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LISCOOL – Smart air-conditioning with cold storage as flexibility provider for automated demand response and virtual power plant supported by cloud based system

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Abstract. This paper describes the main progresses of the LISCOOL – Lisbon Cool energy project. It aims to implement and demonstrate the technical and economic feasibility of air conditioning systems as flexibility providers to different operators on the electricity markets. It promotes consumers as active participants on energy trading and network management, by taking advantage of the flexible load of the AC Systems, providing a suitable solution for large scale deployment of renewable energy sources (RES).

1 Introduction

Lisbon Cool energy project (LISCOOL) is a demonstration project, fully sponsored by New Energy and Industrial Technology Development Organization (NEDO) – a Japanese governmental agency – through a partnership with Portuguese public institutions, namely Câmara Municipal de Lisboa (Lisbon City Council) and LNEG - Laboratório Nacional de Energia e Geologia (National Laboratory for Energy and Geology), a public R&D institution, belonging to the Ministry of Economy and Employment.

This project is being carried out in the city of Lisbon, Portugal between November 2016 until December 2019, to which NEDO has entrusted Daikin Industries, Ltd.. In turn, Daikin has partnered with several European companies to advance with its implementation. Through the installation and aggregation of commercial size air conditioning systems, with an under-development cold storage tank unit, the goal is to assess the technical and economic feasibility of providing energy-related services to electricity grid operators and of empowering end-user by participating on the electric grid management markets.

Within this scope, the project was divided into two phases:

- Phase 1: Installation, system implementation and preliminary operation;
- Phase 2: System improvement, full-scale operation and business feasibility assessment.

This paper focus on the analysis of the operational data retrieved from the Phase 1 operation. After a brief overview on the project and its background, the implemented system is described in a detailed fashion. Lastly, the operational results are analysed, retrieving conclusions on the technical feasibility of the system and future improvements.

2 Project Background and Objective

In recent years, as strong policy has been put in place regarding decarbonisation and renewable energy resources, the latter's share in the energy mix has been steadily increasing. Ergo, due its inherently intermittent production characteristics, energy supply amount becomes unstable, which affects the reliability of the electrical grid. [1]

Moreover, increasing awareness of climate change and economic attractiveness of Distributed Energy Resources (DER) among consumers such as Electric Vehicles (EVs) and energy microgeneration units (e.g. PV solar panels) has led to its fast deployment on distribution network, as the majority of the consumers is present at the low voltage level [2]. This poses another challenge to efficient and safe operations of networks, i.e., within the technical limits, such as control voltage rise and keeping power flows within lines capacity. [2,3]

Even though the supply-side management has been mainly used as strategy for ensuring stability of electrical power systems and can, potentially, solve systemic stability problems as the balancing between supply and demand, it is not efficient in solving local problems, such as voltage rise and reverse power flows at the level of distribution networks, where DER is being installed in a large-scale. [4,5]

There is a growing consensus among policy makers and market participants that demand side flexibility, empowered through Automated Demand Response (ADR), is one critical resource for achieving low carbon, efficient electricity system.

Demand Response, in its basic form, is a change in the power consumption of end-users in response to financial incentives based on the operation requirements of the electrical grid. It can be provided by any industrial, commercial or residential consumers. [4, 6-8]

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With the rise of interconnectivity and smart devices, Demand Response programs are progressively moving towards automation and the industry itself closer to the Smart Grid paradigm. The advances on integrating information and communication technologies (ICT) allow the system operator to interact and effectively coordinate a substantial number of distributed resources in an automated fashion in real time. [6,8]

Demand Response can unblock an immense value not only to grid operators by providing balancing services and thus diverting large investments on infrastructure and capacity resources, but also it can support an efficient operation on local grids, mitigating drawbacks posed by the increasing penetration of DER at low voltage level. [1,4,9]

In parallel, a recent strategy that follows the growing trend of exploring demand side flexibility is a Virtual Power Plant (VPP). The core basis of a VPP is the aggregation and integration of numerous types of producing and/or consuming units, creating a diversified portfolio of independent resources. With such portfolio, the overall load/generation not only becomes more reliable with less intermittency, but also it can be optimized based on the assets' available flexibility and market prices. The aggregation of diverse resources allows a VPP to react quickly to changing conditions, and deliver great values to customers by optimizing supply and demand profiles. [10-12]

In conclusion, the transformation on the electric system and development on ICT devices is creating a conductive environment towards the ADR and VPP systems. In order to be able to enter these growing markets at an early stage, LISCOOL project goal is to implement and demonstrate the technical and economic feasibility of Air Conditioning (AC) Systems as flexibility providers for both ADR and VPP systems.

