Local Energy Oxfordshire

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MVS A3.1 Technical Report

Oxford Behind the Meter (Sackler Library)

Scot Wheeler, Masao Ashtine, Avinash Vijay

Executive Summary

Project LEO is taking an agile approach to developing and testing new flexibility services. This is achieved through minimum viable system (MVS) trials which use the minimum set of requirements to test a new hypothesis or adaptation from previous iterations.

The third type of flexibility service identified as an MVS trial within LEO is demand side response (DSR). Oxford Behind the Meter (OBM) is a LEO plugin project investigating the opportunity of DSR within Oxford city in the provision of both flexibility services and additional benefits made possible through virtual private wires applied across city based organisations. The Sackler Library, part of the Bodleian Libraries, was chosen for the first trials. This was due to it's uniform energy use as a library, high thermal inertia due to book storage, high level of environment monitoring and electricity metering, and its ongoing involvement with other University of Oxford sustainability projects.

MVS A3.1.1 was the first trial run at the Sackler Library. It's aim was to demonstrate the heating, ventilation and air conditioning (HVAC) system could be controlled in response to a DSO request for flexibility and access the impact, if any, on the internal conditions of the building. The DSR flexibility service was scheduled to be a 20 kW increase in demand on Thursday 12th December 2019 between 13:30 and 14:40. This would be provided by the control of two 15 kW HVAC fans. Due to communication issues between the BMS server and the building, the trial was postponed to the following week after the bid stage. This highlighted the need to develop procedures for updating the DSO of asset status and ability to deliver, as well as any penalties for failure to deliver a service.

MVS A3.1.2 was the second trial and was a continuation of MVS A3.1.1 from where the trial had been postponed. MVS A3.1.2 was scheduled for Tuesday 17th December 2019 between 13:30 and 14:40. The trial was successful in demonstrating DSR within a University of Oxford building in response to a flexibility request from SSEN (the DSO), facilitated by the Piclo market platform. An evaluation of process maturity towards full automation for each step within the service procedure was made and is presented in this report. The average process maturity for the trial was 2.2, the lowest of the MVS trials to date. This highlights the next steps which need to be taken to increase automation in future trials, focussing on improved electricity metering at the building, asset and substation, along with more automated control of the flexible HVAC assets.

The measured flexibility delivered was 7 kWh (12 kWh total) over the agreed 1 hour service window at an average power of 7 kW. This is less than the 20 kWh at 20 kW which was submitted as part of the bid for service. The reason for the lower service delivery is mainly our ability to measure and therefore validate the power response of the HVAC fans relative to other baselined energy use within the building. Higher resolution (than the half-hourly meters used here) and more (or redistributed) sub-metering is required to better validate the service. There was also a 10 minute delay in service delivery which meant part of the service was delivered outside of the agreed service window. In line with the bid, the service provider would be paid 35p for the delivered service, resulting in an approximate net loss of £1.16 for the Sackler Library as service provider. The £1 bid was only a proxy offering, but this result will help inform further trials which investigate the commercial viability of such a flexibility service. The control flexibility and optimisation of HVAC systems can offer an organisation additional value beyond that available from local flexibility services alone.

This is the first trial of many within Project LEO to understand the value of DSR services and develop the control strategies necessary to deploy them. Following these initial trials at the

Sackler Library, further work is ongoing which will model the full flexibility potential, considering the whole HVAC system within the internal environment tolerances to maintain user comfort levels. Further work is also underway establishing how to control the BMS systems to allow for better automation of DSR service delivery.

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Introduction

Project LEO (Local Energy Oxfordshire) will demonstrate a Smart Local Energy System (SLES), at county scale, to maximise economic, environmental and social prosperity for the region. LEO is creating a local flexibility market to maximise utilisation of the electricity distribution network, at minimum cost, to provide best value for energy users, generators and Distributed Energy Resource (DER) owners alike.

Project LEO is taking an agile approach to developing and testing new flexibility services, business models and the multi-organisation procedure and communications required to operate a local flexibility market. Each minimum viable system (MVS) trial should represent the minimum stress set of participants and processes which are required to test a new process modification or asset use case. In doing so, new value can be identified and confirmed at a small, quick scale, before significant investment in time, money and user relations are committed; it is intended as a way to manage the risks associated with innovation in an uncertain, changing environment. All trials within Project LEO will be in response to artificial constraints.

The third type of MVS flexibility trials established within Project LEO centres around providing demand side response (DSR) services (the others included electrical storage and flexible generation). Oxford Behind the Meter (OBM) is a plug-in project within Project LEO focussing on implementing and refining coordinated DSR for flexibility services. In Oxford, a significant amount of electricity use is associated with heating, ventilation and air conditioning (HVAC), especially of non-domestic buildings such as the University of Oxford's estates. OBM will investigate how these energy loads can be managed collectively on a local scale across different buildings and organizations in Oxford to maximise the value of flexibility within the city. More information on OBM and the objectives of this group of Minimum Viable Systems (MVSs) can be found in the OBM Specification Report found on the Project LEO SharePoint.

The University of Oxford (UoO) has a large amount of buildings and infrastructure in the city centre; the UoO (not including the Colleges) accounts for around 14% of the city's annual electricity consumption and therefore has the ability to significantly influence local energy use. The MVS A3 trials concern building (DSR) for flexibility services, as stated, with the objective to demonstrate a multi-site, multi-actor coordinated response of building flexibility within the city of Oxford to more effectively balance and operate the system in real time as if behind a single meter.

This report details the learnings captured from MVS A3.1, the fourth MVS trial run as part of Project LEO and the first within OBM. The aim of the trial was to demonstrate DSR control of HVAC in a University of Oxford (UoO) building in response to a Distribution System Operator (DSO) flexibility service request and assess the impact, if any, on the internal state of the building. The Sackler Library hosted this first test which consisted of two trials (with the notation of MVS A3.1.1 and MVS A3.1.2 respectively), coordinated between the UoO (including the UoO Estates Management team), Scottish and Southern Electricity Networks (SSEN), and Piclo, on the 12th and 17th of December 2019. The following sections will comb through the technical insights and learnings from these trials to better understand the main successes and limitations of DSR flexibility through the use of the Sackler Library.

The Sackler Library

Trial Suitability

The Sackler Library (Figure 1) was chosen as the first trial building for OBM and MVS A3.1. The library is part of the Bodleian Libraries, and is located on St. John Street behind the Ashmolean Museum in Oxford city centre. Completed at the beginning of the 21st century, the Sackler

Library is one of the principal libraries of the University of Oxford, mainly holding a large portion of the classical, art historical and archeological works.

Figure 1: External view of the Sackler Library, Oxford.

The Sackler Library is a suitable choice of building within the University for initial DSR trials for a number of reasons and links well with previous work looking at the Bodleian Book Storage Facility in Swindon.

Firstly, libraries tend to have relatively low, non-critical, uniform use throughout the week. Unlike a building with teaching rooms, or critical experimental or IT infrastructure, we expect to see fewer user-activity driven energy peaks and greater freedom to explore the available flexibility.

Secondly, a library, through the very nature of the building and its contents, has a high thermal store which affords the building internal resistance to temperature and air-specific changes. This presents the opportunity for providing a larger or longer DSR flexibility service through the HVAC system, with minimal disruption to Sackler's services and user comfort.

Thirdly, in part due to its role storing some valuable ancient texts, the Sackler Library's internal environment is well monitored and controlled through the University's BMS system. This means the internal conditions of the building can be monitored closely during the trial to ensure they remain within comfort limits, and a wealth of historic data on conditions and related energy use can be used for modelling. The BMS system, accessed through the Trend 963 interface, is used widely across the University's estate and understanding of operation within this trial should be applicable for replication across the estate. There is also moderate electricity metering at the site. Power data can be visualised on the ION metering platform in near real time, with average half hourly data being recorded. The half hourly energy usage is made available through the University's SystemsLink energy monitoring platform.

Finally, the Sackler Library is already the focus of other sustainability projects run by the University's estates department, namely the *Carbon Reduction Programme*. These prior projects mean there are already established relationships between the building managers and the wider estates and sustainability teams. Building on this existing trust has enabled Project LEO to start earlier testing than would otherwise have been possible.

Project LEO Network Context

The Sackler Library is located in Oxford City Centre, within Project LEO's core area defined by the intersection of Oxfordshire's county boundary and Scottish and Southern Electricity Network's (SSEN) network area. The LEO partnership has identified 12 primary focus areas for the LEO and Transition trials which will see further monitoring installed. These areas are defined by the approximate area fed by SSEN's primary substations and selected based on the location of LEO's potential plug-in-projects (PIPs). Three of these (Osney, University Parks and Rosehill) are fully or partly located within Oxford's city boundary. The Sackler Library is connected to the Ashmolean Museum secondary substation, fed from Osney Primary Substation which in turn is fed from Cowley Bulk Supply Point. In the context of OBM, the Sackler Library is one of the potential assets which have been identified within Oxford City. The map in Figure 2 (following page) highlights the position of the Sackler Library within the context of the city boundary, selected primary substation areas for LEO and other potential Oxford-based assets identified as part of the OBM MVS trials.

