The Innovation Hub

for Affordable Heating and Cooling

DCH 7 Knowledge Sharing Report #004
Application Use Case Report

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.

This Project received funding from ARENA as part of ARENA's Advancing Renewables Program.
The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.

Primary Project Partner

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)

Project commencement date

06 May, 2021

Completion date

27 May, 2022

Date published

27 May, 2022

Contact name

T.K Wang

Email

tkwang@vbis.com.au

Project website

https://www.ihub.org.au/dch7-improving-the-accuracy-of-pv-analytics-and-energy-analytics-in-buildings-using-open-asset-standards-and-data-platform-integration/

Table of contents

List of tables and figures

1. SUMMARY

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.

The objectives for DCH 7 were 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
- Quantify Photovoltaic (PV) system operational efficiencies via applications that can be mass deployable for repeatable results. A SaaS based energy analytics application and PV analytics application that utilises the integrated schema deployed into DCH. Deployment will be across 5 buildings. Improved management of building assets including onsite PV generation due to integrated asset classification and semantic modelling.
- Provide a 3D/BIM Model (if BIM available) will be deployed that will showcase attributed from the two applications. This enables an intuitive way for building operators to interact and interrogate with the applications and building to learn critical information about the facility they have been tasked with operating.
- Demonstrate the value of integrated asset classification and semantic modelling for delivery of PV analytics, energy analytics applications and asset performance optimisation. Operational efficiency improvements in service delivery achieved by the application developer due to availability of portable, mass deployable PV analytics and energy analytics applications.
- Global recognition for Australian asset classification system VBIS due to integration with ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) supported semantic modelling framework Brick schema.

This report details how the project team has achieved these objectives set out at the beginning of the project and the use cases of the various applications achieved using Data Clearing House platform, VBIS standard and PrediQ applications.

A total of 20+ applications have been developed, with 8 applications able to fully be deployed utilising the BRICK data model and VBIS asset classification information available. An innovative and intuitive user interface dashboard has also been developed to communicate the outputs of the various applications, including the development of a high-level city-wide 3D view to showcase critical facility information.

The potential energy savings on site and deployment time savings demonstrates the value of redeployable applications using an integrated data schema. Modelling of the application outputs showed potential energy savings between 5% and 20% across the 5 connected buildings, with deployment time being reduced by 20% and 90%. Due to site limitations, the project team was not able to validate the savings using the redeployable M&V application, however the projected savings have been tested and simulated against historical building data used to develop the building performance modelling used by the applications.

2. BACKGROUND

2.1 Project Background.

With an increase in smart devices in buildings and the large-scale adoption of IoT devices, there is substantial opportunity to make use of the large volume of data to improve the performance HVAC equipment and renewable generation assets in buildings. Uses of this data include prediction of available on-site energy generation and more efficient management of HVAC operations to support decarbonisation of buildings.

While data is now becoming available, providing access to the data is becoming increasing challenging due to the various siloed systems technology vendors will require access to. With each building being unique in its platforms and configurations, initial deployment of any new software technology to take advantage of the data being generated can become cost prohibitive due to labour required to customise applications for each building, as well as various additional gateways or APIs to get access to each of the data sources.

This project overcomes these deployment challenges by utilising the Data Clearing House (DCH) initiative that supports building data interoperability through,

i) standardisation of information about buildings and information exchange,
ii) augmenting building data with semantic information.

To further enhance the building data model, VBIS open asset classification standard has been added and linked with DCH based semantic models to demonstrate the benefits of integrated asset and building tagging systems that can be used

2.2 Opportunities from proposed buildings

City of Melbourne, as a project partner, 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

Following on from an initial site audit, the project team was able to confirm energy saving opportunities available on sites and that the buildings were suitable for demonstrating the following project objectives:

1. Improve the reliability of onsite PV generation, contributing to the reduction carbon footprint in building operation.
2. Mass deployable applications for repeatable results utilising integrated schematic building models.
3. Demonstrate the value of integrated asset classification and semantic modelling for delivery of PV analytics, energy analytics applications and asset performance optimisation.

To design appropriate user interfaces and applications, the project team also conducted workshops with City of Melbourne stakeholders which helped frame and guide the development of the application analytics ruleset and user interfaces.

The ability to query the equipment specific information in semantic data models will limit the need for application customisation, reducing the initial investment required by users to adopt new applications within a building/portfolio.

3. APPLICATION DEVELOPED FOR VARIOUS USE CASES

3.1 Applications developed for DCH 7

PrediQ, the project software partner, were able to develop several applications based on the data that could be extracted from each of the proposed buildings.