Also, being Portugal one of the leading European countries in renewable energy deployment [13], the project intends to investigate the technical and non-technical benefits associated with ADR and VPP systems in an urban environment, including the smooth integration of renewable energy sources and in resolving problems at the local grid level.

3 Project overview

LISCOOL project aims to evaluate the effectiveness of AC Systems in ensuring a stable supply of renewable energy by providing the required flexibility to balance the grid. Specifically, the electricity consumption of air conditioning systems is automatically controlled to optimize the renewable energy usage throughout the summer season. In addition, LISCOOL targets the investigation of potential revenue streams and business models availing the AC Systems' power shifting capacity to provide energy related services to market agents, such as retailers or VPP operators.

The project encompasses four office buildings as demonstration sites in the city of Lisbon, where multi-split air conditioning systems were installed. In total, 34 Variable Refrigerant Flow (VRF) systems with a combined power of about 330HP replaced the previous installed air conditioning systems.

In order to enhance the power shifting flexibility of the AC systems, part of those are coupled with cold storage tank units, currently under development. These allow the demand to be adjusted during the AC operation, either increase or decrease in consumption, while mitigating the impact on the end-user comfort. In total, 30 units were installed among the four demonstration sites.

Lastly, as a source of intermittent production on each site, photovoltaic panels were installed as well with a combined peak power of 155kW$_p$.

The locations of office buildings in Lisbon, the number of AC Systems and cold storage tank units, and PV power are depicted in Figure 1.

Figure 1. Installation of AC and PV systems in four buildings in the city of Lisbon, Portugal

For demonstration purposes, two distinct use cases were established:

- **Use Case 1:** Automated Demand Response:
- **Use Case 2:** Virtual Power Plant

In the first use case, the system operator will forward Demand Response requests based on weather forecasts, renewables production and power grid status; whereas the latter will optimize the AC consumption based on the spot market price and PV production forecasts. A detailed description on each use case is done in the following sections.

In parallel, Daikin has developed and implemented a cloud-based system ("*AC Aggregating System*"), which is responsible for collecting the operational information from AC systems and managing the units upon receiving signals from either the ADR or VPP system. The overall system architecture is depicted in Figure 2.

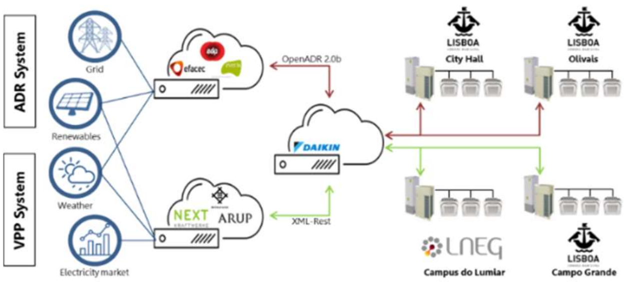

Figure 2. System overview

One of the essential points considered during the project scope definition was the collection (metering) and transmission of performance data from the local sites to server systems. On one hand, operation data and electric consumption data from different components of AC systems, along with weather forecasts, are fundamental to predict the day-ahead load pattern and flexibility on AC systems. On the other hand, from the ADR and VPP operator's standpoint, it is required to have live data with a very high reliability in order to verify the system's compliance with the Demand Response events. On top of it, this data is also valuable for each operator to proceed with its own forecasts, such as PV production. Taking this into consideration, smart meters were installed on each site, which are separately measuring the consumptions of AC system and whole building and PV panels' production.

After an initial design and implementation stage of the system and equipment installation, the system went into operation in May 2018 until the end of October 2018. Throughout this period, signal exchanges between servers and Demand Response events were tested on the four buildings, ensuring an error free operation. The comprehensive system deployment and fully automated operation is scheduled for summer, 2019.

The obtained results during the operation phases of the system will be used to do a comparative evaluation of the performance, energy efficiency and suitability of AC systems to different DR Programs. Also, the value of these platforms for different market players, such as the end-users, retailer or grid operators in resolving issues at the local grid level, will be analysed.

