The Innovation Hub
for Affordable Heating and Cooling

DCH 7 - Knowledge Sharing Report #003
Application Development In Trial Buildings

Improving the accuracy of PV analytics and energy analytics in buildings using open asset standards and data platform integration

27 May 2022

VBIS, CSIRO, PrediQ

About i-Hub

The Innovation Hub for Affordable Heating and Cooling (i-Hub) is an initiative led by the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) in conjunction with CSIRO, Queensland University of Technology (QUT), the University of Melbourne, and the University of Wollongong and supported by Australian Renewable Energy Agency (ARENA) to facilitate the heating, ventilation, air conditioning and refrigeration (HVAC&R) industry's transition to a low emissions future, stimulate jobs growth, and showcase HVAC&R innovation in buildings.

The objective of i-Hub is to support the broader HVAC&R industry with knowledge dissemination, skills-development and capacity-building. By facilitating a collaborative approach to innovation, i-Hub brings together leading universities, researchers, consultants, building owners and equipment manufacturers to create a connected research and development community in Australia.

Primary Project Partner

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Improving the accuracy of PV analytics and energy analytics in buildings using open asset standards and data platform integration

Large scale adoption of technology in buildings has resulted in availability of large volume of data on the performance of HVAC and renewable generation assets. This data can be used for predicting availability of onsite generation, effectively manage HVAC operations and support decarbonisation of buildings.

While operational data exists, application of data driven analytics for accurate predictions will still require customisation of methods/models to specific systems and assets.

This project has utilised the VBIS asset classification open standard linked with Data Clearing House (DCH) based semantic models to demonstrate the benefits of integrated asset and building tagging systems to be used by PrediQ's analytics solutions.

Lead organisation
Virtual Buildings Information System (VBIS)

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1. INTRODUCTION

This document builds on the previous technical knowledge sharing reports from DCH 7, in particular DCH 7 Knowledge Sharing Reports 1 - 2 Building Models, Knowledge Sharing Report 2 - PV Analytics and Energy Analytics Development as well as the Final Project Completion Report.

One of the main objectives for the Data Clearing House DCH 7 project team was to create an integrated schema that bridges the gap in the current siloed approaches to asset meta data models used in the built environment by integrating VBIS asset classification and existing DCH semantic modelling/schema.

The project team was able to successfully achieve this through the creation of integrated semantic model that can be used by application developers familiar with the BRICK sematic model.

This report builds on the previous Knowledge Sharing reports provided during the M6 milestone and will cover semantic model creation, data onboarding, and application development as well as possible next steps.

The report will also provide details on how the deployed applications Improve the reliability of onsite PV generation through deployed PV system and HVAC analytics applications linked with DCH. Eight (8) applications have also been developed that can be mass deployable for repeatable results. This ability to query a semantic model will also demonstrate the value of integrated asset classification and semantic modelling for delivery of PV analytics, energy analytics applications and asset performance optimisation.

City of Melbourne, is a project partner and provided the project team access to the building data from the following buildings:

- Library at the Dock
- East Melbourne Library
- Boyd Community Hub
- Lady Huntingfield Early Learning and Family Services Centre
- Fitzroy Gardens Visitors Centre

2. SEMANTIC MODEL CONSTRUCTION

2.1 Model Construction – Overview

CSIRO was responsible for creation of these models although significant investigation, data gathering and validation to assist the process was undertaken by PrediQ. The semantic model schema used in DCH is an extension of the BRICK schema. We had a particular focus on incorporating the VBIS tagging information into these BRICK models to allow applications access to more detailed information of the assets in buildings. This section discusses the results of, and the processes for, constructing these models.

For the model construction background, scope, VBIS asset classification integration and initial model construction challenges, please refer to DCH 7 Knowledge Sharing Report 1- Building of Data Models for 2 buildings.

To construct the models, over 250 reference material files were sourced. Table 1 shows the breakdown. These files covered aspects such as floor plans, images from Building Management Systems (BMS) screens, solar system manuals, single line diagrams for solar systems, factory acceptance test documents, electrical schematics, as built mechanical systems schematics, commissioning sheets, Engineers reports, service manuals, electrical services operations, BMS downloads and point lists, BACnet scans, functional description documents, asset registers, VBIS asset classification information and as installed electrical diagrams.

Site	#Reference files gathered
Boyd School	57
East Melbourne Library	36
Fitzroy Gardens	53
Lady Huntingfield	52
Library at the Dock	78

Table 1: Reference files per site

VBIS provided the necessary equipment classifications for inclusion into the model. Where asset equipment was identified which did not yet have a classification, VBIS generated the correct classification structure for similar asset groupings to be used in the semantic model. This included Heat Recovery VRF condenser units, solar inverter types and solar panel types (such as monocrystalline solar panels, VBIS: EP-SPS-Pa-MC, vs polycrystalline ones, VBIS: EP-SPS-Pa-PC) which can then be used by the various deployed applications.

Domain experts from CSIRO, familiar with the BRICK schema, collated this information into a series of standardised documents (spreadsheets) that form the basis of the semantic models. Creation of these documents is most of the work in creating the models.   Four interrelated documents are created.

1. The Skeleton file. Contains the names all the equipment and locations to be included in the model and describes BRICK relationships between them.

2. The Points List file. A list of the names of the points ingested into DCH for the building.

3. The Mapping file. Contains three sets of information about all the equipment and locations outlined in the Skeleton file:

    a. The BRICK class of each thing

    b. Any instance metadata that should go in the model for that thing. For DCH 7 this is where the VBIS tag information for each piece of equipment is fed into the model construction process. It is also where things such as serial numbers and other properties such as room areas or Solar Panel orientation can be specified if desired.

    c. Information about how to map points (based on their naming conventions) from the Points List file to those items.

4. The Point Class file. Contains a similar mapping to the Mapping file, but in this instance, it is the mapping from Point names in the Point List file to the BRICK classes of those points. This is also where properties of the points can be set as well such as the phase count or phase identifier in electrical metering points.

These csv's can be complex documents as they represent a complicated network of relationships (a building model graph) in tabular form. Drafting these csv's requires specialised knowledge: building domain expertise, to interpret the reference material, as well as BRICK schema and DCH conventions' knowledge, to translate that information and categorise it into the appropriate BRICK classes and relationships for locations, equipment, and points.

2.2 Model Construction – Summary of Challenges

Construction BRICK models is challenging. Understanding the current installation and connectivity state of the equipment in a building requires sourcing and cross-checking different pieces of information. Documentation is often vast, inaccurate (outdated), and incomplete. It is almost certain site visits are required to clarify and fill in gaps.

Similarly sourcing the information to classify and link the thousands of points to the constructed model is challenging. Identifying what is what and sorting through errors in documentation and system configurations is difficult through the sheer volume of points that often exist.

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Assessing completeness and accuracy of constructed models remains an ongoing challenge. E.g., an historically misnamed point in a BMS system can easily propagate to a misclassified point in a Semantic building model without the error being picked up. In future more tooling to assist in identifying gaps, duplicates, oddities etc in point data need to be developed to assist.

George EP Box's insight over 45 years ago that "All models are wrong, but some are useful" is poignantly relevant in this field. The models need to be complete and arcuate enough to serve the suite of applications wanting to reason over and examine them.   Given the diversity of applications that may be developed in the smart buildings space it is not possible to assert in advance that a specific model is accurate enough or complete enough for any future application that might come along. We can, and have, put in place conventions for how to model buildings beyond the ontology (things like Must, Should, Must Not) that we can check models against to provide confidence that models are likely to be useful, but being able to guarantee 100% completeness and 100% accuracy is not possible.

2.3 BRICK Schema extensions

Since the start of DCH development, the BRICK Schema has had two major releases or evolutions. These releases contain enhancements that people identify as uptake becomes wider. The DCH team has been at the forefront of developing extensions to BRICK especially in the electrical systems modelling space. DCH is built around an extension of BRICK that incorporates those extensions. That extension introduced things such as types of metering, inverters, battery and hybrid systems and points for them. Some of these concepts are now available in the latest versions of BRICK, but some concepts are still unique to DCH. It is one of DCH's objectives to drive alignment with the BRICK community by both feeding into decisions of the community as well as migrating concepts as BRICK evolves.

DCH has introduced several modelling conventions around electrical system including PV system modelling that are used in the City of Melbourne building models.

2.4 Modelling Conventions

For applications to be transferrable across models it is not sufficient for models to follow the BRICK ontology. An extra layer of 'how the BRICK schema is implemented' needs to also be consistent to help application developers formulate the queries that will always give them the correct results across different models.

DCH has created some modelling conventions around Electrical system modelling including PV system modelling which have been followed for these models. An example of a convention around electrical system modelling is the use of the feeds relationship. BRICK ontology is unclear on direction of feeds relationships in the electrical context and whilst it could model direction of power flow, a net metering situation will then require bi-directional feeds relationships. This would make it difficult for applications to identify the metering/electrical equipment hierarchy (aka single line diagram for the electrical system) for each building. To counter this lack of clarity DCH has a convention around using feeds with electrical systems:

> ***brick:feeds*** *: for electrical systems, brick:feeds is used to indicate that two equipment instances are electrically connected. If equipment A is closer to the utility point-of-connection than equipment B, then* `:A` ***brick:feeds*** `:B`*. This convention is followed regardless of direction of physical energy transfer. Electrical equipment only ever feed other equipment; they never feed locations.*

This allows applications that are querying electrical connectivity to get clear, non-ambiguous, results.

2.5 City of Melbourne Models

Appendix 1 contains some statistics and visual representations of the semantic models for the five city of Melbourne buildings.

3. DATA ONBOARDING

3.1 Overview

In the DCH7 project, PrediQ were responsible for getting the data flowing from the sites to DCH. DCH7 was the first DCH project where a non-CSIRO partner onboarded buildings data. Prior to this project all data onboarding into DCH was undertaken by the CSIRO based DCH team.

The aim of DCH is to provide connectivity to allow data to be directly ingested into DCH from edge devices. Examples include gateways on BMS networks that directly send data to DCH, or pipelines that connect IoT device web services to DCH. At the start of the project DCH had limited capability for receiving data so the initial plan was for PrediQ to onboard data into their systems using their existing connectivity services and then use the Senaps REST APIs to push a copy of that data into the Senaps database (Senaps provides the timeseries data functionality for DCH).

As DCH matured it provided mechanisms for gateways to directly send data which included a simpler MQTT based streaming service for data ingestion into DCH. This became available prior to PrediQ developing the interface from their database to Senaps. The mechanisms gateways can use are also available for PrediQ servers to use, and, as it was a simpler workflow, that was the mechanism used.

This MQTT based interface allowed PrediQ to upload data from a range of sources including their gateways that were grabbing live BMS data, manually gathered/downloaded trend logs in csv form where that data was available and PV system web/API interfaces.

3.2 Challenges

As PrediQ were the first external partners onboarding buildings data there were working with the forefront of DCH development. There were some teething problems bringing this all together:

3.2.1 Documentation maturity

During the project when PrediQ were wanting to do the work DCH did not yet have professional level of documentation. This caused some delays. The challenge was met by CSIRO providing support as required, particularly in the form of working example code that correctly interfaced to the MQTT end point.

3.2.2 Limited diagnostic tooling

Tooling to assist external partners in diagnosing connectivity issues as they arose is limited in DCH. This caused significant delays.

One specific example on the challenges presented by limited diagnostic tooling was a tricky connectivity issue which manifested as only some of the data PrediQ sent making it into DCH. This was a handshaking issue between PREDIQ MQTT client code sending data and the CSIRO MQTT broker receiving it. PrediQ's code was connecting to DCH but not waiting for a connection acknowledgement before sending data. Thus, data was queueing up at the DCH end whilst the DCH servers were undertaking the process of confirming that PrediQ were authorised to send in that data (for security purposes). Sending data before getting the connection acknowledgement is not breaking the MQTT specifications (it is a grey area in the spec) but the result was that eventually the DCH broker cancelled the connection because it received too much data whilst it was checking authorisation. The data it had received prior to sending the cancellations did continue through the pipeline and make it into DCH. However, the PrediQ end did not realise there was a problem and continued to send data after the connection was cancelled, and that data did not make it into DCH. Subtleties around this behaviour and difficulties in diagnosing connectivity issues across two organisations made it particularly challenging to get to the root cause of the issue. It took quite some time to diagnose and address, there was back and forth with people in both organisations checking things and saying as far as we can tell our end is correct. The challenge was eventually met by CSIRO providing extra resources that did a deep dive into the raw communications packets that highlighted that the PrediQ code was not following the example provided. The fix was simple once it was identified.

3.2.3 Limited monitoring infrastructure

Once data was flowing there is still a challenge with these systems to validate that data continues to flow. DCH does have Stream health check capabilities that were deployed on the PrediQ data sources, however tooling around them is also limited. It is not easy for the system that provide notifications from that monitoring (SMS, email etc) and what is available is unsophisticated and difficult to set up. Effective notification systems are difficult to build, they are critical for DCH operations and are being considered in future DCH work. Whilst manual checks helped during this project this is an ongoing challenge for DCH.

3.2.4 Limited tooling to validate correctness of data

Whilst data in DCH is viewable there is limited tooling to assist validation of incoming data streams. There are over 2000 data streams coming in from the five buildings. It is not possible for a person to manually check each one. This is a common challenge with onboarding buildings. It is the role of DCH to provide tooling to assist validation of data. Currently errors can go undetected until apps start using specific point data. This is an ongoing challenge for DCH.

4. APPLICATION DEVELOPMENT AND DESIGN

The analytics system is not a simple application, it is a cycle process of learning characteristics of the existing building operating system and continuously trying digital transformation and monitoring, and finding new problems or opportunities based on periodical established goals. The cloud-based application is a tool for its improvement services at the later stage.

A typical application feedback loop is shown in Figure 1
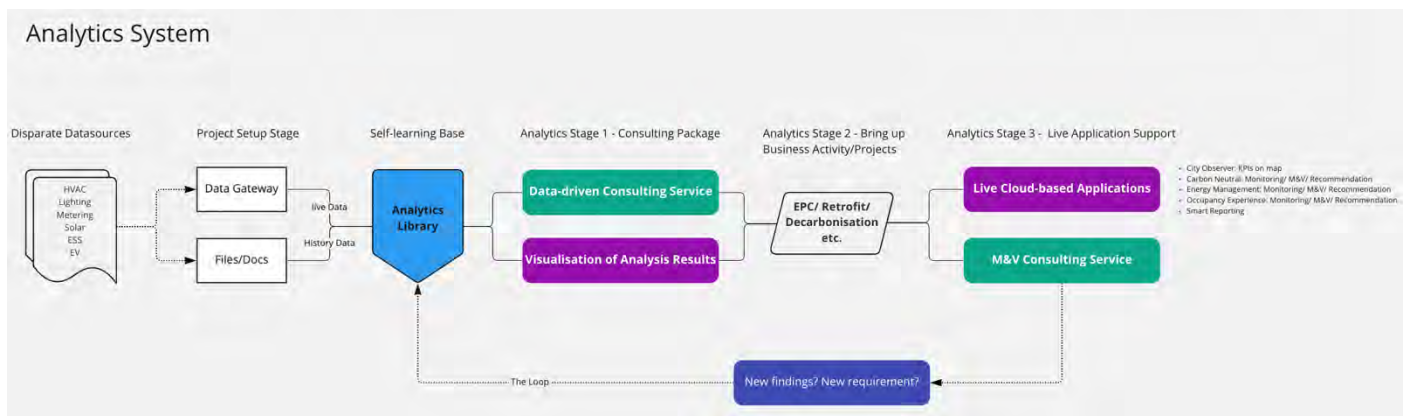
Figure 1: Overview of the designed analytical system

To understand the inputs and initial development of the application by PrediQ, refer to DCH 7 – Knowledge Share Report 2 - Application Development.

For DCH7, one of the main sources for project setup and ingestion of data was using the building model, building data points and VBIS asset classification from the Data Clearing House (DCH) platform.

4.1 Application Development Data Quality

To ensure a smooth data collection, PrediQ deployed the data audit application module on the cloud server to automatically check the progress of data collection every hour. This module sends alerts when abnormal data is detected and generates daily briefing summary to data management personnel. Combining all received data quality reports, it is noted that the below main reasons below impacted data quality:

- In the design of the control system, certain data points were not available for sharing external systems. On some sites this included: electricity meters data points and sensors in HVAC systems that can calculate energy efficiency.
- Data stability within the automatic control systems. For instance, some of controllers would frequently appear offline.
- Very limited access to the API of PV system. While desired data points could be seen on the PV system portal such as with data of related to micro inverters, the same data was not available for use via the PV API.
- Data stability from PV system API.
- Unstable local internet, which can cause failures of gateway data collection.
- A large sample data used for the model training had been impacted by COVID lockdowns. This led to irregular building occupancy rate and patterns, impacting the ability for the system to correctly apply feedback when training the data models.

