case 01: 17/02/2020 → 01/03/2020
    7 am: set-points lowered to 16°C.
    8 am: set-points back to “preferred set point”.
Case 02: 02/03/2020 → 15/03/2020
    4 am: set-point raised 1°C above “preferred set point”.
    6 am: set-points lowered to 16°C.
    9 am: set-points back to “preferred set point”.
Case 03: 16/03/2020 → 29/03/2020
    6 am: set-points lowered to 16°C.
    9 am: set-points back to “preferred set point”.

DR description: Automated load shifting.
DR type: Explicit

Event start: 03/02/2020
Event ends: 12/04/2020

Pilot: Denmark.
Houses participating: Houses 01, 02, 03, 04, 05, 06, 08, 09, 11 and 15.

Precondition: The user needs to authorize the autonomous control of the thermostat.

Components:

Devices (D1.4)	Core services (D4.5)	KPIs (D6.1)
- Smart thermostat Danfoss (DEV) - Heat Meter KAM (DEV) - Gateway (DEV)	- Monitoring (DEV) - Data Repository (TEK/IMP) - Heuristic Optimization (IMP)	- Peak load reduction - Rescheduled demand - Analytical services accuracy - Economic savings during the DR event - Communication performance - DR campaign penetration - Number of user manual actions

UC 06 - MAXIMIZE AUTO-CONSUMPTION FROM GRID CONNECTED PV PANELS

Objective: Energy usage increasing in hours with high PV production in order to optimize auto-consumption.

Operation: The costumer receives a message asking for using more energy during a certain period.

DR type: Maximize auto consumption – Community level.
DR type: Implicit.

Event start: 28/05/2020
Event ends: 30/08/2020[2]

Pilot: Denmark.
Houses participating: All houses.

Precondition:
Case 01: 01/06/2020 → 30/06/2020
- PV production forecast at least 200 kW.
- During the test period 01, the message was sent with information about the hours that the production was supposed to be above the threshold.

Case 02: 18/07/2020 → 31/08/2020
- PV production forecast at least 400 kW
- During the test period 02, the message was sent when the increased minimum threshold was achieved during the day. The hours defined on the message were one hour before and one hour after the maximum point of forecasted production curve during the day.

Components:

Devices (D1.4)	Core services (D4.5)	KPIs (D6.1)
- Smart plugs (DEV) - External Meter Interface (DEV) - Prosumer Meter (DEV) - Gateway (DEV)	- RESPOND APP (TEK) - Monitoring (ENE) - Production Forecast (IMP) - Demand Forecast (TEK) - Data Repository (TEK/IMP) - Optimization (IMP) - Heuristics Optimization (TEK) - User Adapter (TEK)	- Renewable total energy consumption - Rescheduled demand - Analytical services accuracy - Economic savings during the DR event - Communication performance - DR campaign penetration

[2] The event continued, but the data collection for the validation process was until 30/08/2020.

UC 07 - PRICE BASED DR FOR ELECTRICAL ENERGY CONSUMPTION

Objective: To change users' behaviour by stimulating energy consumption during a certain period of the day, based on financial incentives.

Operation: Different prices according to specific periods of the day.
Case 01: 01/11/2019 → 31/03/2020
Price 0€ → From 22 to 12h
Case 02: 01/04/2020 → 26/04/2020
Price 0€ → From 23 to 11h
Case 03: 27/04/2020 → 31/05/2020
Price 0€ → From 15 to 16h and from 22 to 23h
Case 04: 01/06/2020 → 15/08/2020
Price 0€ → From 15 to 17h and from 22 to 00h
Case 05: 16/08/2020 → 31/08/2020
Price 0€ - Houses 02, 03, 04, 06 and 10 → From 15 to 17h and from 22 to 00h
1€ reward - Houses 00, 01 and 12 → 19 to 20h (Threshold: less than 200 Wh in each house)

DR description: Time of Use (ToU).
DR type: Implicit.

Event start: 01/11/2019
Event ends: 31/08/2020

Pilot: Spain.
Houses participating: Houses 00, 01, 02, 03, 04, 06, 10 and 12.

Precondition: The participant needs to be billed by FEN.

Components:

Devices (D1.4)	Core services (D4.5)	KPIs (D6.1)
- External Meter Interface (ENE) - Smart plugs (ENE) - Gateway (ENE)	- RESPOND APP (TEK) - Monitoring (ENE) - Production Forecast (IMP) - Optimization (IMP) - Demand Forecast (TEK) - Data Repository (TEK/IMP) - User Adapter (TEK)	- Energy savings - Reduction of Greenhouse gas emissions - Peak load reduction - Rescheduled demand - Analytical services accuracy - Economic savings during the DR event - Communication performance - DR campaign penetration

UC 08 - MAXIMAL EXPLOITATION OF RENEWABLE RESOURCES

Objective: To analyse if the thermosolar heat water system is being used preferably during sunny hours and therefore it is decreasing the gas usage for domestic hot water (DHW).

Operation: The users should be able to see in the mobile app the current information about thermosolar production and the temperature of the water in the tanks. The idea is to foster DHW consumption in the moments when there are more thermosolar energy available.

DR description: Exploitation of common energy resources.
DR type: Implicit.

Event start: 01/01/2020
Event ends: 10/08/2020

Pilot: Spain.
Houses participating: All houses.

Precondition: The participant has access to the DHW system installed in the building.

Components:

Devices (D1.4)	Core services (D4.5)	KPIs (D6.1)
- Energy Gateway (TEK) - Temperature Sensors (FEN) - Heat meters (FEN) - Solar regulation control unit (FEN)	- RESPOND APP (TEK) - Monitoring (ENE) - Production Forecast (IMP) - Optimization (IMP) - Demand Forecast (TEK) - Data Repository (TEK/IMP)	- Energy savings - Renewable total energy consumption - Rescheduled demand - Analytical services accuracy - Economic savings during the DR event - Communication performance - DR campaign penetration

Observation: Over the deployment of UC8, in the Madrid pilot site, some technical issues were found, so it was not possible to get measurements from the individual water meters and from the boiler meter. As a result, data quality was not sufficient for a quantitative validation of the use case, hence a qualitative validation approach through the interviews with households was made. The complete assessment can be found on deliverable 6.3 [9] and the lessons learned and recommendation in deliverable 6.5 [10].

Table 5 - Event description per use case

The number of participant houses chosen for each of the use cases was defined according to the technology present at the residences and data availability during the demand response events. Section 2 describes each use case in detail.

1.4 KPI CALCULATION METHODOLOGY

This section presents a brief description of the methodology applied for KPI calculation for each of the Use Cases over the validation process. Some KPIs were adjusted after the publication of Deliverable 6.1 [8] to better correspond the final characteristics of the pilot and/or the use case.

Although this document presents the KPIs results, further analysis including lessons learned and recommendations are presented in Deliverable 6.5 [10].

1.4.1 RENEWABLE TOTAL ENERGY CONSUMPTION

The renewable total energy consumption KPI was calculated using the formula described on deliverable 6.1 [8]. The data source of the information was the Influx DB repository, where the historical data of the energy demand and production can be found. Figure 2 shows an example of data gathered from Influx DB, containing information about a electricity meter in a specific range of time. The data are then exported to a CSV file and the KPI calculated in external tools.

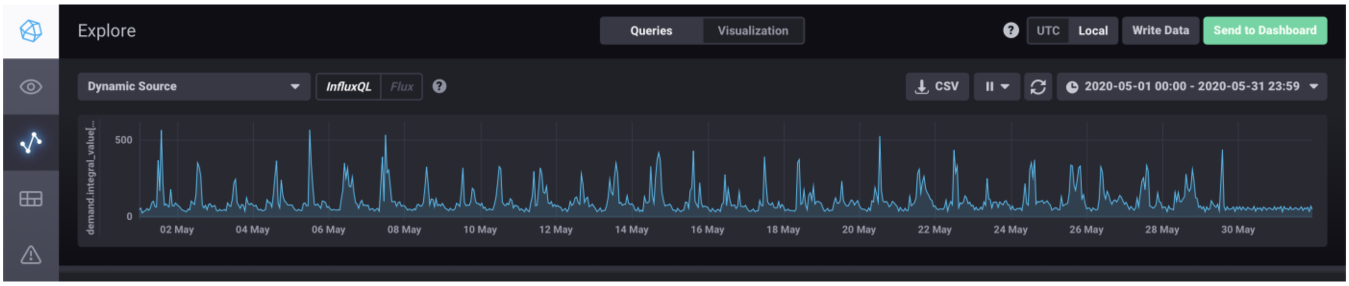


Figure 2 - Example of data collection on Influx DB

1.4.2 ENERGY SAVINGS

The energy savings KPI was calculated using the DEXMA platform, the tool used for the analysis was the M&V which is fully compatible with the IPMVP protocol [16]. This KPI takes into account the measurements from the electricity and heat meters and does not consider the energy saved by the PV generation. In Figure 3 and Figure 4 it is possible to see an example of the system output after calculating the KPI for a Use Case.

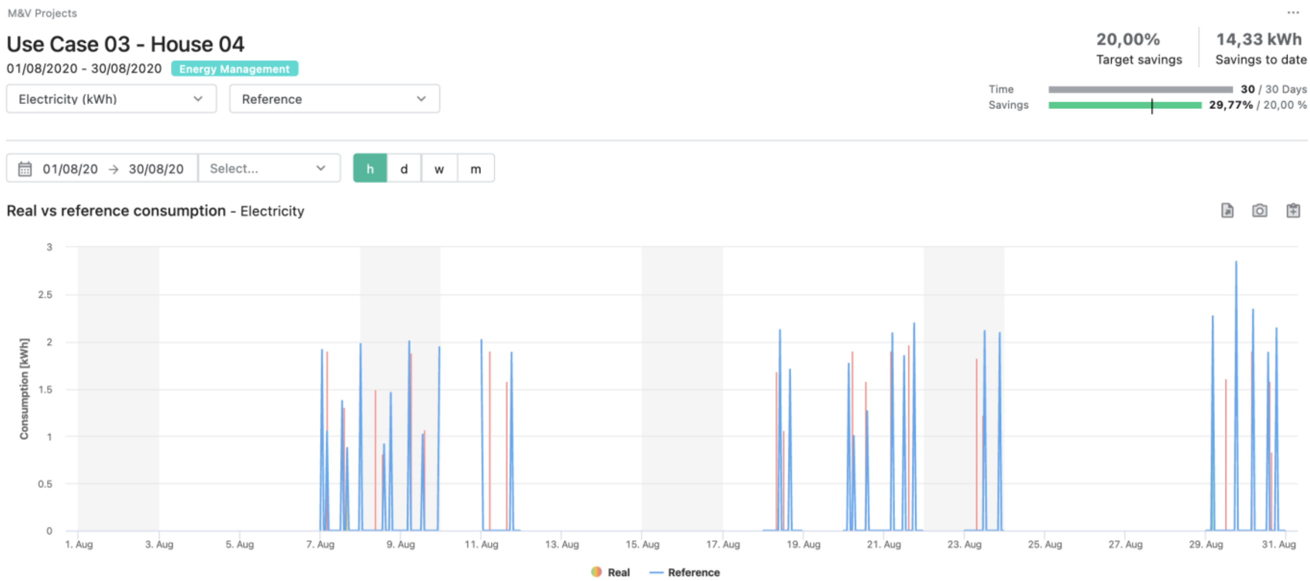


Figure 3 - Energy savings KPI example

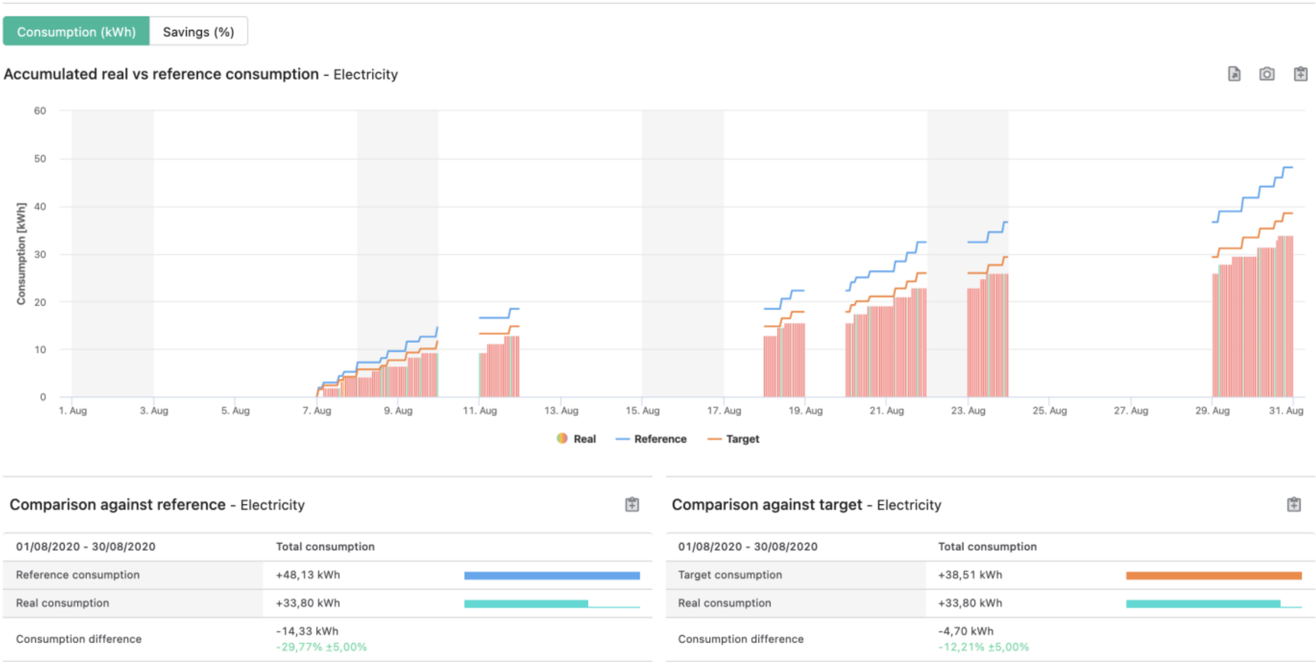


Figure 4 - Energy savings KPI example – 2

1.4.3 REDUCTION OF GREENHOUSE GAS EMISSIONS

The reduction of the greenhouse gas emissions KPI was calculated through the Carbon Emissions App and the Measurement and Verification tool, both on DEXMA platform. The app calculates equivalent carbon emissions from the existing devices. In summary, it is the amount of energy savings converted to greenhouse gas emission equivalent. For each different pilot, the value of CO_2 emissions conversion rate for 2016 was included based on information provided by European Environment Agency [17]. This KPI takes into account the measurements from the electricity and heat meters and does not consider the energy saved by the PV generation.

Figure 5 shows the CO_2 emissions intensity over the years for Ireland, Denmark, and Spain, used as a base for the conversion rate.

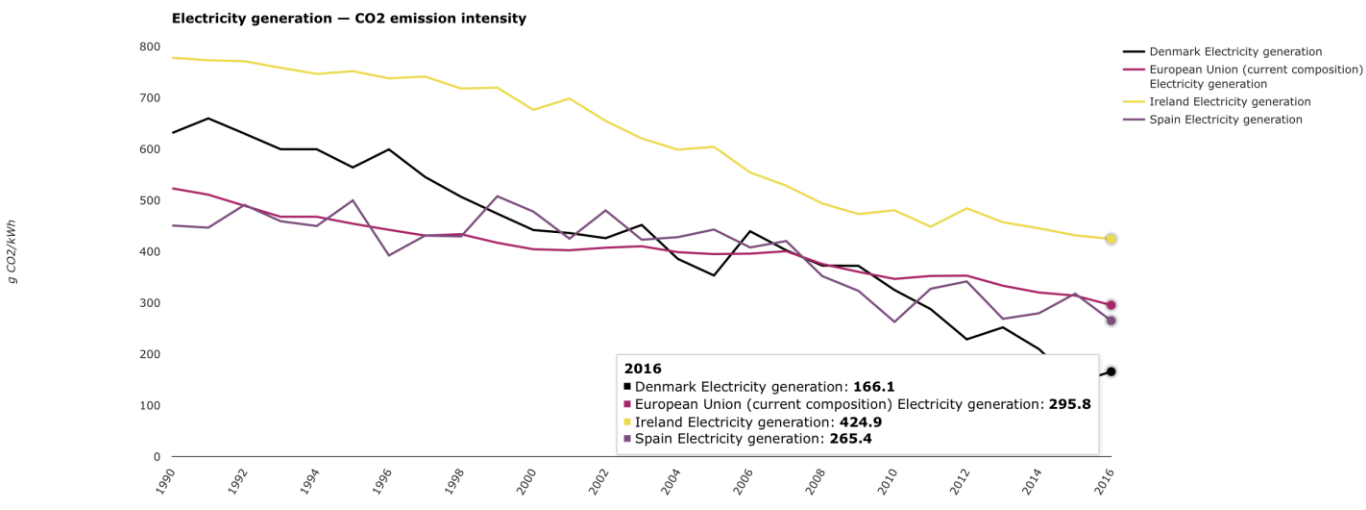


Figure 5 - CO_2 emissions intensity – $kgCO_2/kWh$ per country [17]

In Figure 6, it is possible to see a carbon emission calculation for one house in the Madrid pilot. In this example, the emissions were analysed on basis of electricity meter data between August 24th and August 28th.

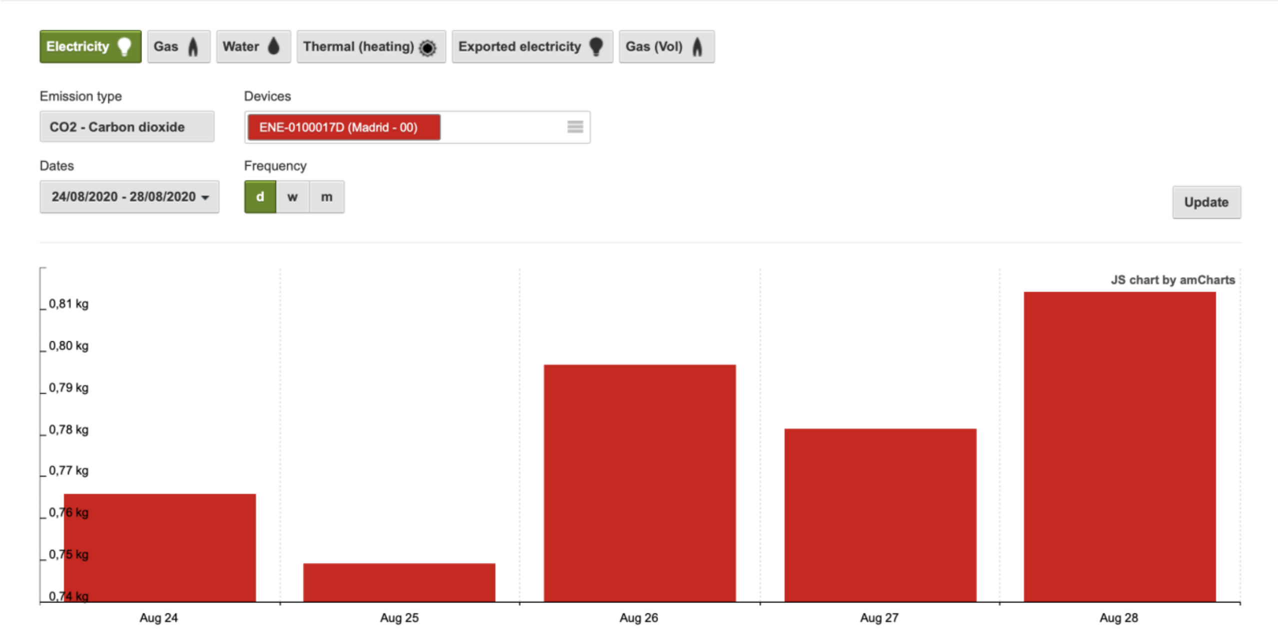


Figure 6 - Carbon emissions KPI analysis example

To validate the Use Cases, the Measurement and verification tool was used in the analysis. Figure 7 presents an example of the carbon emission KPI calculation.

Figure 7 - Example of carbon emission calculations in Dexma platform

1.4.4 PEAK LOAD REDUCTION

The peak load reduction KPI was calculated in an external platform with the historical data collected from Influx DB, similar to the example presented in 1.4.1, and the baseline calculation from DEXMA platform. Figure 8 shows an example of the exported data model from DEXMA platform.

Account	RESPOND PROJECT	**From**	01/11/2019
Customer	RESPOND PROJECT	**To**	31/08/2020
Location	Madrid		
Device	Madrid - UC07 - Aggregated		
	Real consumption [kWh]	**Reference consumption [kWh]**	**Target [kWh]**
TOTAL	16,983.64	17,234.57	17,234.57
AVERAGE	2.37	2.35	2.35
MEDIAN	2.08	2.70	2.70
MAX	10.55	3.51	3.51
MIN	0.46	1.08	1.08
Date and hour	**Real consumption [kWh]**	**Reference consumption [kWh]**	**Target [kWh]**
01/11/2019 00:00	3.49	1.31	1.31
01/11/2019 01:00	3.26	1.18	1.18
01/11/2019 02:00	3.20	1.12	1.12
01/11/2019 03:00	3.32	1.08	1.08
01/11/2019 04:00	3.10	1.08	1.08
01/11/2019 05:00	3.25	2.17	2.17
01/11/2019 06:00	2.51	2.44	2.44
01/11/2019 07:00	1.51	2.85	2.85
01/11/2019 08:00	2.14	2.82	2.82
01/11/2019 09:00	1.86	2.95	2.95
01/11/2019 10:00	2.91	2.80	2.80
01/11/2019 11:00	3.15	2.91	2.91
01/11/2019 12:00	2.29	3.15	3.15

Figure 8 - Example of the model exported by DEXMA platform for baseline reference consumption

1.4.5 RESCHEDULED DEMAND

For calculating the rescheduled demand, the historical data was collected from Influx DB and the baseline calculated from DEXMA platform and/or electricity demand predictions, depending on the Use Case. The KPI was calculated in two different approaches for better validate the Use cases:

- % of the total user demand rescheduled:
  In this analysis, the baseline was normalized and it was possible to validate the % of total electricity demand that was moved in/out the event period.
- Total demand reschedule:
  This analysis allows to analyse if the customer increased the final value of the demand consumption.

1.4.6 ECONOMIC SAVINGS DURING THE DR EVENT

The economic savings KPI was applied to verify the economic savings for the customers during the events. Table 6 presents the original values paid by the customers in Madrid (being P1 outside the event hours and P2 during the event hours).

Table 6 - Use Case 07 Original tariff price

Participant	P1 (€/kWh)	P2 (€/kWh)
Madrid_00	0.149212	0.077917
Madrid_01	0.157262	0.085967
Madrid_02	0.149212	0.077917
Madrid_03	0.157065	0.082017
Madrid_04	0.149212	0.077917
Madrid_06	0.149212	0.077917
Madrid_10	0.149212	0.077917
Madrid_12	0.149212	0.077917

For the Irish pilot, the electricity price used in the use case analysis is from Electric Ireland [18], as presented in Table 7.

Table 7 - Electric Ireland - Electricity prices – Ireland [18]

Electricity Prices & Charges		
Electricity prices per unit (cent per kWh)	**ex. VAT**	**inc. VAT**
Unit rates		
Standard unit price	16.93 c/kWh	19.22 c/kWh

After the data collection and the baseline definition, the KPI was calculated comparing values achieved in and out the specified periods.

1.4.7 COMMUNICATION PERFORMANCE

The communication performance KPI was calculated using Data Quality report on DEXMA platform. The Data Quality Report is very useful to analyse devices according to the quality of their data, calculated taking into account the amount of data received compared to the amount of data expected. In Figure 9 is possible to see an example of the system output for this report.

Account	RESPOND PROJECT	**From**	31/08/2020	
Energetic source	Electricity	**To**	06/09/2020	
Location	**Device**	**Amount of data(%)**	**Data frequency**	**Amount of missing data**
Madrid - 05	ENE-01000187	99.4%	5 minutes	12
Madrid - 10	ENE-010001A4	99.36%	5 minutes	13
Madrid - 00	ENE-0100017D	99.31%	5 minutes	14
Madrid - 01	ENE-0100018D	99.26%	5 minutes	15
Aran - 04	ENE-0C000C2B-a	98.91%	5 minutes	22
Aran - 10	ENE-0C000C19-a	98.86%	5 minutes	23
Aran - 06	ENE-0C000C1B-a	98.81%	5 minutes	24
Aran - 03	ENE-0C000C25-a	98.81%	5 minutes	24

Figure 9 - Data quality report output example

After the data collection, the data was aggregated in an external calculation platform to create the analysis in the correspondent Use Case period.