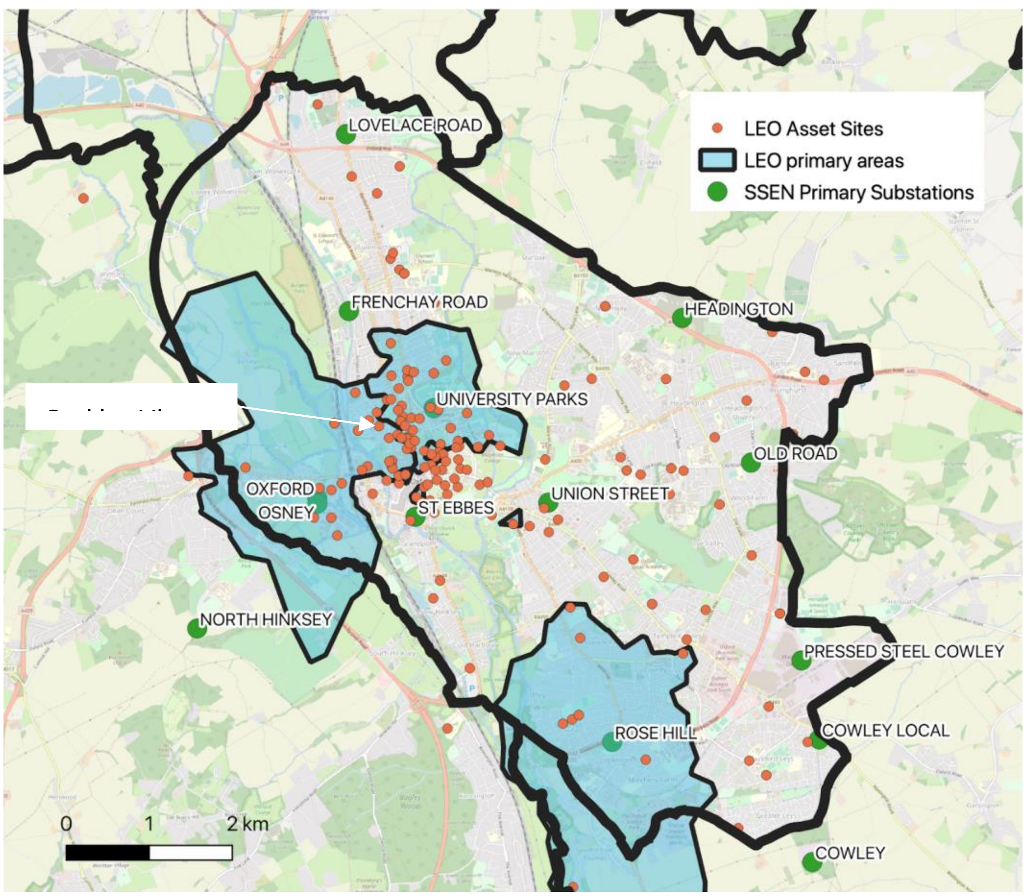

Figure 2: LEO primary substation areas of interest and potential assets for Oxford City.

Further details on heating and cooling

The cooling system of the Sackler Library revolves around a single chiller, while the heating system is regulated by three gas boilers acting on three different zones, according to the building's spatial heating plan (Figure 3). The ventilation is provided from a set of seven AHUs with some AHUs acting across multiple floors.

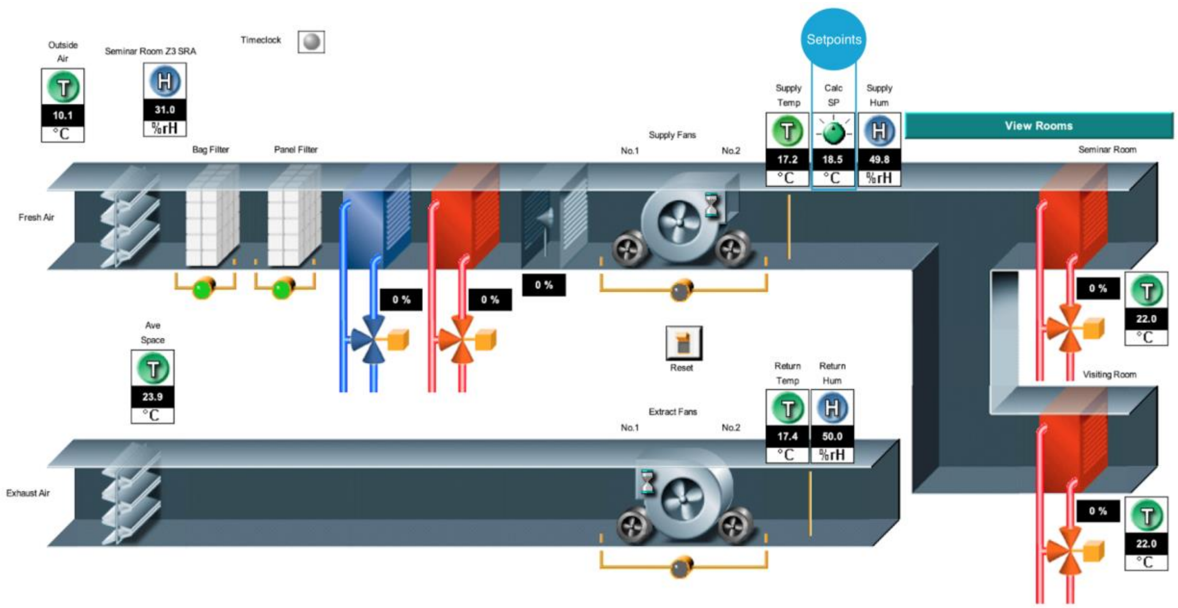

Figure 3: Sample system map (taken from the Trend963 Online Portal) for the AHU (AHU3) which feeds the Seminar room of the 3rd floor (within the Sackler Library.

Sensors are available to measure fan speed, outside air conditions (temperature and humidity), and internal return air temperature and humidity. The AHUs also have the functionality for setpoint tracking (label on Figure 3) for the supply temperature, and therefore are potentially suitable for optimization-based setpoint control strategies for the delivery of flexibility services to the DSO. Additionally, every floor is equipped with internal temperature, humidity and/or CO_2 sensors that record data (real-time output available through Trend963 interface) stored at 15-minute intervals; however not all of these sensors have been mapped through contracted services for data retrieval.

Site Specification

Table 1 contains the LEO site specification data for the Sackler Library. Certain fields are not applicable to this site, while others are unknown or yet to be determined.

Table 1: Sackler Library Site Specification Data

Address	Sackler Library, 1 St John Street, Oxford, OX1 2LG
Location (Lat, Long)	(34.365110, - 89.536560)
Solar Generation Capacity (kW)	0
Other Generation Capacity (kW)	0
Storage Type	N/A
Storage Asset Model	N/A
Storage Capacity (kWh)	N/A
Storage Power (kW)	N/A
Flexibility Type	DSR
Flexibility Capacity (kW)	Unknown
Supply Connection Capacity (KVA)	Unknown
Export Connection Capacity (kW)	Unknown
Voltage Connection (V)	415 V
Connection Offer Reference (SSEN)	N/A
MPAN (Import)	REDACTED
MPAN (Export)	N/A
Secondary Substation Name	Ashmolean Museum

Secondary Substation Code	4902002080
Primary Substation Name	Osney
Primary Substation Code	4902
HV Feeder Name	Gloucester Lane
Other Information	

Potential for Flexibility

This section presents a basic analysis of the electrical energy demand, cost of electricity and associated CO_2 emissions of the Sackler Library over the period of a year. Further details of the building's HVAC system are described, and finally an initial assessment is made as to the potential for flexibility.

Sackler's potential

During the 2019 calendar year, the overall electrical energy consumption of the Sackler Library was 458 MWh, which corresponded to an expense of £57,771. Figure 5 shows the Sackler Library's total daily energy consumption for 2019 (*meter reference: 104190*) calculated from the raw half-hourly data available on SystemsLink. Some gaps in the data are clearly visible, apparent from the daily energy demand recording 0. This is likely due to a comms failure with the metering equipment. The data for the chiller and overall building were cleaned in accordance with the Project LEO Data Cleaning Processes as described on the project's Bitbucket repository (*open-access to LEO Data Coordinators*).[1] Figure 6 shows the same daily energy consumption post data cleaning. The peak energy demand was in July at 2,147 kWh, with a typical range between 900

[1] Project LEO Database Repository; https://bitbucket.org/projectleodata/project-leo-database

kWh (weekends) and 1,400 kWh (weekdays) for the rest of the year. The low usage in late-December is reflective of the closure of the UoO during the Christmas break.