4.2 Application Query of DCH BRICK Model

A core objective for DCH 7 was to implement applications to be redeployable by utilising the information within the DCH building model.

An example of how this was achieved can be seen below. Taking Lady Huntingfield as an example, when the application conducts PV analysis, the application first sends a request to the DCH API to understand the system installed. The response from the API with details of the building PV system information will then be returned.

Building: lady_huntingfield, Query: Q8
{'hypernym': 'Equipment',
 'node': {'model_ref': {'building_id': 'lady_huntingfield',
              'org_id': 'city_of_melbourne',
              'site_id': 'Lady_Huntingfield'},
     'node_id': 'MicroInverter8'},
 'related_nodes': [{'hypernym': 'Equipment',
         'node': {'model_ref': {'building_id': 'lady_huntingfield',
                     'org_id': 'city_of_melbourne',
                     'site_id': 'Lady_Huntingfield'},
             'node_id': 'EM-1.1'},
        'relationship': 'isFedBy',
        'stream_ids': [''],
        'type': 'Electrical_Generation_Meter'},
       {'hypernym': 'Equipment',
        'node': {'model_ref': {'building_id': 'lady_huntingfield',
                     'org_id': 'city_of_melbourne',
                     'site_id': 'Lady_Huntingfield'},
            'node_id': 'PV_Panel8'},
        'relationship': 'feeds',
        'stream_ids': [''],
        'type': 'PV_Panel'},
       {'hypernym': 'Point',
        'node': {'model_ref': {'building_id': 'lady_huntingfield',
                     'org_id': 'city_of_melbourne',
                     'site_id': 'Lady_Huntingfield'},
            'node_id': 'Power_Micro_Inverter_8'},
        'relationship': 'hasPoint',
        'stream_ids': ['dsapi-decisive-bad-progress-Lady_Huntingfield.lady_huntingfield...Power_Micro_Inverter_8'],
        'type': 'Real_Power_Export_Sensor'},
       {'hypernym': 'Point',
        'node': {'model_ref': {'building_id': 'lady_huntingfield',
                     'org_id': 'city_of_melbourne',
                     'site_id': 'Lady_Huntingfield'},

```
             'node_id': 'Energy_Micro_Inverter_8'},
         'relationship': 'hasPoint',
         'stream_ids': ['dsapi-decisive-bad-progress-Lady_Huntingfield.lady_huntingfield...Energy_Micro_Inverter_8'],
         'type': 'Real_Energy_Export_Sensor'}],
  'type': 'Solar_Inverter'}
{'hypernym': 'Equipment',
 'node': {'model_ref': {'building_id': 'lady_huntingfield',
                'org_id': 'city_of_melbourne',
                'site_id': 'Lady_Huntingfield'},
       'node_id': 'PV_Panel6'},
 'related_nodes': [{'hypernym': 'Equipment',
            'node': {'model_ref': {'building_id': 'lady_huntingfield',
                        'org_id': 'city_of_melbourne',
                        'site_id': 'Lady_Huntingfield'},
                 'node_id': 'MicroInverter6'},
           'relationship': 'isFedBy',
           'stream_ids': [''],
           'type': 'Solar_Inverter'}],
 'type': 'PV_Panel'}
```

Building: lady_huntingfield, Query: Q11
get the vbis tag info for node.
PV_Panel6 vbis tag: EP-SPS-Pa-MPERC

Building: lady_huntingfield, Query: Q13
All inverters' power export sensors.
122 pairs found. e.g. ('MicroInverter8', 'Power_Micro_Inverter_8') - ['dsapi-decisive-bad-progress-Lady_Huntingfield.lady_huntingfield...Power_Micro_Inverter_8']

Building: lady_huntingfield, Query: Q14
All inverters' energy sensors.
122 pairs found. e.g. ('MicroInverter8', 'Energy_Micro_Inverter_8') - ['dsapi-decisive-bad-progress-Lady_Huntingfield.lady_huntingfield...Energy_Micro_Inverter_8']

When time series data is acquired, the application analytic rules and models will generate an automatic report of analysis results and write the analysis results into the application. The following Figure 2 shows a brief output of some PV analytic rules. This is a complete example of from DCH data query, data analysis to the final output.

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2 Lady Huntingfield

```
In [5]:  # LH
         engine = create_engine(f"mysql+pymysql://{USERNAME}:{PASSWORD}@{HOST}/uc_iot_2")
         df2 = pd.concat([pd.read_sql(f"SELECT * FROM uc_iot_2.hisvalues_{m:02} h \
             LEFT JOIN uc_iot_2.points p ON h.pointID=p.id WHERE \
             pointId BETWEEN 679 AND 800 AND timeStamp > '2022-01-01';",
             con = engine, parse_dates=[3]) for m in range(1,12)])
         df2.value = df2.value.astype(float)
         df2['date'] = df2.timeStamp.dt.date

In [6]:  accum(df2)
```

Inverter History

Daily Generations

```
Out[6]:
```

	actual	pointId	ideal	impact	factor
date					
2022-01-01	1207090.0	1082628	1540982.0	333892.0	1.276609
2022-02-01	3053508.0	2255475	3891312.0	837804.0	1.274374
2022-03-01	2600129.0	2345694	3440034.0	839905.0	1.323024

Figure 2: Example of analytics rule/ models' output

5. APPLICATIONS IMPLEMENTED

The project was able to are eight (8) specific applications with analytics rules that was able to be populated by the DCH BRICK model that have also been tested for the capability of quick re-deployment in the DCH environment.

Category	Application Analytics Rule Use Case
PV	Live energy generation vs designed energy generation
PV	PV panels attenuation
PV	Unexpected shutdown
PV	Low performance PV panels
PV	PV energy generation forecasting
HVAC	Occupancy experience
HVAC	HHWP/CHWP unexpected running
HVAC	Central plant low delta-T Issue

Table 2: Applications fully mass redeployable on DCH

In addition to the above 8 applications above, a further 20+ optimisation rule solutions were able to be generated and customised for City of Melbourne with some additional manual data collection and configuration. This well exceeded the scope of the project.

All applications developed are listed below and highlight use case analytics rule as well as information derived from the VBIS asset classification and information inputted from the DCH Brick data model.

Application Category	Application / Analytics Detail	Data derived from VBIS	Data Derived from DCH
PV	Live generation vs designed	PV type / Inverter type	PV panel quantity / installation details
	PV Panel Attenuation	PV type / Inverter type	-
	Unexpected shutdown	-	PV panel quantity
	Low performance PV panel	PV type / Inverter type	PV panel quantity / installation details
	Renewables energy optimisation	-	PV panel quantity / metering system
	PV energy generation forecasting	PV type / Inverter type	PV panel quantity / installation details
Building Performance	Occupancy experience	HVAC device type	Sensors' location
	Carbon emission	Mechanical device type	Metering system
	Energy profile - classification and clustering	-	Metering system
	Energy consumption forecasting	-	Metering system
	Building decarbonisation	Mechanical device type	Metering system
	Energy waste out of occupancy hours	Mechanical device type	Mechanical device point details
	Centre plant incorrect controlling	HVAC device type	Central Plant system details

	Control strategy optimisation	Mechanical device type	Mechanical device point details
	Occupants energy wasting habits	HVAC device type	HVAC device point details
	Virtual ESS	HVAC device type	Metering system / major HVAC device details
	ESS	-	Metering system
KPI	Proportion of renewables	-	-
	Building decarbonisation	-	-
	Occupancy experience	-	-
	Energy efficiency	-	-
Data audits	Automatic reporting	-	-

Table 3: Full list of applications developed for DCH7

The following section provides detail on output from the implemented applications previously described that was able to be generated by the data available. This was used to formulate recommendations for use on the User Interfaces which provides the main interaction between City of Melbourne stakeholders and the applications. For user interface detail used to communicate the various use cases of the applications, refer to DCH 7 Knowledge Share Report 4 – Application Use Case Report

5.1 PV systems

All of five (5) connected buildings have rooftop PV power generation systems. The below Figure 3 is the overview of daily power generation of all building. Due to data accessibility issues for the PV system at Library at the Dock the output from that system is not shown in the graph diagram below.
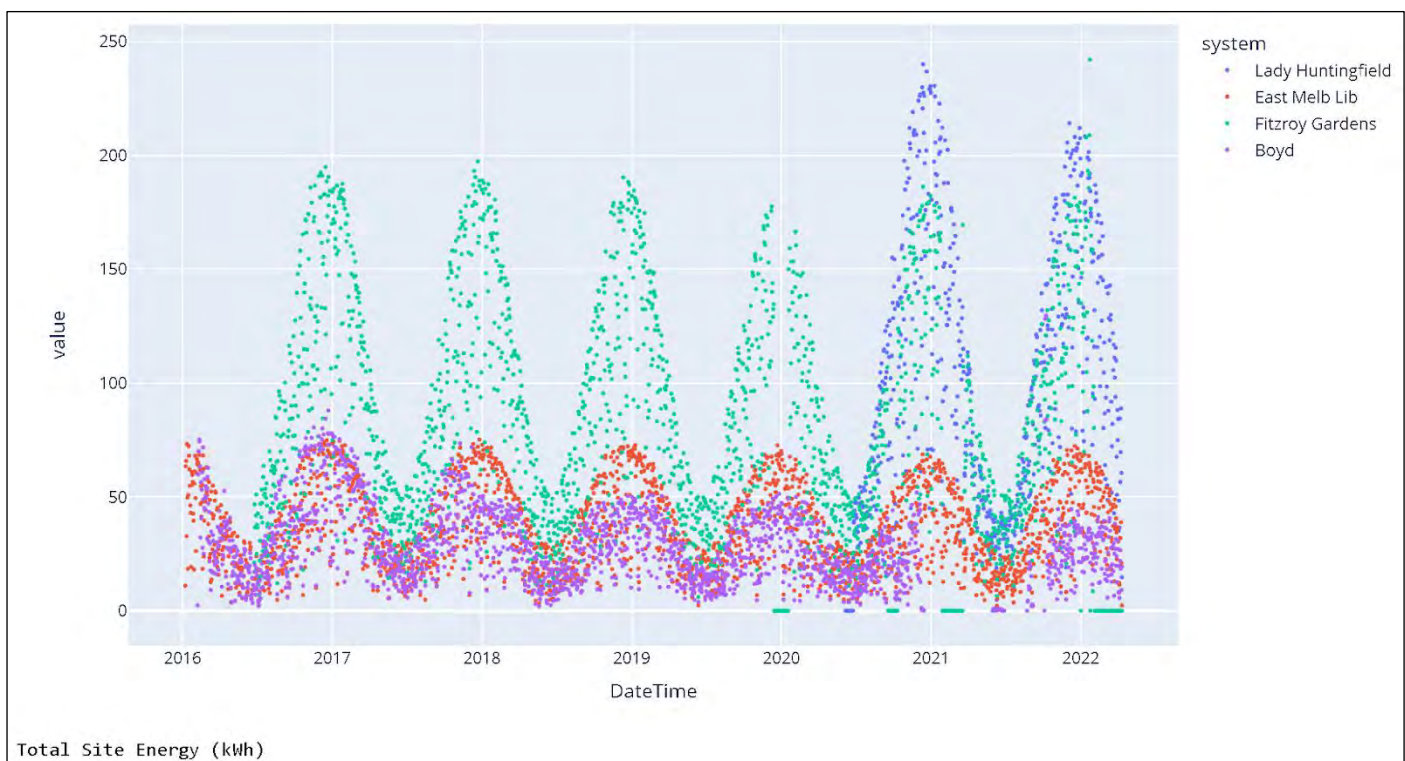
Figure 3: Overview of PV power generation of four (4) buildings

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This this, PrediQ's applications and performance modelling were able to address the below aspects:

- PV operating performance: Including comparison of power generation and designed power generation, PV panel attenuation, and low performance.
- Forecast of PV generation and energy optimisation.

5.1.1 Comparison of designed power generation and actual power generation

This application helps users to understand the actual power generation and be able to compare with designed estimated generation that advised by the salesperson. Taking an example of Lady Huntingfield, below Figure 4 indicates that there's a large gap between designed generation and actual operation. It could be caused by the unexpected weather, but mainly because of changing conditions of the site.
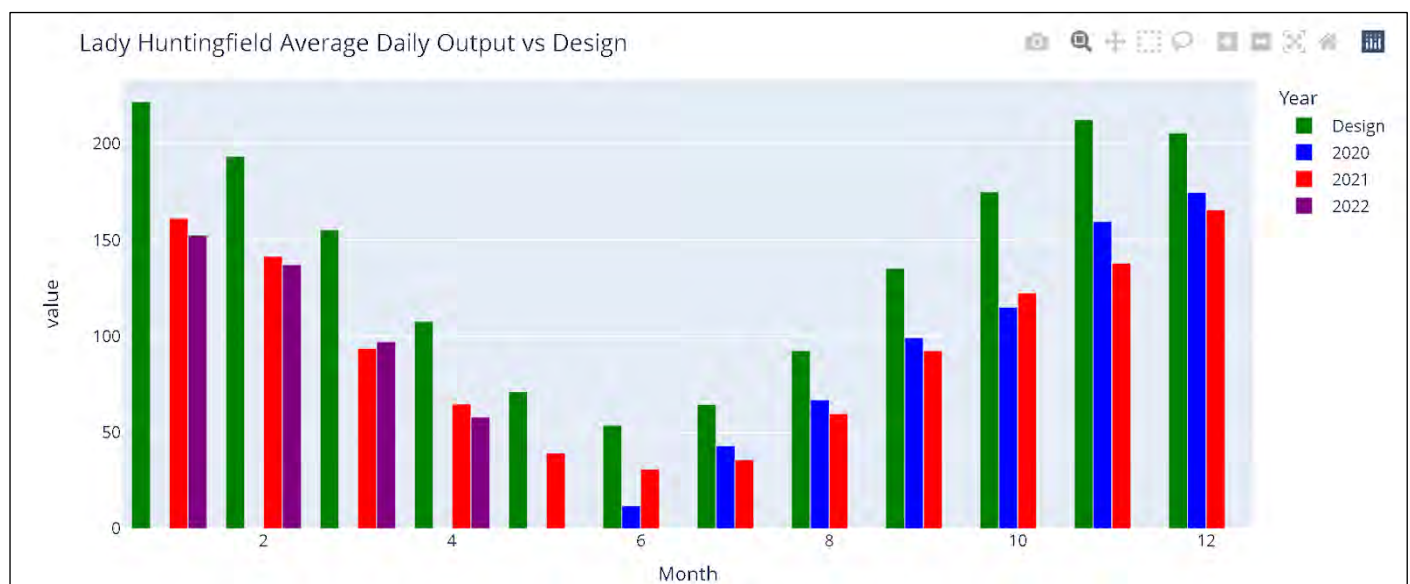
Figure 4: Comparison of designed power generation and actual power generation – Lady Huntingfield

5.1.2 PV Panel Attenuation

PV panel manufacturers normally give a promise of the system attenuation and provide replacement if the system does not perform as per manufacturers design. Taking an example of East Melbourne, the below Figure 5 is the guaranteed attenuation details from the manufacturer:

Through the data model and the functionality provided by this application, it is possible to see actual panel attenuation. While most of panels are still performing within design parameters, a small part of them are indicating high loss due to faults or quality issues.
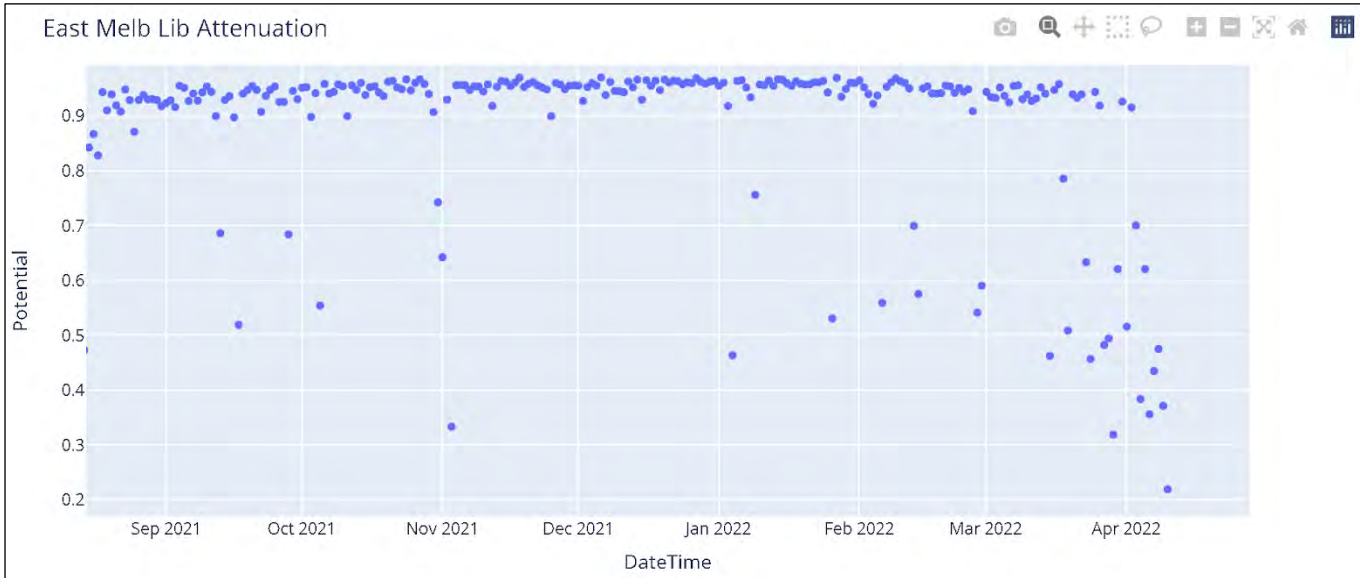
Figure 6: Actual PV panel attenuation – East Melbourne

5.1.3 Low performing PV panels

This application is designed to locate underperforming PV Panels which will help building managers to realise the PV issues at an early stage to ensure an efficient power generation. Below chart is a screen shot of a result of PV analytics for the building – Lady Huntingfield, the result can tell building managers which panels are underperforming and how they are performing.