1.4.8 INDOOR AIR QUALITY

Indoor air quality was analysed and calculated through the Advance Analytics application of DEXMA platform. It shows the real values of CO_2 for each of the houses equipped with Energomonitor sensors. There are no active actions related to the indoor air quality, this way, this KPI is just going to be analysed for understanding if the user started to change the patterns after having access to the data from RESPOND app. Figure 10 shows an example of air quality analysis on DEXMA's advance analytic application.

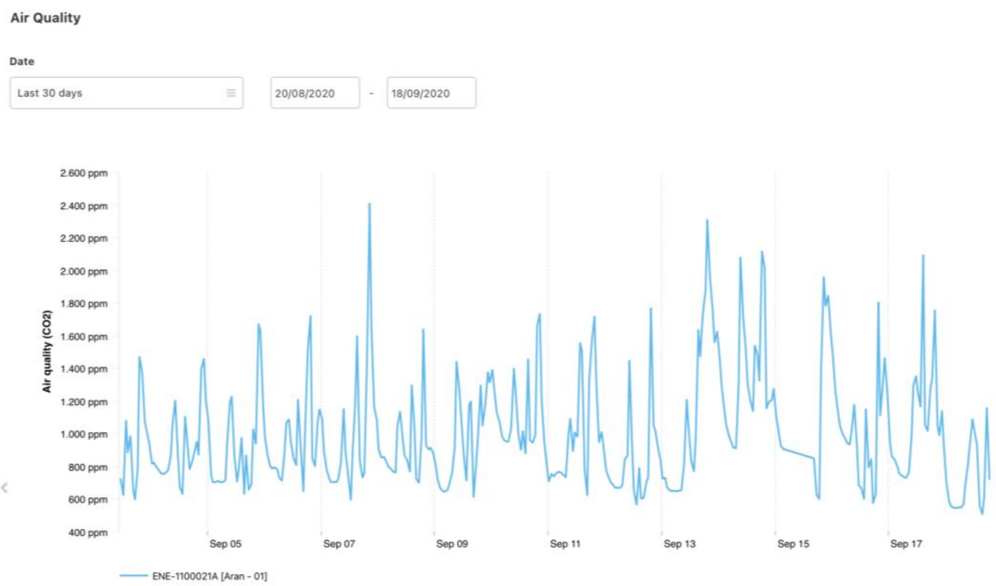


Figure 10 – Example of Indoor air quality.

1.5 BASELINE

The baseline for each of the use cases was defined in an individual manner. It considers the available data and also the days without DR events happening, thus avoiding interfering in the user's behaviour. Table 8 presents the dates related to the use cases.

Table 8 – Baseline definition per use case

Use Case	Baseline Date
Use Case 01	01/03/2020 - 12/04/2020
Use Case 02	01/05/2020 - 31/05/2020
Use Case 03	01/08/2020 - 31/08/2020
Use Case 04	01/07/2020 - 14/07/2020
Use Case 05	03/02/2020 - 16/02/2020
Use Case 06	01/05/2020 - 31/05/2020
Use Case 07	01/08/2019 - 31/10/2019

The resolution of data analysis defined is hourly, because DR events such as peak shaving and rescheduled demand need this type of precision. According to the IPMVP methodology, data backfilling is not allowed [19], this way, periods of missing data were excluded during the calculation process. A complete assessment of data availability is provided for each of the use cases in the next section, as well few more descriptions about the individual baseline process.

2. VALIDATION

The validation process was designed considering the correlation between KPIs and Use Cases applied to the pilots. This section presents the details about the Use Cases deployment and assessment methodology, including the relevant KPI calculation.

2.1 USE CASE 01 - IMPACT OF THE RESPOND APP TO THE USER

The objective of Use Case 01 is to analyse the impact of the app on user behaviour. The main idea is to understand if, after having access to the app data, the costumer changed in some way the consumption during the period. Some of the KPIs were calculated using information from RESPOND DB. Additionally, a few specific questions about this topic were included in the interviews with the participants, for understanding the consumption pattern differences of before and after having access to the technology.

The use case was realized to understand the changes in the participant energy consumption behaviour, by comparing the period before and after the RESPOND app release. This use case started to be applied on 13th of April 2020, which was the day that RESPOND app passwords were sent to the participants. The final date that information was collected was on May 30th. As this experiment aims to verify users' willingness of consumption changes without any request for this kind of action, the dates of the event were selected considering days without any active demand response use case running in the Aran Islands and Aarhus. The Use Case 07 was being applied in Madrid, but as it was running since November 2019 the baseline was already stable and then collected properly.

The list of houses analysed in this event is described in Table 9:

Table 9 - Use Case 01 - Houses participating in the event

Pilot	Houses participating
Aran Islands	03, 05, 06, 08, 10 and 12.
Aarhus	03, 06, 07, 08, 09, 13, 14, 15 and 17.
Madrid	00, 01, 02, 03, 04, 05, 06, 07, 10, 12 and 13.

2.1.1 ASSESSMENT

The assessment of this use case has two main analysis, the quantitative and the qualitative one. This report is focused on the quantitative approach. For more information about the qualitative results, please refer to Deliverable 6.3 [9].

The baseline used for this use case was from 01/03/2020 to 12/04/2020. The main calculations were realized on DEXMA platform for all the pilots. According to the IPMVP methodology, data backfilling is not allowed [19], this way, periods of missing data were excluded during the calculation process. Outliers, such as accumulated values due to communication issues, have also been removed. The main results can be found in the next subsections.

2.1.2 KPI CALCULATION

- **Energy Savings**

The energy savings of Use Case 01 was calculated on DEXMA platform using the M&V tool. The data from electricity meters was aggregated by pilot, as can be seen in the following individual analysis.

Starting with Madrid pilot, Figure 11 presents the main results about energy savings. According to the numbers, there was an energy consumption increase of 6,9% in the first month of usage of the RESPOND app. Since Use case 7 was being applied in the same period and customers had no energy consumption costs during some hours of the day, it is not possible to analyse the energy savings of the Use case 01 in the Madrid pilot. However, in this same period, the Use case 7 results started to improve, showing that the app was increasing the costumer participation in the events by facilitating the communication and notifications.

Furthermore, there was also a temperature increase in Madrid in the same period. That means users probably started to use Air Conditioning more often, hence increasing energy consumption. As there is no baseline for the same period in the year before, it is not possible to isolate this issue.

Figure 11 - Use case 01 - Energy savings Madrid

Moving to the Irish pilot, there was a reduction of 20.28% in energy consumption, as presented in Figure 12. It is not possible to confirm if the savings were just related to the use case application, since there was a change of seasons during the analysed period, where people started to use less energy to heat the residences due to the temperature increase.

Figure 12 - Use case 01 - Energy savings Aran Islands

Finally, Aarhus pilot achieved 4.72% of energy savings, as presented in Figure 13 from DEXMA platform. Overall, as users were not explicit asked to change their behaviour, there was no specific target to be achieved.

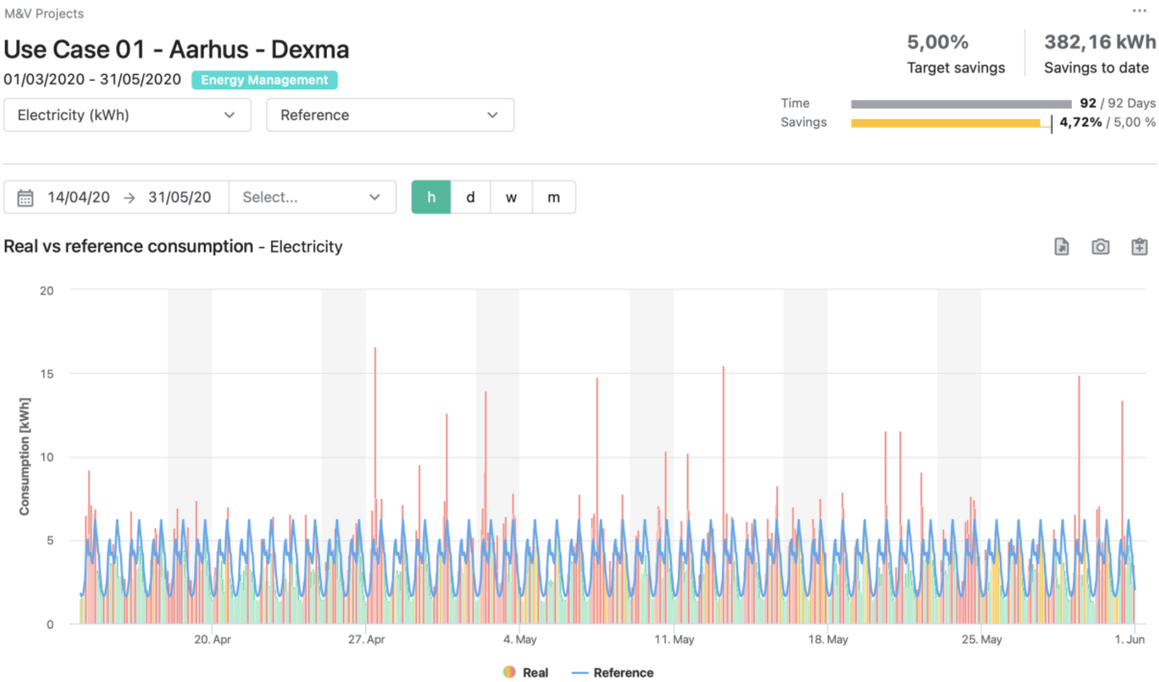
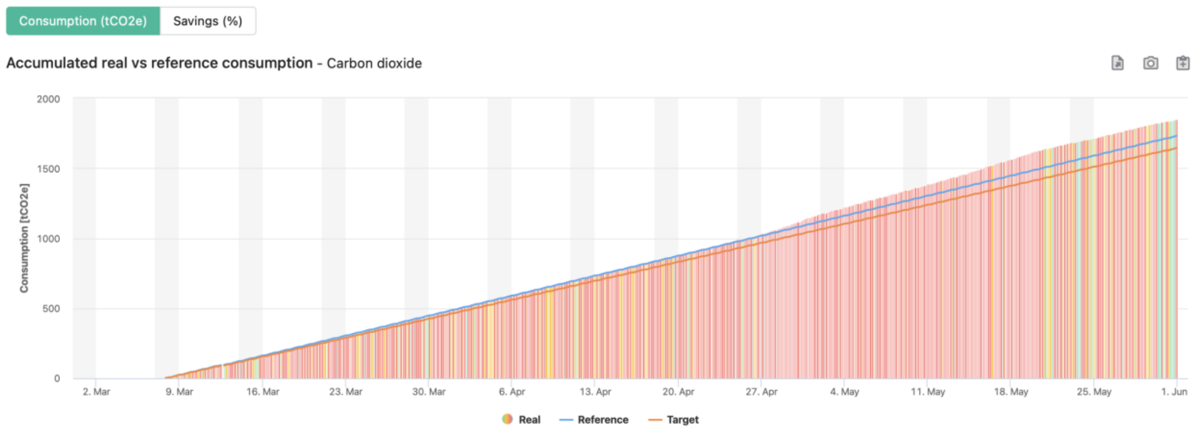


Figure 13 - Use case 01 - Energy savings Aarhus

- **Reduction of greenhouse gas emissions**

The reduction of greenhouse gas emission KPIs was also calculated on the DEXMA platform, following the same premisses as the energy savings KPI. In summary, it is the amount of energy savings converted to greenhouse gas emission equivalent, as presented on subsection 1.4.3.

Figure 14 shows the results for Madrid. Since the energy usage increased in the period, there was no reduction in the CO_2 emissions for the pilot during the application of Use Case 01.



Comparison against reference - Carbon dioxide

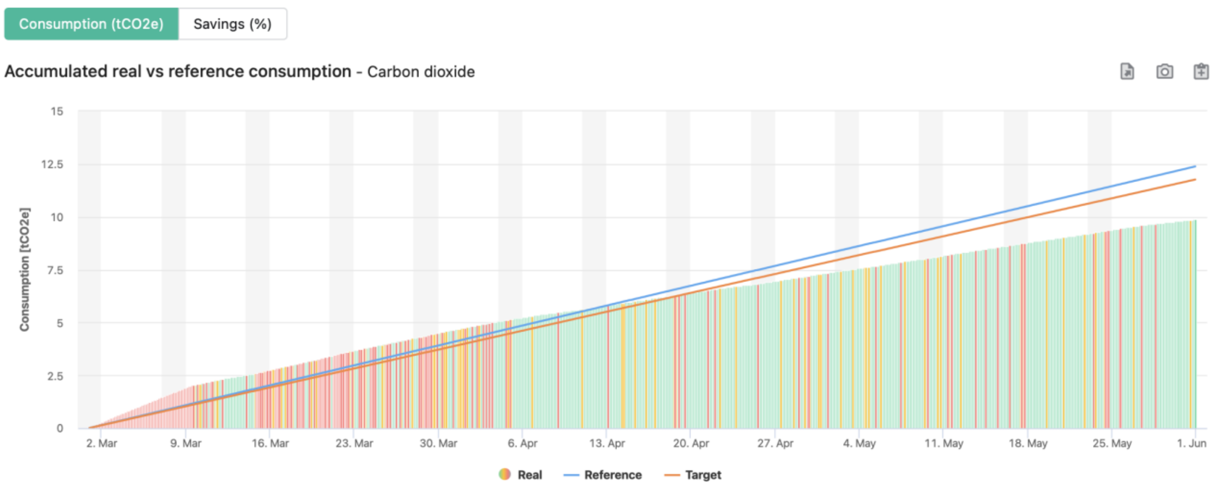
01/03/2020 - 31/05/2020	Total consumption
Reference consumption	+1.731,14 tCO2e
Real consumption	+1.849,82 tCO2e
Consumption difference	+118,68 tCO2e +6,86% ±5,00%

Comparison against target - Carbon dioxide

01/03/2020 - 31/05/2020	Total consumption
Target consumption	+1.644,58 tCO2e
Real consumption	+1.849,82 tCO2e
Consumption difference	+205,24 tCO2e +12,48% ±5,00%

Figure 14 - Use Case 01 - CO_2 consumption in Madrid

Regarding the houses on the Aran Islands, Figure 15 shows the comparison of the carbon emissions between the baseline period and the real one. In this case, there was a total of 2.51 tCO_2e avoided in the period, a reduction of 20.28% compared to the baseline.



Comparison against reference - Carbon dioxide

01/03/2020 - 31/05/2020	Total consumption
Reference consumption	+12,38 tCO2e
Real consumption	+9,87 tCO2e
Consumption difference	-2,51 tCO2e -20,28% ±5,00%

Comparison against target - Carbon dioxide

01/03/2020 - 31/05/2020	Total consumption
Target consumption	+11,77 tCO2e
Real consumption	+9,87 tCO2e
Consumption difference	-1,89 tCO2e -16,09% ±5,00%

Figure 15 - Use Case 01 - CO_2 consumption in Aran Islands

Figure 16 presents the avoided emissions in the Danish pilot. The reduction of emissions was 4.72% (-63.48 tCO_2e).

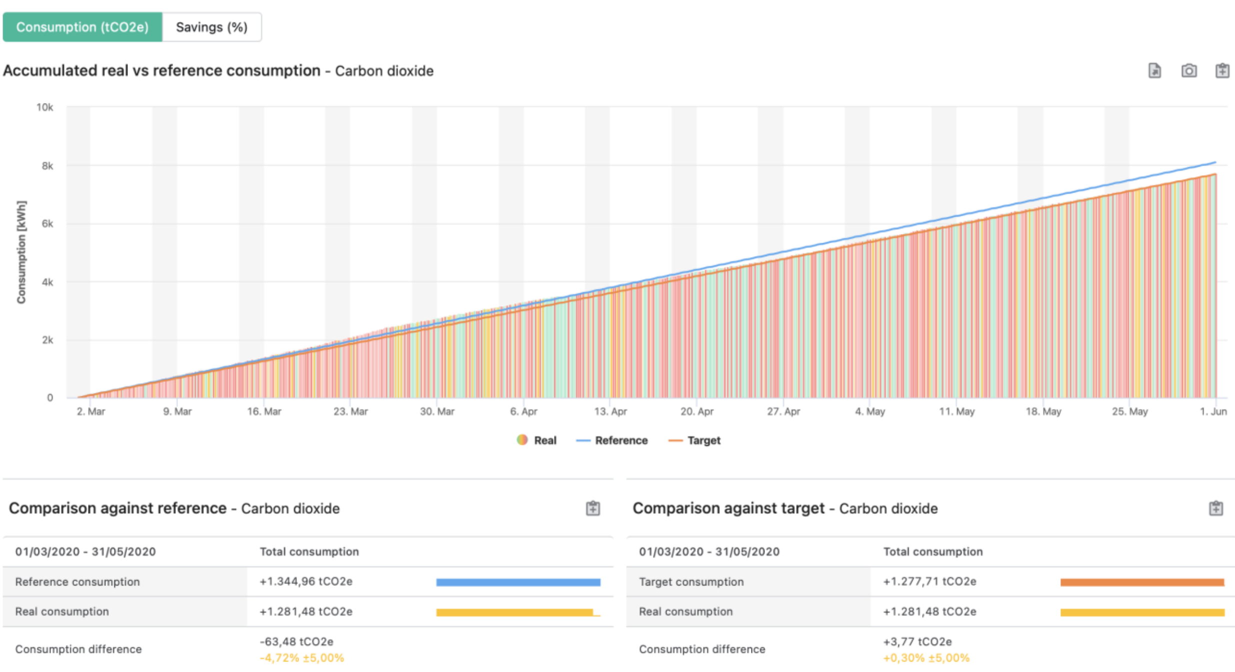
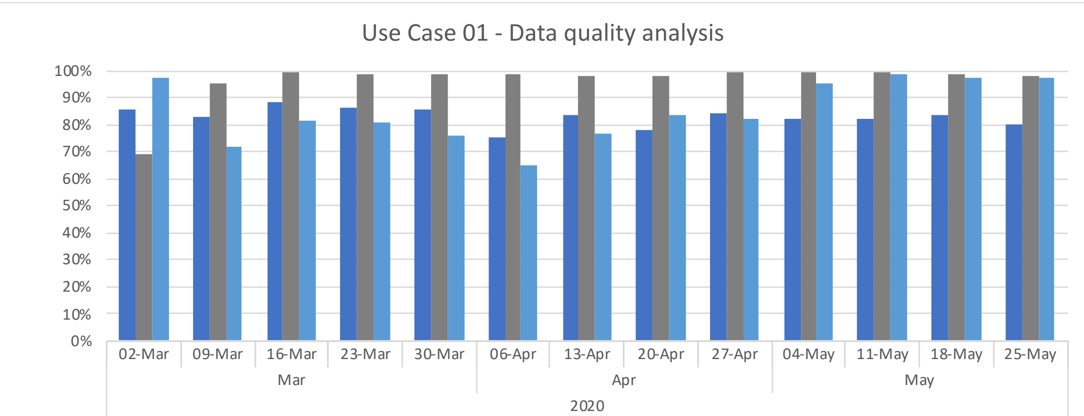


Figure 16 - Use Case 01 - CO_2 consumption in Aarhus

- **Communication performance**

The communication performance KPI verifies the data availability, and it was on average 82% in Aarhus, 99% available in Madrid and 90% in the Aran Islands during the event period (April 13th – May 30th). During the baseline period (March 1st – April 12th), the average was 84% in Aarhus, 93% in Madrid and 79% in the Aran Islands. Figure 17 shows a weekly report of data availability for each pilot.



	02-Mar	09-Mar	16-Mar	23-Mar	30-Mar	06-Apr	13-Apr	20-Apr	27-Apr	04-May	11-May	18-May	25-May
Aarhus	85%	83%	88%	86%	86%	76%	84%	78%	84%	82%	82%	84%	80%
Madrid	69%	95%	99%	99%	99%	99%	98%	98%	99%	99%	99%	99%	98%
Aran	98%	72%	82%	80%	76%	65%	77%	84%	82%	96%	99%	97%	97%

Figure 17 – Use Case 01 - Data quality analysis

In the analysis, some houses were excluded due to a lack of sufficient data. The criteria for exclusion considered cases where less than 60% of information was available in the period. The houses excluded were: Aran Islands - Houses: 01, 02 and 04 and Aarhus – Houses 01, 02, 04, 05, 10, 12, 16, 18, 19 and 20.

- **Indoor air quality**

The indoor air quality was measured in the residences of Aran Islands and Madrid. Over the use case period, the level of CO_2 in the residences was on average 615 and 608 for Ireland and Madrid, respectively. In Figure 18 and Figure 19, it is possible to see the graphs extracted from DEXMA platform with information about each device of the mentioned pilots.

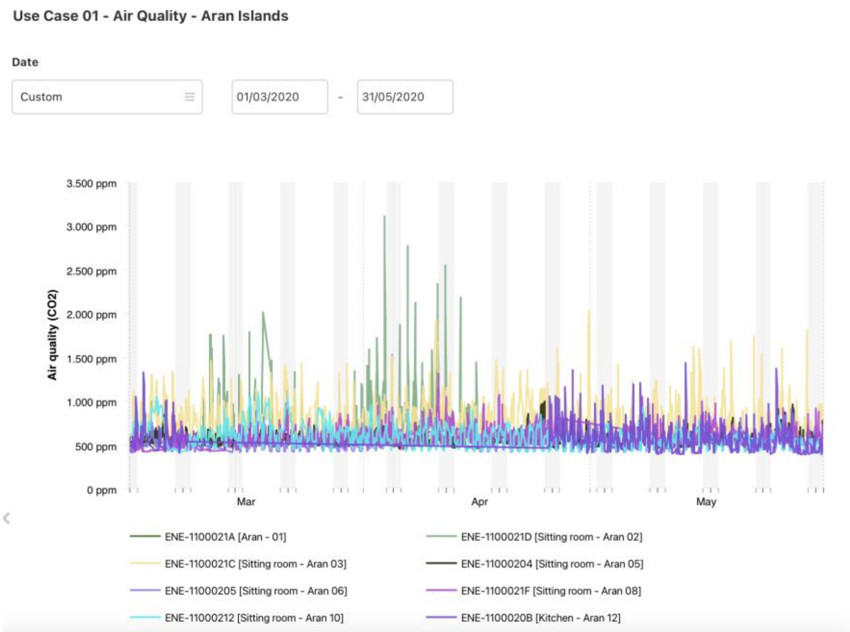


Figure 18 - Use Case 01 - Indoor air quality Aran Islands

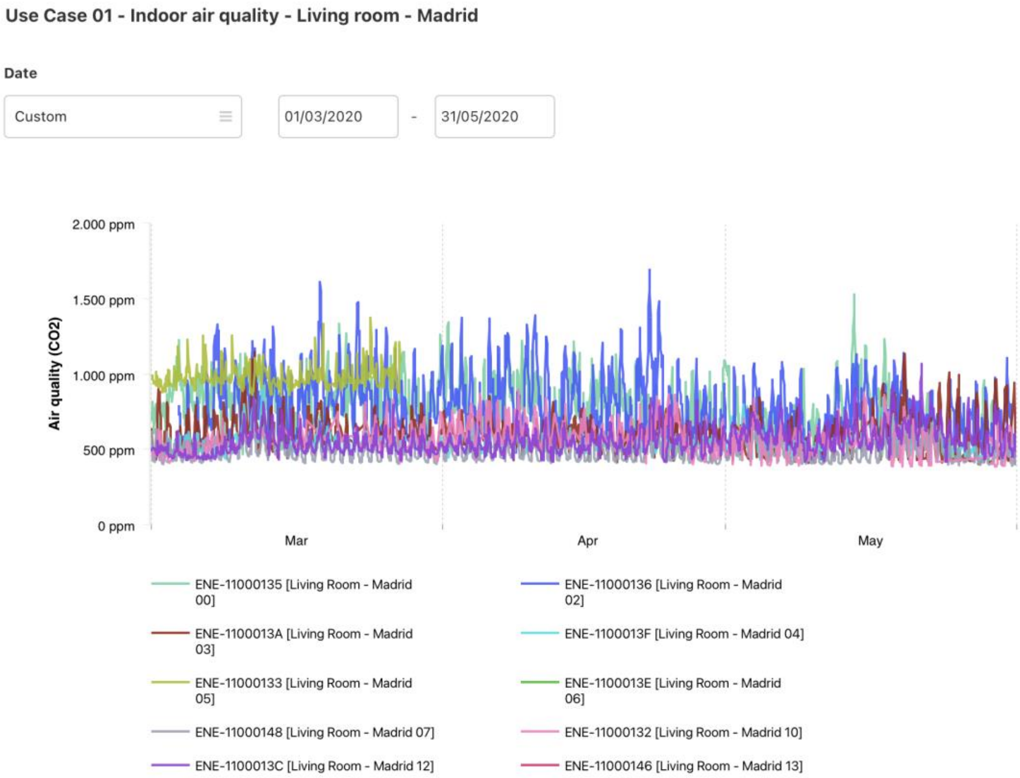


Figure 19 – Use Case 01 – Indoor air quality – Madrid

Additionally, Figure 20 and Figure 21, also from the DEXMA platform, show the average CO_2 level for each of the houses, being March the Baseline, and April and May the analysed values.