Each application provides a use case where the data available can be used to address an issue within the building performance that can lead to improved building performance and energy outcomes.

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 1: 8 Portable applications

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.

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 2: All applications developed or DCH7

In addition to the rules developed by PrediQ, through DCH 7, CSIRO have also further developed the M&V application to also become easily redeployable across multiple buildings.

For application details please refer to Knowledge Share Report 3 - Application Implementation in Trial Buildings

3.2 Semantic Modelling Benefits and Adoption and use of VBIS asset classification.

To achieve a rapid redeployment of analytic rules to different buildings, we need to have a ‘common vocabulary’ to explain the resource of data, relationships of those data, and how to retrieve historical data. An example of this can be seen when developing a thermal model used by the various applications mentioned previously.

Raw data from site does not contain any relational or equipment information. Making sense of his broad mix of devices if often labour intensive and is the main contributor of initial deployment costs.

The benefits the project has been able to derive from the DCH BRICK model has been access to a uniform schema for representing data about buildings and building-installed equipment. For HVAC equipment, this has meant PrediQ were easily able to gain information about how many temperature sensors there could help with thermal modelling, any associated HVAC equipment and which part of building they corresponding to.

There were limitations within the BRICK schema, specifically around the identification of equipment types. This was addressed with the addition of VBIS asset tags to the DCH BRCIK data models. One example of this can be seen at Lady Huntingfield Early Learning and Family Services Centre. The facility primarily utilises Fan Coil Units however no information within the BRICK model is available to identify whether these units are Water or Refrigerated system units. The VBIS asset classification identified these units as Mechanical – Air Condition Fan Coil Unit – Direct Expansion – Ducted In Ceiling or “ME-ACFCU-DX-DIC” which quickly identified that the units were Refrigerated units and thus allowed the correct analytics rules to be applied.

This type of querying can be represented below:

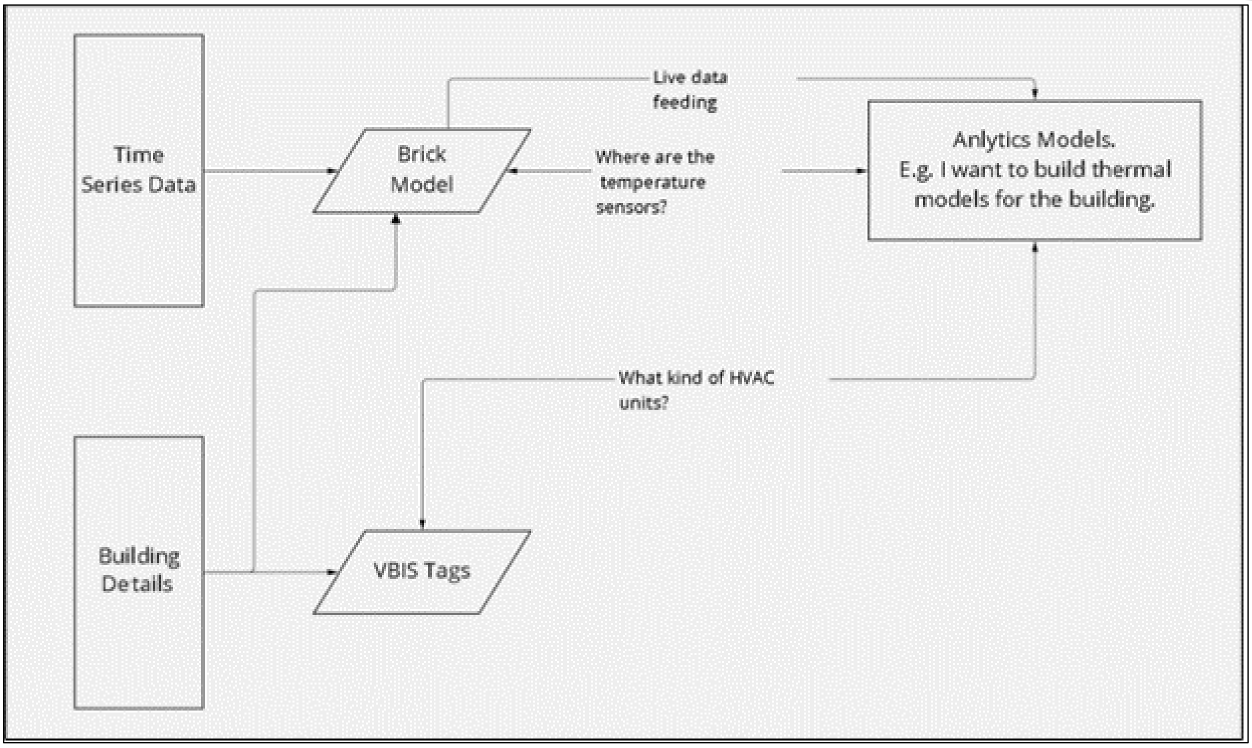


Figure 1: Overview structure of utilising VBIS tags and brick models for analytics modelling