It is anticipated to determine a scalable business model, taking into account each European electricity market specifications in line with the above mentioned project objectives.

3.1. Use Case 1: Automated Demand Response

To implement the use case 1, a partnership was established between Daikin and the Portuguese companies, EDP Inovação S.A. (a Portuguese utility), Efacec S.A. (electric solutions) and Everis Portugal S.A. (IT consulting and service company).

This use case was designed to validate the AC units' flexibility as a viable solution to two major issues associated to the operation of the electrical grid.

In the first case, "*Distributed Energy Resources (DER)*" program's objective function is to maximize renewables auto-consumption on a micro-grid level by shifting AC consumption, thus contributing to the control of voltage and keeping power flows within lines capacity, problems often associated with high penetration of renewables at low voltage level.

Secondly, a "*Direct Load Control (DLC)*" program focuses on the power grid system balancing between supply and demand. It uses the aggregated flexibility of AC systems to solve unforeseen restrictions or emergencies on the electrical grid ensuring its stability.

Since the scope of each DR program is different, they are coordinated in order not to overlap the controls execution. Considering the critical character of DLC events, the DER program is operated continuously, until there is a notice regarding a DLC program event. The latter overrules any previous DER events.

A detailed description of each program is done in the following subsections.

3.1.1 Distributed Energy Resources (DER) Program

The *Distributed Energy Resources* is a program running continuously during the operation phases of the demonstration project with a cyclical communication between both servers – AC Aggregating system and ADR system – concerning the planning and execution of the Demand Response signals.

Daikin, on a daily basis, provides the forecast of AC System's power consumption and flexibility through a day-ahead schedule divided into 30-min periods.

The ADR system gathers information on weather forecasts and power consumption/production on each site, using it to produce the respective forecasts for PV generation. After processing both forecasts, the ADR System sends an optimized consumption schedule.

The AC Aggregating system processes each Demand Response request with Opt-in or Opt-out responses for each event.

Notwithstanding, the AC Aggregating system is also capable, when required, of sending an updated report on the above mentioned forecasts during an intraday operation mode. This allows the ADR System to compute a more granular optimization as there might be significant differences between forecasts and real operation conditions. Considering this, event signals are divided into Slow DR (day-ahead signal) and Fast DR (intra-day signal).

3.1.2 Direct Load Control (DLC) Program

As mentioned above, DLC Program aims at providing support to the network operators on grid management by leading consumers to change their consumptions in response to an emergency event.

This type of Demand Response events is typically generated until 15 minutes before the start time as it is used to tackle operation problems that were not predicted, and thus require fast action controls. For this reason, it implies a direct coordination between the network operator and the available aggregators / assets to participate in these events.

In this specific project case, the role of the network operator and its emergencies are simulated. The ADR operator sends an event based on the latest flexibility forecast provided by the AC Aggregating system.

3.2. Use Case 2: Virtual Power Plant

To carry out a Virtual Power Plant use case, a partnership between Daikin and Mitsui & Co. (a Japanese trading and investment company), Arup (engineering and business consultation) and Next

Kraftwerke GmbH (a German VPP operator) was put in place.

In this case, the main proposition is using AC systems to provide flexibility to the VPP allowing it to optimize its supply and demand profiles, and to improve the trading position on the spot market.

AC Aggregating system computes, on a day-ahead basis, the consumption forecast and available flexibility of the AC systems for each building. Upon receiving that information from Daikin, Next Kraftwerke calculates its own forecasts (spot market price, PV production, etc.) and proposes an optimized AC schedule, in which each use of flexibility is complemented by a priority number. This allows the AC Aggregating system to try to achieve the most optimized schedule possible, based on operational restrictions.

Similar to the previous use case, intra-day mechanisms were also put in place to allow a refined optimization, which takes into account changes in real operation conditions or variations on the market prices.

4 AC System

Undeniably, conventional AC systems already have an intrinsic capability of providing flexibility to the electrical grid, namely through temperature set point variation or load factor control.