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Figure 7: Analytics result of PV performance – Lady Huntingfield

5.1.4   PV generation forecasting models for energy optimisation

The PV generation forecasting model that PrediQ attempted to build has not delivered the wanted result owing to the incompleteness of weather data. The framework of the prediction model is as follows:
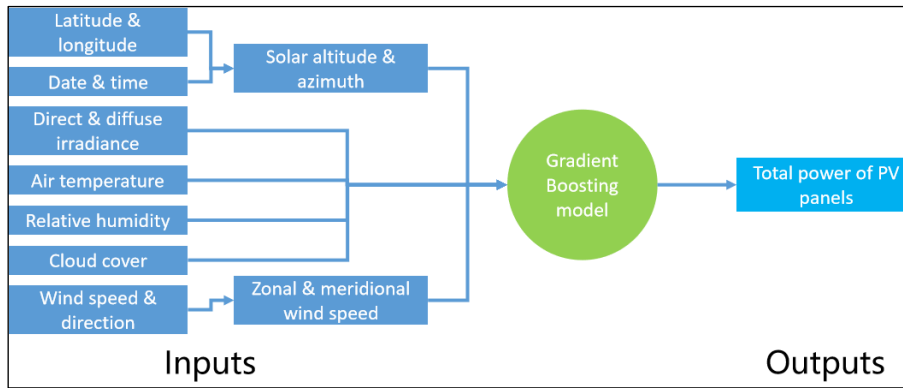
Figure 8: The framework of the prediction model

An example of the simulated forecast model can be seen at Lady Huntingfield which shows the model prediction using historical data
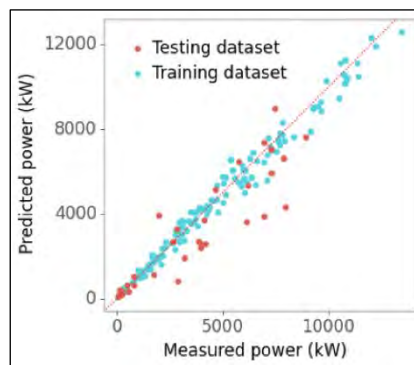
Figure 9: Prediction error in the training and testing dataset
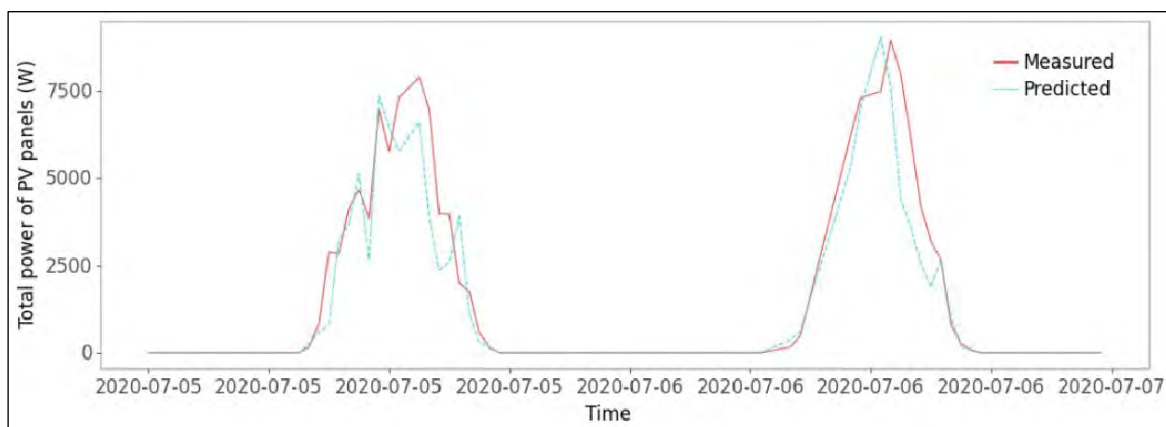
Figure 10: Measured and predicted power in the test datasets

RMSE of PV power in testing dataset = 1532 W
MAPE of PV power in testing dataset = 16.7%
RMSE of daily PV production in testing dataset = 11.2 kWh
MAPE of daily PV production in testing dataset = 12.9%

It is believed that the larger than expected errors may be caused by:

- Lack of training data; only 6 months' data are used for the model training.

- The bias of input data; The irradiance data were not collected on the location of the case study building, leading to a possible bias of irradiance value.

5.2 Building Performance

In building performance, PrediQ focused on HVAC systems and their impact on building occupants and energy use.

5.2.1 Occupancy Experience

This is arguably one of most important KPIs for facility teams. Although data sources that directly links to occupancy experience are very limited (primarily due to access of data was outside of the system the project had access to), the project still attempted to provide some insights with the data available as this is also an important part of energy analysis and can establish a baseline of tenants' impact when implementing other optimisation strategies.

Taking the building – Lady Huntingfield as an example, below Figure 11 shows from occupancy experience analysis indicate various HVAC equipment (separated by area) having abnormal performance recorded.

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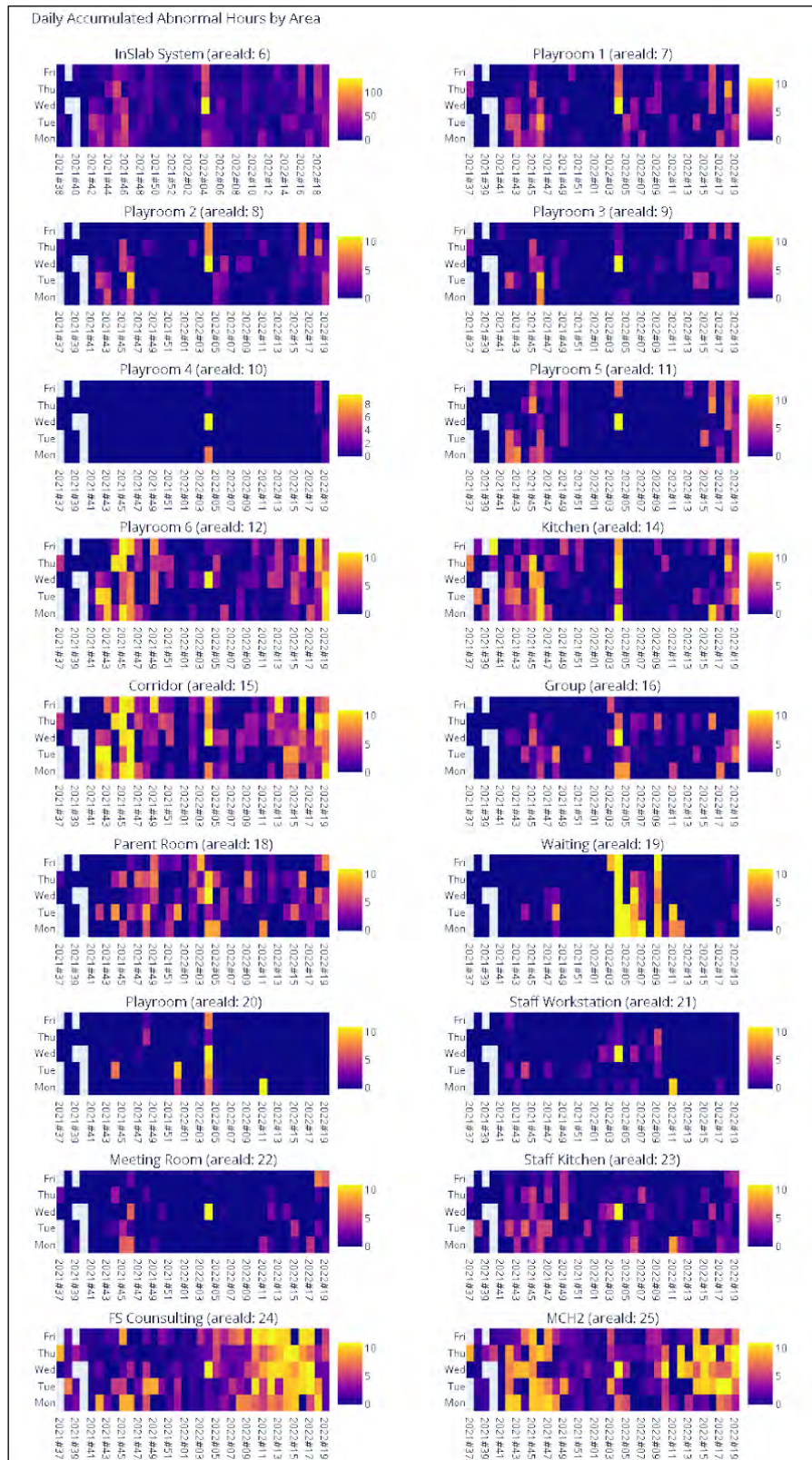
Figure 11: Occupancy experience heatmap breakdown by areas – Lady Huntingfield

As we can see from the above chart, the weather gets warmer in the first quarter of 2022, and the total time of abnormal performance occurring has increased accordingly. The below figure shows the distribution and occurrence ratio of the problem area and equipment from the analysis results which is then presented in the user interface.

Figure 12: Breakdown of comfort issues by areas and equipment – Lady Huntingfield

5.2.2 Energy Consumption and Decarbonisation

When comparing with investment in renewables, expanding on energy storage system, and optimisation of demand side response, reducing energy waste is the most effective, efficient and lowest cost way to achieve improved energy efficiency. For this project, our analytic models and applications for energy saving primarily addresses the following:

- Energy consumption impact based from building occupants

- Abnormal equipment operation

- Optimal device control strategies

Below are examples which have been used by the building performance suite of applications.

5.2.2.1 Energy consumption impact

Below Figure 13 is an example from Lady Huntingfield. It shows that the temperature setting in each room of the building are different for a same period. Inappropriate (too high or too low) thermostat's temperature setting cause waste of energy consumption.

Figure 13: Breakdown of temperature setpoints by data sources – Lady Huntingfield

By using the energy consumption model constructed for DSR (Demand Side Response), below Figure 14 indicates a forecast of corresponding amount of negative energy impact by inappropriate temperature setting.
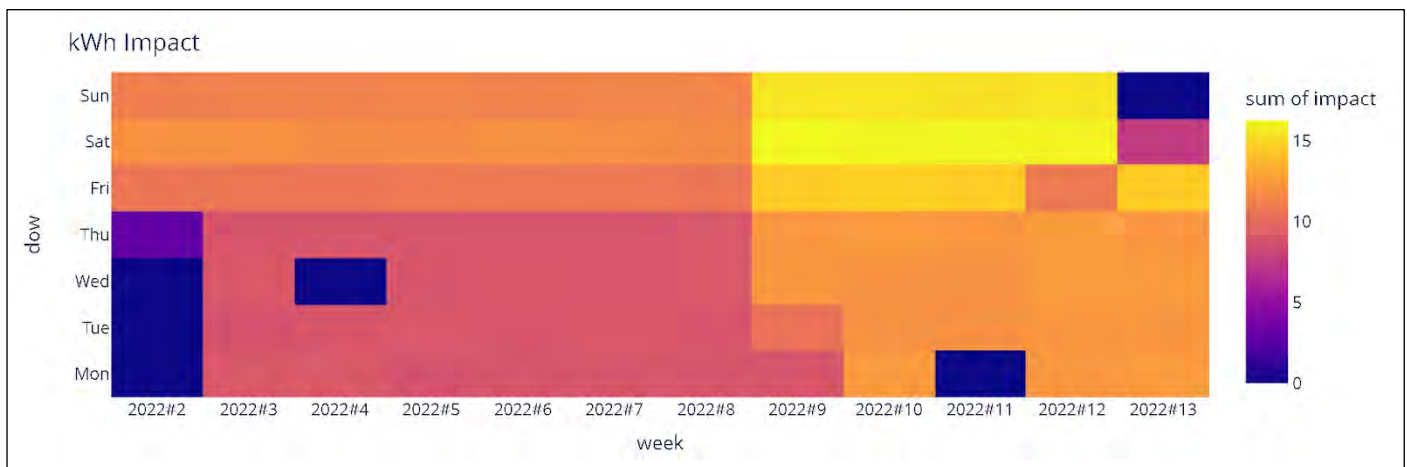
Figure 14: Weekly electricity negative impact caused local thermostat settings – Lady Huntingfield

5.2.2.2 Abnormal Equipment Operation

Another source of negative energy impact is when major building equipment is kept operating while the building is not occupied. Take an example of Boyd Community Hub, below first heat map chart shows the amount of potential energy loss by unnecessary device running, and the second chart in Figure 16 shows the breaking down of energy waste to each single equipment.