VBIS asset classifications have also been used to provide:

- Building equipment relationship reviews. For example if the asset type is an BRICK:Chiller with VBIS: ME-Chr-WC-Sc indicating it is a water cooled scroll chiller, any software vendor on-boarding the DCH model will automatically know to check for Cooling Towers and Condenser Pumps. Without the VBIS Tag, it will require additional effort to identify equipment or potential errors in the model.

- By understanding equipment type, it is then possible to use VBIS tag information for efficiency calculations and improved forecasting. For example, monocrystalline solar panels vs polycrystalline ones. With sufficient sample size, it will also be possible to benchmark similar asset types.

- Performance comparison of different types of devices. As another example, the application platform can show occupants satisfaction against three different types of FCU devices, which are:

    - ME-ACFCU-DX-CC or Mechanical – Air Condition Fan Coil Unit – Direct Expansion – Concealed Ceiling

    - ME-ACFCU-DX-DIC or Mechanical – Air Condition Fan Coil Unit – Direct Expansion – Ducted In Ceiling

    - ME-ACFCU-DX-HW or Mechanical – Air Condition Fan Coil Unit – Direct Expansion – High Wall

  The application system was able to indicate that ME-ACFCU-DX-HW or a High Wall unit has the lowest performance among three of them. This analytics results provide a good reference for future equipment purchase and assists for asset management.

4. USER INTERFACES

To communicate the outputs from the various applications to the end users, an interactive user interface was developed. This interface combines the various applications into different modules focusing on energy performance and carbon zero while also providing a city-wide view of the connected portfolio.

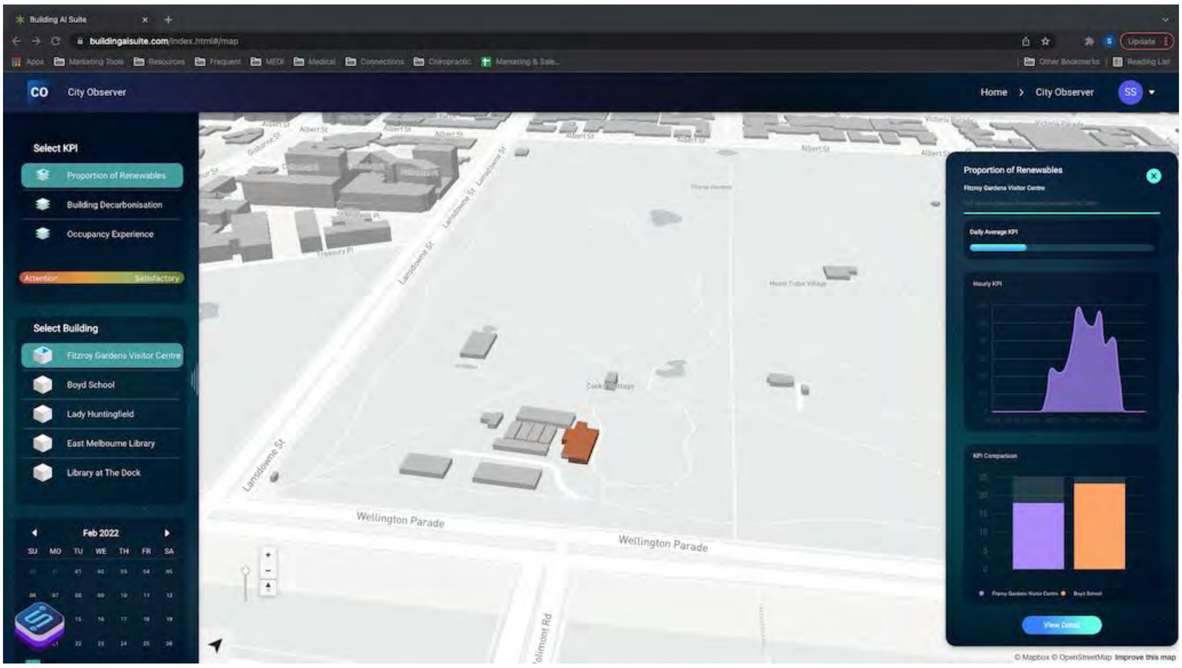
The user interface was also designed to make the application outputs easier to action by users, the application outputs recommended solutions from the applications on the user interface focused on two main areas:

- Operation and maintenance: To assist Facility Management team's daily work to find issues and provide quick responding.
- Project Costing: Visualise analysis result of return on investment (ROI) of project upgrading based on the existing building operation status.