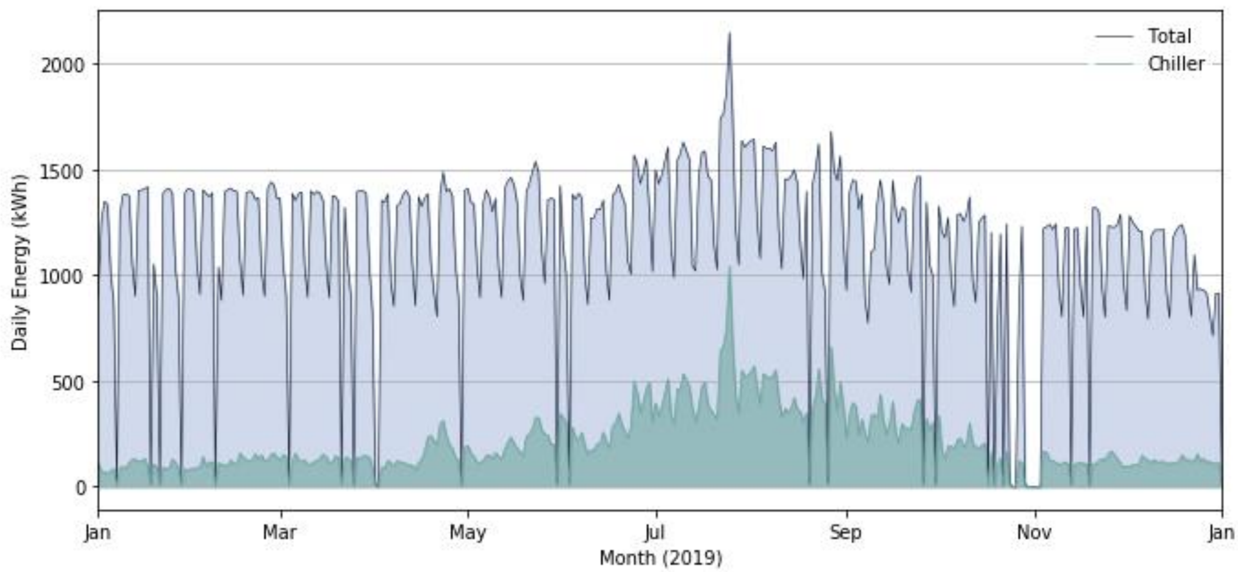

Figure 5: Annual energy usage for the Sackler Library showing averaged daily data for 2019.

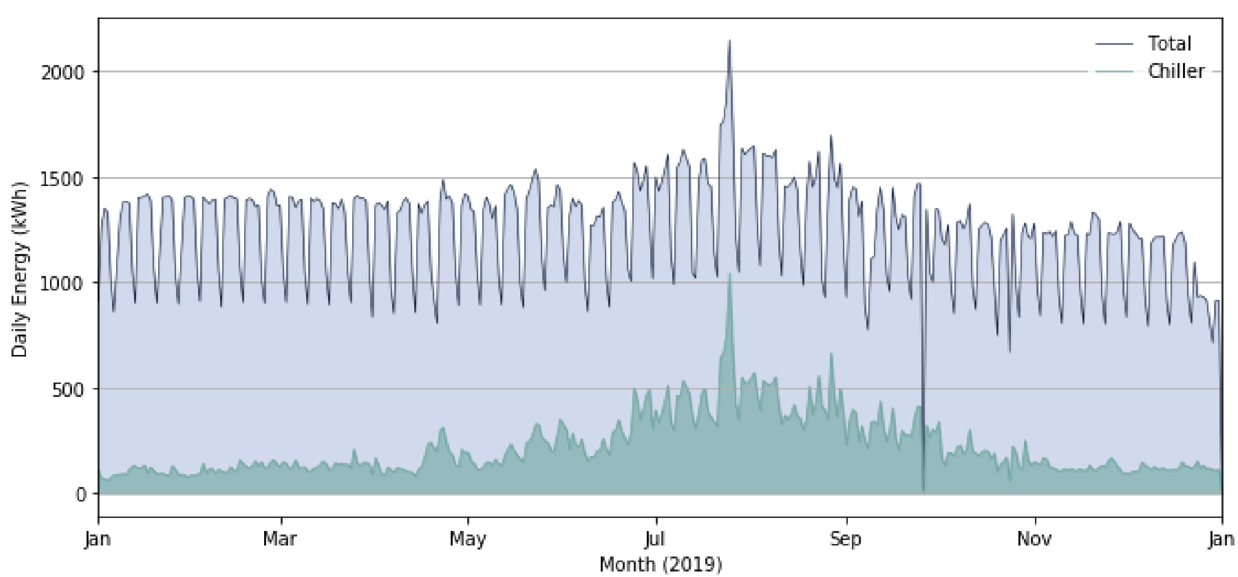

Figure 6: Annual energy usage (cleaned for errors) for the main Sackler Library chiller system showing averaged daily data for 2019, both total and for the chiller.

When looking specifically at the data for the main chiller from the Sackler Library (*Meter reference: 104172*) we can see further details on the peaked energy usage (2,147 kWh) in July of 2019. The periodic dips in energy usage reflect weekend lows, particularly lower on Sunday's, and the noticeable dip in late-December is owing to the UoO closure during the Christmas period. The meter used in this plot, which is tied to the HVAC system of the library, shows an average daily peak of 1,035 kWh on July 25th with an average monthly consumption of 9,713 kWh in the summer months and 4,195 kWh in the winter months of 2019. This day was listed as the second hottest day on UK weather records, with a temperature high of 36 °C being recorded in Oxford[2]. This anomaly is clearly seen when viewing data from the HVAC at the Sackler Library but there is a clear seasonal difference in energy usage owing to the higher usage of the chiller in the summer months. The annual energy consumption of the chiller in 2019 was 80.6 MWh. This corresponds to around 18% of the total energy consumption for the Sackler Library.

[2] Meteoblue Historical data for Oxford City Centre Accessed on Apr 3, 2019. Retrieved here

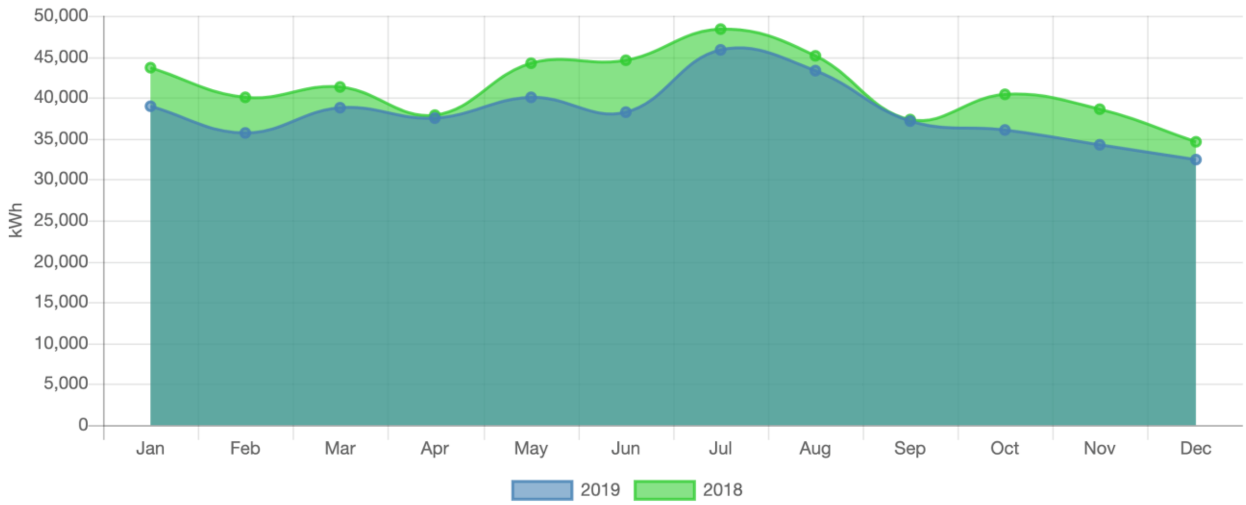

Figure 7: Monthly energy usage for the Sackler Library for 2018 and 2019. The plot was adapted from the *SystemsLink* Platform.

The year 2019 however was, on average, a year of lower consumption for the building than 2018 (Figure 7), with a peak difference in energy usage of 14.3% in June and 7.7% less usage overall in comparison. When looking at the costs associated with this electricity for the Sackler Library (Figure 8), there is generally consistency with the differences in energy usage as seen above, with 2019 being lower in total costs than 2018 (September is a marginal exception). Energy costs were 14.3% higher in 2018 than in 2019, and also given that the overall energy usage was higher, 2018 had ~8% higher CO_2 emissions (188 metric tons of CO_2e) based on the calculations reported by the SystemsLink platform. This reduction in energy use is likely an example of BMS optimisation work carried out by the university's Estate Service's sustainability team alongside engineering consultants Hoare Lea.