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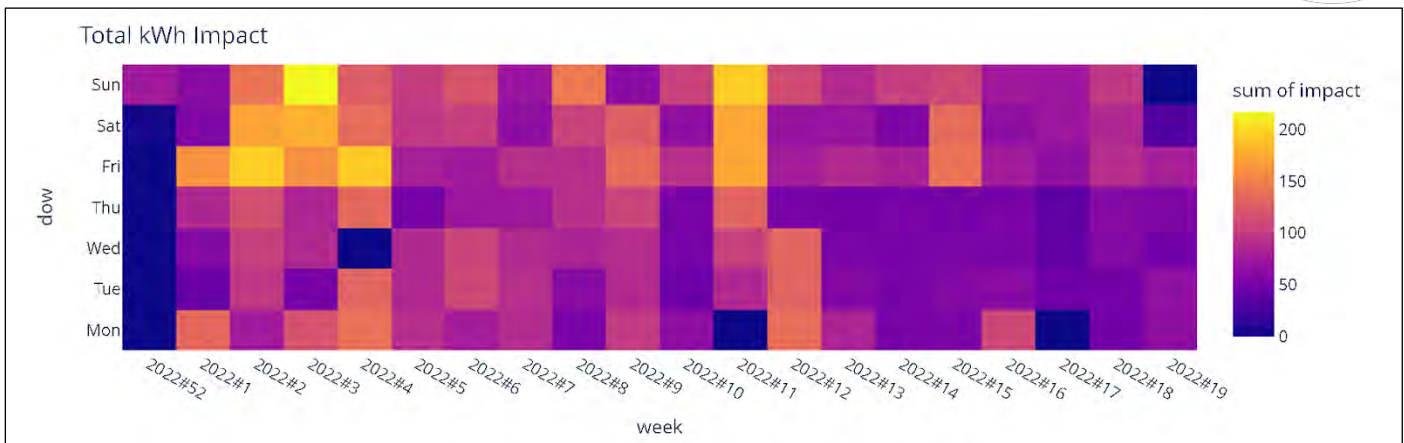
Figure 15: Weekly electricity negative impact by abnormal equipment operation – Boyd Community Hub
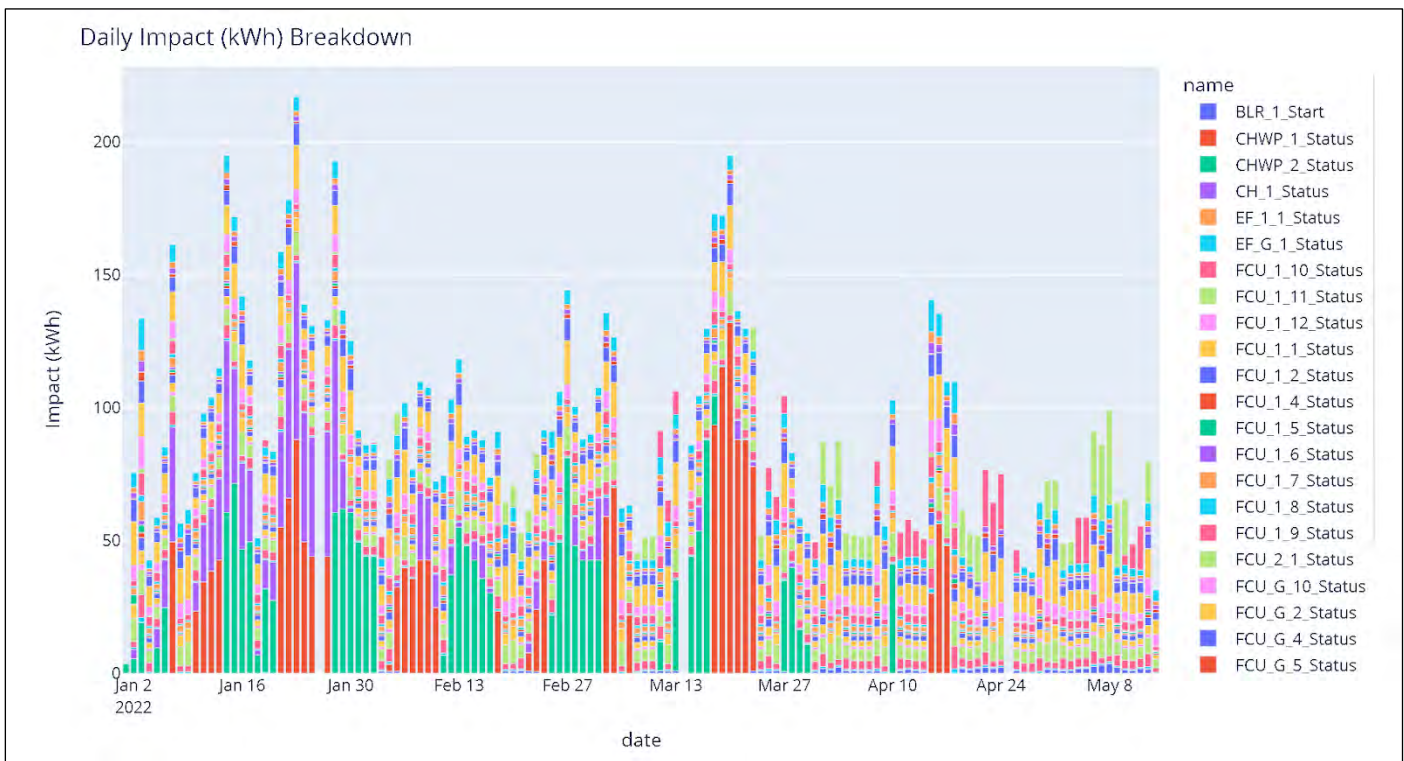
Figure 16: (Below) Breakdown of negative energy impact by equipment – Boyd Community Hub

5.2.2.3 Unexpected Equipment Operation

One of the applications developed tests for unexpected equipment operation. It was identified some connected project building often have their heating/cooling pumps automatic started when not required. Below Figure 17 is the analysis results of East Melbourne Library. It shows that a total of 347.25kWh was wasted between the 52nd week of 2021 and the 13th week of 2022.
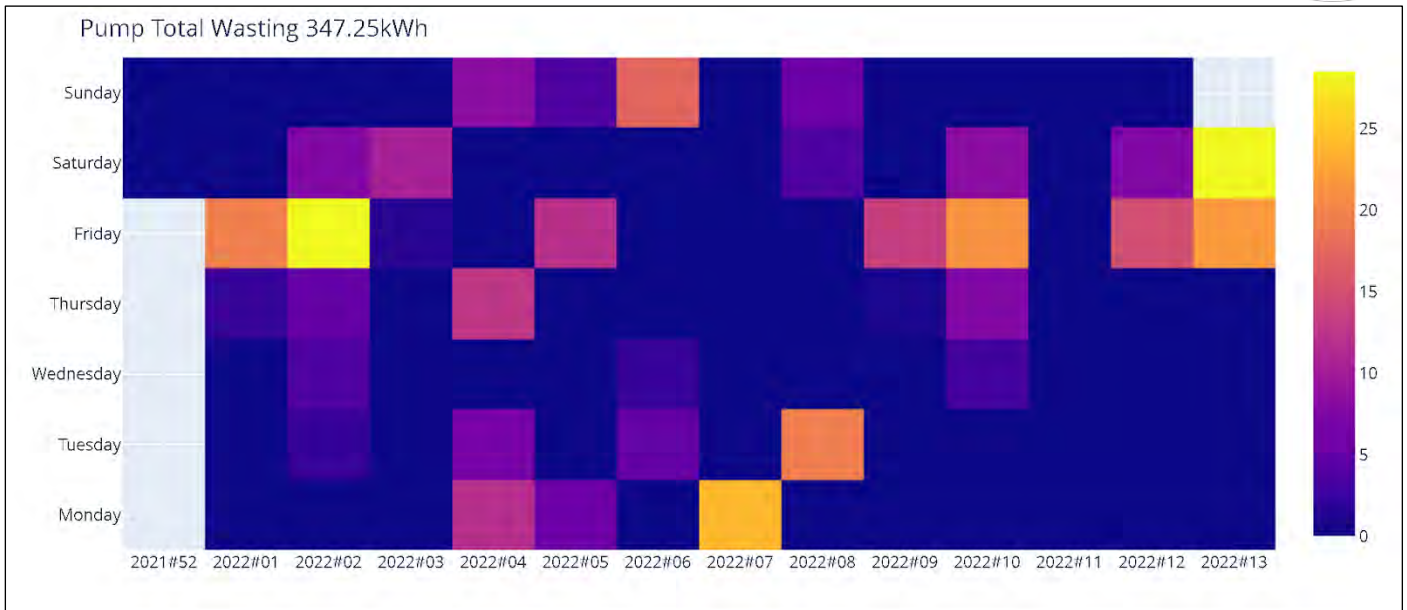
Figure 17: Weekly electricity impact caused by defect control strategies – East Melbourne Library

5.2.2.4 Central Plant Control Strategies

Other recommendations provided through the developed applications related to central plant control strategies. An example of this can be seen at Boyd Community Hub, Fitzroy Garden Visitor Centre, and East Melbourne Library which all indicate incorrect supply temp of central plant. Over-high temperature of heating supply and over-low temperature of cooling supply are all cause a serious waste of energy. Taking Boyd Community Hub as an example, below Figure 18 shows that there was 415kWh of energy wasted caused by unsuitable temperature setpoint during the recent cooling period.
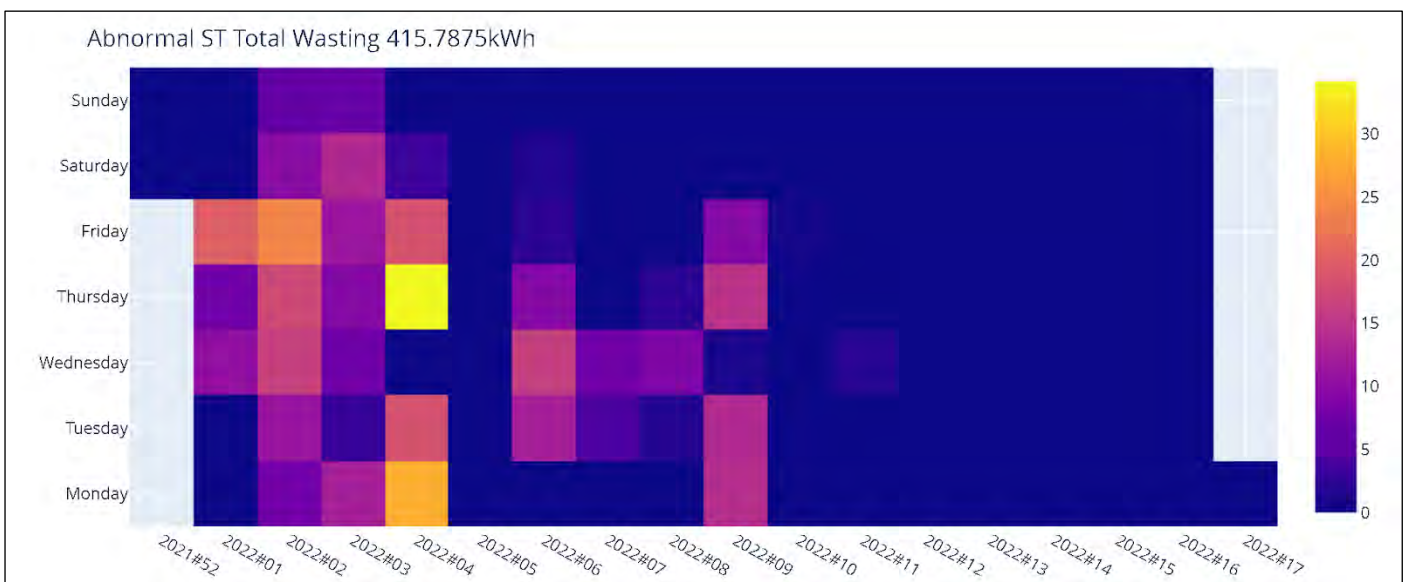
Figure 18: Weekly electricity impact caused by incorrect supply temp of central plant – Boyd Community Hub

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5.2.2.5 Central Plant Delta-T

This application analytic rule tests for low delta temperature (Delta T). Low delta-T syndrome occurs when the temperature difference between the supply and return water is lower than its designed. And significant energy wasting is caused by this issue. Taking an example of Boyd Community Hub, below Figure 19 shows that there are about 200 hours of downtime during the recent cooling period, our analytic model estimates that there is 200kWh of energy waste caused by this issue.
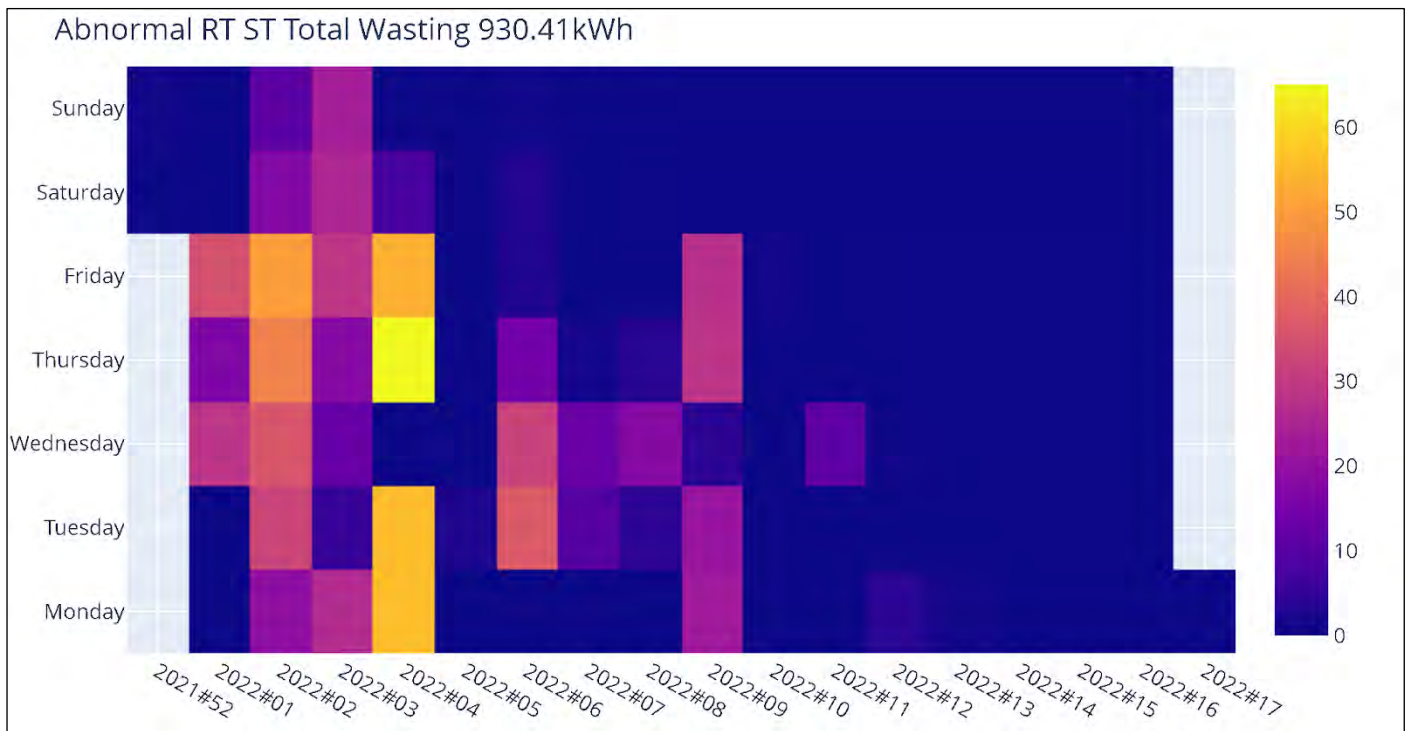
Figure 19: Weekly electricity impact caused by low delta-T syndrome – Boyd Community Hub

5.3 Virtual ESS Model

Comparing with large investment in renewable energy and storage upgrading, Virtual Energy Storage Systems (VESS) only requires little investment and can contribute to demand side response (DSR) efforts. For this project, PrediQ attempted to develop the corresponding control system code to assist the cloud-based analytics model to learn the building characteristics and perform the corresponding DSR. As the project was not allowed to alter the building's setpoints, all studies were tested with simulation models.

PrediQ firstly tried traditional ways to create DSR models, which used battery and energy storage. Below Figure 20 is an example of the optimal solution produced by simulation model for the building – Lady Huntingfield.

Report: DCH 7 Application Development In Trial Buildings
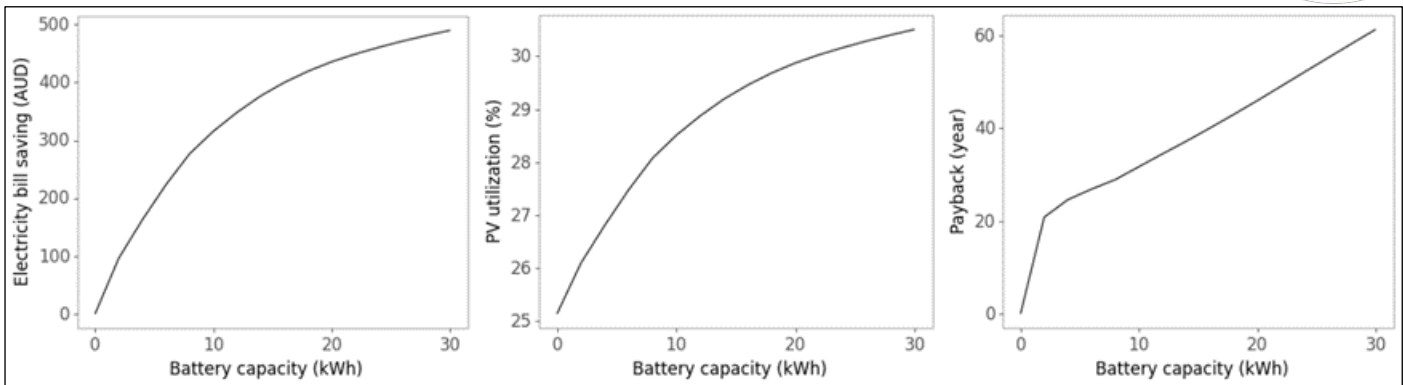
Figure 20: Optimisation performance by using different capacity of batteries - Lady Huntingfield

From the above Figure 20 chart, the annual electricity bill saving, PV utilization and payback period of PV battery with different battery capacities were estimated based on the annual electricity consumption and PV energy generation profiles of Lady Huntingfield. The cost of PV battery is assumed as $1K per kWh. As shown in the above figures, considering the long payback period of PV battery, this would not be a good deal to use battery in this building.