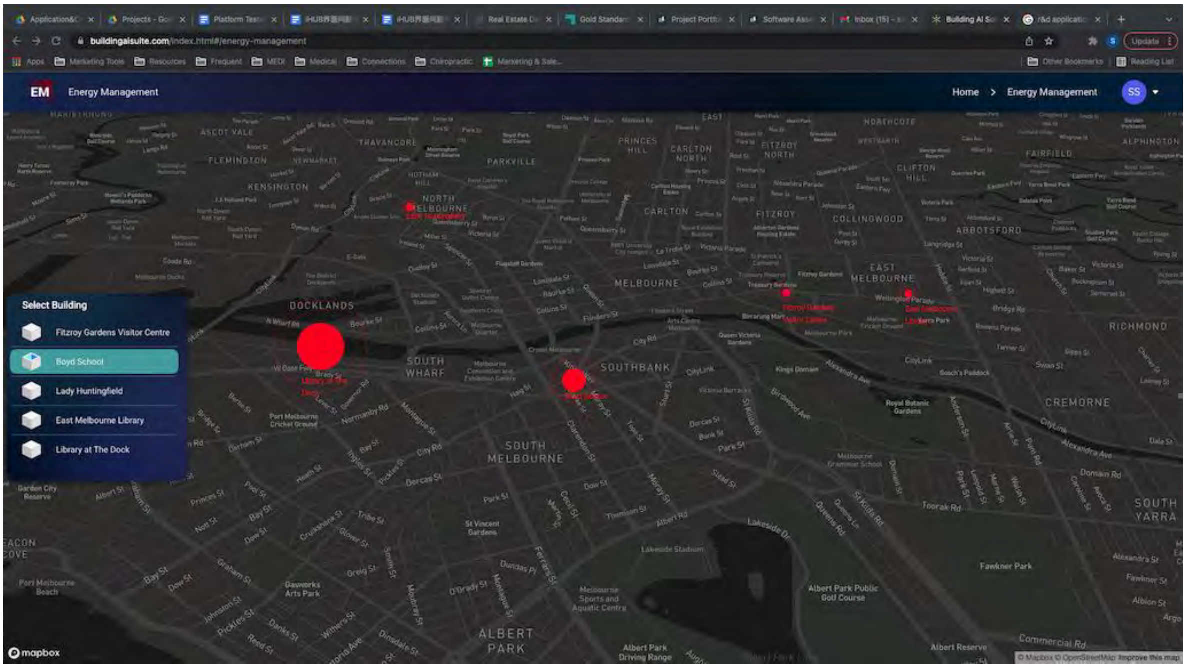
A new method of interaction was also developed for this project by PrediQ. "AI Building Mate" was designed to take the recommendations from the applications and communicate that as actionable items for users. Examples and benefits of this for the end user of this can be seen below.

The user interface developed is system agnostic and there can be accessed via any web browser or alternatively through mobile devices in landscape view.

4.1 Multi-sites Overview

Brief of Functionality	Visualisation of the whole picture of multi-projects management.
Functionality Output and Benefits	• Having “proportion of renewable generation” as a Key Performance Indicator (KPI) which calculates the proportion of renewable generation to the total energy consumption to highlight “lost” generation capacity. • Having “Carbon decarbonisation” as a KPI which calculates the emission production from the source of natural gas. • Colour of the building on the 3D map reflects performance against selected KPI (Green = more satisfied/ no issues, Red = more attention required). • Able to Zoom in/out on the map to oversee the performance of managed buildings. • A Widget pops up on the right when selecting a KPI and a building and shows details of data analysis at hourly intervals, including daily average KPI score, hourly KPI score, and KPI comparison among managed buildings. 

4.2 Quick Access to building performance

Brief of Functionality	Comparing real time energy usage for managed buildings in similar geographical and weather locations.
Functionality Output and Benefits	• Size of the bubble on the map reflects the energy usage of the managed buildings from the last hour. • Able to enter the detail page of energy management by clicking on the bubble. 