Generally speaking, these strategies during Demand Response events may cause an impact on the end-user comfort. In order to mitigate this issue, complementary energy shift strategies, such as pre-cooling, are often necessary. [14,15]

The introduction of cold storage in conventional AC systems, usually in the form of ice, was used to level the daily power load in order to reduce the peak power demand and activate the heat pumps to produce ice at suitable times, e.g., when the electricity price is cheaper. [16]

However, in a future characterized by intermittent electricity production, greater flexibility will be needed either downwards (during demand surplus period) or upwards (during over-supply periods) to respond to quick changes in the electricity supply. [6,17]

The introduction of cold storage tank units that are coupled to the VRF systems enhances its flexibility to respond to changes in the supply by enabling to shift power consumption, either decreasing ("*negawatt*") or increasing ("*posiwatt*") while operating the AC System.

The installed tank unit enable a smooth consumption shift, less curtailment on AC operation (i.e. set-point variation, load control) and reduces possibility of interrupting air-conditioning during Demand Response events, which will therefore result in contributing to a more flexible resource when compared with conventional AC systems.

4.1 Control Optimization

The VRF system installed with the tank units operates in four different modes as shown in Figure 3. The first mode corresponds to the normal AC operation without utilizing the cold storage units. Mode 2 and Mode 3 refer to producing cold storage, whilst Mode 4 is related to the use (consume) of cold storage during AC operation.

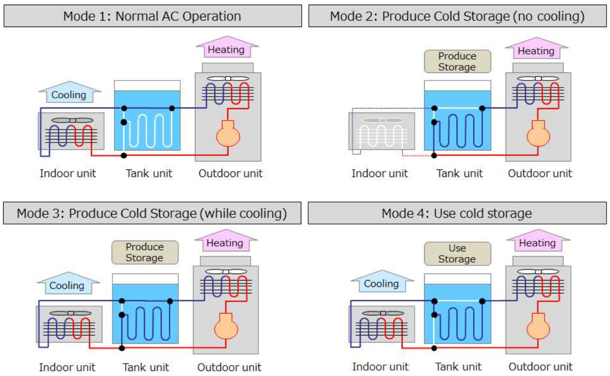

Figure 3. Cold storage operation modes

The main difference between Mode 2 and Mode 3 is that the former activates the heap pump to solely produce the cold storage while there are no cooling requirements in the building (e.g. during the night-time), whereas the latter produces cold storage during the normal operation of the AC system.

The AC system operation and the correspondent refrigerant cycle will be altered to accommodate the introduction of the cold storage – producing or using it – hence varying the power consumption as follows:

Negawatt: During the normal operation of the AC unit, the use of cold storage reduces the required power input in the refrigerant cycle, which decreases the power consumption of the system. In this case, the operation mode resembles the conventional ice storage one. The use of cold storage can be complemented with conventional measures, such as increasing the temperature setpoint, in order to enhance the power shifting capacity of the AC system.

Posiwatt: The power consumption is increased by producing cold storage, either when the system is cooling the rooms or not, which distinguish these units from the ice storage ones. In theory it is always possible to increase power consumption, except when the outdoor unit is operating on its maximum capacity or cold storage is already fully charged.

5 Cloud Server & Communication

More than a cold storage tank unit coupled to VRF systems, the project also encompasses the development of an aggregation system ("*AC Aggregating system*") on cloud-based software architecture. The central server is responsible for managing the power consumption of its assets upon receiving signals (i.e. power consumption targets) from the ADR or VPP systems.

As abovementioned, AC Aggregating system sends the day-ahead and intraday power consumption forecasts and available flexibility to the ADR and VPP systems and receives an optimized schedule proposal or ADR events in return for the AC operation.

For these server to server communications, different protocols were implemented. In use case 1, one of standard Demand Response protocols was used, and in use case 2 a REST-like protocol was adapted to the project specifications. Each type of communication is described in more detail in the following subsections.

5.1 Use Case 1: Automated Demand Response

For the ADR system, the chosen communication protocol was OpenADR 2.0b, as this is specifically developed to facilitate communications related to Automated Demand Response programs. The intention of this protocol is to allow grid operators or utilities to interact with aggregators and control systems that are preprogramed to automatically take action upon receiving DR signals with no manual intervention.

According to the OpenADR 2.0b specifications [18], a hierarchical relation is established between central system and end devices. As a result of this relation, two main actors are identified under the protocol:

- Virtual Top Node (VTN): transmits OpenADR signals to end devices or other intermediate servers
- Virtual End Node (VEN): represents an end device that accepts the OpenADR signal from the VTN.