As there is not reasonable return on investment (ROI) from the traditional method of DSR, we then tried another way to better complete DSR, which is Virtual Energy Storage Systems (VESS). VESS aims to balance the energy of an electrical system by utilizing power distribution strategies and existing HVAC equipment. Through demand management along with real-time control interaction with electricity market prices, VESS not only optimises the energy balance of microgrid systems but also improves both the economy and environment while retaining stable operation.

The VESS model developed aims to achieve energy cost reduction by participating in the demand response period and VESS benefits through the HVAC system. This will be done through flexible adjustment of temperature setpoints without affecting indoor comfort and utilising inherent building infrastructure to optimise operation.

Focusing on HVAC systems, a thermodynamic model was constructed based on room temperature response and characteristics of HVAC systems. During a demand response period, the model is applied to optimise for the minimum conditioning load or the lowest electricity market price with respect to the specific demand response.

In order to achieve this while maintaining comfort in temperature, the temperature setpoint sequence is optimized in the model and returned as the output accompanied by the corresponding HVAC system energy consumption.

The detailed procedure is as follows: A simplified RC model is constructed for the building, and its parameters are fitted using operation data. The identified RC model can then be used to predict the change of indoor temperature and air conditioning power with respect to a temperature setpoint change. A control algorithm is then built upon the RC model and the system load baseline to predict optimal setpoint sequences and power with respect to market price or incentive estimated demand response.

For the final VESS model, inputs of the VESS model:

- response thresholds
- time of beginning and end of demand response period
- upper and lower limit of acceptable indoor temperature and setpoint adjustment steps
- independently estimated load baselines
- predicted price movement (required for price-based demand responses)

Outputs of the VESS model:

- temperature setpoint sequence for pre-cooling/heating and demand response period
- average HVAC system power during the period
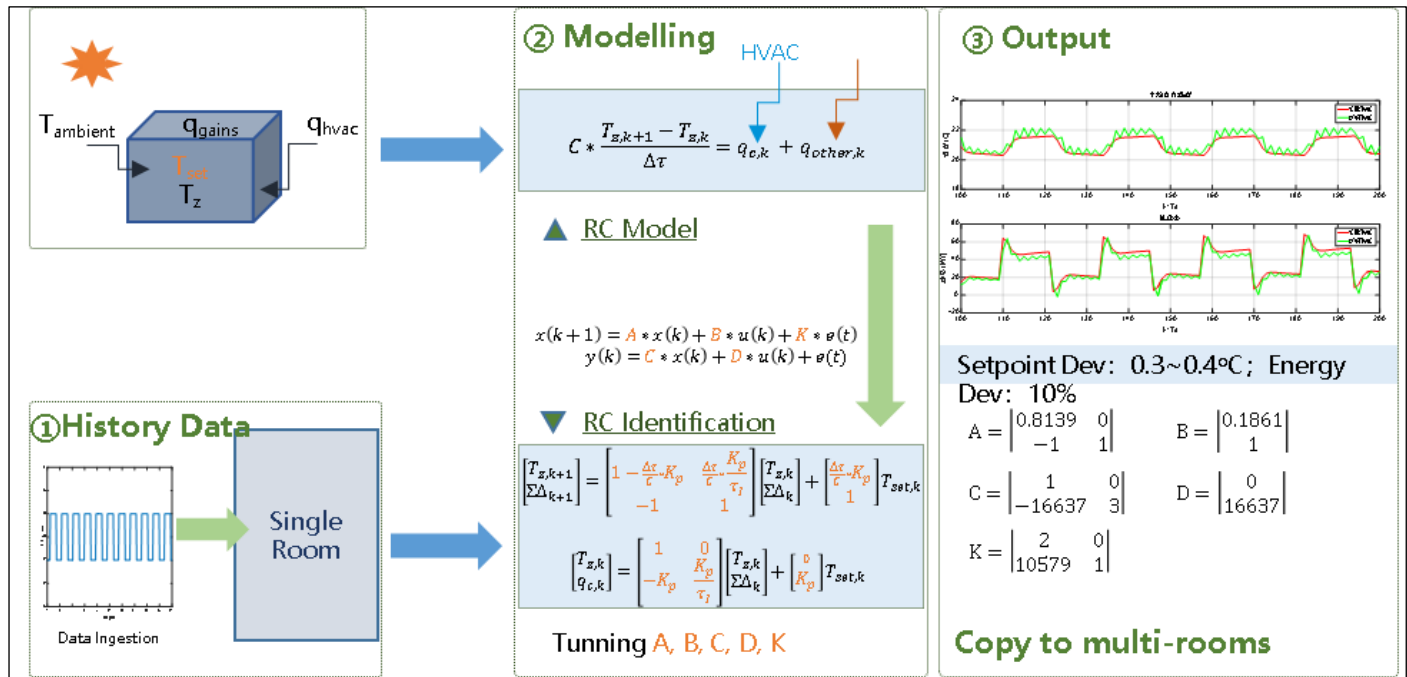
Figure 21: Workflow of RC model

The RC model can be used to predict the impact of setpoint change on the room temperature and HVAC system power consumption. Therefore, it can optimize setpoint sequences with respect to a combination of various control objectives such as: minimising total energy consumption, minimising total electricity fees, load distribution and transfer while meeting the temperature comfort criteria.

Currently, it can be applied specifically to the user-side demand response. Demand responses fall into two categories: price-based and incentive-based. The currently developed algorithms are incentive-based. Moreover, a price-based algorithm can also be achieved by adjusting the objective function.

The below Figure 22 shows an example of DSR completion by a single room model working with control system during the process of DSR. It was selected from the west side area of the ground floor of the Library at the Dock.
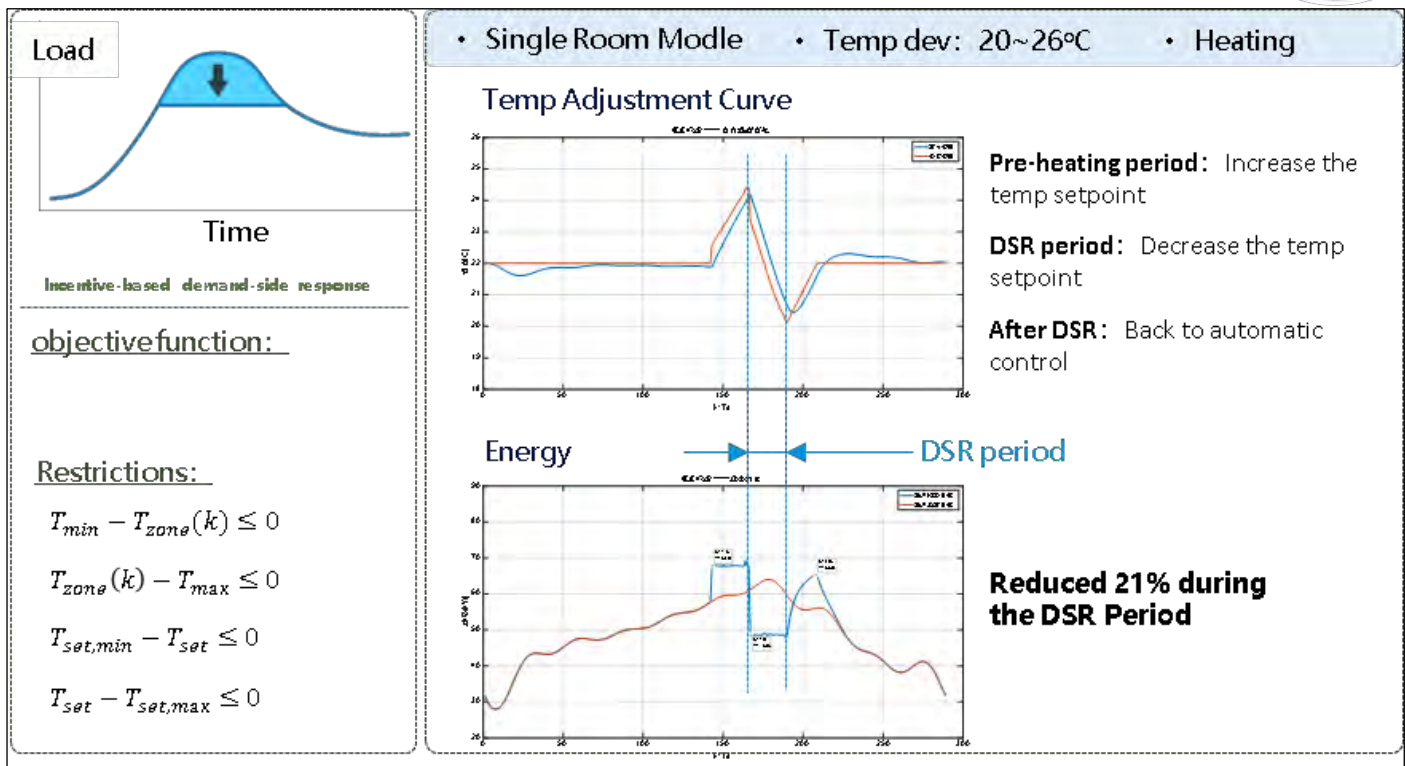
Figure 22: DSR Simulation – Library at the Dock

5.4   Optimisation of energy storage system (ESS) and control system

In the development of the PV related applications, PrediQ also established ESS operation models and control system optimisation models based on the PV generation data and historical data of building energy consumption. The principle this is to find corresponding optimisation strategies by utilising the results of data analysis and testing different parameters to achieve the most suitable solution. For example, data analysis models covering parameters of PV energy generation, building energy consumption and electricity bills. By trying different capacities of energy storage and the setting of charging/discharging rate, and with data information of operating time of building HVAC devices, it is possible to work out a solution with optimal ROI.

6. REDEPLOYABLE MEASUREMENT AND VERIFICATION (M&V) APPLICATION

6.1 M&V – Background

CSIRO developed and implementation of the Measurement and Verification (M&V) application as part of DCH1. M&V analysis uses measurements to determine actual savings of energy, cost and/or greenhouse gases at a site, typically due to some intervention or change to the site equipment and/or operation. The International Building Measurement and Verification Protocol (IBMVP) defines four M&V approaches that are possible depending on the specific case, available data, time and budget.

The application applies the IBMVP Option C: 'whole facility' M&V method. This method is becoming increasingly attractive as the combination of high resolution (i.e., sub-hourly) metering data now available in many buildings, and advanced analytics makes it both easier to deploy, and capable of identifying even small energy savings from data over a shorter duration than was previously possible. This is referred to as M&V 2.0 and is an active area of research. The core of the model is based on a decomposition of the site overall energy consumption into baseload and

temperature dependent components. Hence, it is designed to be applied to whole-of-site or whole-of-building consumption data. M&V Option C uses a model constructed from data over a specified period (known as the baseline period) and compares the predictions of this model with measurements taken over a second period (known as the analysis period). The baseline/analysis periods are chosen to correspond to, respectively, pre and post the specific change to the site of interest.

To perform its calculations the original DCH M&V application required the application installer to identify the points it needed (to calculate the building consumption) each time they wanted to run the application over a site or building.

The vision of DCH is that the application can be pointed at any semantic building model, and it will automatically work out which points to use. A simple vision, but an incredibly significant data science challenge. Tim Berners-Lee first spoke about the concept of the Semantic web in the mid 90's and popularised it in a paper in 2001. The use of semantic modelling (the BRICK Schema) in DCH is being built on top of developments of that community over the last 20 years. Semantic Web is still an unsolved challenge, however across smaller domains the use of semantic technologies can be effective.

As described above the M&V app is concerned with electricity consumption in buildings, with a normalisation process for environmental (temperature) conditions. BRICK defines concepts around electricity metering and generation, and environmental conditions (outside temperature) so BRICK models that contain metering information and temperature data in them can contain all the information that an M&V Option C app might need to run successfully. The challenge is, given metering and sensing connectivity and arrangement on sites can vary significantly, how do we work out which data is the data we need?

In DCH 7 we have transformed how M&V is installed on Sites or Buildings, it no longer requires the installer to specify the required points; it is now portable. The new redeployable version of the app has been installed on the DCH 7 models that have the appropriate metering data (Boyd School, East Melbourne Library and Fitzroy Gardens), as well as several models from other DCH projects.

6.2 Consumption metering in City of Melbourne Buildings

To help frame the challenge in this transformation, let's examine the metering hierarchy for the five city of Melbourne buildings (Figures 23 through 27 below). M&V needs the site consumption data, so according to the diagrams:

6.2.1 Boyd School:

Looking at Figure 23 we have a couple choices, we can take the Main Building Utility Meter data and add on the solar generation data, or we could add up the four sub meters E1...E4 and ignore the solar generation data.
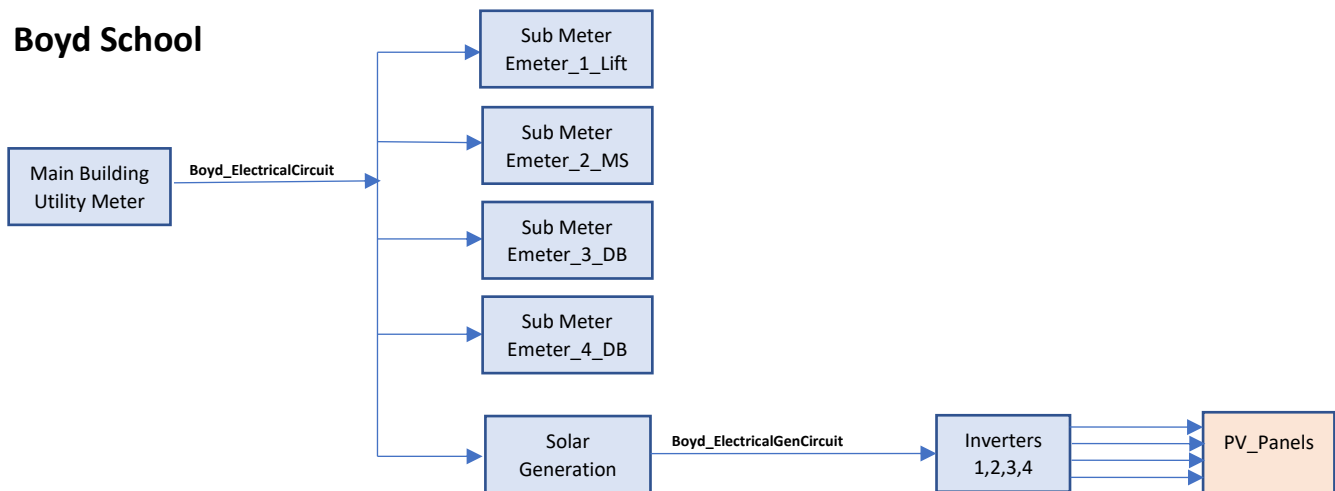
Figure 23: Metering configuration Boyd School

6.2.2 East Melbourne Library:

As you can see in **Error! Reference source not found.**Figure 24 we have no consumption metering available for that site so no solution could be found.

East Melbourne Library
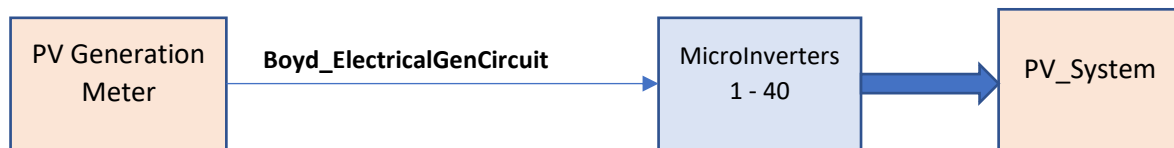
Figure 24: Metering Configuration East Melbourne Library

6.2.3 Fitzroy Gardens:

From Figure 25 we can see the only option is to add up the four sub meters EM-1…4. Note no need to worry about the solar generation data with this configuration.