Year	Data Series	Unit	January	February	March	April	May	June	July	August	September	October	November	December	Sum	Average
2020	ENE-1100021A [Aran - 01]														-	-
2020	ENE-1100021D [Sitting room - Aran 02]				618,89	837,50									-	728,19
2020	ENE-1100021C [Sitting room - Aran 03]				776,08	819,63	779,31								-	791,67
2020	ENE-11000204 [Sitting room - Aran 05]				556,79	573,02	583,53								-	571,11
2020	ENE-11000205 [Sitting room - Aran 06]				509,07	544,45	541,08								-	531,53
2020	ENE-1100021F [Sitting room - Aran 08]				550,75	615,75	590,56								-	585,69
2020	ENE-11000212 [Sitting room - Aran 10]				651	580,33	539,13								-	590,15
2020	ENE-1100020B [Kitchen - Aran 12]				576,79	641,78	544,31								-	587,62

Figure 20 - Use Case 01 - Indoor air quality - Aran Islands - table

Year	Data Series	Unit	January	February	March	April	May	June	July	August	September	October	November	December	Sum	Average
2020	ENE-11000135 [Living Room - Madrid 00]				815,28	754,91	649,88								-	740,02
2020	ENE-11000136 [Living Room - Madrid 02]				815,39	813,12	700,53								-	776,35
2020	ENE-1100013A [Living Room - Madrid 03]				664,76	595,05	621,69								-	627,17
2020	ENE-1100013F [Living Room - Madrid 04]				546,95	539,80	539,01								-	541,92
2020	ENE-11000133 [Living Room - Madrid 05]				976,20										-	976,20
2020	ENE-1100013E [Living Room - Madrid 06]														-	-
2020	ENE-11000148 [Living Room - Madrid 07]				491,49	483,46	488,66								-	487,87
2020	ENE-11000132 [Living Room - Madrid 10]				581,74	626,95	563,97								-	590,89
2020	ENE-1100013C [Living Room - Madrid 12]				524,86	545,98	599,63								-	556,82
2020	ENE-11000146 [Living Room - Madrid 13]														-	-

Figure 21 - Use Case 01 - Indoor air quality - Madrid - table

According to prEN15251 [20], air quality in dwellings can be assessed/classified following four groups:

I. High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons.
II. Normal level of expectation and should be used for new buildings and renovations.
III. An acceptable, moderate level of expectation and may be used for existing buildings.
IV. Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year.

The CO_2 levels for each category should be analysed according to the Table 10:

Table 10 - prEN15251 indoor quality category levels [17]

Indoor Quality Category	Typical Range	Default Value
I	<400	350
II	400-600	500
III	600-1000	800
IV	>1000	1200

Following this set of criteria, the houses analysed in this use case should be allocated in category III, where the typical range is between 600 – 1000. As a result, all the houses stayed in the expected range, and 60% of the houses with available data showed improvement during the period, sometimes achieving values below 600.

2.2 USE CASE 02 - IRELAND - MAXIMIZE AUTO CONSUMPTION CONTROL SWITCHES FOR APPLIANCES

The objective of Use Case 02 is to maximize auto-consumption during periods where there is a peak in energy production. The day before the event, the hourly prediction model estimates the PV production for the next day. This information is used to send a message to the participants of the use case if a pre-defined threshold is achieved. Users can get energy savings and also help to reduce peak load in the grid. In the Aran Islands, if PV production is not consumed, it is directly injected into the grid, without getting any payment from the energy provider.

Based on the RESPOND specific objective of better exploitation of renewable energy using demand forecast tools deployed by the project, this use case is being applied when the prediction of energy production achieves a specific target. The first step was to define which houses were able to participate. In the Aran Islands pilot, there are 9 houses in total, but only houses 01, 02, 03, 04, 05 and 12 have PV production (see subsection 1.1.1), therefore messages were sent only to these 6 houses.

The following message was sent to the participants in English and Gaelic:

"Tomorrow between hh:mm-hh:mm your PV panels are expected to have a period of high production. Try to use your appliances during this period to save money and energy.

Amarach idir hh:mm-hh:mm meastar go mbeidh do phainéileacha fotavóltacha ag ginniúint roinnt mhaith leictreachas. Déan iarracht do chuid fearais tí a úsáid i rith an am sin chun airgead agus fuinneamh a shábháil."

Where the hours were filled based on the prediction hours for the next day.

2.2.1 ASSESSMENT

This use case was applied across two test cases, considering different methodologies for PV production threshold definition. The baseline chosen is the month of May, and it was calculated on DEXMA platform.

Case 01:

In the first period of the application of the Use Case, a message was sent to the customers asking for using the appliances in the next day if the prediction achieved 900 Wh at least for an hour. The demand response events started sending the messages on May 31st. In this test case, the messages were sent in the days described in Table 11.

Table 11 - Use Case 02 - Case 01 days of event

June	Events
1	14:00-16:00
3	12:00-13:00
5	12:00-13:00
8	16:00-17:00

Case 02:

Since messages were not being sent due to the weather conditions in Ireland (PV predictions rarely achieved 900 Wh), in the second test case the idea was to provide a threshold that could result in sending notifications 2-3 times per week on average. The new threshold was then defined as 600 Wh for houses Aran01, Aran03, Aran04, Aran05, Aran12 and 1100W for Aran02, which has a higher capacity PV system. In test case 2, the messages were sent in the days described in Table 12.

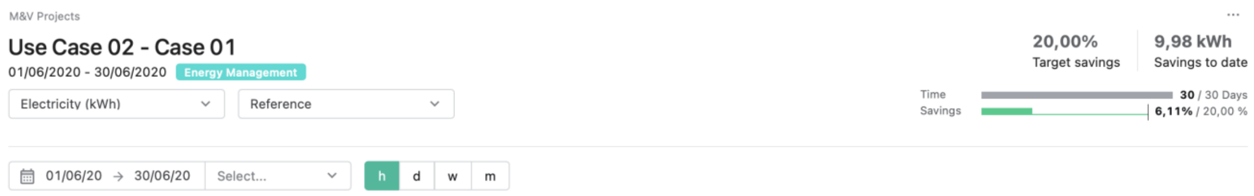
Table 12 - Use Case 02 - Case 02 days of event

August	Events
6	12:00-14:00
7	12:00-14:00
8	14:00-16:00
9	17:00-19:00
10	15:00-17:00
11	17:00-19:00
17	12:00-14:00
19	13:00-15:00
20	15:00-17:00
22	11:00-13:00
28	12:00-14:00
29	15:00-17:00

2.2.2 KPIs CALCULATION

- **Energy savings**[3]

Figure 22 and Figure 23 present the results of test cases 01 and 02, respectively. The KPI calculations performed on the DEXMA platform show a decrease of 6.11% in energy usage from the grid in the first test period, and 21.81% in the second period, considering the aggregated values of the same houses.



[3] The energy savings KPI was not included in this use case analysis in Deliverable 6.1, but we chose to calculate it to validate the use case.

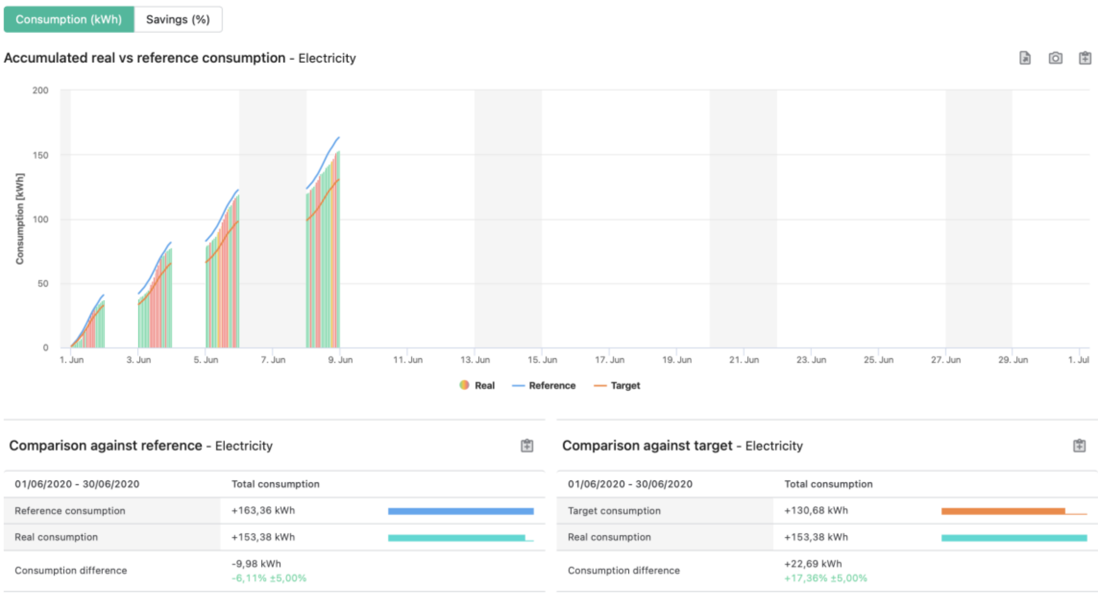


Figure 22 - Use Case 02 – Test Case 01 - Energy savings KPI - DEXMA platform

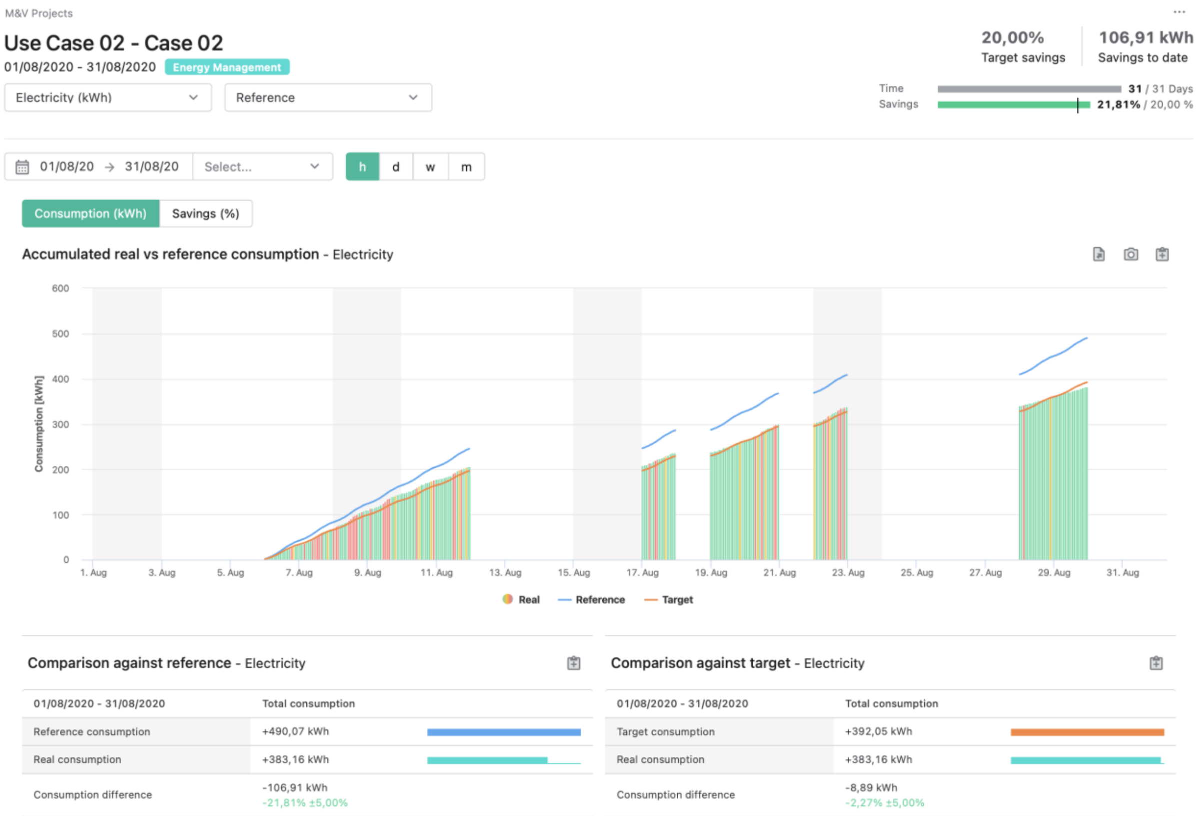


Figure 23 - Use Case 02 – Test Case 02 - Energy savings KPI - DEXMA platform

Figure 24 shows the KPI calculation for the total use case period, where the final result is 17.89% of energy savings.

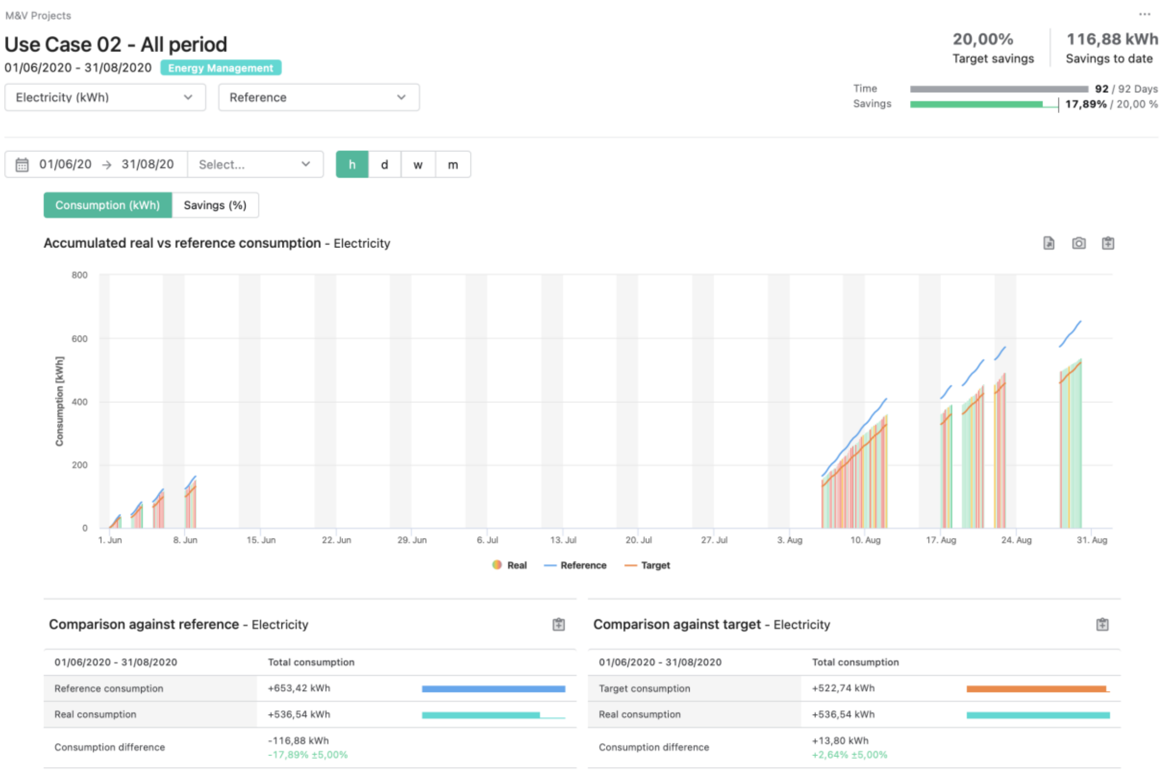


Figure 24 - Use Case 02 – All period - Energy savings KPI - DEXMA platform

- **Reduction of greenhouse gas emissions**

The reduction of greenhouse gas emission KPIs was also calculated on the DEXMA platform, following the same premisses as the energy savings KPI. in summary, it is the amount of energy savings converted to greenhouse gas emission equivalent, as presented in subsection 1.4.3. This use case avoided 49.66 tCO_2e emissions over the entire period.

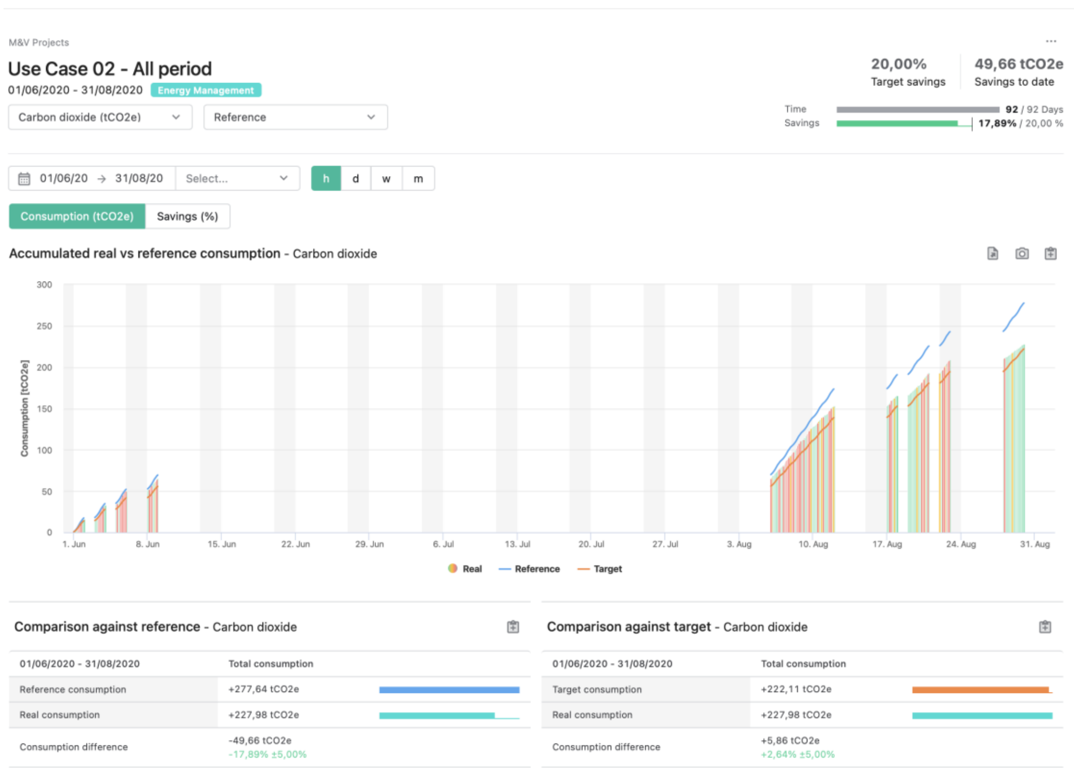


Figure 25 - Use Case 02 – All period - Reduction of greenhouse gas emissions KPI - DEXMA platform

- **Renewable total energy consumption**

The renewable total energy consumption KPI shows the ratio of the total amount of renewable energy produced and the demand at the event period. Table 13 summarizes the amount of PV energy production consumed in each of the days of test cases 01 and 02. The analysis considers the aggregated consumption and production value of the participant houses. As a result, PV production was 72.7% consumed on average over test case 01. Test case 02 presented an even better performance, where on average 79.6% of PV energy produced during the event was consumed, and sometimes reached 100% of usage.

Table 13 - Use Case 02 - Renewable total energy consumption

Date	01/06	03/06	05/06	08/06	Case 01 Avg	06/08	07/08	08/08	09/08	10/08	11/08	17/08	19/08	20/08	22/08	28/08	29/08	Case 02 Avg
PV production (kW)	7.55	4.91	5.16	1.48	4.78	2.68	8.49	7.90	2.69	3.39	2.76	2.06	1.79	2.39	7.61	3.84	0.91	3.87
Consumption (kW)	5.66	3.28	3.10	1.32	3.34	2.73	5.23	5.85	2.30	2.02	2.93	1.68	2.55	2.17	4.24	1.77	2.02	2.96
% of PV	75%	67%	60%	89%	72.7%	100%	62%	74%	86%	60%	100%	82%	100%	91%	56%	46%	100%	79.6%

- **Rescheduled demand**

The rescheduled demand KPI aims to verify if the use case event helped to move demand into the event period. For instance, if the PV production is higher from 15:00-17:00 and the user received a message, it is expected a greater consumption in this period, and less activity before and after the event. After the period of test cases 01 and 02 the real measurements were compared with the baseline, as summarized in Figure 26. According to the baseline analysis, it was expected that 6.70% of the daily load would be in the event period for test case 01. However, after applying the demand response events, the real data showed 8.71% of the load in the period, which represents a demand increase of around 30% in the event hours. On the other hand, test case 02 did not present the same performance, with a 1% of load decrease during the event, compared to the baseline.

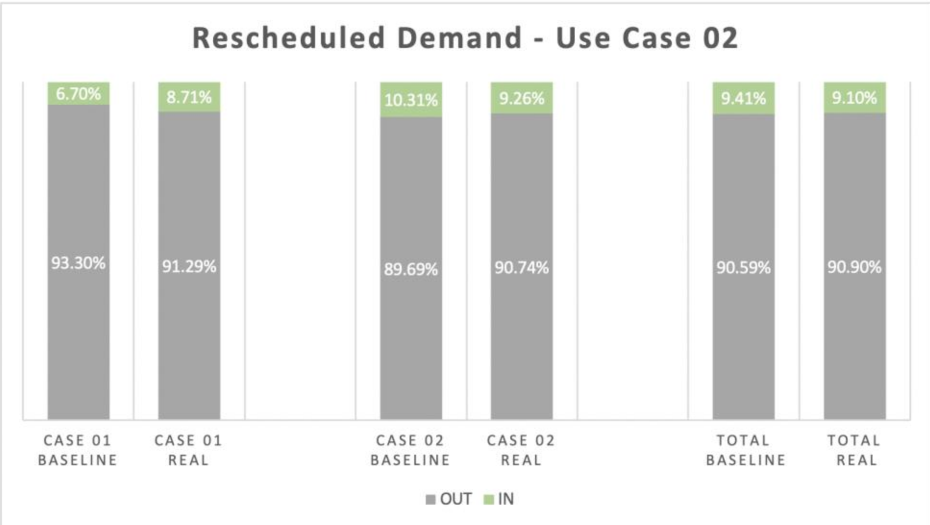


Figure 26 - Use Case 02 - Rescheduled demand

- **Economic savings**

The economic savings KPI compares the difference between the average baseline energy cost and the energy cost during the DR event. It considers the amount of energy consumed from the grid, so using appliances when the PV production is higher during the event reduces the final costs. Table 14 shows the aggregated values for all the houses over the complete experiment (test case 01 and 02). As a result, energy from the grid represented only 4% of the total necessary during the event, which is 20% less than the expected baseline. The electricity price follows Table 7.