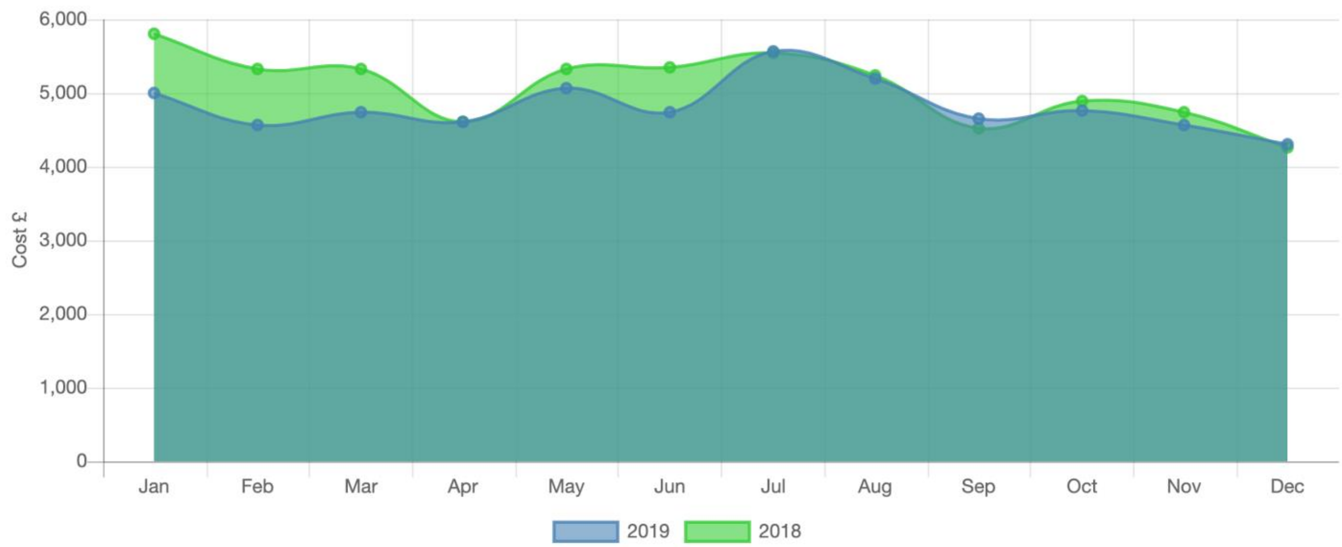

Figure 8: Monthly energy costs for the Sackler Library for 2018 and 2019. The plot was adapted from the *SystemsLink* Platform.

Two example weekday half hourly power demand profiles associated with the 10th and 90th percentile days (for total energy demand) are shown in Figure 9 below. In both examples, the baseline nighttime consumption is consistently in the range of 20 - 40 kW. For the low energy day, the daytime power is in the range 50-80 kW, with the chiller having a small contribution with a peak power of 10 kW. For the high energy day, the daytime power ranges from 50 - 110 kW with the chiller contributing a peak power of 40 kW. This chiller load gives an indication of the range in flexible power available at the Sackler Library. The actual value could be greater than this when the other components of the HVAC system, such as the fans, are included. The extent to which such a flexible service can be maintained will depend on the building's reaction to the flex event. Both these considerations will be explored further with detailed modelling of the building’s BMS system, and the expected response of the internal environment following HVAC control.

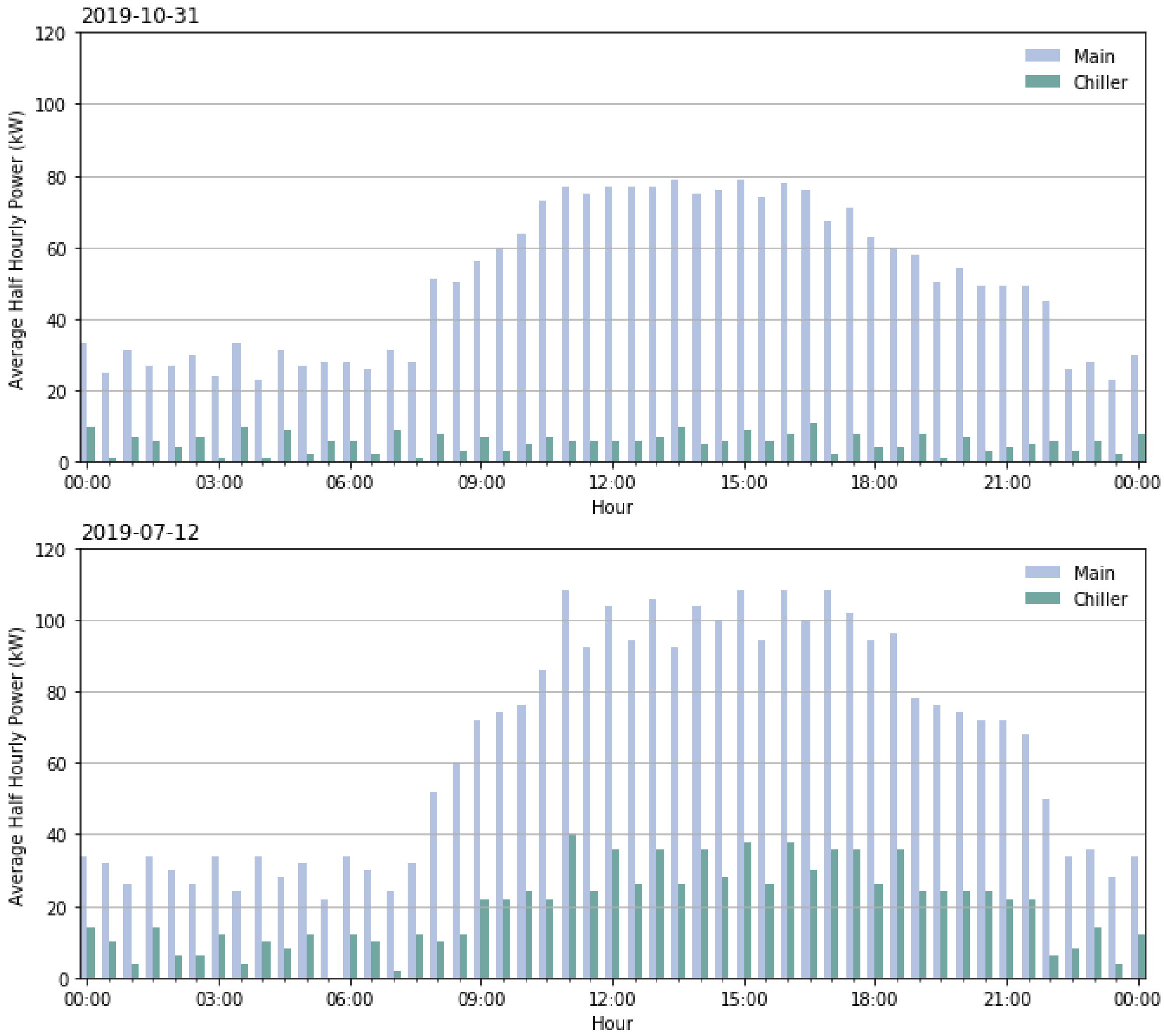

Figure 9: Typical daily half hourly power profiles of the Sackler Library showing the relative contribution of a chiller. Top: Thursday 31st October 2019 (10th weekday percentile day). Bottom: Wednesday 12th June 2019 (90th weekday percentile day).

MVS A3.1 Trials at Sackler

The OBM MVS trials commenced with the demonstration of basic HVAC control at the Sackler Library in December 2019. The first MVS trial, MVS A3.1.1, was scheduled to take place on the 12th of December 2019, with the second trial, MVS A3.1.2, taking place on the 17th of December 2019. Please note that the MVS notation takes the form of 'MVS [*MVS Group {A}*][*Flexibility Service Type {3}*][*Trial Number {1}*][*Attempt Number {2}*]' where the entries in the '*{}*' indicate the equivalent notation for the second attempt of the first trial as a reference. This section will discuss the main findings, both generic procedural and trial specific, from both of these trials, presenting the key learnings and hurdles experienced in the execution of the Sackler Library OBM flexibility events.

Trial Details

The objective of MVS A3.1 was to demonstrate basic DSR control of HVAC in the Sackler Library in response to an SSEN flexibility service request and assess the impact of such a response on the internal state of the building.

Participants

Below is a list of the key trial participants with the form: **Role:** *Company [Persons responsible (Initials)]*.

MVS coordinator: *University of Oxford* [*Scot Wheeler (SW)]*

Distribution System Operator (DSO): *SSEN [Andrew Waterston (AW)]*

Flexibility Market: *Piclo [Kelsey Devine (KD)]*

Service Provider: *University of Oxford [Martin Taylor (MT)]*

Data User: *University of Oxford [Masao Ashtine (MA)]*

Asset and Service Description

The HVAC DSR response will be provided by two 15 kW fans with variable speed drives, controlled manually through the University of Oxford's BMS system. The DSR response is expected to be a 20 kW increase in building demand.

Data

All data generated as part of these trials was shared through the Project LEO Data Log and can be accessed by project partners through the Project LEO Data Catalog. Instructions for accessing this data for project partners can be found in the Project LEO Data Sharing Guide available on the Project LEO Sharepoint.

Risks

The following risks were identified and mitigated against as part of the trial.