4.3 Monitoring of Building Energy Performance

<table>
<tr>
<td>Brief of Functionality</td>
<td>

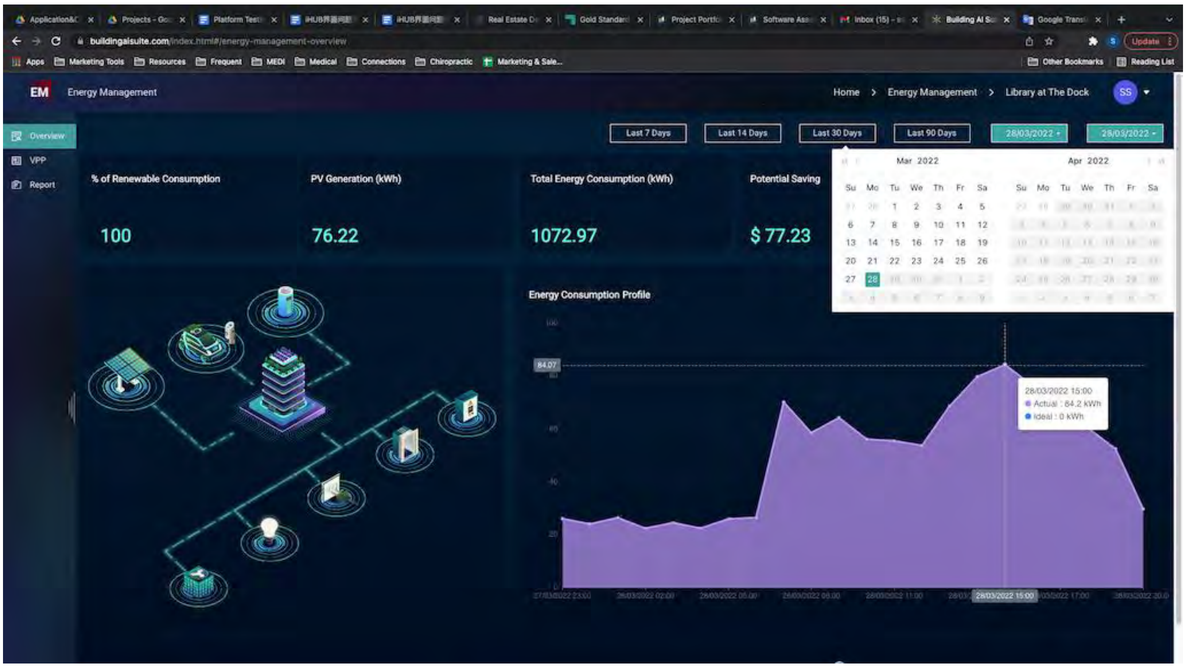
Calculate energy consumption and energy saving from transformative solutions and enable users to see the full saving of their actions.
Visualise analytics output that are of interest.

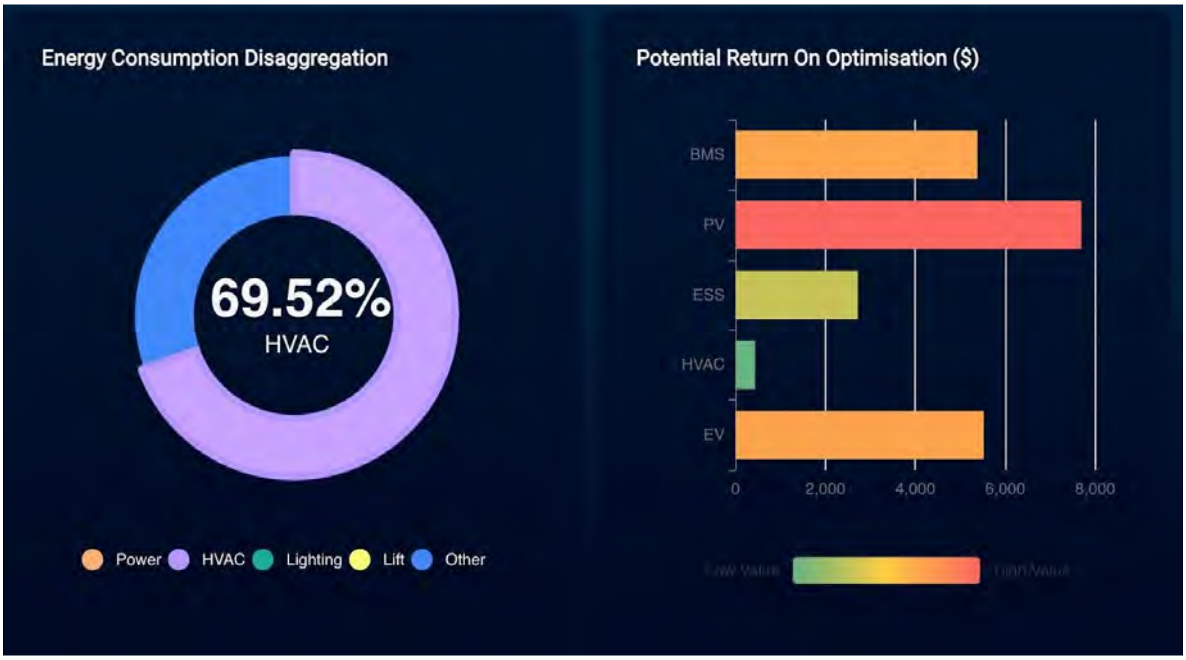
</td>
</tr>
<tr>
<td>Functionality Output</td>
<td>