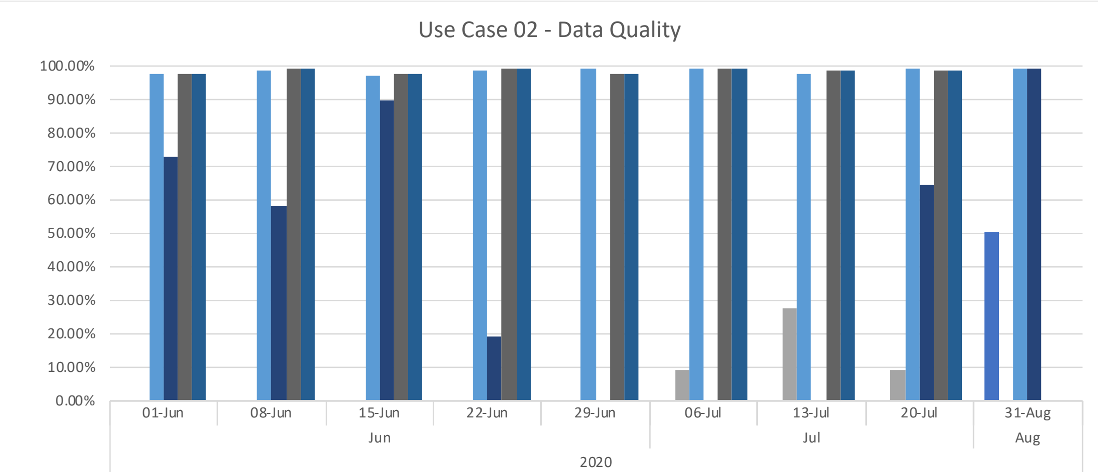
It is important to note that the costs are very related to the way that end users distribute their load over the day, and that is some of the reasons the information from the RESPOND App can be helpful. For instance, if the PV production is high and achieved 2 kWh, the user has to be aware and try to avoid exceed this value by controlling the amount of load to use at a certain time to optimize the usage, otherwise the amount of energy bought from grid can be greater than expected.

Table 14 - Use Case 02 - Economic savings

		Total Consumption	Total from Grid	% from Grid
Real	(kW)	48.85	2.09	4%
	(EUR)	€ 9.39	€ 0.40	
Baseline	(kW)	61.45	14.90	24%
	(EUR)	€ 11.81	€ 2.86	

- **Communication performance**

The communication performance KPI verifies the data availability to guarantee that all the data required for calculating the KPIs are in the database and ready for being used. In Figure 27 it is possible to see the status of data quality in the analysis of Use Case 02. This way, Houses 03, 05 and 12 were chosen on the validation process due to the availability of data.



	01-Jun	08-Jun	15-Jun	22-Jun	29-Jun	06-Jul	13-Jul	20-Jul	31-Aug
Aran - 01	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	50.20%
Aran - 02	0.00%	0.00%	0.00%	0.00%	0.00%	9.23%	27.63%	9.23%	0.00%
Aran - 03	97.42%	98.41%	97.07%	98.46%	98.81%	98.86%	97.57%	98.76%	98.81%
Aran - 04	72.72%	58.04%	89.38%	19.10%	0.00%	0.00%	0.00%	64.19%	98.91%
Aran - 05	97.47%	98.76%	97.42%	98.76%	97.37%	98.81%	98.41%	98.71%	0.00%
Aran - 12	97.57%	98.81%	97.52%	98.81%	97.22%	98.86%	98.61%	98.41%	0.00%

Figure 27 - Use Case 02 - Data quality Chart

2.3 USE CASE 03 - IRELAND - PV PANEL – OPTIMAL PROFILE OF USE FOR HEAT PUMPS

The aim of Use Case 03 is to maximize PV self-consumption by generating an optimal profile of use for heat pumps. This use case can be performed in different ways, such as fully-automated operation of the heat pumps, which can achieve better energy savings and does not rely on the user's behaviour, or manually operated, following a similar methodology as use case 02 where users have to play their role and perform the actions when necessary. The next subsections present the methodology and results of this use case.

The initial idea for this use case was an automated model, but the heat pump systems of the houses in the Aran Islands do not have available technology for this kind of remote operation and an installation of an additional device from Mitsubishi is needed. Mitsubishi was willing to install those devices, but due to COVID-19 restrictions all the travels had been suspended for months, hence the installations did not happen before the use case trials.

As a second plan, we moved to a calibrated simulation using the Building Simulator (BS) - (NUIG), considering the IPMVP option D. The overall methodology is similar as Use Case 02, where at the night before the event the PV production prediction model verifies which will be the hour in the next day where production is expected to be high, and simulates the optimal heat pump profile to be performed by the users to achieve best energy savings and greater PV self-consumption.

The Building Simulator operation model can be found in deliverable 4.5 [6]. For this use case, it is used specifically to optimize DHW heating, by changing the operation mode and boosting the tank temperature when PV production is higher, thus avoiding heating actions during peak hours by creating a buffer of hot water. The operation mode 1 is the standard mode, where the temperature range is from 40°C to 50°C. In mode 2 the maximum threshold is increase and temperatures can go up to 55°C.

2.3.1 ASSESSMENT

The test environment used was house 04 model of Aran Islands. As input for the Building Simulator, we selected 10 days in August where PV production prediction was considered good enough to help with the heat pump system operation. The predictions informed the peak hour of PV production for each of the days and were used as part of the rule-based control defined on deliverable 4.5 [6]. The model was then simulated and, as a result, presented the optimal operation modes to be set for each of the hours, as can be seen in Figure 28. The operation modes can be set manually by the user or autonomously, if technology for remote control is available.

	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
07-Aug	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1
08-Aug	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
09-Aug	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1
11-Aug	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1
18-Aug	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1
20-Aug	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1
21-Aug	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1
23-Aug	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1
29-Aug	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1
30-Aug	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1

Figure 28 – Use Case 03 - Operation modes output schedule.

Another BS output is the expected control action hours and also estimated tank temperature over the day. Figure 29 shows a dashboard of two of the simulated days.

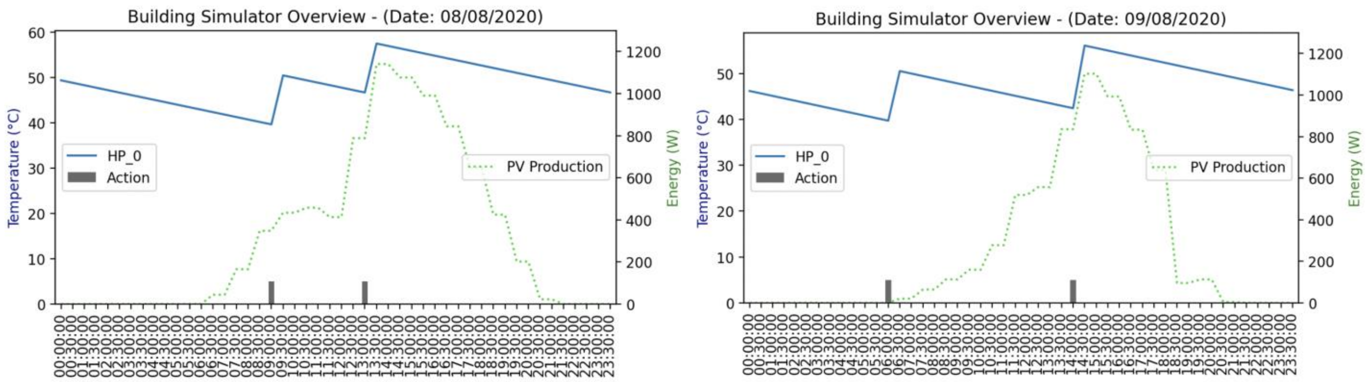


Figure 29 – Use Case 03 - Building Simulator dashboard.

Considering only operation mode 1 without PV self-consumption optimization, the heat pump would heat the tank to 50°C and then stay on hold until the temperature drops to 40°C, heating again to 50°C and so on. This mode can be costly, as it does not verify the best time to perform the actions, which may be at night when there is no PV production and the energy demand peak is usually higher. The rule-based operation mode provided by the BS checks the PV production schedule and anticipate actions to achieve economic savings, without losing users' comfort. For instance, the right chart of Figure 29 shows the tank temperature (blue line) dropping to 40°C at 6 am. This automatically turns on the heat pump and heats the water to 50°C. However, different from the standard mode 1, it turns on once again with operation mode 2 at 2 pm due, to the high PV production. This action boosts the tank temperature to 55°C, thus it does not need to turn on again after 6 pm where the energy cost is possibly higher.

Finally, the BS results were compared with the real data from the heat pump energy meter to assess the estimated performance, through different KPIs.

2.3.2 KPIs CALCULATION

- **Energy Savings**

  The results from the Building Simulator were uploaded to the DEXMA platform and compared with the heat pump consumption real data (baseline). As a result, almost 30% of energy from the grid could be saved if the actions had been performed as the BS output schedule, mostly due to using the heat pump when the peak PV energy was higher. This performance could drop to around 25% because the real world can face more uncertainties related to users' behaviour. For instance, BS considers an ideal profile of DHW usage, while the real user can suddenly decide to use all the water at once, making the control system activate more times over a day.

  Figure 30 and Figure 31 show the Energy Savings Calculated on DEXMA platform for each of the 10 analyzed days. Overall, the optimal BS model achieved on average 29.77% of savings when compared to the baseline, and overperformed 12.21% when compared to the 20% of the energy savings target.

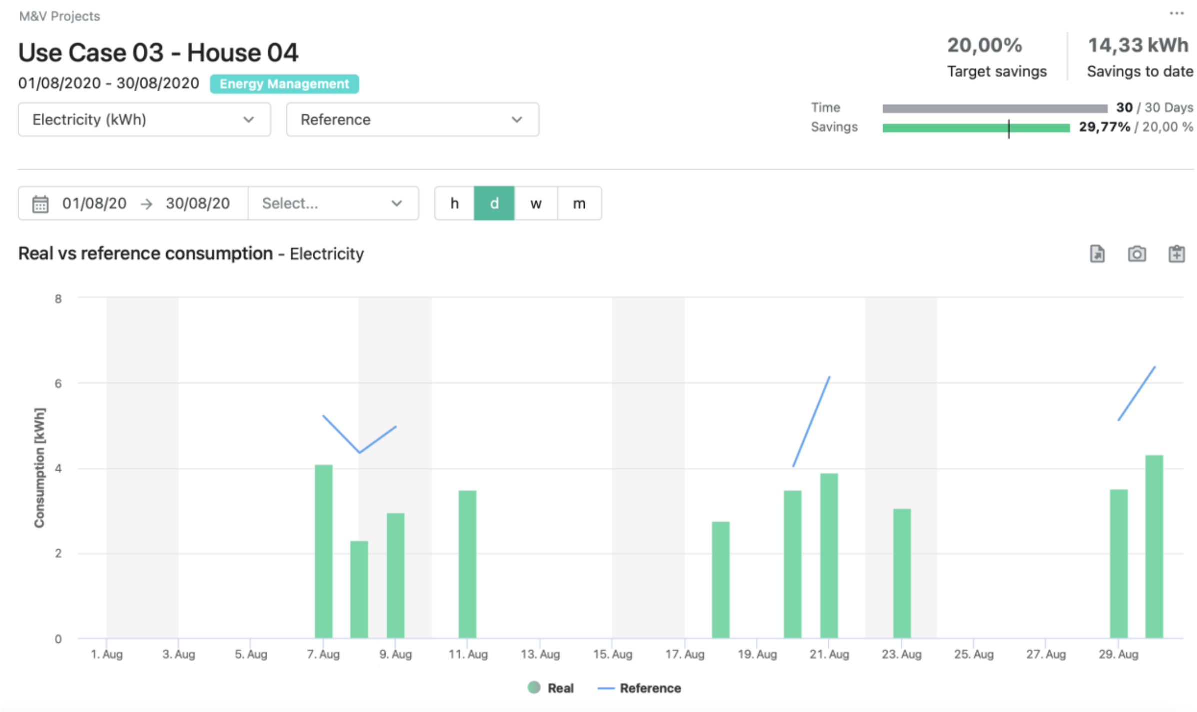


Figure 30 – Use Case 03 - Energy savings KPI - DEXMA 01

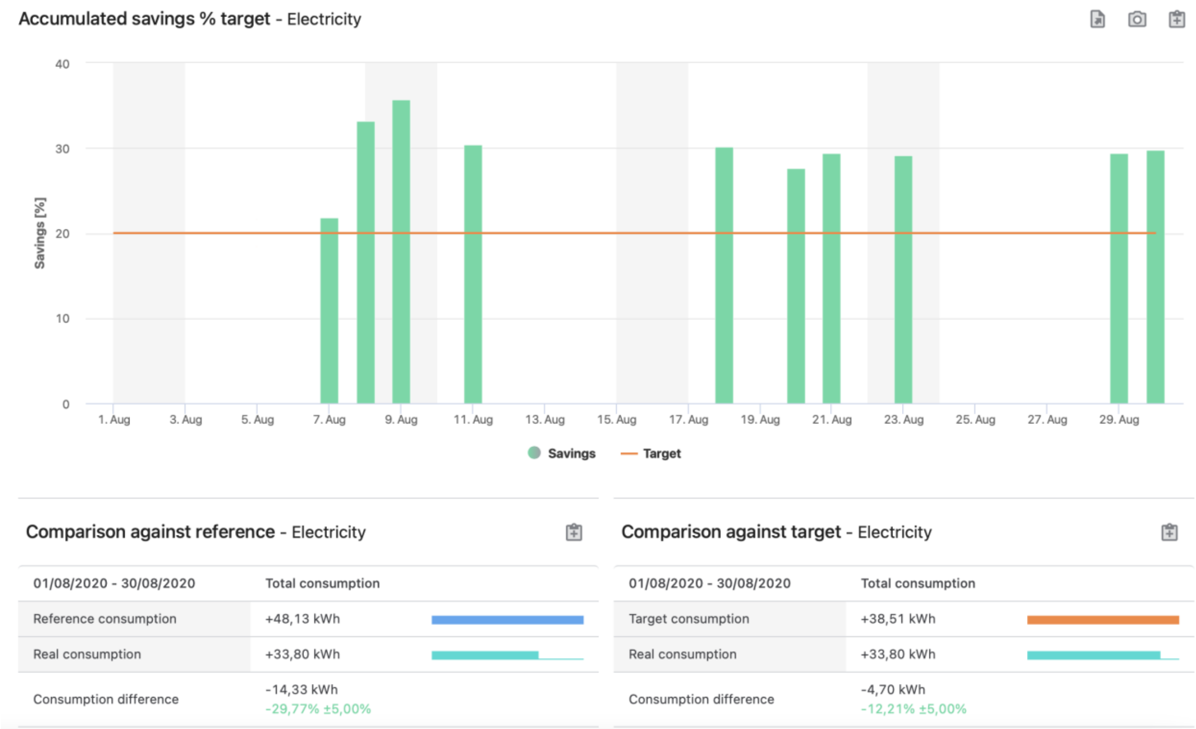


Figure 31 – Use Case 03 - Energy savings KPI - DEXMA 02

- **Reduction of greenhouse gas emissions**

  The reduction of greenhouse gas emission KPIs was also calculated on DEXMA platform, following the same comparison parameters as the energy savings KPI. It is the amount of energy savings converted to greenhouse gas emission equivalent, as presented on subsection 1.4.3, hence the reductions also achieved 29.77% on average. Figure 32 shows the details about the calculations on DEXMA platform.

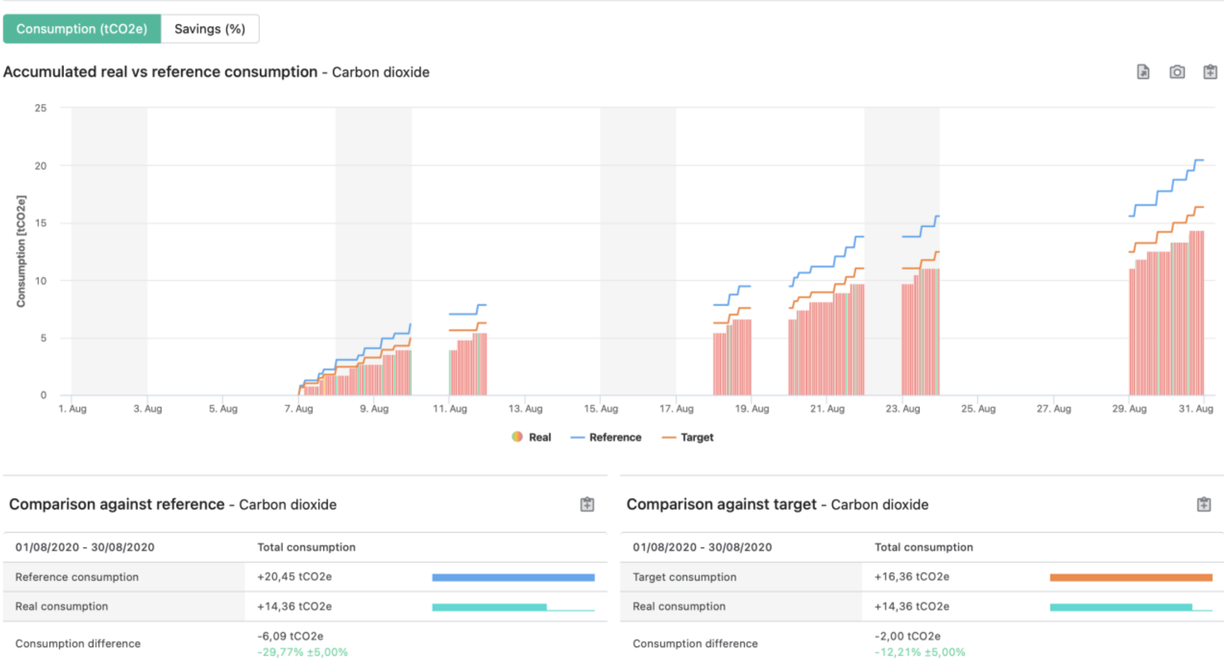


Figure 32 - Use Case 03 - Reduction of greenhouse emissions KPI

- **Reschedule demand**

  Rescheduled demand KPI was calculated considering the total demand consumed inside the period of higher PV production incidence (10 am to 6 pm) and out of it, considering the average of the 10 analyzed days. In the real data, only 37% of the heat pump consumption was inside the PV event range, while this value achieved 57% for the BS optimized model, an increase of 20%. Figure 33 presents the average consumption for both optimized and real data, including also the average of PV production. Note that one of the benefits of the BS model is the peak reduction and load shifting, as the peak load that was originally between 6 pm and 8 pm in the real data was moved to hours before in the optimized version.

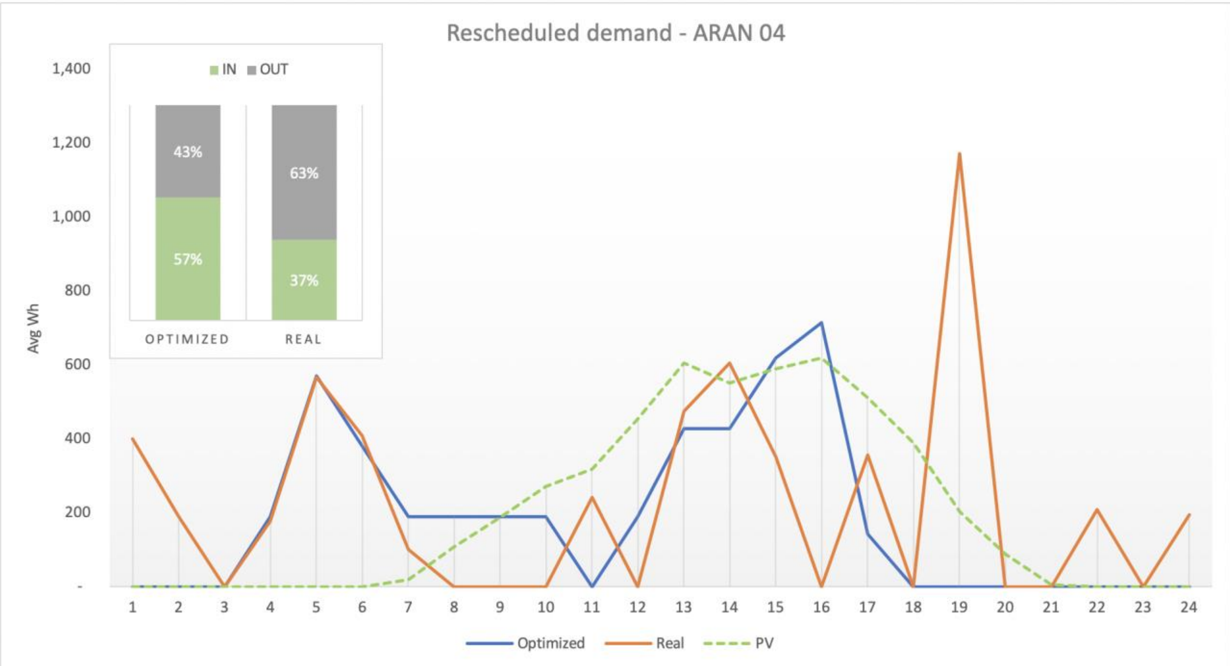


Figure 33 – Use Case 03 - Rescheduled demand - Aran 04

- **Renewable total energy consumption**

  The renewable total energy KPI was calculated by comparing the amount of real PV consumed and the optimal PV consumption. For comparison purposes, it considers that PV production is used exclusively for heat pump actions. As presented in the previous KPI, there is a higher concentration of heat pump activity in the period of PV production, hence renewable is better explored in the optimal BS model. For each of the days, it was calculated the amount of renewable energy used, as can be seen in Table 15. On average, the BS optimal model improved renewable energy usage by 39.14%. August presented a negative value, possibly because the initial status of the tank temperature was much different between real and simulated, hence the initial actions happened in periods without PV.

Table 15 – Use Case 03 - Renewable total energy consumption.

	07-Aug	08-Aug	09-Aug	11-Aug	18-Aug	20-Aug	21-Aug	23-Aug	29-Aug	30-Aug	Total
Real PV consumption (Wh)	1,411.01	1,501.75	835.64	403.54	503.04	267.27	489.57	411.32	182.80	374.28	6,380.21
Optimal PV consumption (Wh	1,158.91	1,499.69	1,331.94	1,281.51	1,067.77	804.93	887.47	765.13	770.08	916.19	10,483.63
PV consumption increase	-22%	0%	37%	69%	53%	67%	45%	46%	76%	59%	39.14%

- **Economic savings**

  The economics savings KPI was calculated by comparing the amount of real energy consumption and the optimal BS model. It considers the amount of energy necessary to perform the control action minus the value of PV production. For instance, if the DHW heating action consumes 2 kWh and the PV production at that specific time is 1.2 kWh, it will be necessary to consume 800 Wh from the grid. The electricity price used in the calculation is from Electric Ireland [18], presented in Table 7.

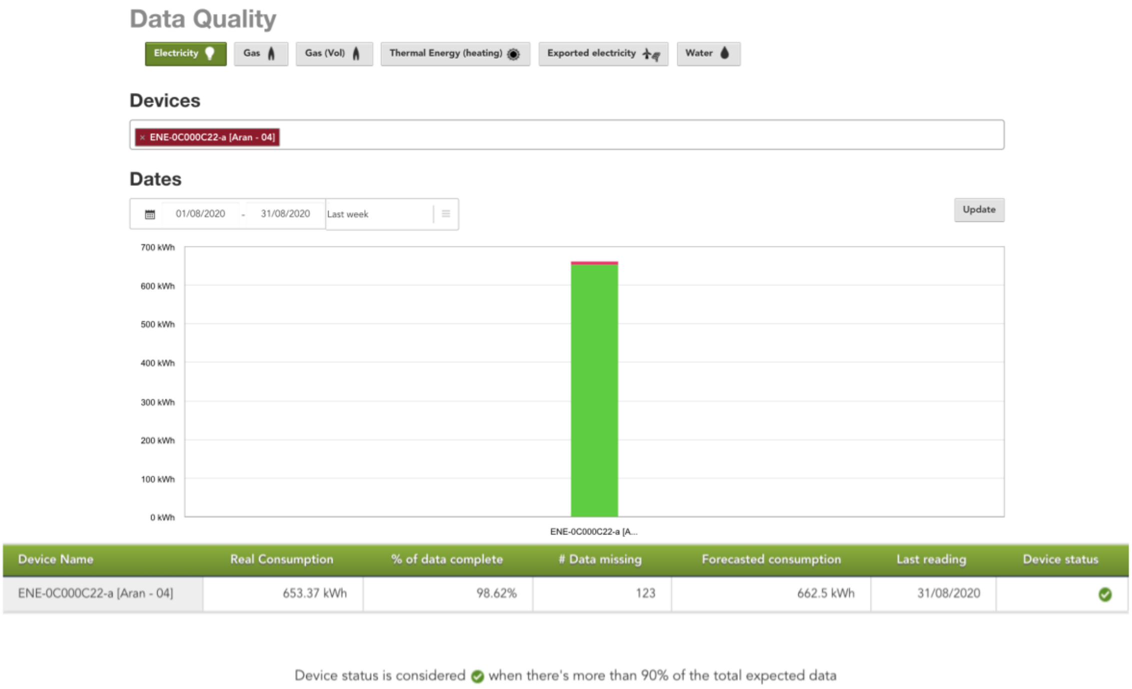
  Comparing the consumption from the grid of the 10 analysed days of both real and optimal model, the 29.77% of energy reduction represents a total of EUR 2.75 economic savings. That means users can save around EUR 100.00 annually by changing the heat pump schedule. Table 16 shows a summary of the economic savings. It is important to notice that this gain is only related to a heat pump and the hour of the highest PV production. If other appliances are involved, such as the ones presented in Use Case 02, it can bring further savings by using the whole potential of PV production for the hours after and before the production peak.