Table 2: MVS A3.1 risks

Risk	**Associated step**	**Partner responsible**	**Impact (1-5)**	**Likelihood (1-5)**	**Total (1-25)**	**Mitigation**
Trial affects building users' experience	9	UoO	2	1	2	Trial is being run outside of undergraduate terms so user numbers are expected to be low. First part of the trial will run early in the morning for the same reason.
CO_2 levels go beyond user comfort limits.	9	UoO	3	1	3	An increase in fan speed should decrease CO_2 levels so it's unlikely to lead to a breach of the upper unsafe limit. If limits are breached, the BMS will revert back to standard operation.
Temperature/Humidity levels go beyond user comfort limits.	9	UoO	1	1	1	Altering the fan speed should not lead to a change in temperature or humidity as the rest of the BMS system should compensate. If limits are breached, the BMS will revert back to standard operation.

Temperature/Humidity levels go beyond book storage limits.	9	UoO	1	1	1	Altering the fan speed should not lead to a change in temperature or humidity as the rest of the BMS system should compensate. If limits are breached, the BMS will revert back to standard operation.
Internal BMS monitoring is not sufficient to measure building response.	11	UoO	2	2	4	Temporary sensors can be installed to track internal conditions in the relevant areas.
University electricity metering equipment not sufficient to measure power response.	11	UoO	2	2	4	Temporary monitoring equipment can be installed at the building connection point.
SSEN are not able to monitor local substation.	10	SSEN	2	2	4	University metering at the building connection point will be used for verification.
Failure of asset to respond	9	UoO	1	1	1	Dispatch will be coordinated from the site to mitigate BMS connection issues.
Subcontractors required to install necessary kit	9, 11	UoO	2	4	8	Current kit is used for the first iteration and will inform what further kit is necessary.

MVS A3.1.1 - 'Failure to Deliver

The first attempt of the MVS A3.1 trial resulted in a failure to execute to completion; despite this, some key information and learnings were gained. The trial was originally planned as a 20 kW demand turn-up event, to run for 1 hour between 13:30 and 14:30 on the 12th of December, 2019. The increase in demand would have been achieved by increasing the fan speed of two, 15 kW fans from their standard day setpoint of 42% capacity to 100%. As this was the first DSR trial at the building, only the fan speeds were changed (as opposed to temperature set points) as this was expected to lead to minimal disruption to the internal environment of the building, but still produce a large enough power shift to observe at the building's point of connection. The trial was to be preceded by a shorter 30-minute test at 8:00 am on the same day, outside of building opening hours, to ensure the trial didn't negatively impact the internal conditions of the building.

Prior to the trial date, the Sackler Library's BMS experienced communication problems as a result of an upgrade to the Ashmolean BMS gateway (of the Ashmolean Museum) through which the Sackler Library is connected. As this limited the ability to remotely control the asset, or to collect internal building condition data, it was decided to postpone the trial to the following week. However, steps 1 through 7 were still successfully completed within MVS A3.1.1.

1. The artificial constraint was defined by the planned service description above, a 20 kW increase in demand at the Ashmolean secondary substation.

2. SSEN registered the constraint competition with a service period from the 12th of December until the 20th of December, so that if the trial were to be postponed, the service window would remain open during the following week.

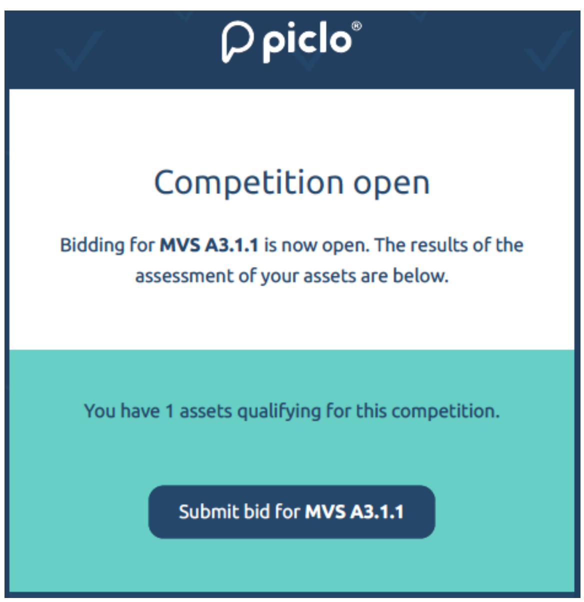

Figure 10: A screenshot of an email notification received by service providers with qualifying assets within the competition area.

3. The UoO registered the Sackler Library as a DSR flexibility resource on the Piclo platform via the Piclo asset spreadsheet (which is available through the Project LEO data portal). Certain fields were completed with proxy data and will be updated as further trials and monitoring inform more accurate values; these are listed below:

Table 3: Asset parameters where proxy values were used and uploaded to the Piclo LEO platform when registering the asset.

Asset Characteristic	**Value used in trial**
Active Power (Export) (MW)	0.03
Active Power (Import) (MW)	0.03
Maximum Import Capacity (MVA)	0.03
Maximum Export Capacity (MVA)	0
Technical Response Time (HH:MM:SS)	00:15:00
Maximum Run Time (HH:MM:SS)	02:00:00
Minimum Run Time (HH:MM:SS)	00:30:00
Recovery Time (HH:MM:SS)	02:00:00

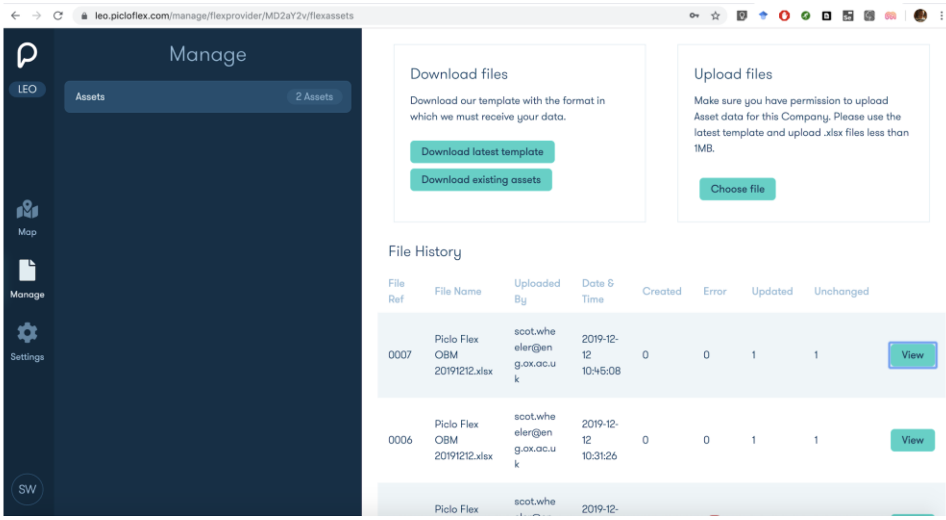

Figure 11: Screenshot of the asset characteristics upload page on the Piclo platform.

4. The UoO was assumed to be registered with SSEN as a provider of flexibility services.

5. The UoO updated the asset status on the Piclo LEO platform to ‘Operation’ by uploading an updated version of the Piclo asset spreadsheet.

6. A bid of £25/MW/h (*rate for delivering at a certain power output*) and £25/MWh (*rate for total delivered energy*), equivalent to £1 for the total service, was submitted at 10:52 am on the 12th of December. It was the only bid submitted as part of the competition.

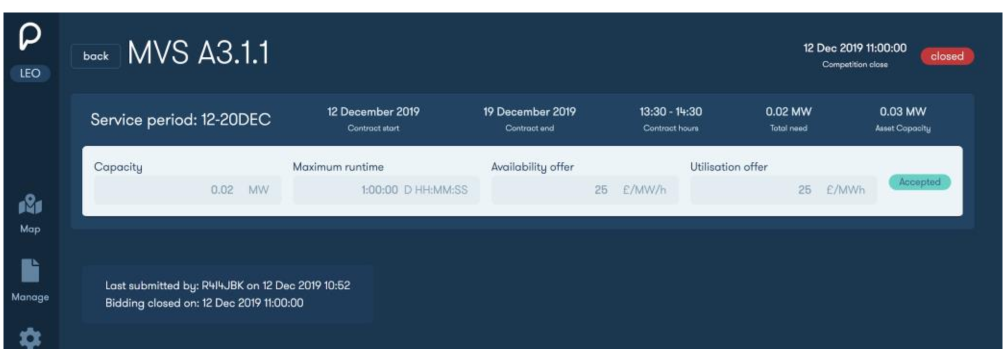

Figure 12: Screenshot of the service providers bid submission confirmation on the Piclo platform.

7. The bid was accepted by SSEN at 15:20 of the same day.

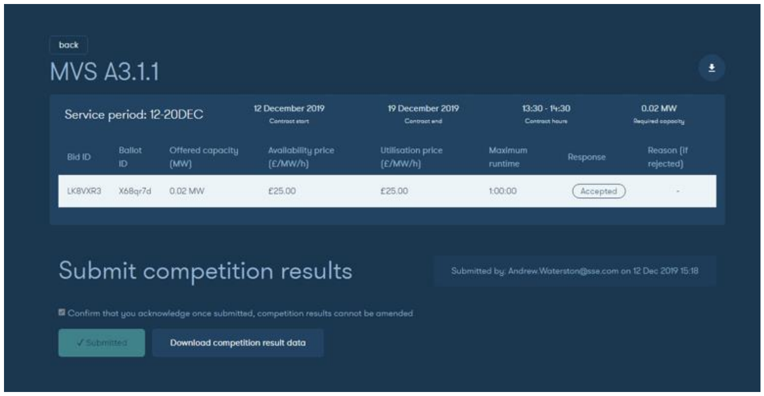

Figure 13: Screenshot of the DSO's competition closure and bid acceptance confirmation on the Piclo platform.