Consequently, this use case has been design to follow a top down approach, where the ADR system is the VTN and the AC Aggregating system behaves simultaneously as the VEN to the ADR system and as the VTN to the AC Units.

As a starting process, it is required to register the VEN into the VTN. The VEN ID and reporting capabilities are sent to VTN, allowing it to recognize the type of signals to be expected. Only upon completion of the registration phase, a VEN can be eligible for participating in DR programs/events.

During the daily communication between the ADR and AC Aggregating system, two main interactions as defined on OpenADR 2.0b specifications are used: oadrReport and oadrDistributeEvent. Firstly, oadrReport allow a VEN to send updated information (e.g. forecasts) to a VTN. The type of reports is specified during the registration phase. Secondly, oadrDistributeEvent is used by a VTN to send out DR events to the VEN(s). VEN, in this specific case, AC Aggregating system has freedom to accept (opt in) or reject (opt out) each request.

5.2 Use Case 2: Virtual Power Plant

Taking into account the established partnership with an existing VPP operator, the server communication specifications are already well-defined as part of a business as usual stance for Next Kraftwerke. Notwithstanding, some adaptations were required, namely the forecasts and the introduction of priority concept on DR events.

The used format for data interchange is a REST-like XML-API, of which all the required information for automated data exchanges was kindly made available by Next Kraftwerke.

Whereas OpenADR 2.0b was designed to become a *de facto* standard for ADR communications, REST protocol, as a general web service, is easy to implement and it has many architectural properties suitable for such business model as scalability, security, reliability and extensibility. It is therefore a viable and practical option on a business oriented solution.

6 Results

As previously stated, throughout the summer of 2018, the preliminary operation of the overall system proceeded as scheduled. Throughout this phase, signal exchanges between servers and actual Demand Response events were tested. It was primarily focused on identifying and correcting errors in order to smoothly transition from manual to automated operation.

After the necessary adjustments and adaptations to the logic and processes, all schedule exchanges and optimizations worked reliably and operational data was retrieved. On the following subsections an example for each use is analysed in more detail.

6.1 Use Case 1: Automated Demand Response

On the ADR system, both “Distributed Energy Resources” and “Direct Load Control” programs were tested.

Regarding DER program, an optimized daily schedule is sent to the AC Aggregating system, which is responsible for accepting or refusing the DR events. On Figure 4, the daily consumption on October 19th 2018 for Lisbon City Hall is represented. In total, throughout this day, eight DR events were received and accepted.

Additionally, the forecast and the existing flexibility issued on a day-ahead from AC Aggregating system are also plotted in Figure 4. Due to lack of operational data, the forecasting algorithm it is still not accurate as desirable, which greatly impacts the optimized schedule.

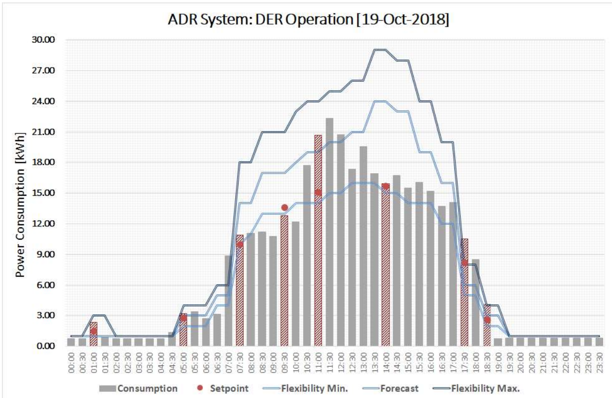

Figure 4. ADR operation: DER Program (19/10/2018)

Nevertheless, focusing on the events received and consequent response, the AC system showed a good compliance, as the deviation from the target was less than 1kWh for most of the events. However, in one case, the AC System did not comply as expected and the actual consumption surpassed the setpoint in about 5,5kWh. The information related to each DR event is presented on Table 1.