Table 16 – Use Case 03 - Energy savings summary.

	Total
Real consumption (Wh)	48,133.37
Optimal consumption (Wh)	33,802.09
Real (EUR)	€ 9.25
Optimal (EUR)	€ 6.50
Economic savings (EUR)	€ 2.75
Economic savings (%)	29.77%

- **Communication performance**

  The experiment conducted in this use case used only information about real energy consumption of the heat pump from House 04 – Aran Islands. As can be seen in Figure 34 from DEXMA platform, this device presented a good data quality, with 98.62% of data availability in August 2020.



Device Name	Real Consumption	% of data complete	# Data missing	Forecasted consumption	Last reading	Device status
ENE-0C000C22-a [Aran - 04]	653.37 kWh	98.62%	123	662.5 kWh	31/08/2020	✓

Figure 34 – Use Case 03 – Data quality analysis – DEXMA – Total period.

2.4 USE CASE 04 - IRELAND - PEAK SHAVING USE CASE

Use case 04 was designed to evaluate the customer's behaviour in relation to decrease of the carbon emissions during an hour in one day of the week, by decreasing their energy usage. The main idea of the use case was to send a manual notification one hour before the peak consumption in Ireland, asking people to decrease the usage of the electricity without any financial incentive. Table 17 shows the summary of the use case:

Table 17 - Use Case 04 - Event Description

	Description
Period	August 01th until August 11th
Number of events	3
Participating houses	Aran Islands houses (01,02,03,04,05,06,08,10 and 12)
Duration of the DR event	1 hour

The main premisses of the Use Case 04 are:

- To reduce the energy demand in some periods by asking users for turning off appliances.
- There will be no different tariffs or incentives – The customers will be doing this with the objective of reducing their carbon emissions in the period.
- The messages were sent about one hour before the time that the customers are requested to perform the action, and not one day before like the other use cases.

Nowadays, the Aran Islands are connected to the electricity grid in Ireland. According to Eir Grid [15], Ireland had on average more demand of energy between 17h and 18h during the first days of July (see Figure 35).

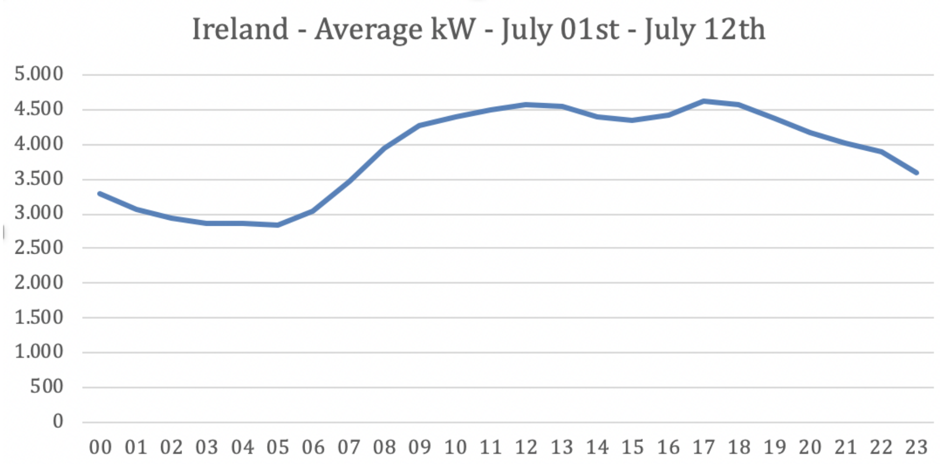


Figure 35 – Use Case 04 - Ireland - Hours with high energy demand (July/2020) [15]

2.4.1 ASSESSMENT

The baseline period was the first two weeks of July 2020 and the DR events happened in August 2020. Although the average peak in Ireland is between 17:00-18:00, before sending the message this range was confirmed on the demand system prediction provided by EirGrid [15], as can be seen in Figure 36 for the first day of event (August 4th).

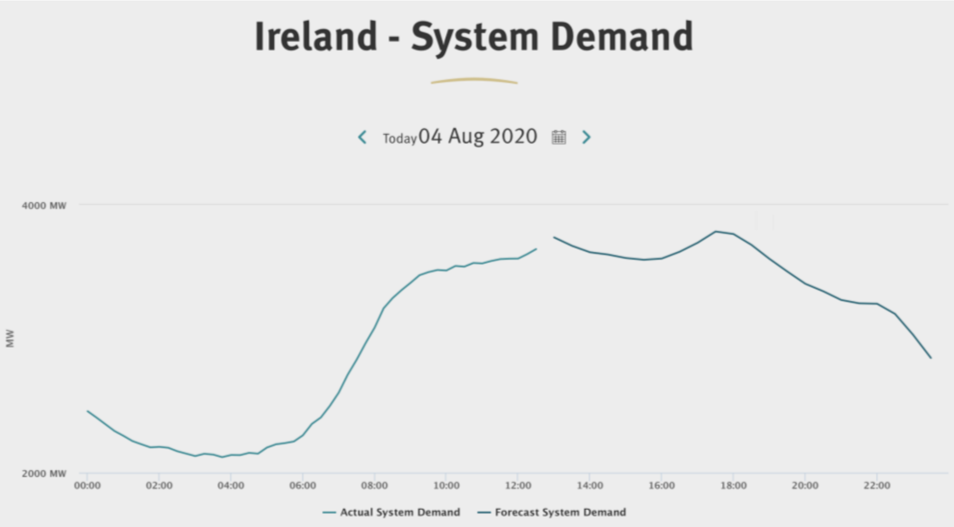


Figure 36 – Use Case 04 - Demand system prediction Eir Group [15]

To isolate the assessment of this use case, the three event days were select considering days without other use case running, especially Use Case 02 that asks users to consume more at a specific period. The idea is not to have more than one use case in a day to avoid user misunderstandings. Table 18 list the event dates, the message was sent one hour before the specified hours.

Table 18 - Use Case 04 - Hours of event

	Date	Hour of the event
Event – Day 01	04/08/2020	17h – 18h
Event – Day 02	06/08/2020	17h – 18h
Event – Day 03	11/08/2020	17h – 18h

The messages were sent as a RESPOND App notification in both English and Gaelic languages, as follows:

“Electricity consumption of Ireland peaks within the next few hours, which means higher CO_2 emissions. Turn off some of your appliances between hh:mm and hh:mm - and help us with saving the climate.”

“Buaicfidh tomhaltas leictreachais na hÉireann sna cúpla uair amach romhainn, rud a chiallaíonn astaíochtaí CO_2 níos airde. Múch cuid de do chuid fearais idir hh:mm agus hh:mm - agus cuidigh linn an aeráid a shábháil.”

Figure 37 shows an example of notification received in an IOS device.

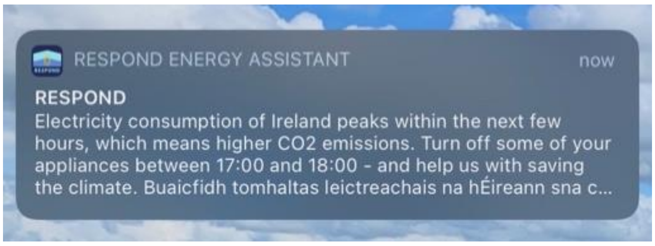


Figure 37 – Use Case 04 - Example of how the message was delivered in a IOS device

2.4.2 KPIs CALCULATION

- **Energy Savings**

The baseline period chosen was 01/07 – 15/07, since two weeks are enough time for accurately forecasting long-term building energy consumption [19]. As a result, it was observed a 14.73% of energy savings in the aggregated three days of event. As can be seen in Figure 38 from DEXMA platform, August 4th presented an almost the same amount of energy for real and reference baseline. On the other hand, August 6th and 11th had a lower values compared to the baseline.

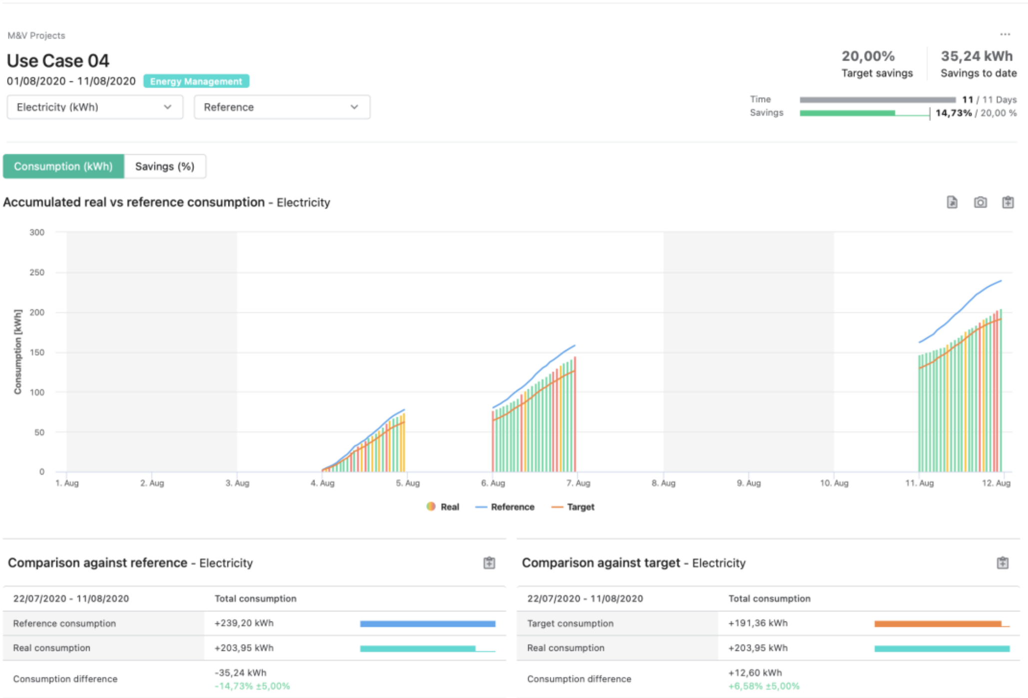


Figure 38 - Use Case 04 - Energy savings KPI DEXMA platform

- **Reduction of Greenhouse gas emissions**

The main objective of the use case was not to give financial incentives to the participants, but to reduce the CO_2 emissions in a certain period. The CO_2 reduction achieved in the Use Case was 14.97 tCO_2e during all the period of the analysis, which represents a 14.73% reduction compared to the baseline, as can be seen in Figure 39. The Reduction of greenhouse gas emission KPIs was also calculated on DEXMA platform, following the same comparison parameters as the energy savings KPI. It is the amount of energy savings converted to greenhouse gas emission equivalent, as presented on subsection 1.4.3.

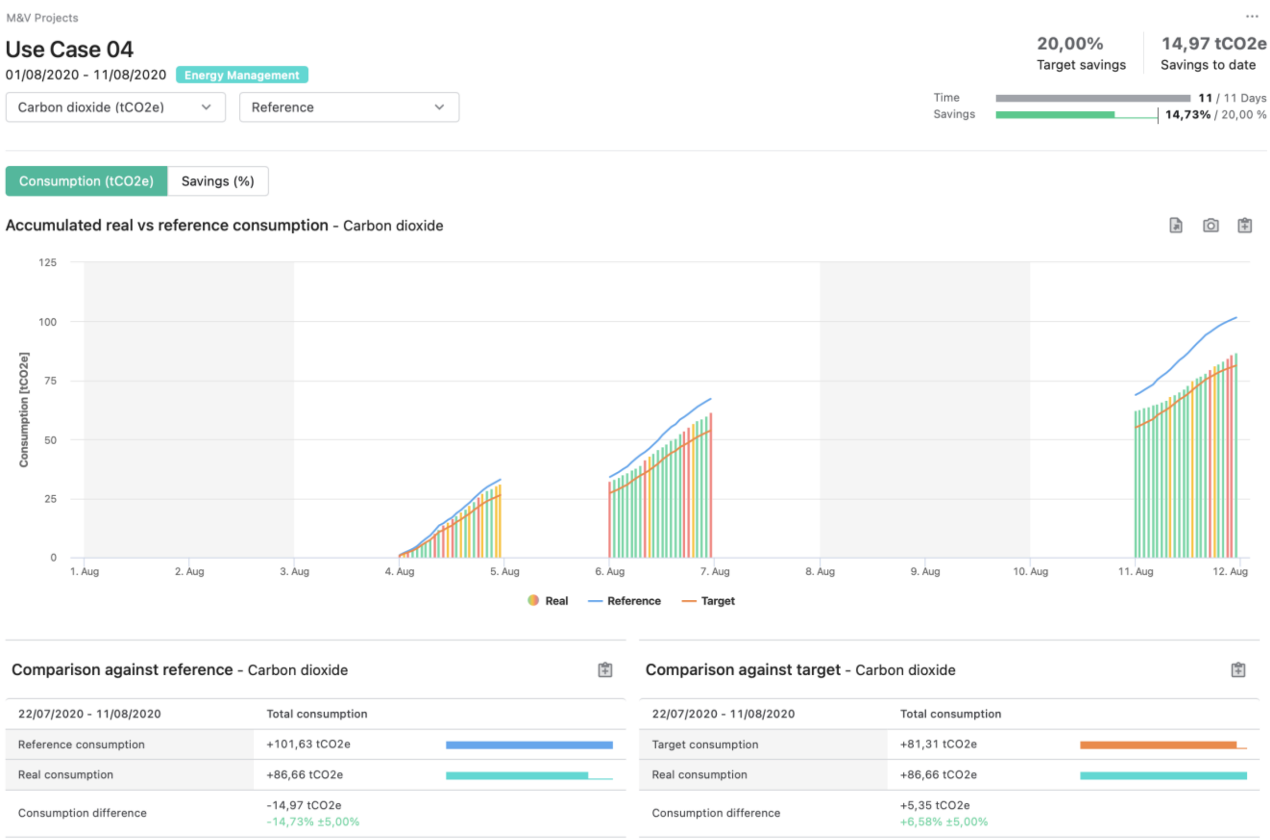


Figure 39 - Use Case 04 - Reduction of greenhouse gas emissions

After analysing the consumption of the individual appliances (heat pump, washing machine, and dishwasher) it was also verified that an additional 4.37 tCO_2e could be avoided in the period of the event, if all the costumers had done the action.

- **Peak load reduction**

The hourly analysis of the users consumption behaviour shows that there is no significant reduction in the peak load during the event period 17:00-18:00, compared to the baseline. As can be seen in Figure 40, the average energy consumption for both baseline and real have approximately the same value. As this KPI uses the electricity meter information for calculation purposes, loads that are not individually measured as part of the RESPOND project may have an impact on the final results.

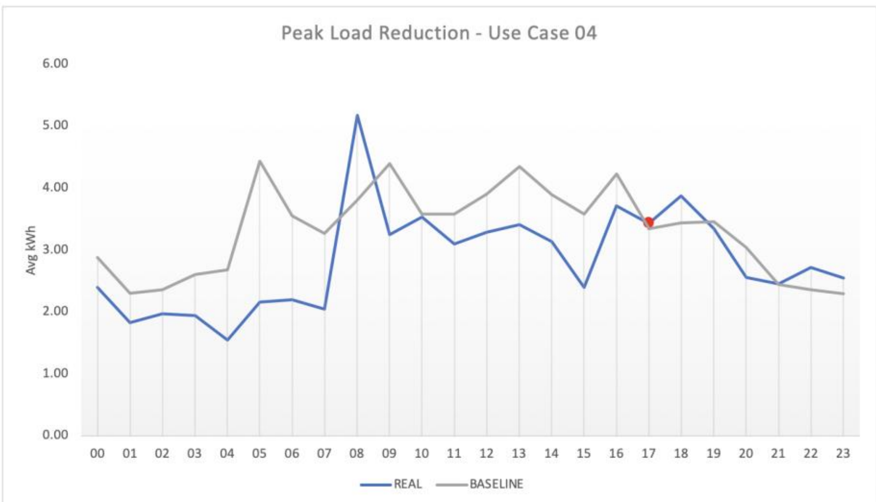


Figure 40 - Use Case 04 - Peak load reduction

- **Rescheduled demand**

 The rescheduled demand KPI aims to verify if the use case event helped to move demand out of the event period. As users are expected to reduce the energy usage between 17:00-18:00, it is expected a lower consumption in this period. Figure 41 summarizes the load shifting for each of the event days. The first day presented a decrease in energy consumption in the event period, but days two and three presented an increase. Overall, considering the three days aggregated, the expected load during the events expected to be 4.19% of the daily load according to the baseline. However, the real data shows a slightly higher rate of 5.05%.

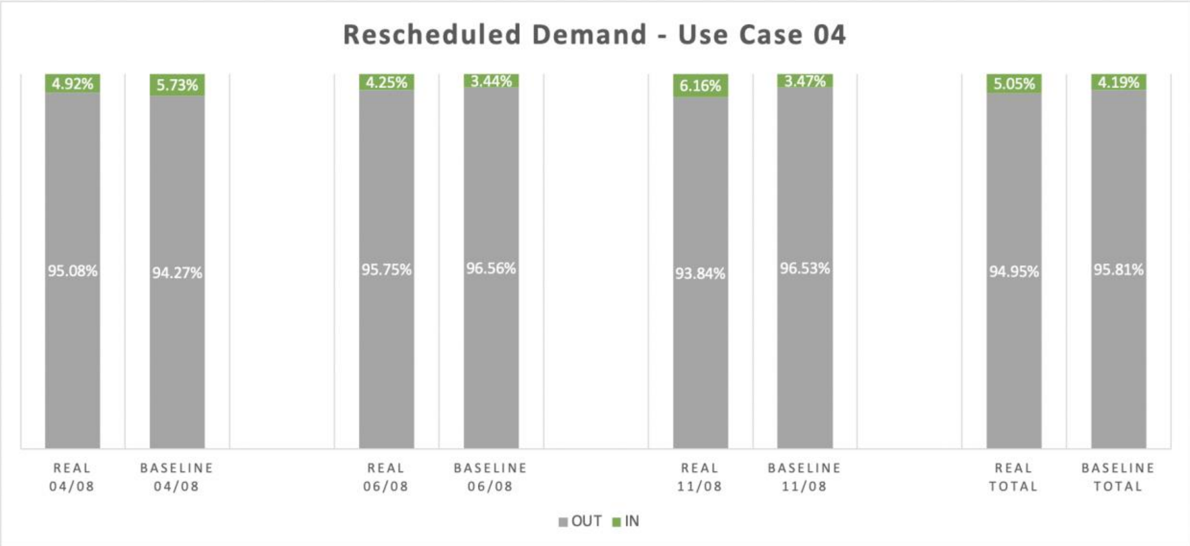
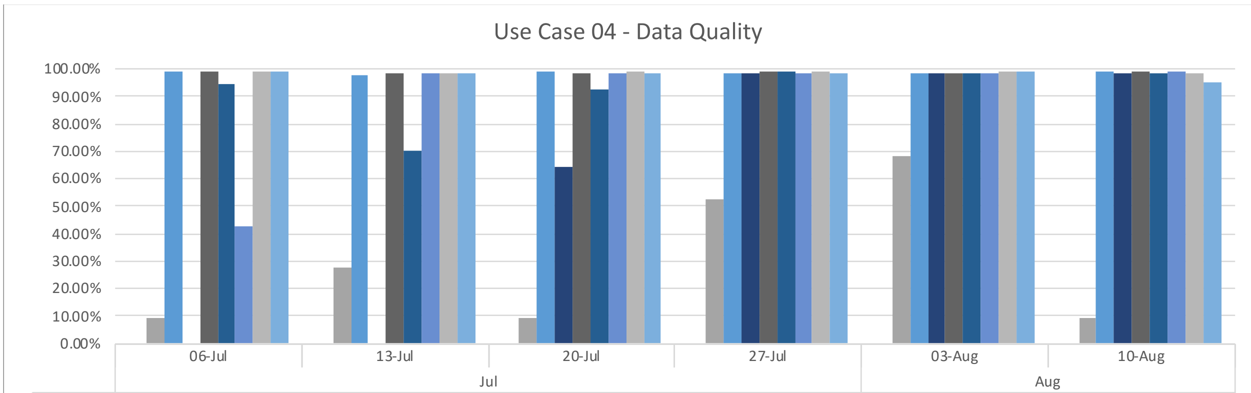


Figure 41 - Use case 04 - Rescheduled demand

- **Communication performance**

The communication performance KPI verifies the data availability to guarantee that all the data required for calculating the KPIs are in the database and ready for being used. In Figure 42 it is possible to see the status of weekly data quality in the analysis of Use Case 04. This way, Houses 02, 04 and 08 were excluded and not considered in the validation process due to the missing data over the baseline period. House 01 shows 0% of data availability because it was not included in DEXMA platform by the experiment period, but the gateway was sending information to RESPOND DB, hence it was included in the use case analysis.



	06-Jul	13-Jul	20-Jul	27-Jul	03-Aug	10-Aug
	Jul				Aug	
Aran - 01	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Aran - 02	9.23%	27.63%	9.23%	52.83%	68.01%	9.08%
Aran - 03	98.86%	97.57%	98.76%	98.56%	98.12%	98.81%
Aran - 04	0.00%	0.00%	64.19%	98.56%	98.51%	98.61%
Aran - 05	98.81%	98.41%	98.71%	98.76%	98.71%	98.76%
Aran - 06	94.44%	70.54%	92.41%	98.86%	98.61%	98.71%
Aran - 08	42.41%	98.31%	98.61%	98.66%	98.61%	98.76%
Aran - 10	98.86%	98.61%	98.81%	98.86%	98.76%	98.71%
Aran - 12	98.86%	98.61%	98.41%	98.61%	98.76%	95.19%

Figure 42 - Use Case 04 - Data Quality Chart

2.5 USE CASE 05 - DENMARK - LOAD SHIFTING DISTRICT HEATING SYSTEM

The aim of Use case 05 is to change the heating consumption load during a certain period to decrease the peak in the usage curve, without affecting users comfort. For a number of reasons, the district heating supplier would like to make it possible to time-shift some of the heat delivered to homes. The most important reason for this is that the supplier in various areas are experiencing a problem with delivering enough heat (e.g. if there has been new-built of homes) – especially in the morning when the demand for heat peaks due to many people taking a shower more or less simultaneously. This means that the supplier either have to invest in upgrading the pipes in the ground (which might cost a lot of money and make the heat more expensive for customers) or – alternatively – find ways to time-shift some of the consumption away from the peak hours.

One way to do the latter is to install modern thermostats in homes that can control the heating during the day/morning. In this way, the company can switch off the heat shortly during the few hours with peak consumption in the morning. Of course, only with the prior acceptance from the tenants. For buildings like those in ALBOA, the housing association at the Danish pilot site, this is expected to only result in a limited drop in temperature during the few hours when the heating is switched off. Roughly, it is estimated, that the temperature drops about 1°C per hour. To maintain the temperature within a comfortable range, the temperature may be slightly raised before turning off the heat.

2.5.1 ASSESSMENT

The first part of this use case was to identify the peak load period. Figure 43 shows an example from March 2018 (data provided by the district heating company in Aarhus).

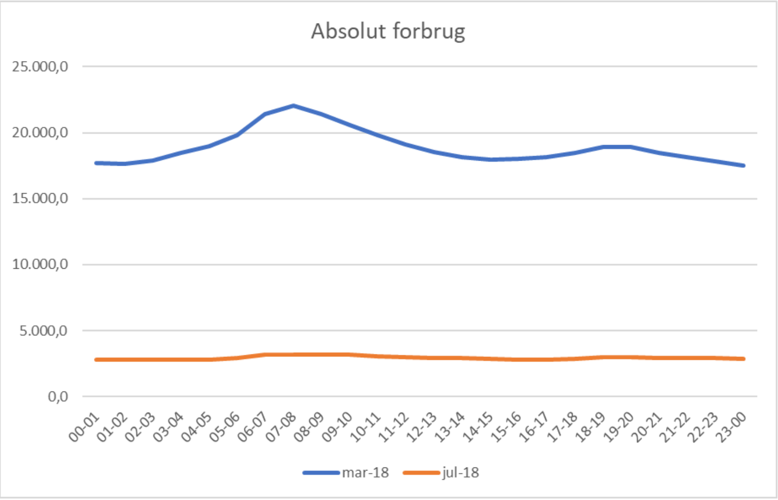


Figure 43 - Use Case 05 - Peak hours in the morning during the winter month

Based on the peak hour shown above, it was decided to do a series of experiments where thermostats in ten participating dwellings are switched off, by lowering the set-point to 16°C for one hour from 7 am to 8 am and 3 hours from 6 am to 9 am during weekdays.