Able to easily find “PV generation”, “energy consumption” at the top of the Energy Management overview page.
Able to choose the time period by selecting ‘start date’ and ‘end date’, or simply click on the available options of ‘last 7 days’, ‘last 14 days’, ‘last 30 days’ or ‘last 90 days’.
Able to find out how much the building can potentially save by taking proposed suggestions and solutions.

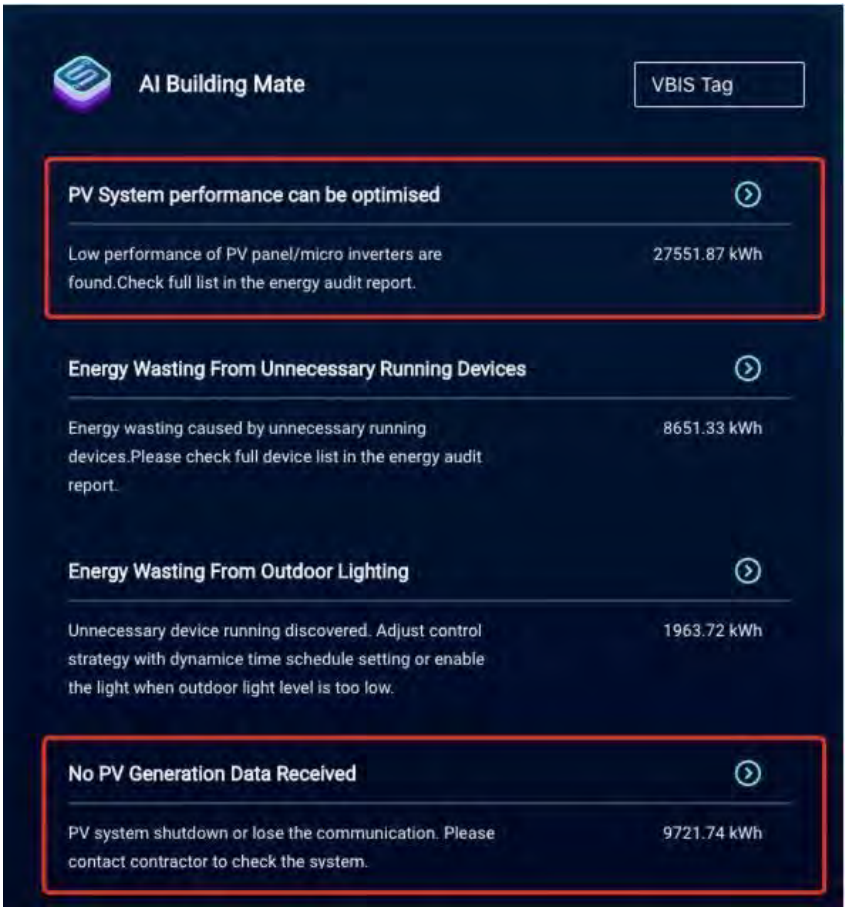
Able to see hourly energy usage.
Able to find out total energy usage for a specific period by selecting options of dates.
Able to see a pie chart that indicates proportion of energy consumption from specific building system parameters.
Able to see a bar chart that overviews and compares how much potential return can get by taking different optimisation strategies.