Fitzroy Gardens
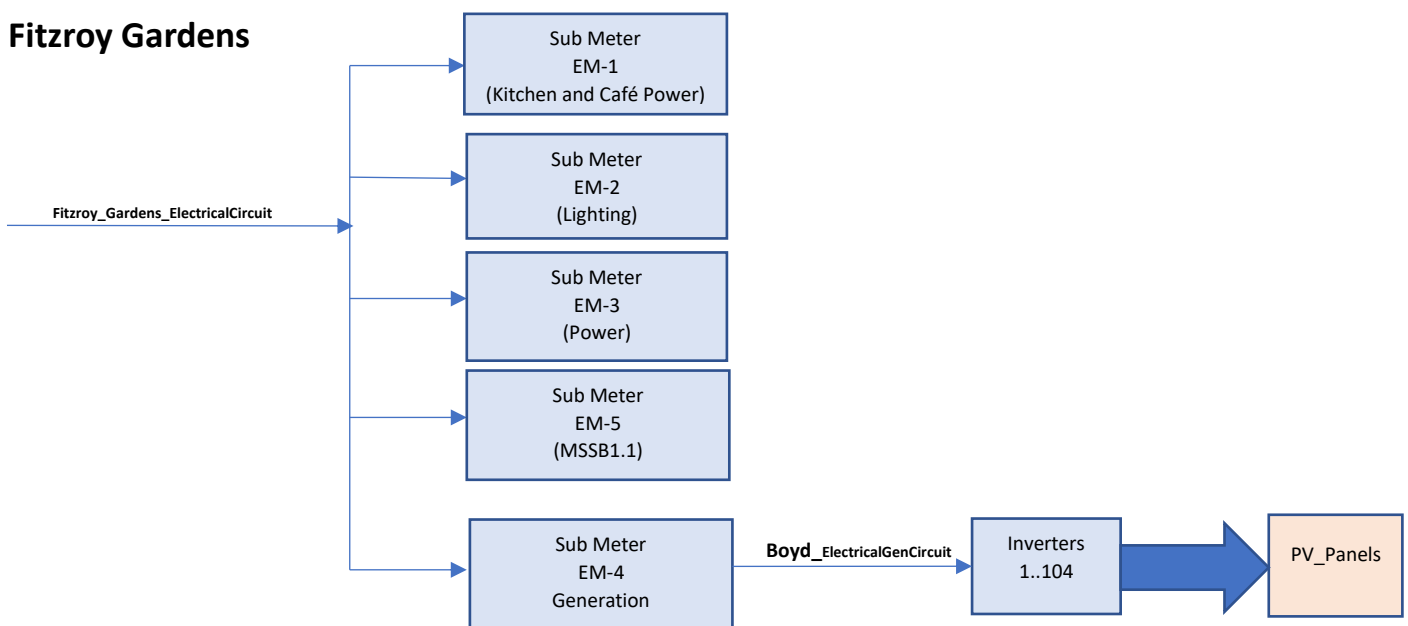
Figure 25: Metering Configuration Fitzroy Gardens

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6.2.4 Lady Huntingfield:

According to Figure 26 we also have two options, Take EM-G.9 and add on the generation data from EM-1.1, or add up all the non-generation sub meters (EM-G1...8 and EM-1.2 & EM-1.3).
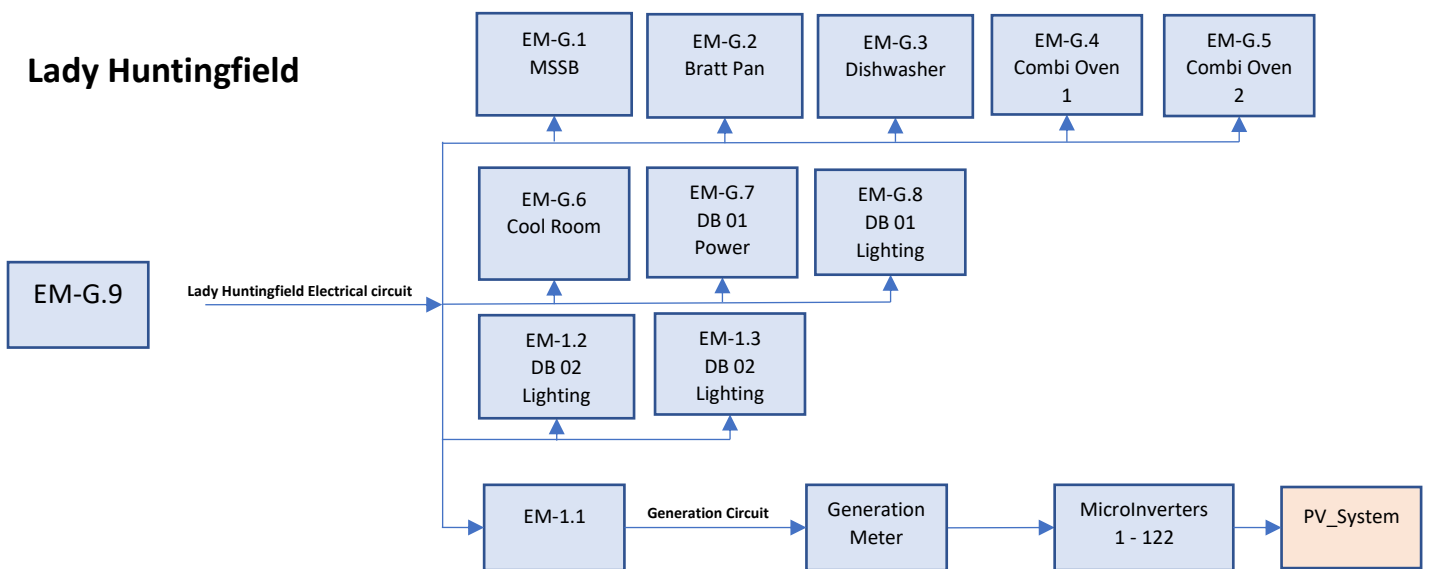
Figure 26: Metering Configuration Lady Huntingfield

6.2.5 Library at the Dock:

As per Figure 27 we can see one solution is to add up Sub Meters EM_L01_001, EM_L01_002, EM_L01_007 & EM_L03_005. There are alternate solutions as well - instead of using EM_L01_001 we could alternatively add up all the meters downstream of it (ditto of EM_L01_002).

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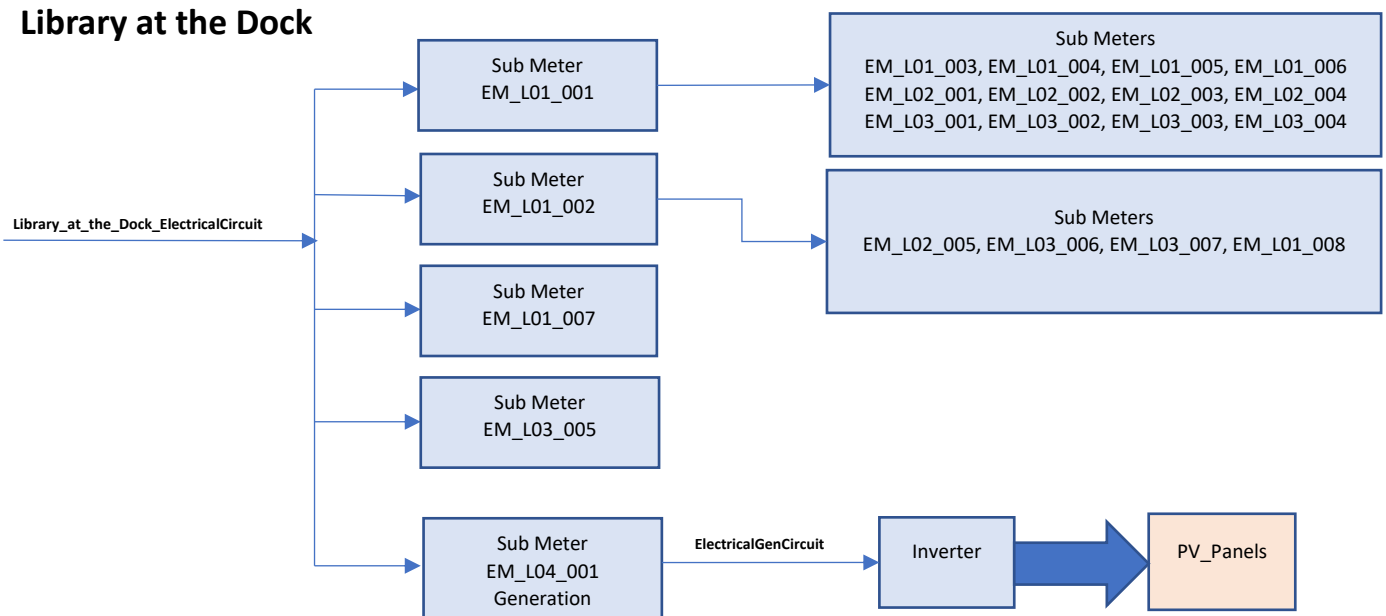
Finding the correct meters is not the full picture. The M&V app requires time-series or point data from the identified meters. Doing this in an automated way also has challenges as meters can have many points – Table 4 shows the 83 points we get from the EM-1 meter at Fitzroy Gardens. M&V needs consumption (power). In this instance the point that M&V is interested in is *EM_1_Kitchen_Cafe_Power_kW_Calc*. In contrast Table 5 shows the full set of points we get from the PV generation system at East Melbourne Library. There is only 3, which is quite minimal.

|			
EM_1_Kitchen_Cafe_Power_LineV_Calc	EM_1_Kitchen_Cafe_Power_P1_LineV_Calc	EM_1_Kitchen_Cafe_Power_P2_LineV_Calc	EM_1_Kitchen_Cafe_Power_P3_LineV_Calc
EM_1_Kitchen_Cafe_Power_LineV_LSW	EM_1_Kitchen_Cafe_Power_P1_LineV_LSW	EM_1_Kitchen_Cafe_Power_P2_LineV_LSW	EM_1_Kitchen_Cafe_Power_P3_LineV_LSW
EM_1_Kitchen_Cafe_Power_LineV_MSW	EM_1_Kitchen_Cafe_Power_P1_LineV_MSW	EM_1_Kitchen_Cafe_Power_P2_LineV_MSW	EM_1_Kitchen_Cafe_Power_P3_LineV_MSW
EM_1_Kitchen_Cafe_Power_PF	EM_1_Kitchen_Cafe_Power_P1_PF	EM_1_Kitchen_Cafe_Power_P2_PF	EM_1_Kitchen_Cafe_Power_P3_PF
EM_1_Kitchen_Cafe_Power_V_Calc	EM_1_Kitchen_Cafe_Power_P1_V_Calc	EM_1_Kitchen_Cafe_Power_P2_V_Calc	EM_1_Kitchen_Cafe_Power_P3_V_Calc
EM_1_Kitchen_Cafe_Power_V_LSW	EM_1_Kitchen_Cafe_Power_P1_V_LSW	EM_1_Kitchen_Cafe_Power_P2_V_LSW	EM_1_Kitchen_Cafe_Power_P3_V_LSW
EM_1_Kitchen_Cafe_Power_V_MSW	EM_1_Kitchen_Cafe_Power_P1_V_MSW	EM_1_Kitchen_Cafe_Power_P2_V_MSW	EM_1_Kitchen_Cafe_Power_P3_V_MSW
EM_1_Kitchen_Cafe_Power_kVA_Calc	EM_1_Kitchen_Cafe_Power_P1_kVA_Calc	EM_1_Kitchen_Cafe_Power_P2_kVA_Calc	EM_1_Kitchen_Cafe_Power_P3_kVA_Calc
EM_1_Kitchen_Cafe_Power_kVA_LSW	EM_1_Kitchen_Cafe_Power_P1_kVA_LSW	EM_1_Kitchen_Cafe_Power_P2_kVA_LSW	EM_1_Kitchen_Cafe_Power_P3_kVA_LSW
EM_1_Kitchen_Cafe_Power_kVA_MSW	EM_1_Kitchen_Cafe_Power_P1_kVA_MSW	EM_1_Kitchen_Cafe_Power_P2_kVA_MSW	EM_1_Kitchen_Cafe_Power_P3_kVA_MSW
EM_1_Kitchen_Cafe_Power_kW_Calc	EM_1_Kitchen_Cafe_Power_P1_kW_Calc	EM_1_Kitchen_Cafe_Power_P2_kW_Calc	EM_1_Kitchen_Cafe_Power_P3_kW_Calc
EM_1_Kitchen_Cafe_Power_kW_LSW	EM_1_Kitchen_Cafe_Power_P1_kW_LSW	EM_1_Kitchen_Cafe_Power_P2_kW_LSW	EM_1_Kitchen_Cafe_Power_P3_kW_LSW
EM_1_Kitchen_Cafe_Power_kW_MSW	EM_1_Kitchen_Cafe_Power_P1_kW_MSW	EM_1_Kitchen_Cafe_Power_P2_kW_MSW	EM_1_Kitchen_Cafe_Power_P3_kW_MSW
EM_1_Kitchen_Cafe_Power_kvar_Calc	EM_1_Kitchen_Cafe_Power_P1_kvar_Calc	EM_1_Kitchen_Cafe_Power_P2_kvar_Calc	EM_1_Kitchen_Cafe_Power_P3_kvar_Calc
EM_1_Kitchen_Cafe_Power_kvar_LSW	EM_1_Kitchen_Cafe_Power_P1_kvar_LSW	EM_1_Kitchen_Cafe_Power_P2_kvar_LSW	EM_1_Kitchen_Cafe_Power_P3_kvar_LSW
EM_1_Kitchen_Cafe_Power_kvar_MSW	EM_1_Kitchen_Cafe_Power_P1_kvar_MSW	EM_1_Kitchen_Cafe_Power_P2_kvar_MSW	EM_1_Kitchen_Cafe_Power_P3_kvar_MSW
EM_1_Kitchen_Cafe_Power_kWh_Calc	EM_1_Kitchen_Cafe_Power_P1_A_Calc	EM_1_Kitchen_Cafe_Power_P2_A_Calc	EM_1_Kitchen_Cafe_Power_P3_A_Calc
EM_1_Kitchen_Cafe_Power_kWh_LSW	EM_1_Kitchen_Cafe_Power_P1_A_LSW	EM_1_Kitchen_Cafe_Power_P2_A_LSW	EM_1_Kitchen_Cafe_Power_P3_A_LSW
EM_1_Kitchen_Cafe_Power_kWh_MSW	EM_1_Kitchen_Cafe_Power_P1_A_MSW	EM_1_Kitchen_Cafe_Power_P2_A_MSW	EM_1_Kitchen_Cafe_Power_P3_A_MSW
EM_1_Kitchen_Cafe_Power_kWh_Neg_Calc			
EM_1_Kitchen_Cafe_Power_kWh_Neg_LSW			
EM_1_Kitchen_Cafe_Power_kWh_Neg_MSW			
EM_1_Kitchen_Cafe_Power_kvarh_Calc			
EM_1_Kitchen_Cafe_Power_kvarh_LSW			
EM_1_Kitchen_Cafe_Power_kvarh_MSW			
EM_1_Kitchen_Cafe_Power_Hz			

Table 4: Fitzroy Gardens EM_1 Meter Points

Device_Reporting
Energy_Produced
Power_Produced

Table 5: East Melbourne Library PV generation Meter Points

To enable portable apps the BRICK schema, the modelling and the application queries need to work together to ensure applications only find the points of interest and no others.

6.3 M&V Querying

To make the M&V app portable across models we need to introduce a set of queries which will find the above solutions (where they exist). With M&V this is done with two queries – A Consumption query and a Generation query. The first query finds the set of topmost meters that cover all components of the model. i.e. any meters that don't have parent meters above them. The second query then identifies any generation that is happening below those found meters because true consumption in the buildings will need that accounted for.

This is where the power of semantic models is realised. Because the models include the meters, and the feeds relationships between them, we can construct a single query for each of the "Consumption" and "Generation" use cases that will find the needed solution (if one is available) irrespective of the metering configuration in the building.

To assist with query development DCH has developed BRIQL (BRICK Query Language). BRIQL is a buildings domain mapping over the industry standard, but much more complex, SPARQL semantic querying system. This enables application developers to create portable applications without having to become SPARQL experts.

The BRIQL queries used in for M&V are in Appendix 2 BRIQL Queries for M&V, and the results of the app running on the Library at the Dock building can be seen below.