Based on the focus group interviews carried out in RESPOND work package WP3 it was decided to include one experiment with preheating prior to switching off the heat. It was decided to preheat with 1°C for 2 hours, prior to switching off the heat for 3 hours. From an energy point of view, it may be preferred not to preheat. Therefore, it was decided to also do experiments both with and without preheating, as shown in the table. The Test Weeks are defined in Table 19, where it is possible to see the final dates that the event was applied without the baseline periods. Additional information about the tests can be found in Table 20.

Table 19 - Use case 05 - Hours of event

Date		Hour of the event
Event 01	17/02/2020 → 01/03/2020	7 am: set-points lowered to 16°C 8 am: set-points back to "preferred set point"
Event 02	02/03/2020 → 15/03/2020	4 am: set-point raised 1°C above "preferred set point" 6 am: set-points lowered to 16°C 9 am: set-points back to "preferred set point"
Event 03	16/03/2020 → 29/03/2020	6 am: set-points lowered to 16°C 9 am: set-points back to "preferred set point"

Table 20 - Use Case 05 - Event description

	Baseline period	Switched off for one hour	Switched off for three hours
Doing nothing – Baseline 1	Test week 1-2	-	-
With preheating +1°C for 2 hours	-	-	Test week 5-6
Without preheating	-	Test week 3-4	Test week 7-8
Doing nothing – Baseline 2	Test week 9-10		

Occupants had around two months before the event for adjusting the thermostats to their own preference, before they are being remotely controlled automatically. The preferred temperature level in each room of a dwelling is adjusted by the tenants themselves as they are used to do it. As a result, the thermostats in each room of all dwelling will have a specific preferred set-point on the thermostats that can be read remotely. This is the starting point for the experiments, and the set-points that all thermostats will return to after they have been remotely controlled during the morning peak hour.

All thermostats are following the same plan, except the thermostats in the bathroom (on first floor) that are not remotely controlled but are as the occupants have adjusted them. This is to meet a desire for maximum thermal comfort in the bathroom and not to increase the risk for mold growth in the bathroom.

The reason for not just totally turning off (or adjusting to a very low set-point, e.g. 5°C) the thermostats is twofold. 1) To ensure that the temperature does not get "too low", i.e. outside what the tenants can accept from a thermal comfort point of view, and 2) to make sure the temperature in the dwelling does not get so low that it creates problems for the building due to condensation on walls, such as molds.

After finishing the use case tests, a total of 146 control actions have been performed in the participating houses 01,03,04,05,06,08 and 09 (houses 02, 07, 11 presented technical issues). For the KPI calculation stage, two different baselines were created. The first considers all the houses in the Aarhus pilot, to show the impact of the actions in the community. The second baseline evaluate only the changes over the use case participants. Both are calculated from test week 1 and 2.

2.5.2 KPIs Calculation

- **Energy Savings**

The energy savings KPI were calculated on DEXMA platform. As the events have a different methodology, an aggregated and individual analysis was performed, as can be seen in Figure 44, Figure 45, Figure 46 and Figure 47, where the baseline is only the use case participants. Overall, 14.36% of savings was achieved in the entire use case period. The reduction was 6.31% in the first test, where the temperature setpoint was lowered for just 1 hour. The second test (weeks 5 and 6) achieved even more savings, reaching 9.36%, where pre-heating was realized and the setpoint was reduce for 3 hours. Finally, the last experiment (week 7 and 8) overperformed the previous experiments with 27.46% of savings. In this case, there was no pre-heating and the setpoint was reduce for 3 hours.

Figure 44 - Use Case 05 - Energy savings - 17/02/2020 - 29/03/2020

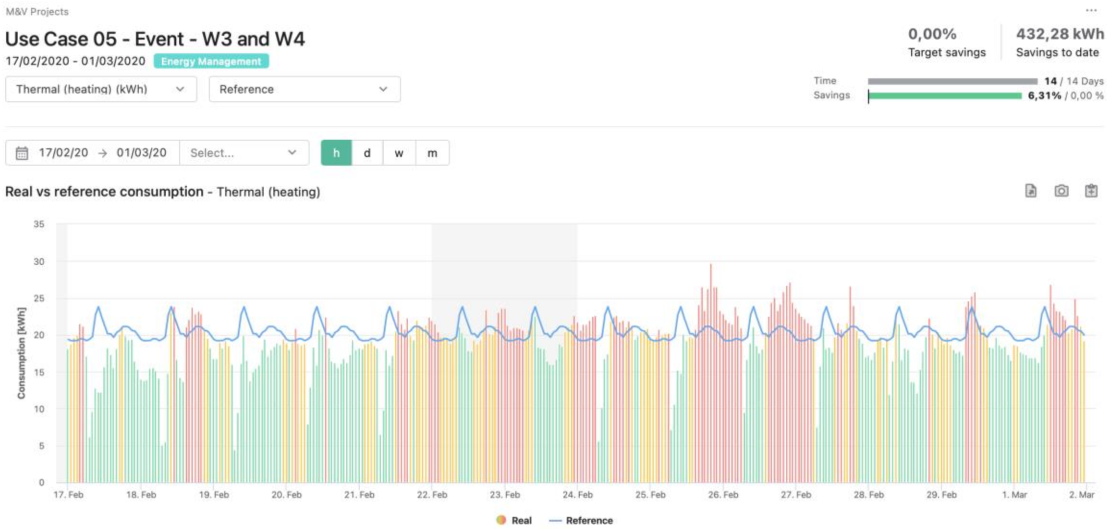


Figure 45 - Use Case 05 - Energy savings - 17/02/2020 - 01/03/2020

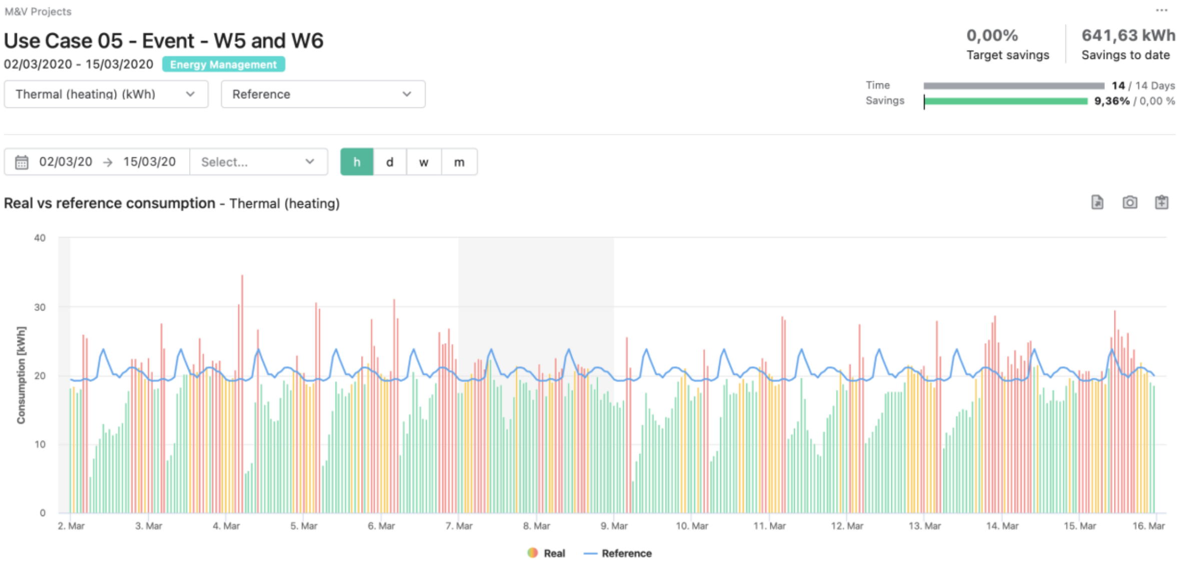


Figure 46 - Use Case 05 - Energy savings - 02/03/2020 - 15/03/2020

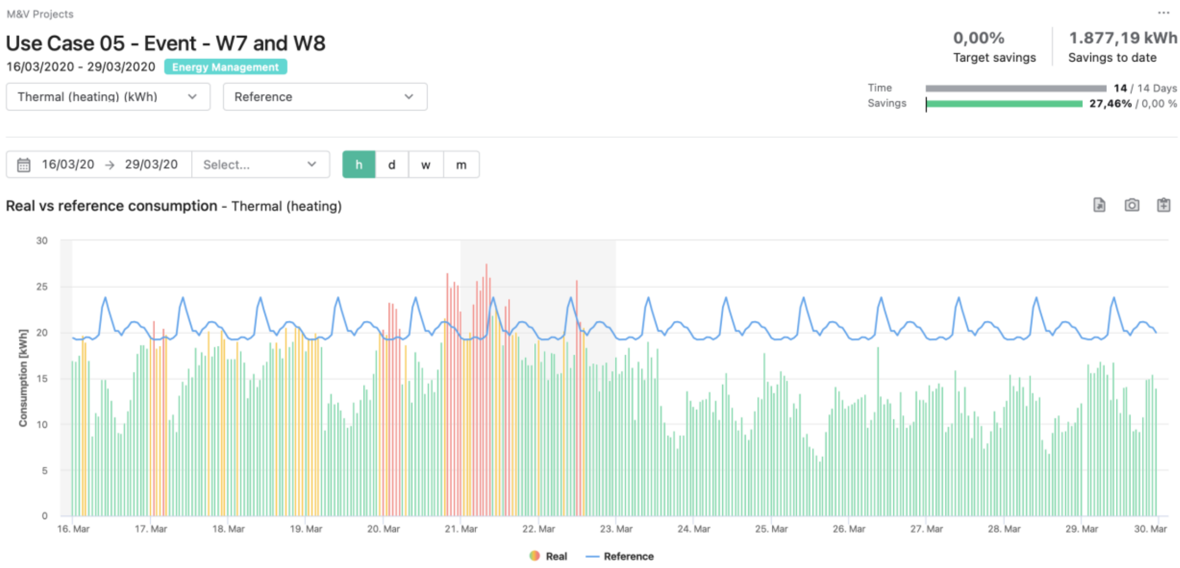


Figure 47 - Use Case 05 - Energy savings - 16/03/2020 - 29/03/2020

Considering all the active houses of Aarhus pilot as a baseline, it is possible to see that the average savings was 11.50% (the previous value considering only participant houses was 27.46%). That means that adding more houses to this use case would possibly bring higher energy savings in quantitative terms. Table 21 and Table 22 present the aggregated and individual results of the performed tests.

Table 21 - Use Case 05 - All Heat meters of the project

Name	Type	Target	Saved %	Saved	
Use Case 05 - All thermal	Energy Management	0,00%	11,50	4.984,82 kWh	42 / 42 Days 11,50% / 0,00 %
Use Case 05 - All thermal - W7 and W8	Energy Management	0,00%	22,71	3.276,26 kWh	14 / 14 Days 22,71% / 0,00 %
Use Case 05 - All thermal - W5 and W6	Energy Management	0,00%	8,72	1.261,80 kWh	14 / 14 Days 8,72% / 0,00 %
Use Case 05 - All thermal - W3 and W4	Energy Management	0,00%	3,09	446,77 kWh	14 / 14 Days 3,09% / 0,00 %

Table 22 - Use Case 05 - All meters in the event

Name	Type	Target	Saved %	Saved	
Use Case 05 - Event - W7 and W8	Energy Management	0,00%	27,46	1.877,19 kWh	14 / 14 Days 27,46% / 0,00 %
Use Case 05 - Event	Energy Management	0,00%	14,36	2.951,10 kWh	42 / 42 Days 14,36% / 0,00 %
Use Case 05 - Event - W5 and W6	Energy Management	0,00%	9,36	641,63 kWh	14 / 14 Days 9,36% / 0,00 %
Use Case 05 - Event - W3 and W4	Energy Management	0,00%	6,31	432,28 kWh	14 / 14 Days 6,31% / 0,00 %

- **Reduction of Greenhouse gas emissions**
  The Reduction of greenhouse gas emission KPIs was also calculated on DEXMA platform, following the same comparison parameters as the energy savings KPI, but only for the aggregated values of houses participants in the event. It is the amount of energy savings converted to greenhouse gas emission equivalent[4].

[4] The value used for calculating this KPI was the average CO_2-intensity of the heat provided by the district heating in Aarhus in 2020 calculated so far: 38.1 kg CO_2 / MWh [22]

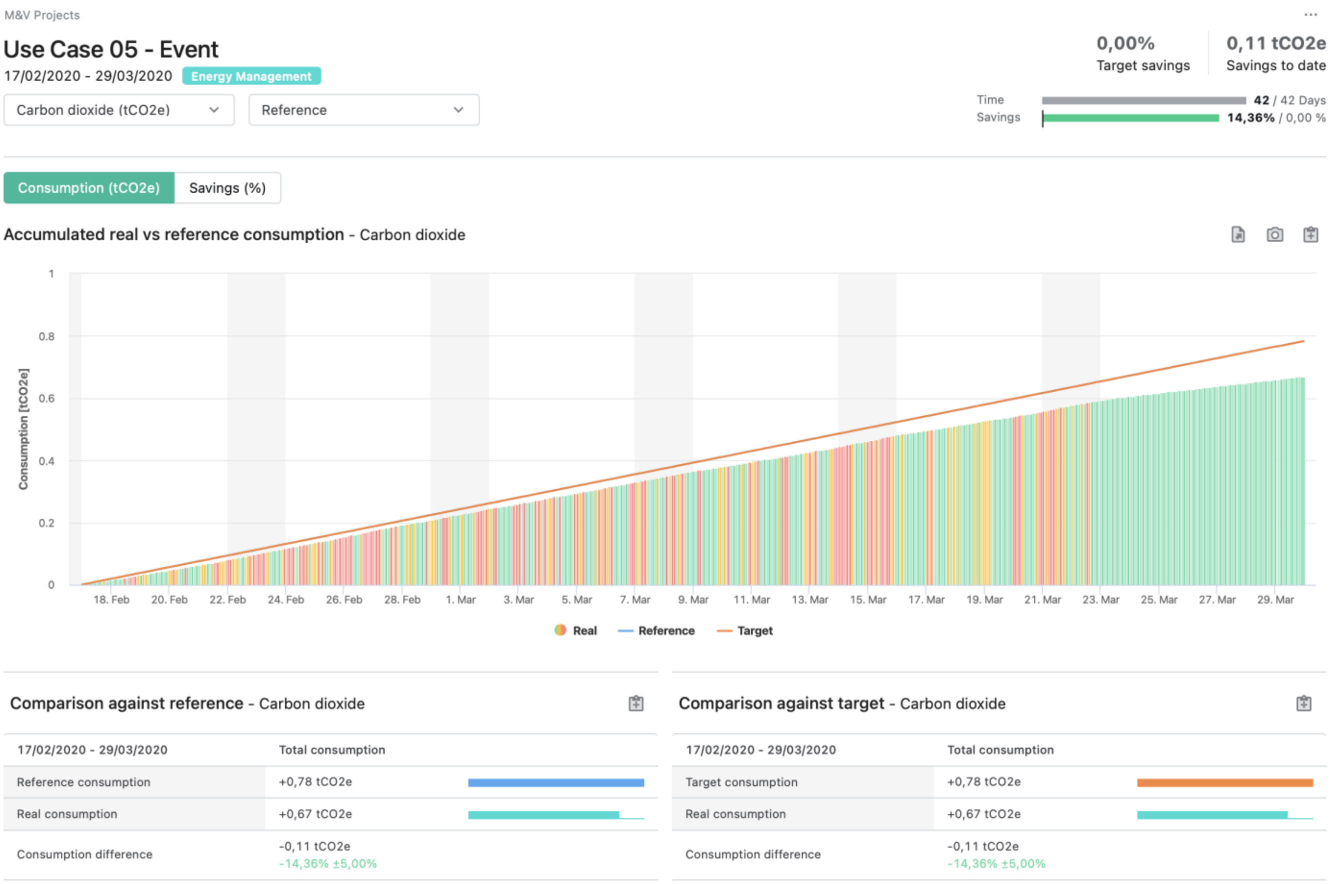


Figure 48 - Use case 05 - Reduction of Greenhouse gas emissions

- **Peak load reduction**

The peak load reduction was analysed for both participants in the use case and community. It also considers individual results for each of the events. Starting with the house participants, the load peak was reduced by 33 kWh in the first experiment. The second test presented an increase of 30 kWh due to the pre-heating stage (4 am), but also presented a reduction of around 30 kWh over the day out of the pre-heating period. Finally, the third test showed an almost 90 kWh of reduction in the peak. The overall load in the third test is around 20 kWh lower when compared to the baseline, which in the end can represent a peak reduction of 70 kWh if normalized. Figure 49 to Figure 51 show the graphs related to the event houses only.

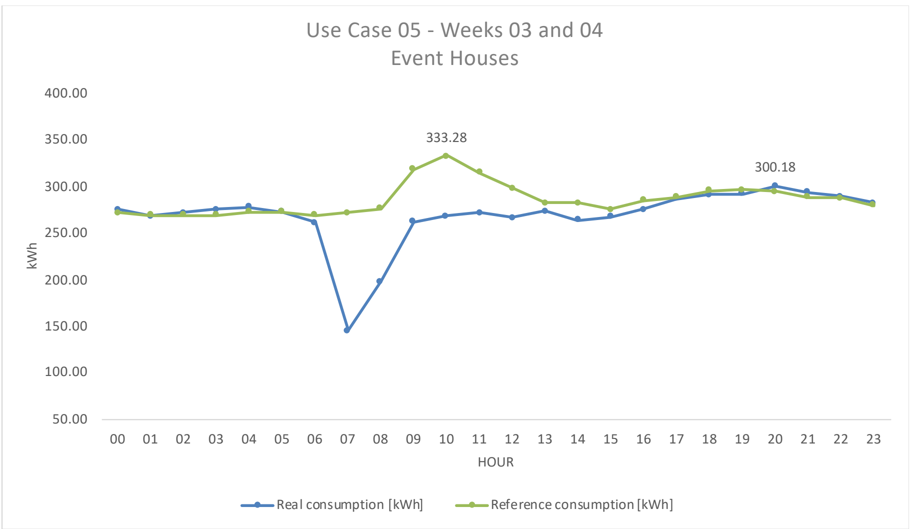


Figure 49 - Use Case 05 - Peak load reduction - 17/02/2020 - 01/03/2020 - Event houses

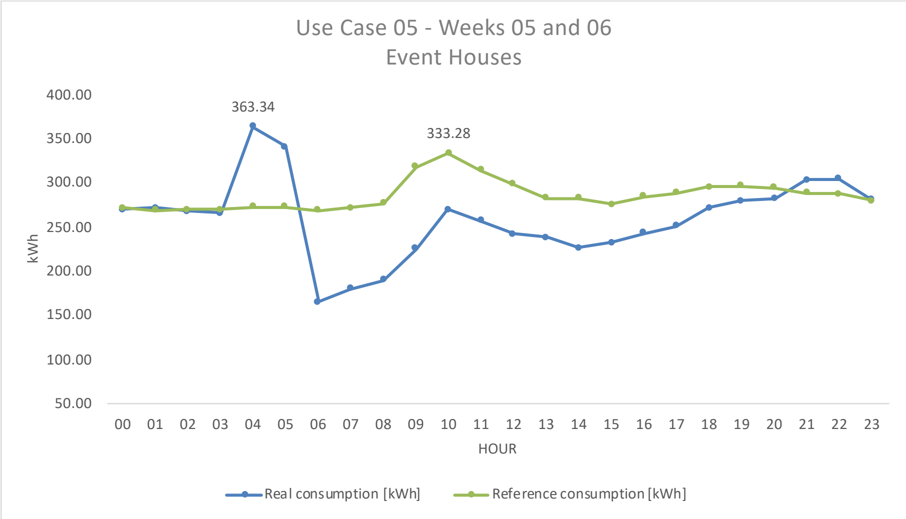


Figure 50 - Use Case 05 - Peak load reduction - 02/03/2020 - 15/03/2020 - Event houses

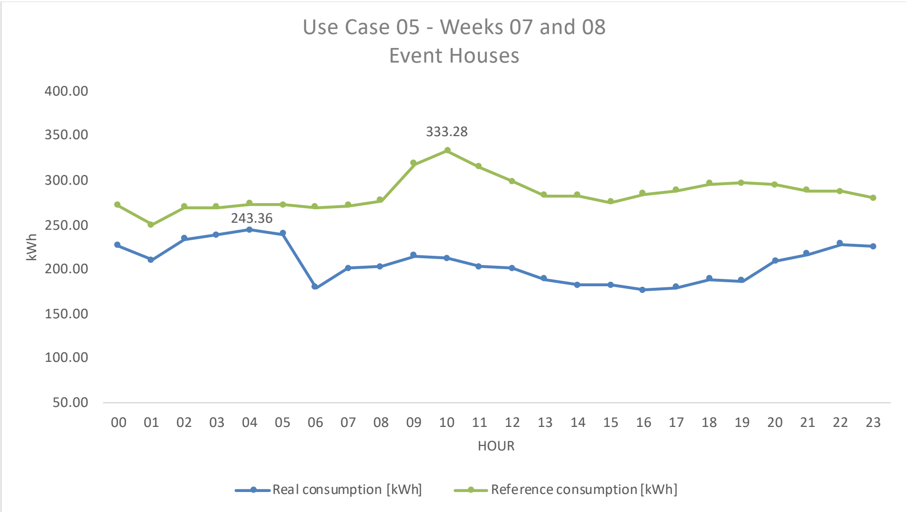


Figure 51 – Use case 05 - Peak load reduction - 16/03/2020 - 29/03/2020 - Event houses

- **Rescheduled demand**

The rescheduled demand KPI aims to verify if the use case event helped to move demand out of the event period. Apart from the pre-heating period, it is expected a lower consumption in the periods where the setpoint was lowered. Figure 52 summarizes the load shifting for each of the tests. Week 3 and 4 experiment showed a reduction of 50% of the load originally in the event period, as the baseline line concentrated 4% of the total daily load in the period, which was reduced to only 2% after the DR event. In a similar analysis, weeks 5 and 6 test case achieved a 25% of reduction of load in the event period. Finally, the last experiment (week 7 and 8) had the same value of load for both baseline and real.

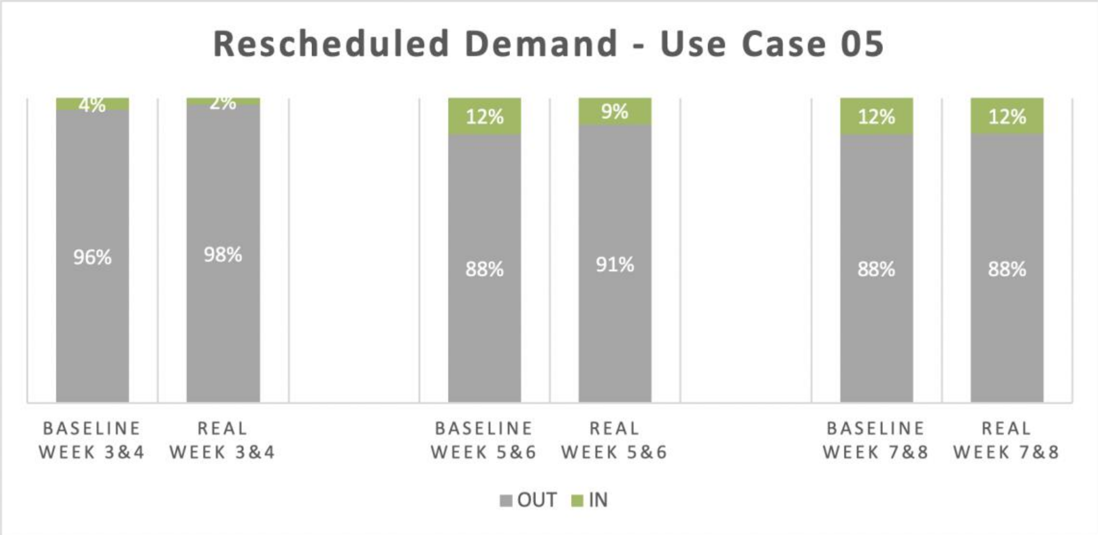


Figure 52 - Use Case 05 - Rescheduled demand

- **Communication performance**

In this use case, the device source of information was the smart-thermostat (DEV-Danfoss). Although the installation of this equipment was done in 10 houses, houses 02, 07, and 11 were removed from the assessment due to technical reasons. Houses 01, 04, 06, and 08 presented some issues over the experiments, but the data collected was sufficient for the assessment. Table 23 summarizes the weekly number of actions/events performed, which means that the communication was successful in those days.