Table 1. DER program events (19/10/2018)

Time [UTC]	Setpoint [kWh]	Real [kWh]	Deviation [kWh]	Abs. Error
01:00 – 01:30	1,50	2.35	0,85	56,7%
05:00 – 05:30	2,80	3,23	0,43	15,3%
07:30 – 08:00	10,02	10,87	0,85	8,5%
09:30 – 10:00	13,62	12,80	-0,82	6,0%
11:00 – 11:30	15,12	20,65	5,53	36,6%
14:00 – 14:30	15,70	15,92	0,22	1,4%
17:30 – 18:00	8,25	10,50	2,25	27,2%
18:30 – 19:00	2,60	4,16	1,56	60,1%

On an earlier stage of the operation, the DLC program was also tested. The results on August 16th 2018 for Olivais building are presented on Figure 5. In total 4 *negawatt* events – half of which had 1h duration - and 1 *posiwatt* event were received by the AC Aggregating system.

Contrary to the DER program, in which the optimization process is highly dependent on the accuracy of the forecasts, the DLC case relies solely on the available flexibility at the moment of the grid emergency. For this reason, there is a clear difference between the baseload and the consumption in the course of a DR event.

Moreover, based on the Table 2 values, the AC System displays a great accuracy achieving the consumption target, with deviations below 1kWh for all events (the maximum absolute error is 13,4%).

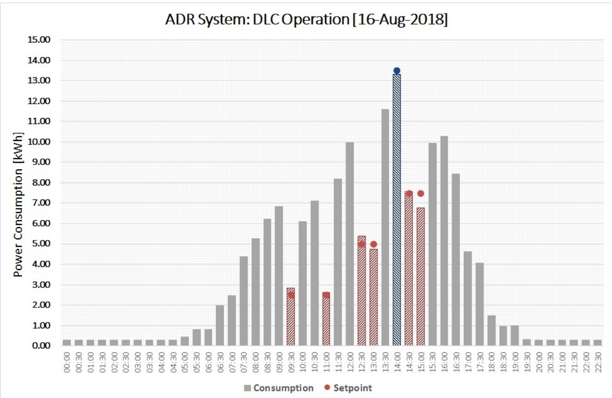

Figure 5. ADR operation: DLC program (16/8/2018)

Table 2. DLC program events (16/08/2018)

Time [UTC]	Setpoint [kWh]	Real [kWh]	Deviation [kWh]	Abs. Error
09:00 – 09:30	2,50	2.84	0,34	13,4%
11:00 – 11:30	2,50	2,62	0,12	4,7%
12:30 – 13:00	5,00	5,38	0,38	7,6%
13:00 – 13:30	5,00	4,74	-0,76	5,1%
14:00 – 14:30	13,50	13,33	-0,17	1,3
14:30 – 15:00	7,50	7,57	0,07	0,9%
15:00 – 15:30	7,50	6,77	-0,83	9,8%

6.2 Use Case 2: Virtual Power Plant

In the VPP use case, the operator, Next Kraftwerke, issues an optimized schedule based on the AC consumption forecast and spot market prices. To each flexibility request, a priority value is assigned in order the AC Aggregating System can determine which events to accept and refuse based on operational restrictions.

On Figure 6, the AC consumption on October 19th 2018 for LNEG building is plotted. During the day-ahead negotiation, the AC Aggregating system accepted five requests to reduce consumption.

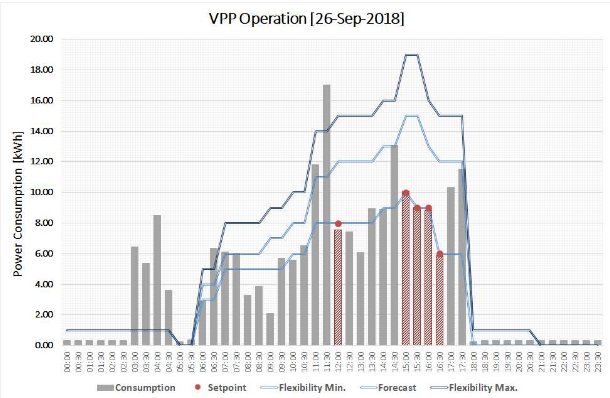

Figure 6. VPP operation example (26/9/2018)

Similar to the previous DER case, the forecast has a negative impact on the optimization as the error between the predicted and actual vales is significant. As mentioned above, it's worth noticing that this data refers to the preliminary phase of operation.

On Table 3, the details on each event are described. During this day, it is noteworthy the accuracy of the AC System in achieving the defined target. The absolute deviation in all events was lower than 0,50kWh (maximum error was 6,0%).