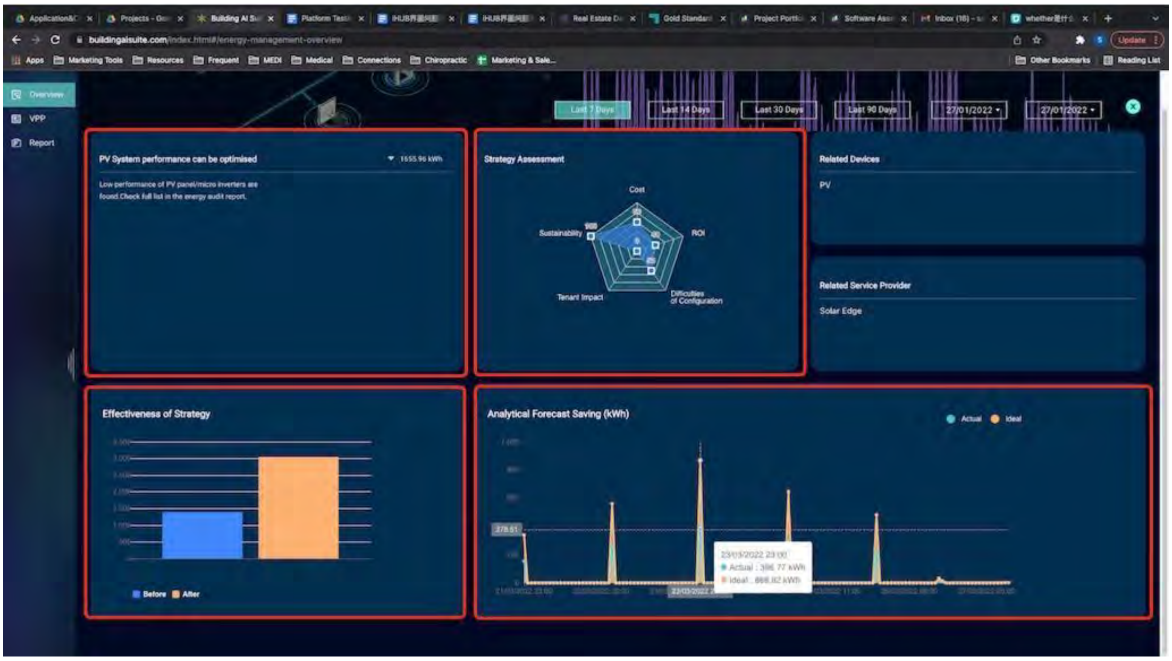
</td>
</tr>
</table>


EM
Energy Management
Home > Energy Management > Library at The Dock
Overview
VPP
Report
Last 7 Days
Last 14 Days
Last 30 Days
Last 90 Days
28/03/2022
29/03/2022
% of Renewable Consumption
100
PV Generation (kWh)
76.22
Total Energy Consumption (kWh)
1072.97
Potential Saving
$ 77.23
Mar 2022
Apr 2022
Energy Consumption Profile
28/03/2022 15:00
Actual : 84.2 kWh
Ideal : 0 kWh

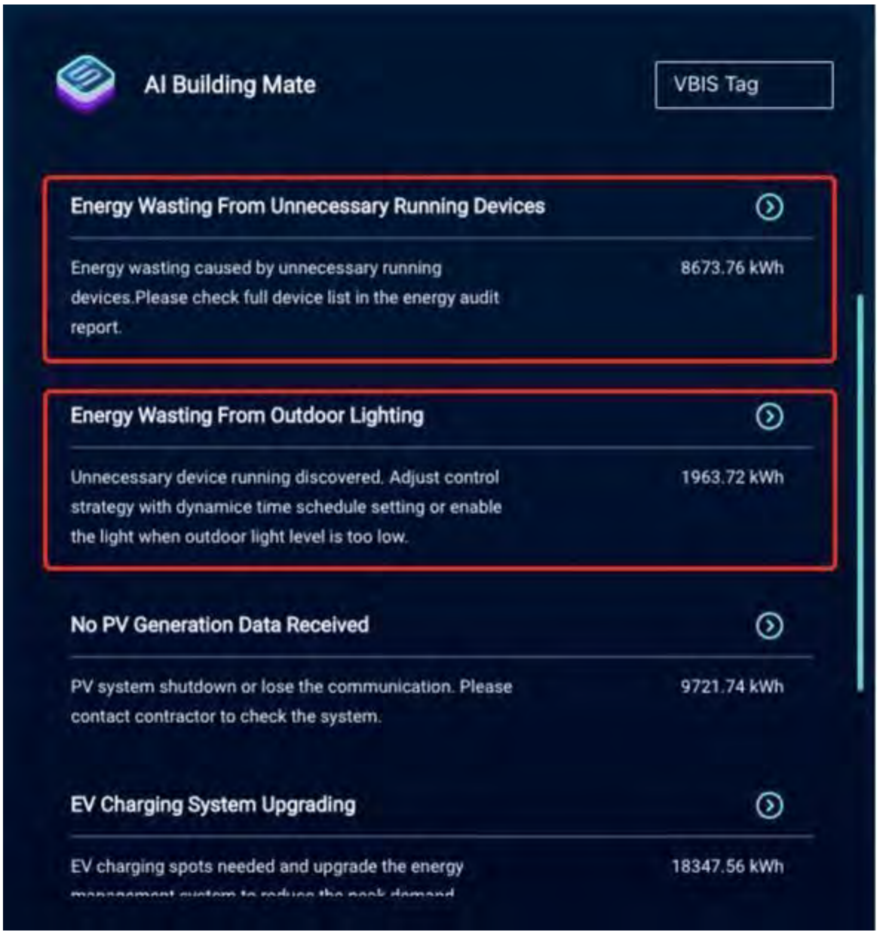

Energy Consumption Disaggregation
69.52%
HVAC
Power
HVAC
Lighting
Lift
Other
Potential Return On Optimisation ($)
BMS
PV
ESS
HVAC
EV
0
2,000
4,000
6,000
8,000