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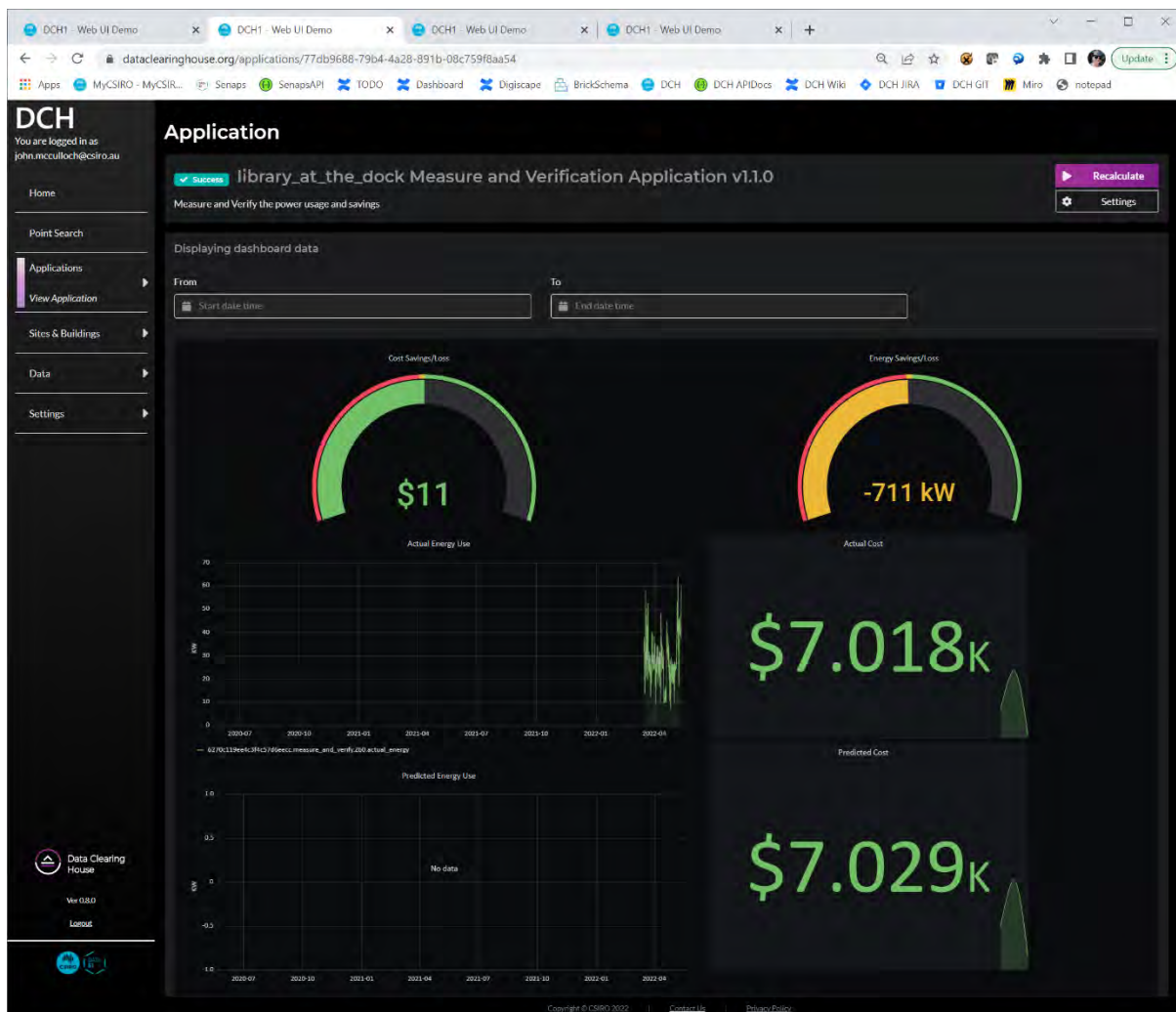
Figure 28: Library at the Dock M&V results

6.4 M&V portability challenges

Whilst the above description gives and overview of how M&V was transformed from an application that needed to be given the specific data it needed to one that could query models to find the meters, some of the challenges around only finding the appropriate points from the meters remain (highlighted by the large number of points for that EM-1 meter at Fitzroy Gardens in Table 4). Several challenges remain.

1. There's a meter there but where's the timeseries data? In the above examples in some instances there were multiple solutions. For M&V to be truly portable it needs to be able to explore that space of solutions. A casing example is Lady Huntingfield. The meter of choice is EM-G.9. It exists in the model as it physically exists in the building, but in this project no power data from that meter is available. Our existing implementation of M&V does not have this ability to explore the solution set, if it did it could determine that there was data available from all the sub meters so it could use those. For this project, to get it to install on Lady Huntingfield, we altered the model to disconnect the feeds connection between EM-G.9 and the other meters. That way the other meters appear to have no upstream 'parent' meters so are found by the query and used for the solution. To overcome this the M&V app needs to be extended so it can explore the solution set to see if it can find any valid solution.

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2. Energy Points vs Power Points. Currently the M&V application looks for power data. Whilst it could do its calculations on energy data, that is currently not implemented. I.e., if a site has metering of energy but not power then M&V won't find a solution. To overcome this the M&V app needs to be extended to use energy data as an alternative to power data.

3. Import points, net points, and export points. The current M&V app looks specifically for import power points, but a solution can also be found using net power points. The BRICK schema supports the differentiation so, like with energy points to overcome this limitation the M&V app needs to be extended to use net data as an alternative to import data.

4. Energy data accumulation. Energy data can be reported in several ways relating to the aggregation period and reset time. Some energy data aggregates continuously, some provide daily totals etc. This information can be captured in BRICK models. It is future work for the M&V app to query this information and make correct calculations based on it.

5. Phase data. As you can see with Table 4 power and energy data can be supplied as total or per phase. Querying for power points for a meter could result in a single total of all three phases point, or could be three single phase points, or could be all four. Like aggregation data, phase information can be encoded in the model (it is included in one of the DCH7 models), however M&V does not factor that into its queries. Utilising that information to choose the correct point(s) is future work. Currently M&V will work if we get a total power point or if we get three single phase power points but the app will erroneously double up if we get all four points. For this project we adjusted the model (by reclassifying the points we didn't want to find as generic points.

6. Duplicate data. Whilst we didn't encounter it in the DCH7 data ingestion for some of the other DCH model we have seen duplication (even triplicate) points on some meters. This is where a meter will have multiple points of the same data. This is tricky to handle semantically. Brick does allow for multiple timeseries data to be assigned to a single Point but at this stage, that level of subtlety of model construction and data handing is yet to be incorporated into the DCH ecosystem.

7. Other oddities in Points. There will always be points coming in that are unusual in some way that will make them not fit in the BRICK schema. The example, again referring to Table 4, is the series of points postfixed with MSW and LSW. These points are the numerical components that get combined to give the true values of the measurements from the meter. Currently these points are classified as generic 'Points' in the models so applications looking for specify types of points will not accidently find them. Whilst that is a workable solution, further consideration of the best way to manage this type of data in DCH should be undertaken.

7. APPLICATION IMPLEMENTATION NEXT STEPS

Whilst the DCH7 project demonstrated that the DCH platform is ready for early adopters to use there are several areas where functionality can be improved to give a better customer experience.

1. VBIS tags – partial tag search
   o Currently VBIS tagging can be represented in models and the query engine can answer questions such as "Find me the set of equipment with this VBIS tag?", or "What is the VBIS tag of this piece of equipment?". Given the VBIS tagging paradigm is hierarchical, a useful extension of the query engine would be if you could ask "Give me the set of equipment that are types of air filtration products?" This is essentially "Find me the set of VBIS tags that start with 'ME-AFP'?". This partial matching capability is not currently available but is something that can be added.

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2. Align DCH with BRICK community
   o Given DCH started when brick was on its initial release there are some extensions to BRICK that DCH made that have now been included in the latest BRICK releases. However, in some instances the choice of implementation between DCH and the BRICK community vary.   Now that these concepts are formally part of BRICK, DCH should roll back its additions and switch to the new BRICK conventions. An example is DCH adopted a class-based approach to import, export, and net in electrical metering, whereas BRICK went for a properties-based approach. Where DCH have extensions that are yet to be adopted we should also be actively feeding those choices back into the BRICK community for discussion.

3. Move model construction process to online
   o Currently model construction is done by the CSIRO DCH team offline and subsequently uploaded to DCH. A critical step will be to provide online methods for model construction.

4. Improve the platform's model validation tooling
   o Currently DCH provides little feedback on correctness and coverage of models when they are uploaded. Validation tooling to pick up issues such as rooms being "located on" floors can be enhanced. Note whilst a "room being located on a floor" sounds like a reasonable thing for a novice modeller to do, the correct BRICK relationship between rooms and floors is that rooms are "part of" floors. BRICK has many such conventions and for people new to the field it can be difficult to get everything correct initially.   DCH can improve it's tooling to identify such issues and help modellers understand the norms and conventions expected.

5. BRIQL query interface
   o One of the most important things that application developers need to adjust to when moving their applications to DCH is working with the query engine. i.e., Application developers usually have a good understanding of their application IP, however, to make that application be redeployable in DCH they need to "plug in" a query interface to the front end of their applications. Currently there is no interactive query testing/development interface to assist application developers play, learn and test in this space.

6. Improve documentation for modellers and external app developers
   o Related to the above point, documentation for app developers and modellers can be improved. Application developers need to know about the norms and conventions as they need to write queries to find things that are modelled using the norms, and clearly modellers need to know the norms to generate models that will yield correct responses to well-formed application queries.

Additional areas for development specifically related to the DCH M&V Application:

7. Configuration
   o Currently an application developer can specify a set of configuration parameters that the user can set to drive the application. With M&V, for example, one of the key ones is the two time periods over which you want to M&V application to assess. Currently these configuration details are unfriendly for the user to adjust, and they cannot be adjusted before the application first executes.   Changing editing of these to a graphical interface will be a significant improvement as well as changing the application deployment to allow them to be set prior to the application running for the first time.

8. Multiple instances of an application on a building
   o For some applications different users may want to run the application with different configurations, but currently an application can only be installed on a building a once with a single configuration.

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Adjusting the system so each user can have their own configuration, and even allowing users to have multiple configurations would help users.

8. CONCLUSIONS

DCH 7 set out to create an integrated data schema that could be used by application developers to enable mass redeployable applications. This project has achieved its objectives and successfully demonstrated this by onboarding 5 City of Melbourne buildings into the DCH environment, creating semantic models of each building that incorporates VBIS asset classification tagging which can be used by 20+ analytic applications, 8 of which can be fully deployed with minimal external interactions. The applications developed will not only improve on site PV generation but also address HVAC operational opportunities as detailed in the report.

This project also experienced the challenges of on-boarding buildings, both from incorrect or incomplete building documentation and from having external (non-CSIRO) providers connect and on-board buildings into DCH. A number of these challenges can be addressed through thorough site audits in the case of incorrect or incomplete building information, and documentation and diagnostic tool sets for external providers.

Additionally, through the deployment of these applications, DCH 7 has been able to show the process required for end-to-end DCH adoption from connection of new buildings, to data modelling, asset identification and classification and subsequent use in analytic applications and M&V applications, with the greatest value being the ability to mass deploy applications on the DCH platform. The mass redeployability of the applications also demonstrate the operational efficiency improvements in service delivery that can be achieved by the application developer due to availability of portable, mass deployable PV analytics and energy analytics applications.

The recommendations provided for future platform development will help ensure the Data Clearing House platform can be more easily adopted by modellers and external app developers.

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Boyd School

Unique triples	3653
Total number of parts	1904
Unique types of entities	100
VBIS tags	153
Total number of Points	567

Boyd School BRICK Model statistics
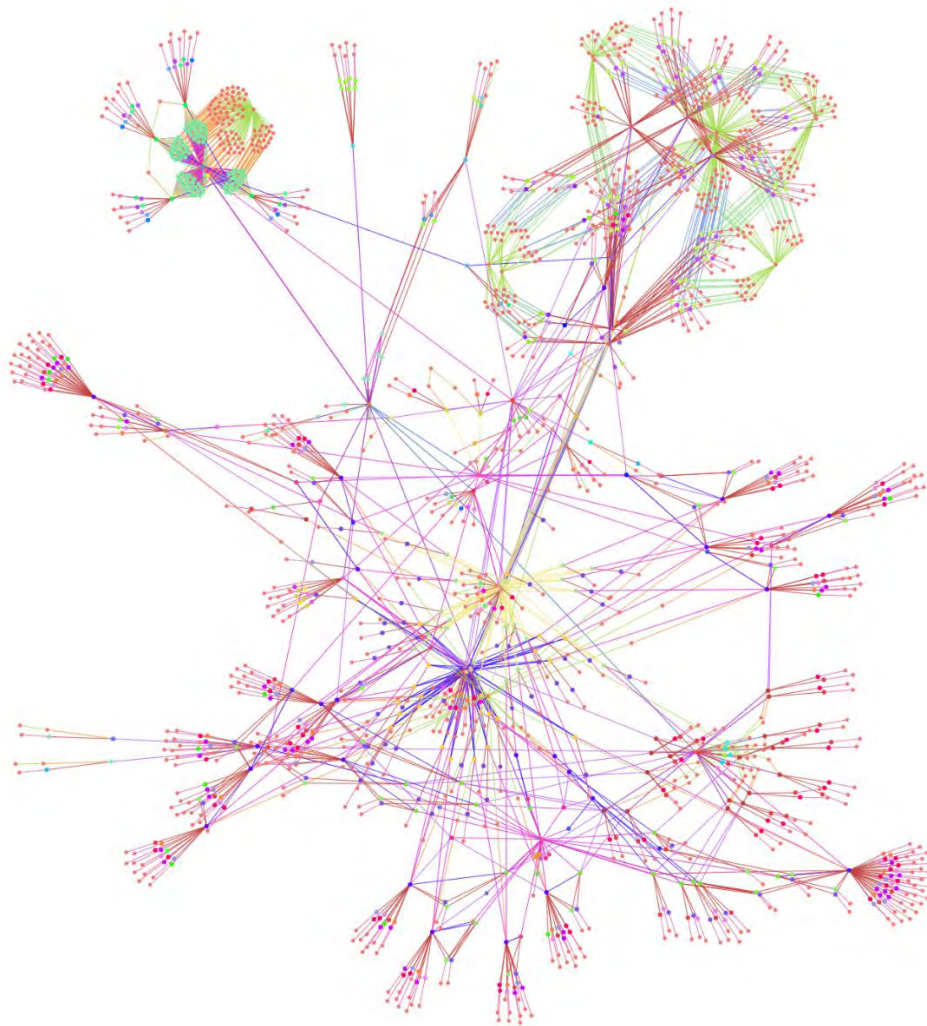
Visualisation of BRICK model of Boyd School

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East Melbourne Library

Unique triples	1729
Total number of parts	989
Unique types of entities	85
VBIS tags	145
Total number of Points	259

East Melbourne Library BRICK Model statistics
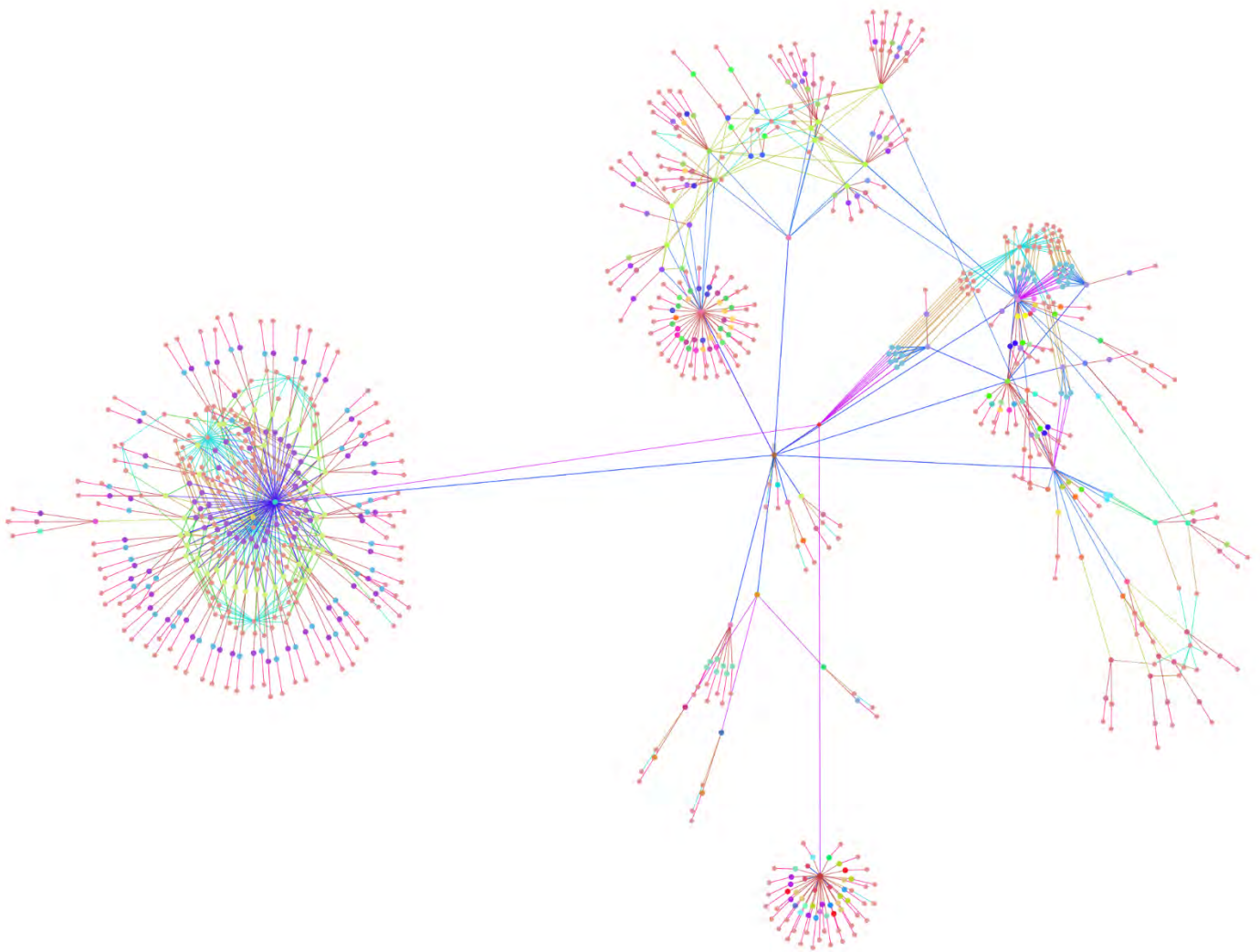
Visualisation of BRICK model of East Melbourne Library