At this point, the trial was stopped in the hope communication issues between the central BMS server and the building could be fixed. The early 8:00 am test still went ahead as planned with manual control of fan speed and was deemed a success. As the trial saw a failure to deliver the turn-up using the HVAC system at the Sackler Library, no data were collected, thus limiting technical insights, promoting the second attempt of the MVS trial as seen in the next section.

MVS A3.1.2 - 'Completed'

The rescheduled trial occurred on the 17th of December during the same time window with label MVS A3.1.2 to highlight it is the second attempt of the first trial. To minimise unnecessary time for other associated LEO partners involved in the MVS trial, the successful steps of MVS A3.1.1 were not rerun (as per the Procedural Templates on Sharepoint), MVS A3.1.2 continues from the point at which MVS A3.1.1 failed.

8. SSEN sent the dispatch request on the 16th of December for a scheduled service delivery between 13:30-14:30 the following day, Tuesday 17th December. This was in the form of a text message sent from AW at SSEN to SW at UoO and can be seen in Figure 14.

Figure 14: Screenshot of the dispatch request text message sent by SSEN to the UoO.

9. As BMS communications with the building were still an issue, the Sackler HVAC asset was operated manually on the day of the trial as seen in Figure 15. Due to human error in controlling the HVAC system manually, the control of ramping up the fans to 100% capacity caused a small delay, beginning the delivery of the flex event at 13:40 and ending 10 minutes after the scheduled time at 14:40.

Figure 15: Engineer Martin Taylor (*a*) from the UoO Estates Management Team manually controlling the Trend BMS System (*b*) at the connection point for the MVS A3.1.2 trial which ran between 13:30-14:30 (one hour as shown in (*c*)) on December 17th, 2019.

10. There was no monitoring in place at the local secondary substation as the SSEN monitoring equipment was yet to arrive for use within Project LEO, while resource and time constraints didn't allow the installation of temporary metering (which was being used for MVS A1.1).

11. Thus, data collection was restricted to the standard UoO electricity metering at the building common connection point. The resolution of the output data were at a lower resolution (half hourly) than what would have been possible through metering at the local secondary substation. A live feed of the building power consumption was available through the ION portal, however, data is only saved as half hourly averaged data. The power data (real, reactive and apparent) were available to University Estates staff through the ION portal, while University researchers have access to average half hourly real energy.

There are 13 electricity sub-meters present within Sackler, however the majority of these monitor lighting circuits following previous lighting replacement work within the building. 1 sub-meter monitors a chiller.

12. No settlement was made as part of this trial.

13. The research evaluation is presented in the following section.

14. The procedural learnings and feedback have already been evaluated and are presented in the MVS Procedural Learnings Phase 1 (Jan 2020) document.

Discussion of Results

Procedural Learnings

The key procedural learning which came from MVS A3.1.1 highlighted the need for an established two-way communication strategy between the DSO (SSEN) and the service provider, particularly relating to failure or delay in service delivery. Within the trial, this happened through personal phone conversations between SW at UoO and AW at SSEN. The trial saw a failure to deliver on the original scheduled date and important questions were raised, such as, what processes need to be in place for the DSO to be notified of this failure, and what is the mechanism that follows to procure reserve services (through another service provider if needed) if a failure happens after bid acceptance but before dispatch requests.

Although the MVS A3.1.2 trial ran to completion successfully, there were a few critical learnings from the running of the DSR event. The most important involves the manual operation of this service and the needed improvement in automation within MVS trials. Within the LEO MVSs, ‘Process Maturity’ is defined as the quantifiable evolution of an MVS group based on whether the MVS procedures fall within five categories of operation: ‘Unknown’, ‘Proxy’, ‘Manual’, ‘Partial Automation’ and ‘Full Automation’. Further details on the assignment of these categories can be found in the OBM Specification Report found on the Project LEO SharePoint. Table 4 below gives the specific details of the process maturity of MVS A3.1.2 to highlight critical areas of future development.

Table 4: Condensed ‘Process Maturity’ report for MVS A3.1.2. For brevity of this report, some fields have been summarized textually/removed. Red (1) represents the lowest rating.

Procedure Step	PMS	PMS score	Reason	To reach next stage
1	Unknown	1	There is no established methodology for identifying flexibility services as part of the MVS process.	DSO driven trial service criteria.
2	Manual	3	Spreadsheet is filled out manually and uploaded to the Piclo LEO platform.	Constraint registered through API interface.
3	Manual	3	Spreadsheet is completed manually for each asset and asset update, and uploaded to the Piclo LEO platform.	Asset managed through browser and API interface.
4	Unknown	1	DSO is yet to define requirements or process for registering as a commercial supplier of flexibility	The requirements and process for registering as a commercial supplier of flexibility. A contract.
5	Manual	3	Asset status updated to 'Operation' by uploading new version of Piclo asset spreadsheet.	Asset managed through browser and API interface.
6	Manual	3	Manual determination of bid, input through Piclo LEO browser interface.	Asset modelling informs bid price, input through API.
7	Manual	3	A manual selection of the winning bids by DSO personnel.	Aided decision making based on optimum financial option, delivery risk and system impact modelling.
8	Proxy	2	Dispatch signal is a text message between DSO MVS coordinator and service provider coordinator private phone.	Dispatch signal sent via the Piclo leo platform, or official facilitator route.
9	Manual	3	University of Oxford dispatched asset through on-site operation.	Remote operation of asset.

10	Unknown	1	No secondary substation monitoring was installed.	Some form of monitoring to be installed.
11	Manual	3	Average half hourly metering installed and accessed manually through the University of Oxford ION system.	Data accessible to the project directly via ION or API.
12	Unknown	1	No settlement has been made.	Proxy form of settlement.
13	Unknown	1	Yet to occur, awaiting data.	Data
14	Manual	3	MVS procedure feedback is provided through the live learnings document and digested in the generic MVS learnings report.	
Average		**2.2**		

MVS A3.1.2 had an average process maturity of 2.2 which is the lowest of the all the MVS trials up to the running of A3.1.2 (PM Score range: 2.2-2.5). The largest gaps in improving the procedural steps of the MVS revolved around the lack of high-resolution data and metering (both at the substation and asset site) as well as the lack of automation in the delivery of the service itself (manual operation of the HVAC system led to unexpected errors).

Owing to the MVS trial having a delay of 10 minutes in delivering the service as a result of human error during manual control, important questions were raised around how strict should the windows for dispatch be, and what penalties, if any, might apply for delays in service stemming from an MVS trial.

Technical Learnings

Figure 16 below shows the average half hourly power consumption over the full period of December 17th for both the overall building's usage and for a sub-metered chiller. It also includes the expected flexibility power delivered (based on a 20 kW power shift due to fan speed) displayed with orange bars, relative to an estimated baseline shown with a black line. A basic estimation of the baseline was made by taking an average of the power consumption in the periods directly before and after the event.

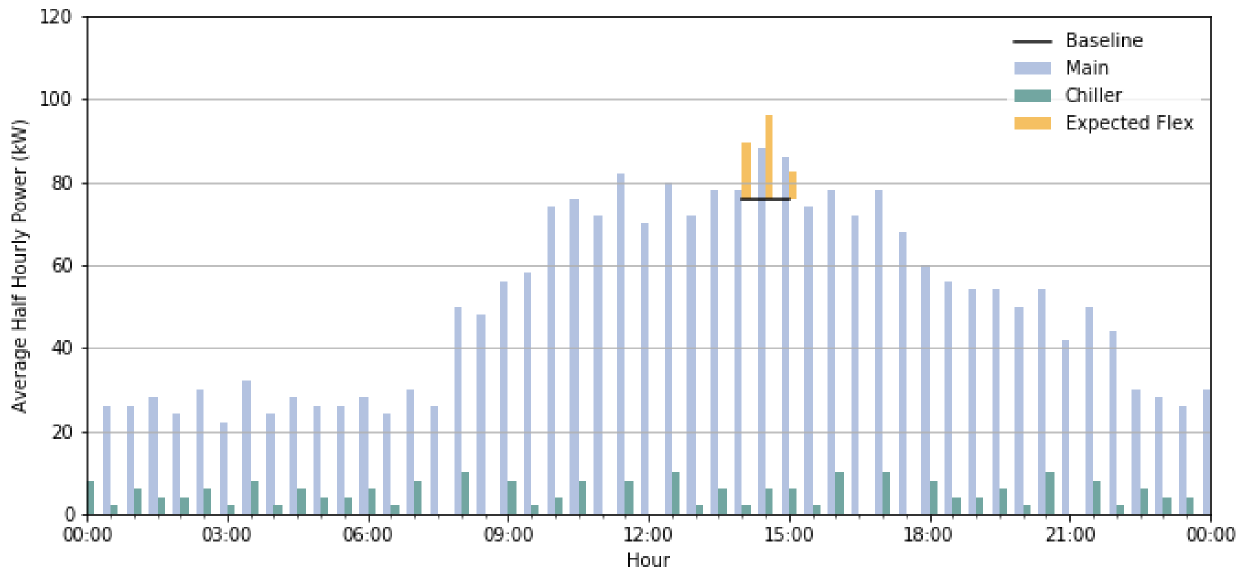

Figure 16: Power readings from the Sackler Library connection point for December 17th, 2019. The MVS A3.1.2 trial was run between 13:40-14:40 and the data show averages of the previous 30-min interval.