Table 23 - Use Case 05 - Communication performance

Dwelling No.	Test week 3 17. February - 23. February	Test week 4 24. February - 1. March	Test week 5 2. March - 8. March	Test week 6 9. March - 15. March	Test week 7 16. March - 22. March	Test week 8 23. March - 29. March
DR action	7 am: set-points lowered to 16°C 8 am: set-points back to "preferred set point"		4 am: set-point raised 1°C above "preferred set point" 6 am: set-points lowered to 16°C 9 am: set-points back to "preferred set point"		6 am: set-points lowered to 16°C 9 am: set-points back to "preferred set point"	
Aarhus_01	0/5	0/5	2/5	4/5	4/5	5/5
Aarhus_03	5/5	5/5	5/5	5/5	4/5	5/5
Aarhus_04	5/5	4/5	4/5	4/5	3/5	0/5
Aarhus_05	5/5	3/5	5/5	3/5	4/5	5/5
Aarhus_06	5/5	5/5	4/5	4/5	0/5	0/5
Aarhus_08	5/5	4/5	4/5	5/5	0/5	0/5
Aarhus_09	5/5	5/5	5/5	5/5	5/5	4/5

2.6 USE CASE 06 - DENMARK - MAXIMIZE AUTO-CONSUMPTION FROM GRID CONNECTED PV PANELS

The objective of Use Case 06 is to maximize auto-consumption during periods when there is a peak in energy production. The day before the event, the hourly prediction model estimates the PV production for the next day. This information is used to send a message to the participants of the use case when a pre-defined threshold is achieved. The performed actions help to reduce peak load in the grid.

Based on the RESPOND specific objective of better exploitation of renewable energy using demand forecast tools deployed by the project, this use case is being applied when the prediction of energy production achieves a specific target. Different from Use Case 02, where PV panels are installed in individual dwellings, the danish pilot has a PV system with higher capacity shared among all the apartments of the building, including the ones that are not participating in the RESPOND project. Moreover, the PV energy not used is sold to the grid and the price is lower than the energy bought by the households later on.

Once a minimum PV production threshold is defined, the following message asking users for increasing their energy consumption in the specified time is sent, considering the production forecast for the next day:

"I morgen er der overskud af solcelleproduceret strøm fra Næringen/Nyringens eget solcelleanlæg. Hvis du flytter forbrug til mellem kl. hh:mm-hh:mm så hjælper du med at bruge lokalproduceret energi. Det er miljøvenligt og samtidig sparer ALBOA penge. Du kan f.eks. flytte forbrug af vaskemaskine eller opvaskemaskine."

In English:

"Tomorrow between there will be a surplus production of solar power from Næringen/Nyringens[5] own PV installation. If you move consumption to kl. hh:mm-hh:mm, you help utilize your local PV power. It is environmentally friendly and ALBOA saves money. Things to move could be dishwashing or clothes washing, for instance."

Where the hours were filled based on the prediction hours for the next day.

2.6.1 ASSESSMENT

This use case was applied across two test cases, considering different methodologies for PV production threshold definition. The baseline used in the validation process is the month of May, and it was calculated on the DEXMA platform. The threshold of 200 kWh was defined for Event 01. There are two PV panels in the system, which are almost alike in production, and the overproduction starts around 100 kWh for each, hence 200 kWh was analysed considering both aggregated. Figure 53 shows and example of the PV profile for each of the PV panels, from 2018 week 18.

[5] The name of the local division of the ALBOA social housing association in Aarhus.

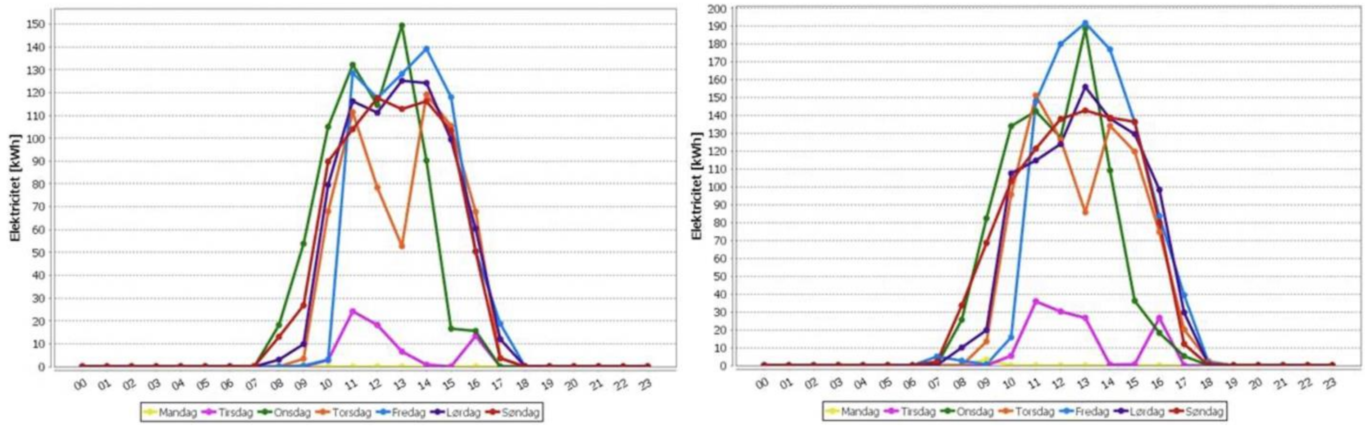


Figure 53 - PV production profile Aarhus (Week 18 - 2018) – Monday through Sunday.

After one month of tests (June 2020), it was verified that the minimum threshold was achieved in all days, hence notifications were sent every day to the users, considering different hours of utilization due to the PV prediction forecast. In order to create a new test case, a study about the real PV production was made by PUPIN, where the idea was to identify threshold values to reduce the number of notifications over the week. The results showed the percentage of notifications users would receive for different threshold values, considering data from July and August 2019 (similar period of evaluation of the present tests), as summarized in Table 24.

Table 24 - Use Case 06 - % of event days that would receive the message according to threshold definition.

Threshold	150 kWh	200 kWh	300 kWh	350 kWh	400 kWh
% of days	97%	92%	75%	61%	41%

Taking all of the previous into consideration, it was decided a new threshold of 400 kWh. This makes the second "notification trial" distinctively different from the present one (where the residents get notifications every day). This choice of threshold would translate into about 3 notifications per week (on average - depending on the specific weather forecasts). The message sent in the first and the second events were the same, but the second limited to two hours around the maximum PV peak of the day in question. Table 25 shows the dates and thresholds defined for the events.

Table 25 - Use Case 06 - Threshold

	Date	Threshold
Event 01	01/06/2020 → 30/06/2020	200 kWh
Event 02	01/08/2020 → 31/08/2020	400 kWh

2.6.2 KPIs CALCULATION

- **Renewable total energy consumption**

  To calculate the total renewable energy consumption, the first step was to identify the hours of most incidence of events for each of the tests periods (June and August). As June had a 200 kWh threshold, users were asked to consume more energy during large periods over the day (11 hours on average per day). Also, it was identified that almost 90% of the event hours were distributed between 7 am to 6 pm. Regarding August events, the 400 kWh threshold was achieved 18 days in the month, and the incident event hours were also stricter, with 90% of them happening between 10 am and 3 pm. The period of the event was 2 hours a day in August. The last two columns of Table 26 shows a heat map of the event distributions for each of the test cases.

Table 26 - Use Case 06 - Renewable total energy consumption

Hour	Baseline (kW)		Consumption (kW)		PV production (kW)		Events distribution (%)	
	Jun/20	Aug/20	Jun/20	Aug/20	Jun/20	Aug/20	Jun/20	Aug/20
00	78.73	47.24	80.64	53.71	0.00	0.00	0%	0%
01	76.88	46.13	84.80	51.85	0.00	0.00	0%	0%
02	80.92	48.55	85.47	48.63	6.54	0.00	0%	0%
03	80.89	48.53	78.12	49.71	47.89	0.00	0%	0%
04	109.34	65.60	109.32	63.80	209.01	1.44	0%	0%
05	148.83	89.30	144.89	81.00	621.13	60.68	0%	0%
06	175.57	105.34	171.11	87.76	1,442.12	354.07	4%	0%
07	171.29	102.77	165.49	95.99	2,739.09	1,140.15	7%	0%
08	178.74	107.24	160.32	108.57	4,393.77	2,345.42	8%	3%
09	224.59	134.76	163.40	127.65	5,944.19	3,773.30	8%	6%
10	169.99	101.99	171.36	94.51	7,063.86	5,114.90	9%	6%
11	152.24	91.35	159.56	102.71	7,935.69	6,003.30	9%	33%
12	165.71	99.43	165.15	94.11	8,535.27	6,510.28	9%	36%
13	158.89	95.33	184.34	155.20	8,665.48	6,537.84	9%	8%
14	189.65	113.79	198.37	116.45	8,120.30	6,300.62	9%	6%
15	300.20	180.12	272.93	155.29	7,259.58	5,769.78	9%	3%
16	281.50	168.90	265.12	125.68	6,132.00	4,796.88	7%	0%
17	235.18	141.11	219.92	115.05	4,628.35	3,599.51	6%	0%
18	221.61	132.96	193.09	104.72	3,033.85	2,170.32	5%	0%
19	187.11	112.27	167.91	97.13	1,489.38	897.02	1%	0%
20	157.48	94.49	147.34	95.03	502.64	209.09	0%	0%
21	130.06	78.04	137.49	80.51	124.75	21.47	0%	0%
22	102.54	61.52	116.78	68.48	16.17	0.03	0%	0%
23	88.80	53.28	109.63	63.56	0.00	0.00	0%	0%
Total	**3,866.72**	**2,320.03**	**3,752.57**	**2,237.13**	**78,911.04**	**55,606.09**	**100%**	**100%**

After identifying the events, the second step was to calculate the aggregated energy consumption of the participant houses during the period specified in the messages sent. Then, the ration of PV production and the aggregated consumption was calculated and compared with the baseline values. The baseline considers the number of events in the month, this way there is one baseline for June (30 days of event) and another for August (18 days of event).

The results show that the rate of energy consumed and PV production during the first test case (June) decreased by 4.58% when compared to the baseline. As the event periods were 11 hours on average, it is not easy to isolate whether users participated in the event or kept the consumption as usual. Additionally, 11 hours of event comprehend almost all of the PV production period. It is important to notice that the PV is also used for other users that are not part of the RESPOND project. The second test case (August) with a stricter period event achieved positive results. It was observed a 12.18% increasing in energy usage in the period of events.

- **Rescheduled demand**

  The rescheduled demand KPI aims to verify if the use case event helped to move demand into the event period. As the messages asked users to consume more energy, it is expected a greater consumption in the period. Figure 54 summarizes the load shifting for each of the tests. Similarly to what happened in the renewable energy consumption KPI, the first test case (June) showed a reduction of 1% of the load originally in the event period, as the baseline line concentrated 57.62% of the total daily load in the period, which was reduced to 56.65% after the DR events. On the other hand, the second test case (August) a positive performance, achieving a 16.33% of energy increase during event the period.

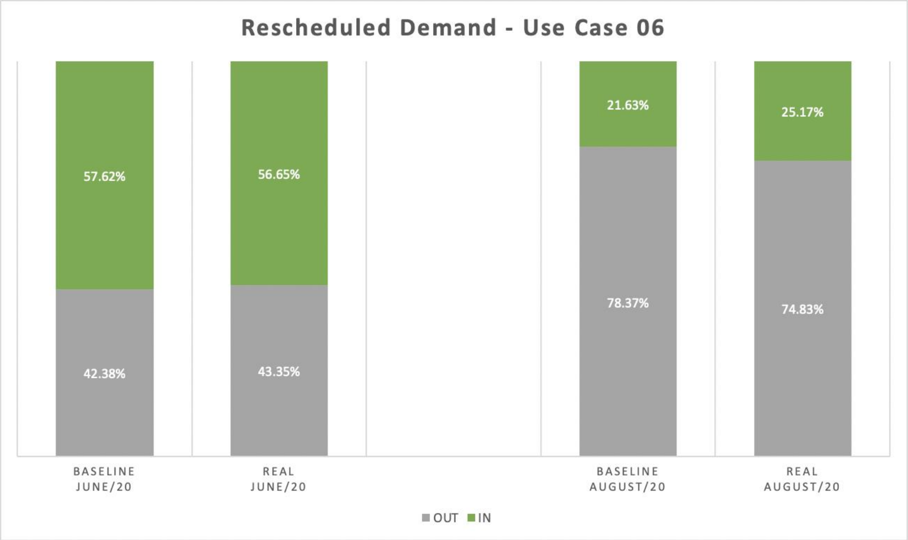
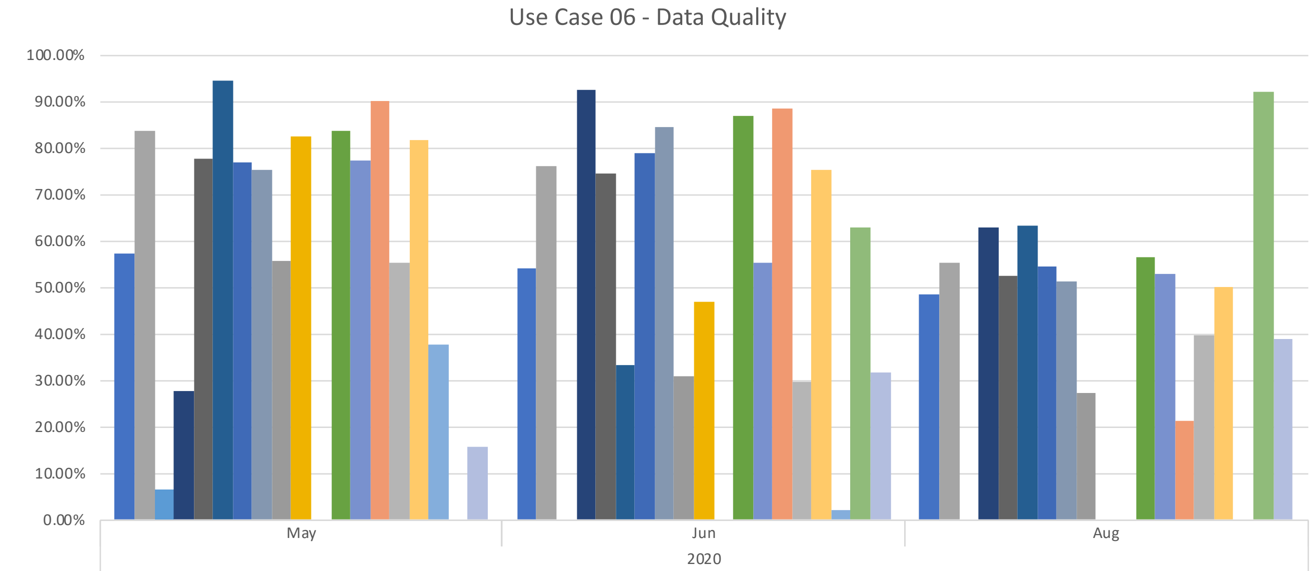


Figure 54 - Use Case 06 - Rescheduled demand

- **Communication performance**

The communication performance KPI verifies the data availability to guarantee that all the data required for calculating the KPIs are in the database and ready for being used. In Figure 55 it is possible to see the status of weekly data quality in the analysis of Use Case 06. This way, Houses 04, 08 and 12 were excluded and not considered in the validation process. Some of the houses did not present complete data over the days, but each case was verified individually to have the highest possible number of participant houses on each day of the events. For instance, house 11 presented approximately half of data availability in June and no data in August, so it was considered only during specific days in the first test case. The baseline also considers only the days with available data for each of the houses.



	May	Jun	Aug
Aarhus -01	57.11%	54.08%	48.41%
Aarhus -03	83.71%	75.94%	55.19%
Aarhus -04	6.76%	0.00%	0.00%
Aarhus -05	27.92%	92.32%	62.92%
Aarhus -06	77.56%	74.54%	52.70%
Aarhus -07	94.26%	33.37%	63.14%
Aarhus -08	77.00%	79.01%	54.37%
Aarhus -09	75.36%	84.56%	51.21%
Aarhus -10	55.72%	31.13%	27.32%
Aarhus -11	82.65%	46.95%	0.00%
Aarhus -12	0.00%	0.00%	0.00%
Aarhus -13	83.57%	86.71%	56.65%
Aarhus -14	77.09%	55.44%	52.90%
Aarhus -15	90.16%	88.56%	21.24%
Aarhus -16	55.17%	29.86%	39.82%
Aarhus -17	81.71%	75.11%	50.11%
Aarhus -18	37.68%	2.17%	0.00%
Aarhus -19	0.00%	62.82%	92.05%
Aarhus -20	15.77%	31.74%	39.05%

Figure 55 - Use Case 06 - Data Quality Chart

2.7 USE CASE 07 - MADRID - PRICE BASED DR FOR ELECTRICAL ENERGY CONSUMPTION

The aim of Use Case 07 is to stimulate energy consumption during a certain period of the day, by offering financial incentives to the end-users. The Time of Use (ToU) model has been chosen, where users have different energy prices during some hours. Besides bringing financial savings for the users, another benefit of this model is peak reduction, as different tariffs motivate users to anticipate or delay actions to avoid expensive hours.
This use case was applied over 5 different test cases, as summarized in Table 27.

Table 27 - Use Case 07 - Event Period

	Date	Hour of the event
Case 01	01/11/2019 → 31/03/2020	From 22 to 12
Case 02	01/04/2020 → 26/04/2020	From 23 to 13
Case 03	27/04/2020 → 31/05/2020	From 15 to 16 & from 22 to 23
Case 04	01/06/2020 → 31/08/2020	From 15 to 17 & from 22 to 24
Case 05	16/08/2020 → 31/08/2020	From 19 to 20 (1€ reward)

2.7.1 ASSESSMENT

This subsection describes each of the test cases, the tariffs applied, and participant houses. The baseline is based on August, September, and October of 2019 and was calculated on DEXMA platform. The KPIs calculated in the next subsection considered all the participant houses aggregated in test cases 01 to 04, and there is also an additional individual assessment for one of the houses. The test case 05 analysis was developed exclusively in terms of economic savings since the period of event is shorter and participant houses reduced.

Case 01

Description: This first test case started in November 2019, before the RESPOND app release. The users were informed about the special tariff scheme, which considers no costs for using appliances in the event period.

Participating Houses: Madrid_00, Madrid_01, Madrid_02, Madrid_03, Madrid_04, Madrid_05, Madrid_06, Madrid_07, Madrid_10, Madrid_12, Madrid_13.

Price scheme: EUR 0.00 from 22:00 to 12:00, standard otherwise.
Date: 01/11/2019 → 31/03/2020

Case 02

Description: This test case follows the same methodology as Case 01, but the time to use the benefit was updated considering the summer season.

Participating Houses: Madrid_00, Madrid_01, Madrid_02, Madrid_03, Madrid_04, Madrid_05, Madrid_06, Madrid_07, Madrid_10, Madrid_12, Madrid_13.
Price scheme: EUR 0.00 from 23:00 to 13:00, standard otherwise.
Date: 01/04/2020 → 26/04/2020

Case 03

Description: The test case 03 started after the RESPOND app release, allowing notifications about the event times. Also, instead of having one large event period, there are two small periods of event.

Participating Houses: Madrid_00, Madrid_01, Madrid_02, Madrid_03, Madrid_04, Madrid_05, Madrid_06, Madrid_07, Madrid_10, Madrid_12, Madrid_13.

Price scheme: EUR 0.00 from 15:00 to 16:00 & from 22:00 to 23:00, standard otherwise.
Date: 27/04/2020 → 31/05/2020

Case 04
Description: The test case 04 follows the same methodology as Case 03, but the event hours were increased by one in each period, as the previous times were considered too short to perform the actions.

Participating Houses: Madrid_00, Madrid_01, Madrid_02, Madrid_03, Madrid_04, Madrid_05, Madrid_06, Madrid_07, Madrid_10, Madrid_12, Madrid_13. (Houses 00, 01 and 12 stopped to participate in this test on 15/08 and were moved to case 05)
Price scheme: EUR 0.00 from 15:00 to 17:00 & from 22:00 to 24:00, standard otherwise.
Date: 01/06/2020 → 31/08/2020

Case 05
Description: The test case 05 has a different methodology when compared to the other tests. Instead of having periods with no energy costs, the participants are now rewarded if they reduce energy consumption in the event period. According to the IEA – International Energy agency, there is a peak in energy usage at 7 pm in Spain, therefore 19:00 to 20:00 is the event period chosen [21].

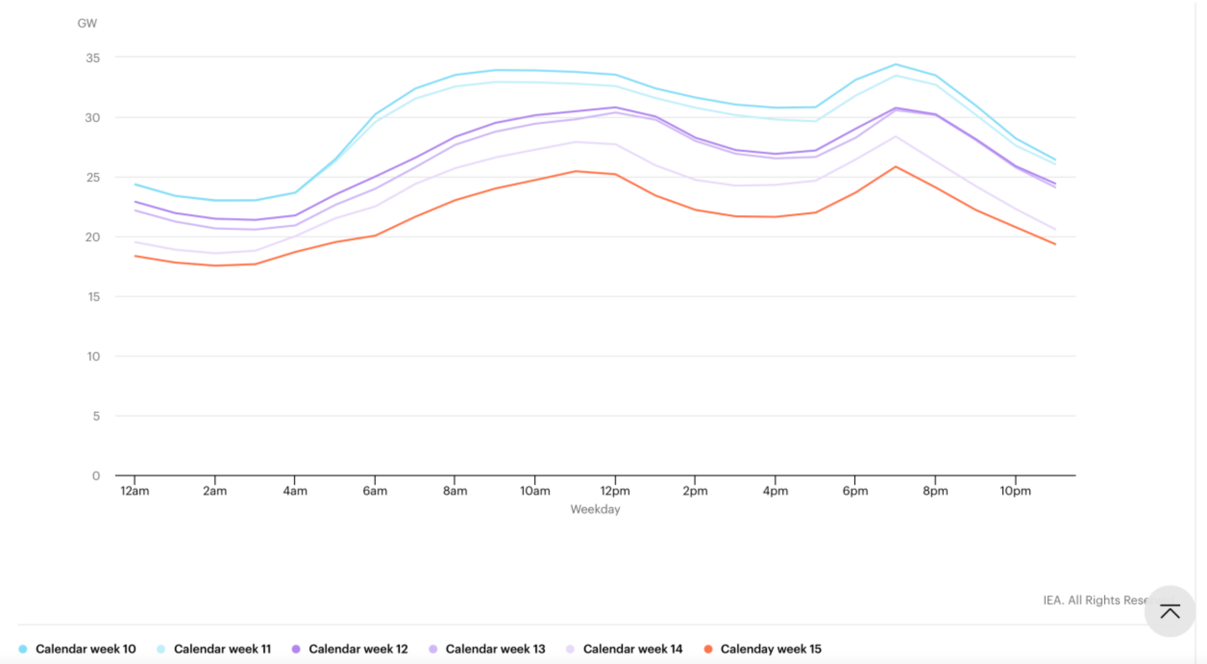


Figure 56 - Hourly profile of electricity demand in Spain, weekdays, early 2020 [21]

Prior to the realization of this test case, the historic data of the three participant houses in this event was analyzed, and a threshold of 200 Wh was defined as a maximum allowed consumption users can have in order to receive the reward. According to the analysis, the houses achieved this value on average 35% of the days in the period 19:00 to 20:00, considering the two months that preceded the events.