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Fitzroy Gardens

Unique triples	3471
Total number of parts	2050
Unique types of entities	86
VBIS tags	241
Total number of Points	616

Fitzroy Gardens BRICK Model statistics
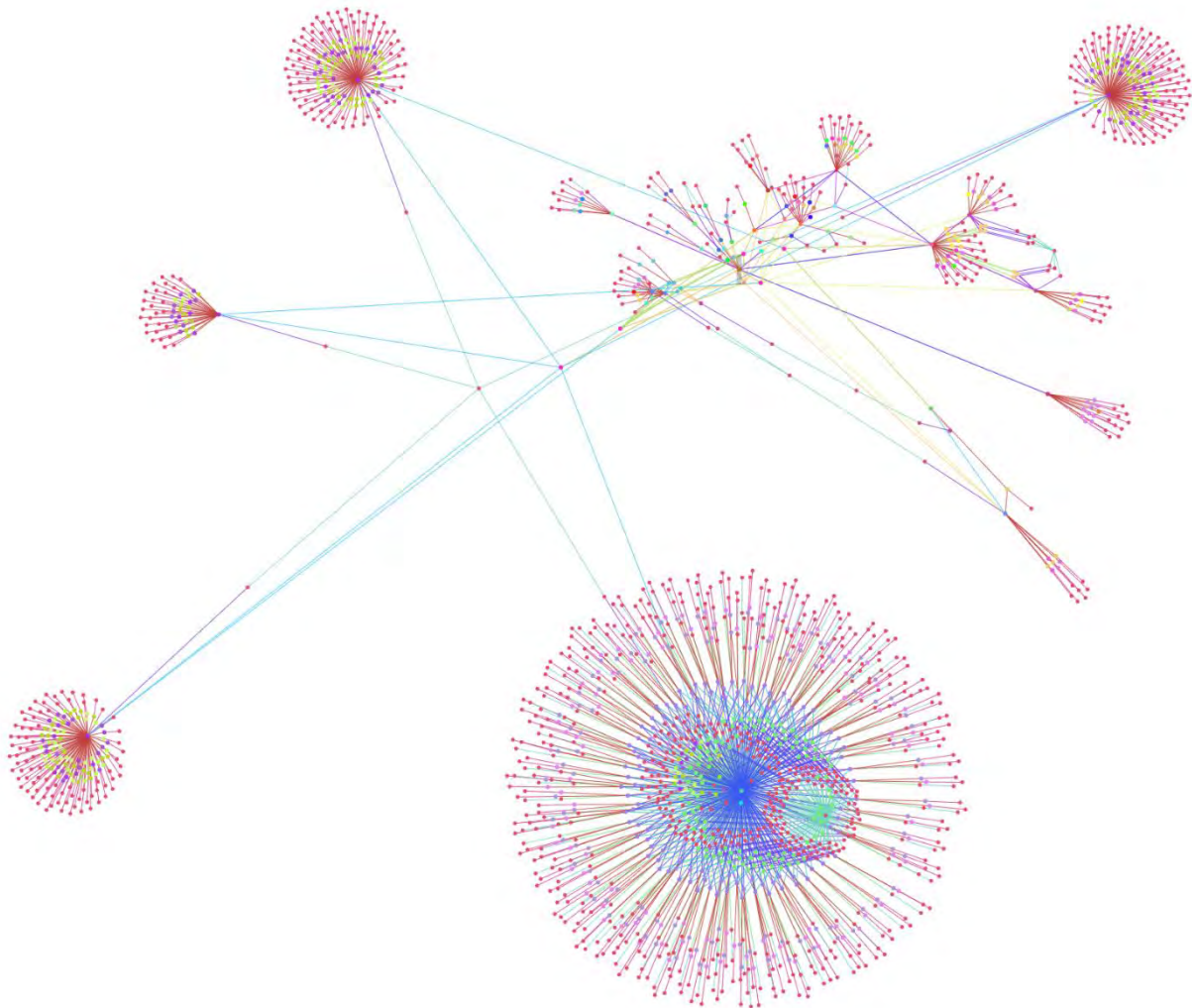
Visualisation of BRICK model of Fitzroy Gardens

Lady Huntingfield Early Learning and Family Services Centre

Unique triples	5686
Total number of parts	3236
Unique types of entities	96
VBIS tags	446
Total number of Points	927

Lady Huntingfield BRICK Model statistics
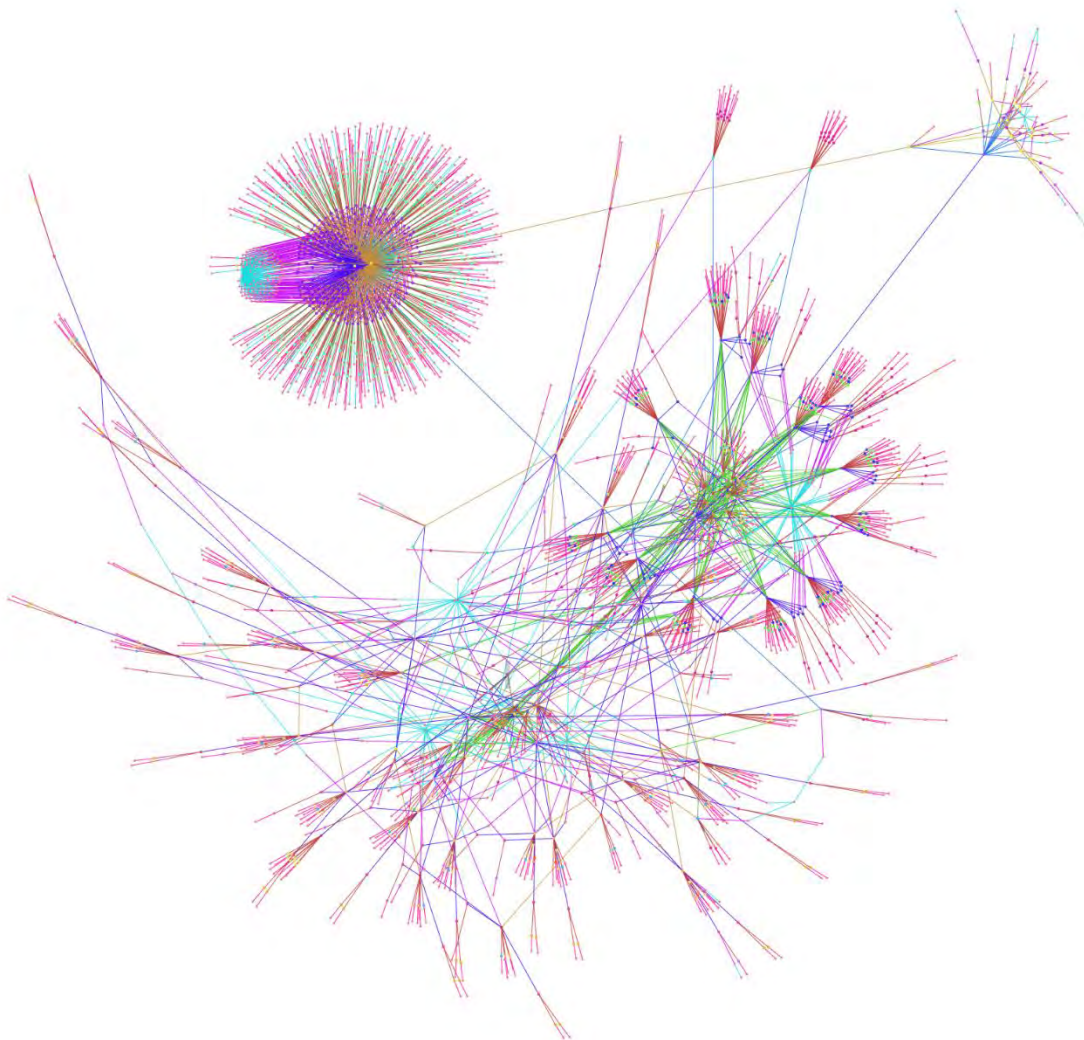
Visualisation of BRICK model of Lady Huntingfield

Library at the Dock

Unique triples	4775
Total number of parts	2776
Unique types of entities	147
VBIS tags	115
Total number of Points	1071

Library at the Dock BRICK Model statistics
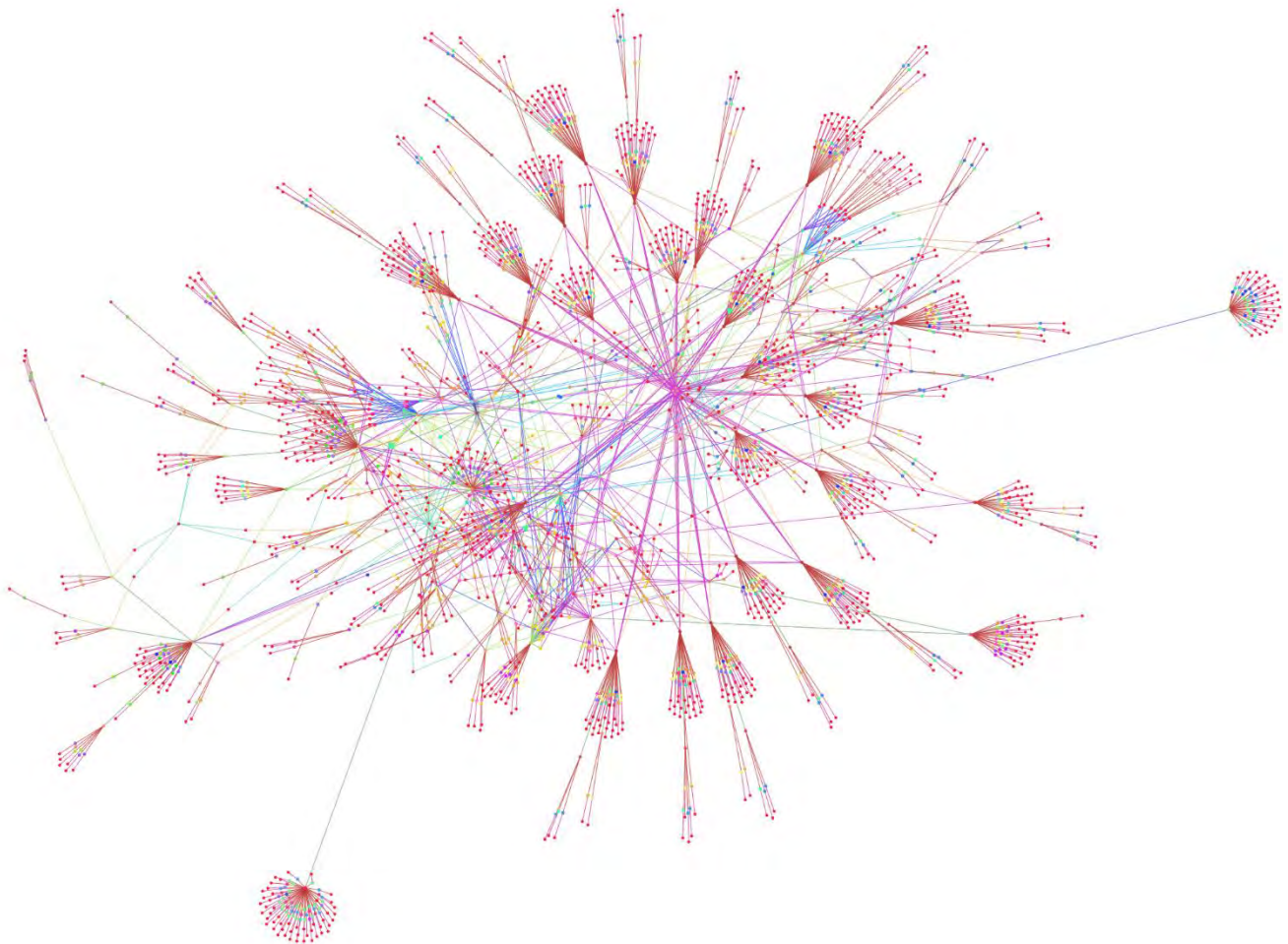
Visualisation of BRICK model of Library at the Dock

Consumption Query

```json
{
    "models": [
        {
            "org_id": "city_of_melbourne",
            "site_id": "insert site ID here",
            "building_id": "insert building ID here"
        }
    ],
    "query_def": {
        "mode": "select",
        "variables": [
            {
                "var_type": "node",
                "name": "buildingMeter",
                "output": true,
                "fetch": [
                    "id",
                    "type",
                    "pointinfo"
                ],
                "brick_type": {
                    "match": "isa",
                    "type": "Electrical_Meter"
                },
                "fetch_points": [
                    {
                        "match": "isa",
                        "type": "Real_Power_Import_Sensor"
                    }
                ]
            },
            {
                "var_type": "node",
                "name": "parentMeter"
            }
        ],
        "query": {
            "nested": [
                {
                    "paths": [
                        {
                            "from_ref": "parentMeter",
                            "properties": [
                                {
                                    "property": "feeds",
                                    "min": 1
                                }
                            ],
                            "to_ref": "buildingMeter"
                        }
                    ],
                    "types": [
                        {
                            "name": "parentMeter",
                            "brick_types": [
                                {
                                    "match": "isa",
                                    "type": "Electrical_Meter"
                                }
                            ]
                        }
                    ],
                    "retain": "absent"
                }
            ]
        }
    }
}
```

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Generation Query

```json
{
    "models": [
        {
            "org_id": "city_of_melbourne",
            "site_id": "insert site ID here",
            "building_id": "insert building ID here"
        }
    ],
    "query_def": {
        "mode": "select",
        "variables": [
            {
                "var_type": "node",
                "name": "point",
                "output": true,
                "fetch": [
                    "id",
                    "type",
                    "streams"
                ],
                "brick_types": [
                    {
                        "match": "isa",
                        "type": "Real_Power_Export_Sensor"
                    },
                    {
                        "match": "isa",
                        "type": "Active_Power_Sensor"
                    }
                ]
            },
            {
                "var_type": "node",
                "name": "genMeterOrInv",
                "brick_types": [
                    {
                        "match": "isa",
                        "type": "Electrical_Generation_Meter"
                    },
                    {
                        "match": "isa",
                        "type": "Inverter"
                    }
                ]
            },
            {
                "var_type": "node",
                "name": "upstreamMeter",
                "brick_types": [
                    {
                        "match": "isa",
                        "type": "Electrical_Meter"
                    }
                ]
            },
            {
                "var_type": "node",
                "name": "upstreamGenMeter"
            }
        ],
        "query": {
            "paths": [
                {
                    "from_ref": "point",
                    "properties": [
                        {
                            "property": "isPointOf"
                        }
                    ],
                    "to_ref": "genMeterOrInv"
                },
```

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```json
                {
                    "from_ref": "genMeterOrInv",
                    "properties": [
                        {
                            "property": "isFedBy",
                            "min": 1
                        }
                    ],
                    "to_ref": "upstreamMeter"
                }
            ],
            "nested": [
                {
                    "paths": [
                        {
                            "from_ref": "genMeterOrInv",
                            "properties": [
                                {
                                    "property": "isFedBy",
                                    "min": 1
                                }
                            ],
                            "to_ref": "upstreamGenMeter"
                        }
                    ],
                    "types": [
                        {
                            "name": "upstreamGenMeter",
                            "brick_types": [
                                {
                                    "match": "isa",
                                    "type": "Generation_Meter"
                                }
                            ]
                        }
                    ],
                    "retain": "absent"
                }
            ]
        }
    }
}
```

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