When comparing to the expected shift in power, it is clear that the flex event did not provide the expected power shift at the building's point of connection during the delivery window and this shift is not large enough to obviously stand out from the building's typical consumption.

Table 5: Measured and expected power shift during the service delivery window. The values are for the preceding half hour to the timestamp, i.e. the values for 14:00 represent what happened between 13:30 and 14:00.

Timestamp	Measured Power (kW)	Estimated baseline (kW)	Measured power shift (kW)	Expected power shift (kW)	Difference (kW)
14:00	78	76	2	13	-11
14:30	88	76	12	20	-8
15:00	86	76	10	7	3

There are a number of factors which may have contributed to the observed shift in power being different to that which was expected. Firstly, the expected power shift of 20 kW was a reserved estimate based on fan affinity laws, $P_1/P_2 = (n_1/n_2)^3$ where P is power and n is the fan speed in rpm, taking two 15 kW fans from 42% (630 rpm) to 100 % (1500 rpm). This assumes that the fans actually consume 15 kW when running at 100%. Further metering at the HVAC components is required for an actual measurement of the fans consumption.

Secondly, the building's BMS system might have responded to the manual perturbation with negative impacts for the desired flex. As it was a cold day, the outside air had a lower temperature than the internal building. As this air was pulled into the building at a higher rate due to the increase in fan speed, the BMS system might have reduced the chiller load, partially negating the increase in fan power. In the periods around the flex event, the chiller was oscillating between 10 kW and off. During the flex event, the chiller registered a maximum power of 6 kW. Therefore, this small reduction in chiller power contributed slightly to the lower building power observed, but isn't the only reason. In future trials, controlling the DSR event through BMS setpoints (such as the internal temperature setpoint) rather than individual HVAC components, will help ensure the BMS algorithms don't counteract the intended change.

Finally, the baseline is a basic estimate using the average of the power measured in the periods immediately before and immediately after the event. The actual energy use of the rest of the building (especially non-HVAC load) cannot be measured with the current sub-metering available within the building. It could be that the non-HVAC load happened to vary by an amount similar to the flex event, during the same period. Further analysis shows that the half-hour by half-hour change in power on a weekday between 12:00 - 17:00 has a standard deviation of 3.2 kW (Figure 17).

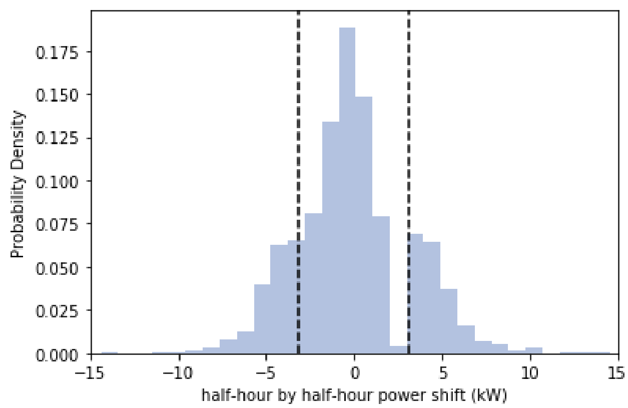

Figure 17: Half-hour by half-hour power shift at the Sackler Library for weekdays in the period 12:00-17:00.

Therefore, it's not unreasonable to conclude that the difference in expected power shift and the measured power shift has a significant contribution from typical variations in the power consumption of the building. This highlights the importance to consider this in further development of service validation, particularly when the size of the flexibility service is of a similar order to that of the variability in power consumption of the site. Future analysis will need to utilise more accurate baselining methodologies, or ensure that the asset being flexed is sub-metered so a direct measure of the power shift can be made and therefore validated. This question around baselining is an important one which the wider Project LEO consortium must answer as the project progresses.

Unfortunately, due to the BMS communication between the building and the central BMS server being down, data was not recorded for the internal state of the building. However, on site measurements by SW and MT during the trial revealed that there was no change in the internal temperature of the building as a result of the trial. There was a very small increase in sound levels from the HVAC system within the main study areas, however, these were minimal and would unlikely have been noticed by library users. The building's internal environment is well monitored with BMS sensors located throughout the building; including temperature, humidity and CO2. However, capturing this data can be a laborious manual task at present. Automated data capture and storage on university servers through additional software such as Tridium Niagra, will allow further detailed analysis across the university estate.

Commercial Learnings

Questions around the commercial operation of DSR were not the primary focus of this trial, however, some basic insights can be observed. Based on a validation method of measuring at the building's point of connection using the flat baseline above, an extra 12 kWh of energy was provided as part of the service (only 7 kWh were provided during the competition service window of 13:30-14:30 as a result of the delay). Using a rate of 12.6 p/kWh (from Sackler's annual electricity spend and usage), providing this service cost around £1.51. This is not accounting for the personnel time required to manually provide the service amongst other operational and maintenance costs. The bid made for the service was £25/MW/h and £25/MWh. Depending on how power delivery is validated, an average flex power of 7 kW was delivered during the agreed 1 hour window, worth 17.5p, while 7 kWh of energy was delivered during the agreed 1 hour window, also worth 17.5p. Therefore, the amount the service provider would have been paid for the delivered service would have been 35p, a deficit of £1.16.

While the value of DSR within local network flexibility services is a prime focus for Project LEO, there is additional financial value which can be extracted through better visibility and control of an organisation’s BMS. This can be in the form of energy and maintenance savings through improved component and system efficiency, avoidance of high energy pricing such as DUOS and TUOS charges and higher self consumption of onsite (or virtual) renewable generation.

Social Learnings

As with commercial learnings, questions around the social impact of the flex event were not the focus of this MVS. It is however worth noting that the relationships which have previously been established between Martin Taylor in the University Sustainability Team, and the building staff at the Sackler Library, were critical in allowing for this trial to go ahead in such a short timeframe. As further MVS trials are run, a stakeholder analysis will be considered as part of the MVS trial. Internal conditions within the building were unaffected by the trial, however future DSR trials which may intentionally change the internal conditions of the building, need to monitor the users experience as a result of the flexibility service.

Key Performance Indicators

Table 6: Specific MVS Key Performance Indicators (KPIs) with values for MVS A3.1 Sackler Library where applicable.

KPI	**Value**
Capacity under flexible control	20 kW
Impact on network utilisation (constraints)	N/A
Service response time	5 minutes
Levelized cost of flex event (full flex process, cost per kW and cost per kWh)	N/A
Additional generation capacity unlocked	N/A
Number of customers participating in the Project LEO service	1
Number of vulnerable customers / ‘energy	0

poor' customers participating in the Project LEO service	
Net benefit/cost to participants	-£1.16
Estimation/measurement of CO2 impact of the Project LEO service	N/A
Impact on non-participants	N/A

Key Learnings Summary and Future Work

The MVS A3.1.1 and A3.1.2 trials using the Sackler Library for the delivery of DSR services to a DSO (SSEN) provided a number of insights to better understand the processes needed to make such flexibility services feasible within the context of Project LEO's proposed flexibility market. Though MVS A3.1.1 was technically a 'failure to deliver' as the trial was rescheduled for a few days later, the project gained key insight around DSR operations, particularly around the scheduling of flexibility services, communications of asset status, and the potential for penalties as a result of failures to deliver. A3.1.2 highlighted the urgent need for higher resolution metering and in particular sub-metering in the context of building DSR. Without this data, baselining and service validation are very difficult, particularly if the relative shift in power is of a similar order to the building's typical load. Monitoring at the substation is also required to further assess the impact of the flex event on the wider network. While this trial only showed very low flexibility potential from the HVAC fans at the Sackler Library, the intention was to demonstrate these could be controlled. Work is still needed on the BMS of the building to effectively improve the process maturity to reach more automated levels of control. Further work will also need to focus on the true potential for flexibility within the whole HVAc system within the building, and if scaled up across the Universities estate, what the potential impact on the network could be.

Optimising control: Preliminary findings

This section will discuss some very preliminary work in improving the modelling of UoO assets for the OBM trials. It describes a method for determining the thermal characteristics of a building using sensor readings of indoor temperature, ambient temperature and heat consumption. Models such as these are essential to the operation of the flexible asset. For instance, thermal models such as the ones described within this section, serve as the link between the flexibility available and the required indoor temperature conditions in a building. Decisions regarding the heating system consuming more or less electricity have an impact on the indoor temperature which will have limits based on a wide variety of factors and users of the buildings at hand. This is particularly important to the Sackler Library which, owing to its sensitive contents, will need to operate within certain environmental conditions to prevent damage to any of the books and collections housed in the building.