Table 3. VPP operation results (26/9/2018)

Time [UTC]	Setpoint [kWh]	Real [kWh]	Deviation [kWh]	Abs. Error
12:00 – 12:30	8,00	7,54	-0,46	6,0%
15:00 – 15:30	10,00	10,10	0,10	1,0%
15:30 – 16:00	9,00	9,04	0,04	0,4%
16:00 – 16:30	9,00	8,81	-0,19	2,2%
16:30 – 17:00	6,00	5,85	-0,15	2,5%

As the optimization is based on the spot market price, it is also relevant to take into consideration the financial impact. The VPP performance for the month of September at LNEG is stated on Table 4.

Based on the original forecast and the real consumption, there was a reduction of 7.3% and 8.5%, respectively in terms of supply contract with the retailer and spot market price.

Table 4. VPP Performance at LNEG for September 2018

	Amount [kWh]	Price Supply Contract	Price Spot Market
Original forecast	3,6353	€ 195.38	€ 138.64
Opt. schedule (theoretical)	1,910	€ 151.84	€ 105.61
Opt. schedule (real)	1,858	€ 181.15	€ 129.63
Rel. change (Ori - The.)	-6.07%	-22.29%	-23.82%
Rel. change (Ori - Real)	-8.60%	-7.29%	-8.45%

However, at this moment, such analysis is still inconclusive as there has been a very limited scope for price optimisation and the schedule forecast requires an improvement. So far, the basic principle of achieving a lower price by schedule optimisation was successful, but it will require more data to positively determine the added value for the end-user and VPP operator.

6.3 Results overview

The shifting potential and controllability of the AC systems, coupled with cold storage, were confirmed based on the obtained results. A high accuracy on reaching the consumption target for each event was achieved.

However, it is not possible yet to infer about the increase or reduction of consumption with respect to a baseline. In the current situation, there are significant differences between AC system's forecast and actual consumption due to lack of operational data.

Moreover, this difference has also an effect on both the ADR and VPP logic counteracting each optimization and, consequently, it impacts also the financial analysis and business model assessment. Nonetheless, it is expected to improve forecast accuracy as more data is retrieved until the start of the fully automated operation.

A comprehensive analysis on the technical and non-technical benefits of AC systems providing services to ADR and VPP systems is expected by the end of the demonstration project.

7 Future Works

The results discussed in the previous section were obtained during the preliminary operation of the ADR and VPP systems.

As a preparation for the full system deployment, during the summer of 2019, the partners will focus on improving the reliability of exchanged signal values between different parties (i.e. forecasts, optimized schedules, among others) and on enhancing the robustness of ADR and VPP platforms for precise control and measurements.

Regarding the flexibles loads, further investigation and evaluation on the operational performance of AC system with cold storage tank units (e.g. efficiency improvement, controllability) will be required.

From a business feasibility perspective, assessments on the economical values of AC system's flexibility and the required specifications and functions are necessary in order to integrate such systems in existing energy or balancing markets. Notwithstanding, before considering transferring the concept of flexibility from commercial air conditioning to electricity markets, an analysis of the regulatory situation in the individual target markets is compulsory. Requirements about Demand Response, e.g. metering standards or allowed deviations from the consumption target can have an impact on the rollout of such system.

7 Conclusions

In conclusion, LISCOOL project entails an aggregating platform promoting consumers as active participants on electricity markets by taking advantage of the flexible load of the AC systems.

On top of it, distinct methods are being tested through two operational scenarios in this demonstration project. The goal is to unlock the value of demand response for different players along the value chain. The first is based on network management providing a service to the grid operator (ADR system), while the second is based on energy trading and optimization of supply and demand profiles (VPP system).

The effective and optimized operation of the VRF systems, integrated with cold storage tank units, through either ADR or VPP systems enables a smooth integration of renewable energy sources in the power grid. It increases the electrical power quality and indirectly contributes to reduce greenhouse gas emissions. From an end-user perspective, it can bring lower electricity costs and new revenue streams.

Lastly, the system was considered and designed to have high scalability and versatility. On one hand, it allows the aggregation, integration and control of numerous AC systems on a local, regional or national scale. On the other hand, the AC Aggregating system can connect and provide Demand Response related services to different entities, such as retailers, grid or VPP operators as it is able to communicate through different protocols.

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