Participating Houses: Madrid_00, Madrid_01, Madrid_12.
Price scheme: Standard. 1€ reward if energy consumption is less than 200 Wh from 19:00 to 20:00.
Date: 16/08/2020 → 31/08/2020

2.7.2 KPI CALCULATION

- **Energy savings:**

The energy savings for the complete period of use case 07 were calculated in DEXMA platform. The results show that the variation was almost zero considering all the participant houses aggregated, as can be seen in Figure 57. Based on this use case objective, this may be considered a good achievement, since the idea was not to decrease the consumption, but change the period of usage. As most of the use case period users had free tariffs over the day, even an increasing of energy consumption was expected.

Figure 57 - Use Case 07 - Energy savings on the Use Case period

Just to illustrate a behaviour of a single dwelling, a deeper analysis was carried out for House 01. For this house, there is an increase of 19.3% in the energy utilization during the total period of the events and also considering each of them individually, as summarized in Table 28.

Table 28 - Use Case 07 - House 01 - Energy savings

Name	Type	Target	Saved %	Saved	
Use Case 7 - House 01	Energy Management	20,00%	-19,30	-202,97 kWh	305 / 305 Days -19,30% / 20,00
Use Case 7 - House 01 - Case 04	Energy Management	20,00%	-20,98	-68,68 kWh	76 / 76 Days -20,98% / 20,00
Use Case 7 - House 01 - Case 03	Energy Management	20,00%	-24,94	-38,70 kWh	36 / 36 Days -24,94% / 20,00
Use Case 7 - House 01 - Case 02	Energy Management	20,00%	-29,21	-32,71 kWh	26 / 26 Days -29,21% / 20,00
Use Case 7 - House 01 - Case 01	Energy Management	20,00%	-10,77	-42,27 kWh	152 / 152 Days -10,77% / 20,00

- **Reduction of Greenhouse gas emissions**

The reduction of greenhouse gas emission KPIs was also calculated on DEXMA platform, following the same comparison parameters as the energy savings KPI. It is the amount of energy savings converted to greenhouse gas emission equivalent, as presented on subsection 1.4.3. Since there were no energy savings in this use case, there is no direct reduction on the greenhouse emissions, as can be seen in Figure 58.

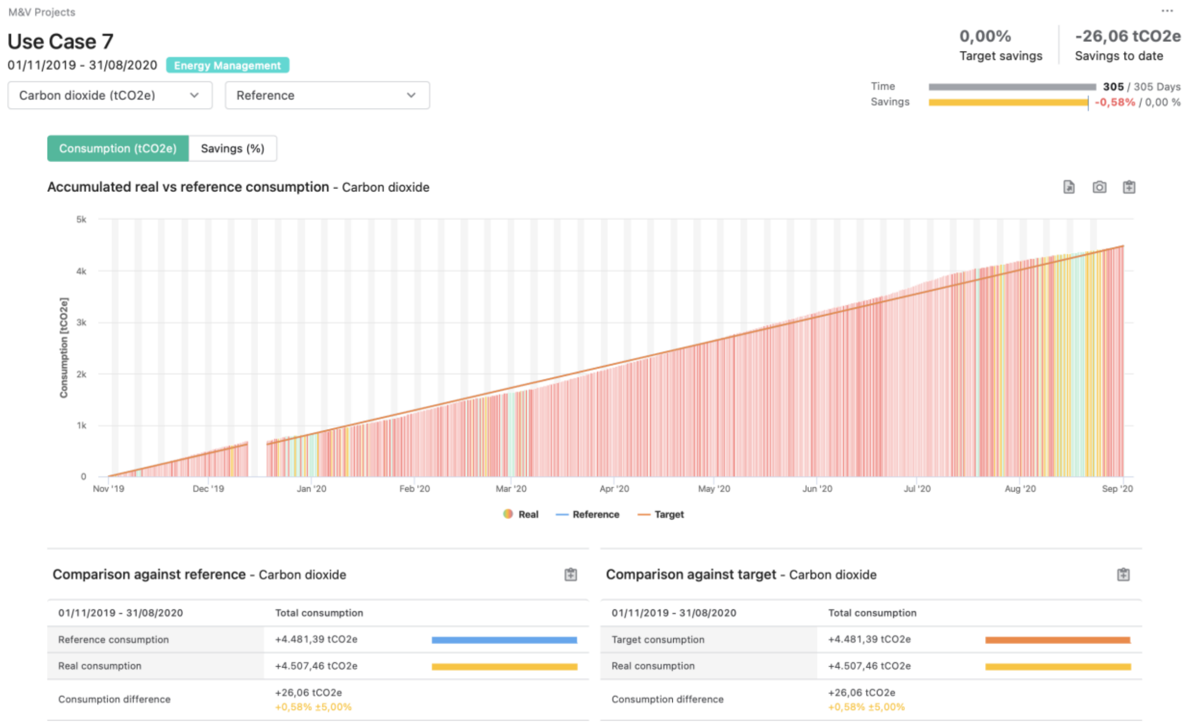


Figure 58 - Use Case 07 - Reduction of greenhouse emissions on the Use Case period

- **Peak load reduction**

As this use case offered incentives for energy utilization during certain hours, it is expected an increase of energy usage in the event period. In this KPI, the peak load from the baseline was compared with the peak load from the real data. It was observed that the peak happened during the event periods for each of the test cases, with an increase ranging from 32% to 44% considering the aggregate houses. House number 01 presented a similar performance over test cases 02 and 04, but reached a higher peak increase in test case 01 (77%) and a decrease of 11% in case 03. Table 29 summarizes the peak reduction results.

Table 29 - Use case 07 - Peak load reduction

	All Houses	House 01
Case 01	44 %	77 %
Case 02	32 %	28 %
Case 03	34 %	- 11%
Case 04	36 %	36 %

- **Rescheduled demand**

The rescheduled demand KPI aims to verify if the use case event helped to move demand into the event period. As the use case gives incentives if energy is consumed during the event, it is expected a greater consumption in the period. Figure 59 shows the results for each of the test cases for the aggregated houses. Test cases 01 and 02 had a wider event period (14h/day), so according to the baseline, the expected load concentration during the events is 48% on average. However, the real values show a slight decrease in load concentration (-1% on average). On the other hand, test cases 03 and 04 had a shorted event period (2 and 4 hours, respectively), which makes easier the identification of rescheduled demand. The load concentration during the event period increased from 18.90% to 22.15% in test case 03, which represents 17% of more activity in the period. Test case 04 presented an even higher performance, going from 26.69% to 34.87%, which represents a 30% demand increase in the event period.

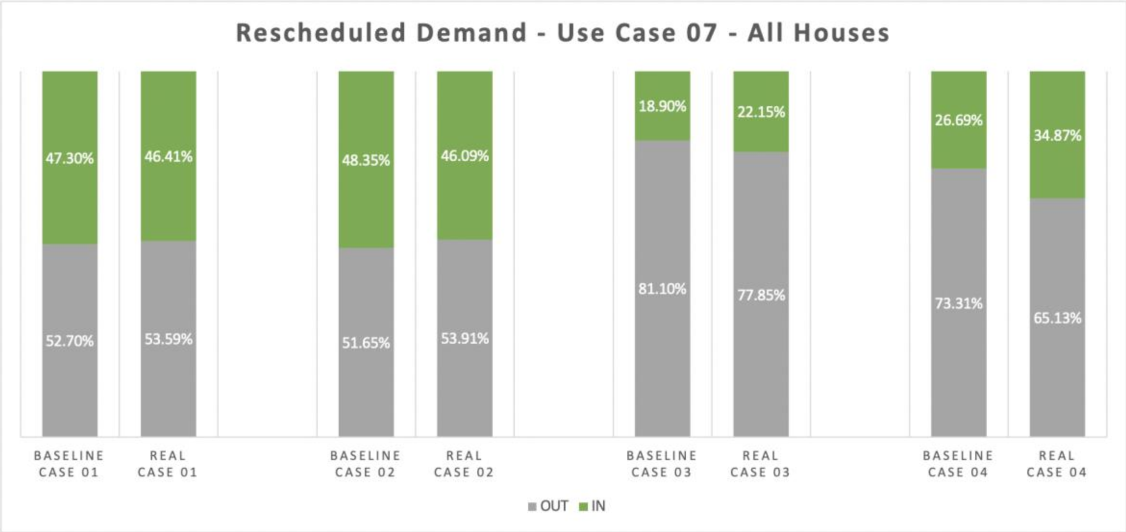


Figure 59 - Use Case 07 - Rescheduled demand - All houses

In a similar analysis, house 01 followed the same pattern for test cases 01 and 02, with just a small decrease in the load concentration. Test case 03 presented a 6% of load activity increase in the event period (from 17.21% to 18.33%), and test case 04 achieved the best performance, achieving almost 65% of increase (from 24.72% to 40.72%), as can be seen in Figure 60.

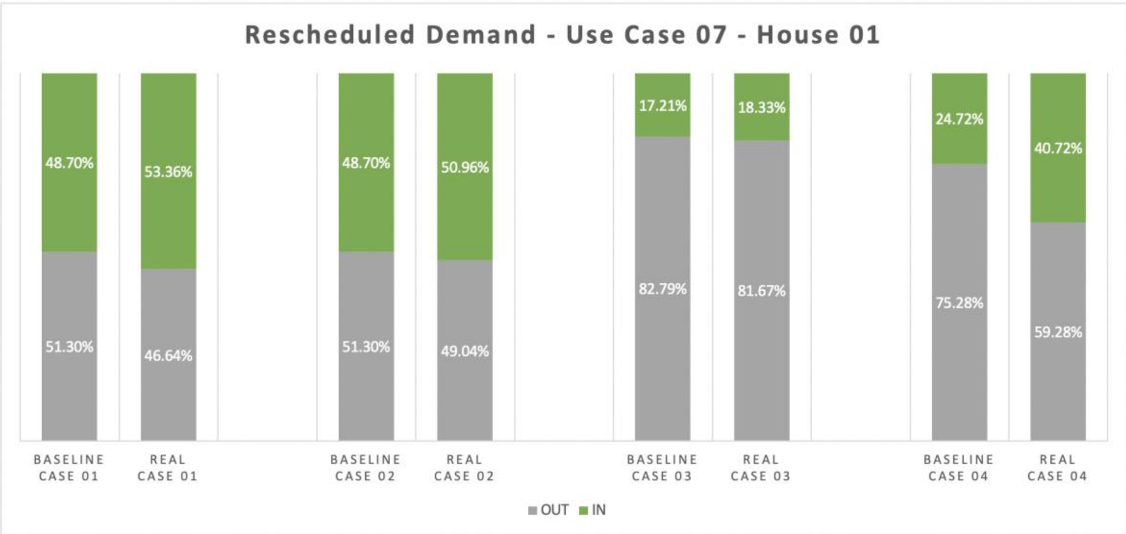


Figure 60 - Use Case 07 - Rescheduled demand - House 01

- **Economic savings during the DR event**

The economic savings were calculated for each of the houses across the test case periods, considering prices from subsection 1.4.2. As expected, test cases 01, 02 and 04 presented the highest savings for the aggregated houses, as they have a longer event period and were applied in a higher number of days. The total economic savings achieved in the use case period was EUR 568.89. The detailed information of savings separated by houses and test cases can be found in Table 30.

Table 30 - Use Case 07 - Economic Savings.

	Case 01	Case 02	Case 03	Case 04	Case 05	Total
Madrid_00	37.47	8.44	3.06	13.88		62.86
Madrid_01	31.39	7.52	1.60	14.45		54.96
Madrid_02	86.89	18.50	6.00	31.90	3.33	146.63
Madrid_03	57.88	11.35	4.09	13.40	1.43	88.14
Madrid_04	16.98	3.74	0.59	5.38	0.69	27.38
Madrid_06	64.66	12.18	2.77	10.34		89.95
Madrid_10	22.07	6.61	2.30	16.91	2.55	50.44
Madrid_12	28.11	5.37	1.80	13.26		48.54
Grand Total	**345.45**	**73.71**	**22.21**	**119.52**	**7.99**	**€ 568.89**

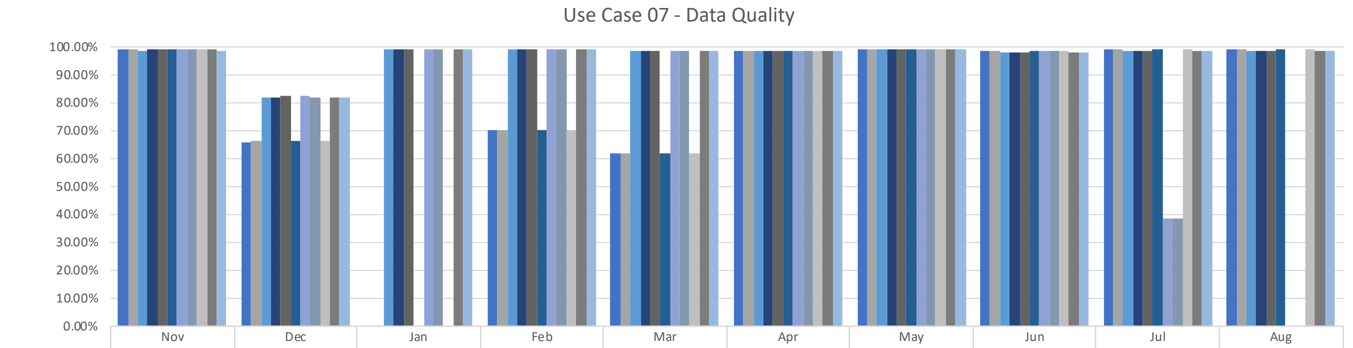
Regarding test case 05, a separated analysis was carried out to identify the potential savings according to different thresholds for the three participant houses. After analysing the threshold of 200Wh defined previously, it was identified that this value was achieved 66 times. That would represent a EUR 20.00 reward for house 00, EUR 30.00 for house 01, and EUR 16.00 for house 12. As a comparison, a threshold of 300 Wh would have triggered 82 events, with EUR 23.00, EUR 38.00, and EUR 21.00 rewards for the houses 00, 01, and 12, respectively. In summary, the threshold can be changed according to the amount of energy to be reduced during peak times, as this affects the number of reward payments. Table 31 shows a detailed analysis of the threshold comparison for each of the participant houses.

Table 31 - Use Case 07 - Case 05 Threshold comparison

Threshold [200 Wh]	Weekday	Madrid_00	Madrid_01	Madrid_12	Threshold [300 Wh]	Weekday	Madrid_00	Madrid_01	Madrid_12
19-Aug	Wed.	114	194	192	19-Aug	Wed.	114	194	192
20-Aug	Thursd.	124	200	546	20-Aug	Thursd.	124	200	546
21-Aug	Frid.	118	176	449	21-Aug	Frid.	118	176	449
22-Aug	Sat.	132	184	172	22-Aug	Sat.	132	184	172
23-Aug	Sun.	131	196	484	23-Aug	Sun.	131	196	484
24-Aug	Mon.	139	234	592	24-Aug	Mon.	139	234	592
25-Aug	Tue.	132	177	728	25-Aug	Tue.	132	177	728
26-Aug	Wed.	119	121	483	26-Aug	Wed.	119	121	483
27-Aug	Thursd.	131	151	835	27-Aug	Thursd.	131	151	835
28-Aug	Frid.	132	166	566	28-Aug	Frid.	132	166	566
29-Aug	Sat.	577	175	215	29-Aug	Sat.	577	175	215
30-Aug	Sun.	176	159	253	30-Aug	Sun.	176	159	253
31-Aug	Mon.	169	164	134	31-Aug	Mon.	169	164	134
01-Sep	Tue.	287	150	252	01-Sep	Tue.	287	150	252
02-Sep	Wed.	106	131	343	02-Sep	Wed.	106	131	343
03-Sep	Thursd.	193	112	109	03-Sep	Thursd.	193	112	109
04-Sep	Frid.	193	123	360	04-Sep	Frid.	193	123	360
05-Sep	Sat.	113	117	233	05-Sep	Sat.	113	117	233
06-Sep	Sun.	315	109	176	06-Sep	Sun.	315	109	176
07-Sep	Mon.	468	236	120	07-Sep	Mon.	468	236	120
10-Sep	Thursd.	620	236	314	10-Sep	Thursd.	620	236	314
11-Sep	Frid.	489	178	344	11-Sep	Frid.	489	178	344
12-Sep	Sat.	1088	196	341	12-Sep	Sat.	1088	196	341
13-Sep	Sun.	646	127	386	13-Sep	Sun.	646	127	386
14-Sep	Mon.	291	137	345	14-Sep	Mon.	291	137	345
15-Sep	Tue.	677	198	160	15-Sep	Tue.	677	198	160
16-Sep	Wed.	405	130	416	16-Sep	Wed.	405	130	416
17-Sep	Thursd.	692	165	284	17-Sep	Thursd.	692	165	284
18-Sep	Frid.	122	210	162	18-Sep	Frid.	122	210	162
19-Sep	Sat.	92	238	164	19-Sep	Sat.	92	238	164
20-Sep	Sun.	536	151	99	20-Sep	Sun.	536	151	99
21-Sep	Mon.	102	150	103	21-Sep	Mon.	102	150	103
22-Sep	Tue.	252	139	130	22-Sep	Tue.	252	139	130
23-Sep	Wed.	417	126	146	23-Sep	Wed.	417	126	146
24-Sep	Thursd.	492	160	661	24-Sep	Thursd.	492	160	661
25-Sep	Frid.	309	242	129	25-Sep	Frid.	309	242	129
26-Sep	Sat.	323	262	158	26-Sep	Sat.	323	262	158
27-Sep	Sun.	191	123	149	27-Sep	Sun.	191	123	149
% of Achievement		53%	79%	42%	% of Achievement		61%	100%	55%

- **Communication performance**

The communication performance KPI verifies the data availability to guarantee that all the data required for calculating the KPIs are in the database and ready for being used. In Figure 61 it is possible to see the status of weekly data quality in the analysis of Use Case 07.



	2019		2020							
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Madrid - 00	99.07%	65.91%	0.00%	70.04%	61.79%	98.35%	98.94%	98.50%	98.99%	99.16%
Madrid - 01	99.02%	65.93%	0.00%	70.04%	61.79%	98.36%	98.94%	98.52%	98.97%	99.14%
Madrid - 02	98.63%	82.01%	98.85%	98.94%	98.34%	98.44%	98.85%	97.82%	98.66%	98.33%
Madrid - 03	98.71%	82.01%	98.85%	98.97%	98.37%	98.49%	98.88%	97.86%	98.66%	98.39%
Madrid - 04	98.71%	82.05%	98.89%	98.91%	98.31%	98.46%	98.85%	97.82%	98.65%	98.35%
Madrid - 05	99.02%	65.98%	0.00%	70.10%	61.83%	98.35%	98.94%	98.55%	98.95%	99.12%
Madrid - 06	98.86%	82.11%	98.94%	98.89%	98.26%	98.40%	98.89%	98.45%	38.22%	0.00%
Madrid - 07	98.98%	82.02%	99.05%	98.97%	98.13%	98.51%	98.92%	98.44%	38.23%	0.00%
Madrid - 10	98.99%	65.95%	0.00%	69.98%	61.78%	98.35%	98.95%	98.55%	98.96%	99.12%
Madrid - 12	98.74%	81.97%	98.89%	98.97%	98.28%	98.45%	98.86%	97.86%	98.66%	98.45%
Madrid - 13	98.55%	82.00%	98.89%	98.95%	98.37%	98.49%	98.86%	97.82%	98.64%	98.39%

Figure 61 - Use Case 07 - Data quality Chart

3. CONCLUSION

Overall, the use cases with automated actions had a higher impact in terms of energy and CO_2 savings, peak load reduction, and rescheduled demand, as they do not rely on user's behaviour. This can be seen in the results from UC05 and simulations of UC03, and could also possibly be applied on UC2, UC4 and UC6 if technology is available in the home appliances and users give their consent for remote control. It is important to observe that the automated actions should also reflect the users' needs and ensure comfort, so the qualitative analysis should verify customer acceptance regarding the performed tests.

The financial incentives applied on UC7 (ToU) had a positive effect in the DR events, and could possibly be extended to UC04 (CO_2 reduction emissions) and UC06 (community PV system). It is important to balance the rewards to be conceded and the expected energy to be reduced/rescheduled to achieve the acceptance level of participants desired and not overstimulate consumption in the event period, which can create a new peak load.

UC01 has a high dependence on the user's knowledge about the RESPOND app. The results of this use case could have improved in the period through additional training to ensure that all the households had the app installed and understood what information could help them to save energy and control the devices, as this use case relies on consumers awareness and willingness to perform actions without any direct incentive, except for saving money from reducing energy consumption.

The rest of this section summarizes the main results, including additional comments for each of the use cases. As mentioned before, the analysis presented in this document considered exclusively the quantitative assessment approach. Therefore, along with the qualitative analysis provided by deliverable 6.3 [9], it provides inputs for deliverable 6.5 - Lessons learnt and recommendations [10], as some of the results can be better understood considering both views.

USE CASE 01 - IMPACT OF THE RESPOND APP TO THE USER

The energy consumption and CO_2 emissions increased by 6.86% in the Madrid pilot, which may be related to the COVID-19 (people staying home due to the restrictions). Aarhus and Aran Islands pilots presented a reduction of 4.72% and 20.28%, respectively, which can be related to the RESPOND App and also the climate (warmer temperatures after App release, less heating necessary in the houses). The air quality for Aran and Madrid presented enhancements, staying in the category III of prEN15251.

USE CASE 02 - IRELAND - MAXIMIZE AUTO CONSUMPTION CONTROL SWITCHES FOR APPLIANCES

The energy consumption and CO_2 emissions decreased by 17.89% over the use case period. Regarding renewable consumption, on average 72.7% of the PV production was consumed in test case 01, and 79.6% in test case 02. Rescheduled demand had the best results in test case 01, with a 30% demand increase during the event hours. Compared to the baseline, 20% less energy from the grid was necessary to perform the actions.

USE CASE 03 - IRELAND - PV PANEL – OPTIMAL PROFILE OF USE FOR HEAT PUMPS

The energy consumption and CO_2 emissions decreased by 29.77% over the test case. The rescheduled demand shows that the optimized model presented 54% more load activity in the event period, with renewable energy consumption 39.14% higher compared to the baseline.

USE CASE 04 - IRELAND - PEAK SHAVING USE CASE

The energy consumption and CO_2 emissions decreased by 14.73% over the use case period, which may be related to the COVID-19 (people staying home due to the restrictions). Rescheduled demand and peak load remained steady.

USE CASE 05 - DENMARK - LOAD SHIFTING DISTRICT HEATING SYSTEM

The energy consumption and CO_2 emissions decreased by 14.36% on average in the participant houses over the use case period. The test case performed in the last two weeks of the use case achieved even more savings, reaching 27.46%. Peak load reduction of up to 50% was achieved in some of the week periods.

USE CASE 06 - DENMARK - MAXIMIZE AUTO-CONSUMPTION FROM GRID CONNECTED PV PANELS

Total renewable energy consumption achieved up to 12.18% of increase over the use case period. The rescheduled demand analysis showed a 16.33% of more load activity in the event hours. Differently from the initial idea, this scenario focused solely on the influence of societal values ("doing something for the common good of the neighborhood and environment") on people's motivation for participating in demand shifting. Nevertheless, positive results were achieved even though there were no financial incentives.

USE CASE 07 - MADRID - PRICE BASED DR FOR ELECTRICAL ENERGY CONSUMPTION

The energy consumption and CO_2 emissions were steady over the use case period, compared to the baseline. A peak reduction of 36.5% on average was achieved across the different test cases. The rescheduled demand analysis showed an up 30% increase in load activity during the event hours. The results show that higher savings were achieved over time, it may be related to the user awareness about the event hours and the access of information through the RESPOND app.

All the assessment was done based on the available data from the RESPOND database. The use case tests did not assess if users had or not the app installed/working, as this can change over the days and is related to user behaviour. For instance, users could have faced some technical/operational issues with their smartphones, such as no battery in the moment of the event message. Another behaviour issue is the user not being at home during the event period, thus not being able to perform the expected actions. This kind of interference is assessed by the interviews (deliverable 6.3).

The RESPOND App was released in April 2020, right after the COVID-19 started to spread over the world. Some countries, including Ireland, Denmark, and Spain created new rules and restrictions, including working from home policies, and schools and retail closings. This way, people started to stay home for much longer periods and that changed their energy consumption behaviour, which may have an impact on the baseline comparison.

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