Initial work around this has used grey box models to demonstrate the usefulness of these models to OBM. The essence of the grey box model lies in the application of an electrical analogy to a thermal system which compares current in an electric circuit to heat flow in a thermal circuit. Similarly, voltage corresponds to temperature (differences/potential), electrical resistance corresponds to thermal resistance, and electrical capacitance corresponds to thermal capacitance (the thermal store of the books in Sackler for instance). Thus, the heat transfer between the thermal mass of each room and the building envelope can be described by a Resistance-Capacitance (RC) network. Within the context of OBM, we are most interested in the impact of decreasing or increasing heat supplied or extracted on the temperature inside a building such as the Sackler Library.

Preliminary work has begun quantifying the extent to which the electrical power supplied can be varied. At each point of time during the modelling, the limits which the asset building can either decrease or increase power consumed without violating the temperature limits are calculated. These limits will better support future trials of OBM at Sackler or otherwise so that some form of automated control can regulate the building while providing a DSR service to the DSO. Decreasing power consumed is referred to as downward flexibility and increasing power consumed is referred to as upward flexibility. With regards to the Sackler Library, the downward flexibility of the building is based on chiller usage. The variation of downward flexibility is shown in Figure 18 (*left*) based on data collected from SystemsLink, and it is apparent that the use of the chiller in the summer months leads to the possibility of providing downward flexibility, with the highest mean values of downward flexibility occurring in June and July.

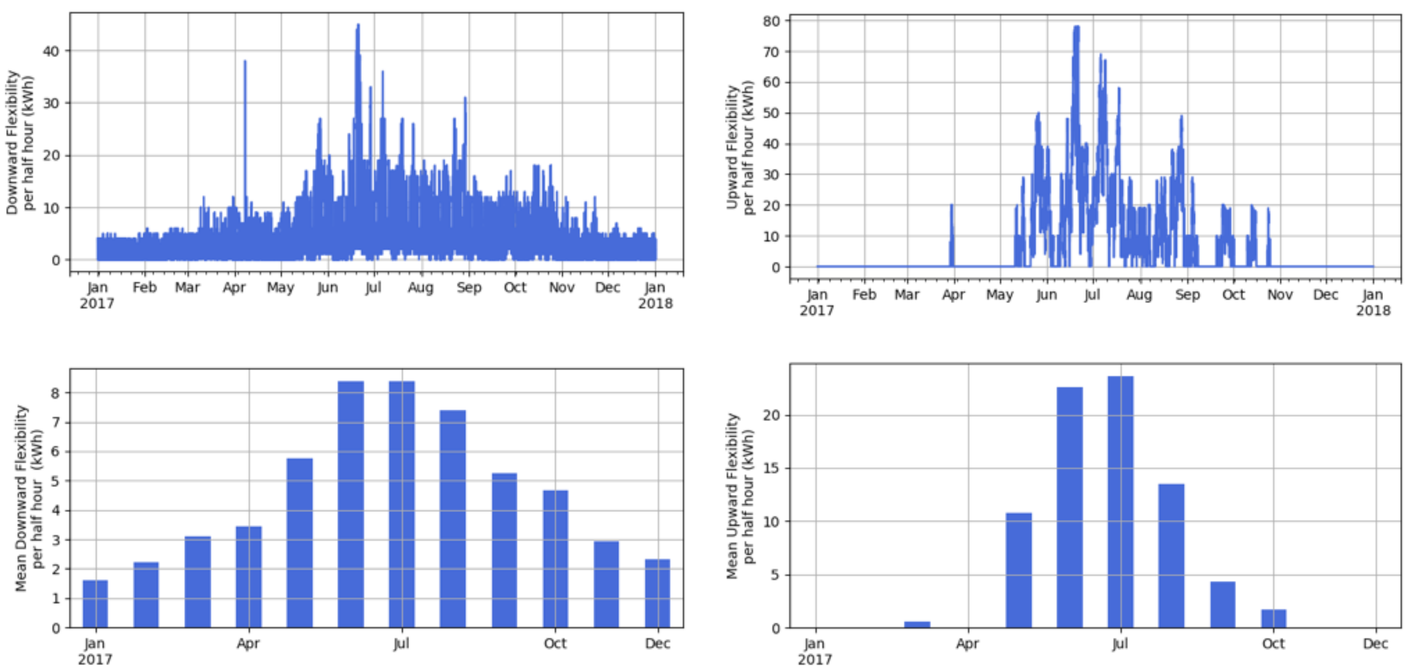

Figure 18: Downward (*left column*) and upward (*right column*) flexibility from the Sackler Library.

Upward flexibility is related to the lower limit on temperature. Initial work calculated upward flexibility based on how much additional power can be consumed by the chiller. The model described above was used to determine the highest additional power that can be consumed before the system hits the lower bound on temperature (Figure 18, *right*). Overall, results indicate that the Sackler Library can provide more flexibility in the summer months with the mean value of flexibility per half hour during these months lying around 7.5 kWh downward and 17.5 kWh upward. This translates to 5% downward and 11% upward flexibility without violating comfort/safeguarding limits.

Improving the BMS

As each building comes online with the automated modelling, demand trade and feedback loop, the estate as a whole will have a larger flex capacity which can be utilised in a local energy parket. However, the current BMSs alone are not sufficient to integrate the LEO OBM concept into the UoO buildings. The scheduled plan within the UoO is to retain the current BMS with minimal modification; thus, Project LEO must interface with this system with the following considerations:

1. Resilience of the buildings' operational purpose
    a. Health and safety of users
    b. Archive material conditioning
    c. Laboratory operation
    d. IT services operation
2. Comfort for building users
3. Efficient energy consumption of the building - responsible carbon impact (reduction where possible)
4. Current BMS has final control to act as the failsafe that will be triggered if the safety, operation or comfort limits are violated

To enable the buildings to operate as controllable DSR flexibility assets, an interface is required between the current BMS system and the control algorithms. This interface would run on a server within the university, in parallel to the current Trend 963 graphical user interface (GUI), alongside a database to store historic BMS data. This will also provide an interface to a computational host for the main algorithms needed for modelling, optimisation and control of DSR flexibility services within OBM which responds to external market signals such as LEO. A diagram for the proposed setup is shown in Figure 19.

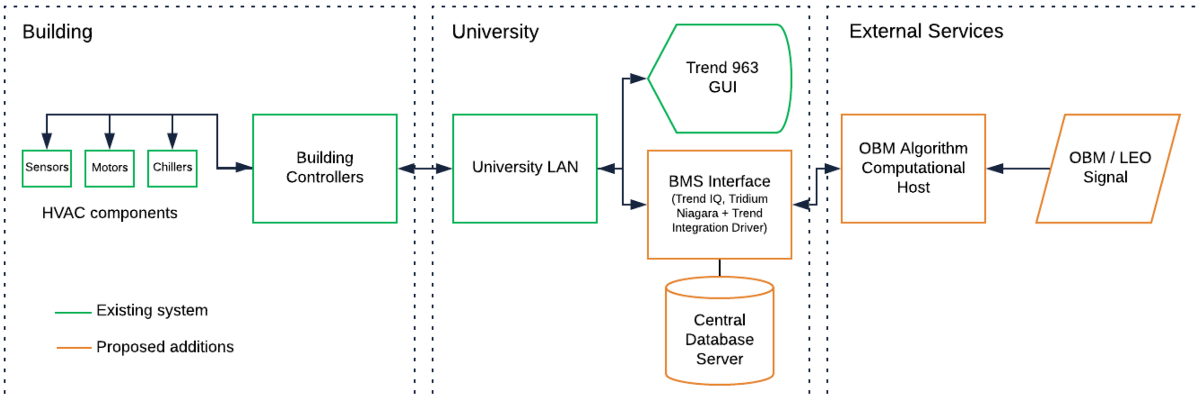

Figure 19: BMS interface that enables communication between the control system and building.

Next steps

The OBM trials with the Sackler Library have shown the nascency in the development of DSR as a service for the DSO within the UoO. Future work will look at the following steps as priorities for improving the process maturity of the MVS trials, the technical analysis of the data coming out of these trials and the impact of the flexibility service on user comfort:

1. Improve the metering and data resolution at both the asset site and the primary substation to better assess the value created through a flexibility event using DSR as a service.

2. Focus on the continued automation of the control systems of the building of interest to improve the timely delivery of the flexibility service.

3. Use preliminary findings to narrow down further suitable buildings within the UoO estate (and through LEO partners) that present greater downward/upward flexibility to demonstrate the value in these services to both the provider and DSO.

4. Through interaction with building users, measure the impact of the flexibility of service user comfort level, and establish the tolerances users are willing to accept for the benefits (financially, socially and environmentally) associated with offering flexibility.

More information on the schedule of upcoming OBM MVS trials and modelling can be found in more detail through the previously mentioned OBM Specification Report.