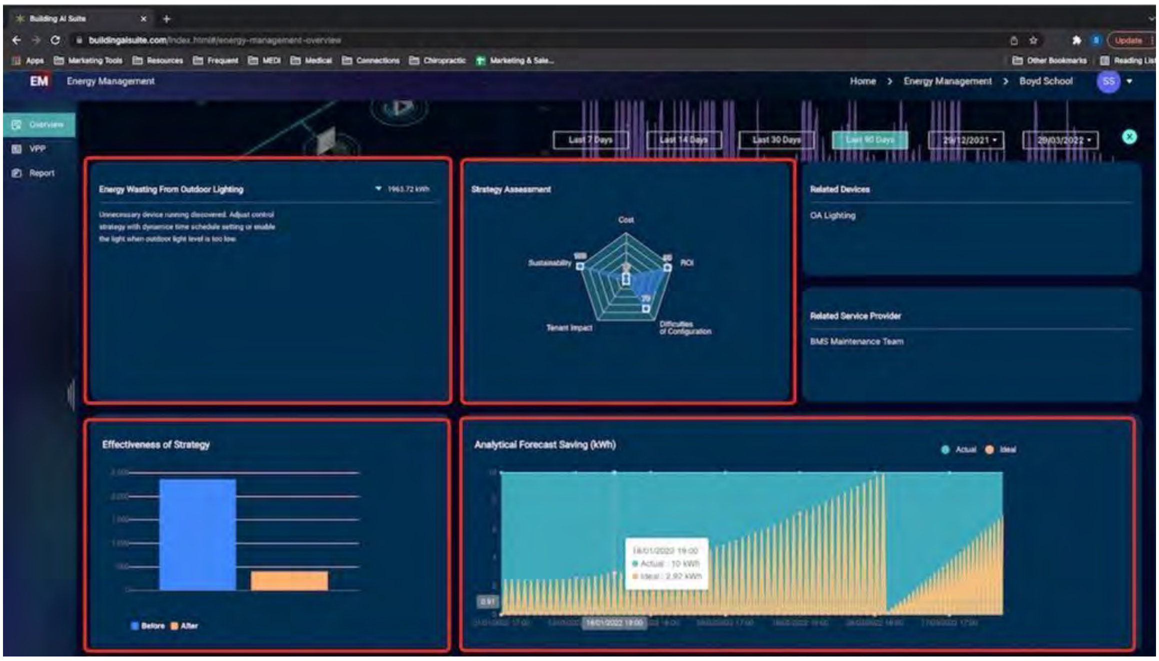
4.4 Energy Management – AI Solution - PV Maintenance Recommendations

Brief of Functionality	Generate alerts for performance and maintenance needed for critical equipment such as PV systems to ensure energy efficiency and the most efficient forms of renewable energy.
Functionality Output	• Able to find alerts for inefficient PV generation and solutions from the "AI Building Mate" box. • Detailed page pop-up when clicking on the specific alert. • Able to see full savings from taking the action suggested. • Able to compare the actual PV performance with optimised performance. • Able to see the solution assessment in five (5) dimensions to assist users to decide whether to take the suggestion. 

	 Overview VPP Report Last 7 Days Last 14 Days Last 30 Days Last 90 Days 27/01/2022 27/01/2022 PV System performance can be optimised Low performance of PV panel/micro inverters are found.Check full list in the energy audit report. Strategy Assessment Cost Sustainability ROI Tenant Impact Difficulties of Configuration Related Devices PV Related Service Provider Solar Edge Effectiveness of Strategy Before After Analytical Forecast Saving (kWh) Actual Ideal

4.5 Energy Management – AI Solution – Finding Energy Waste

Brief of Functionality	Prevention of excessive energy consumption and operational inefficiency through real-time monitoring of specific building systems by capturing changes in the external environment and analytic rules to generate timely response to find abnormal situations.
Functionality Output	• Able to find alerts for excessive energy consumption and solutions from the "AI Building Mate" box. • Detailed page pops-up when clicking on the specific alert. • Able to see full savings from taking the action suggested. • Able to compare the actual energy consumption with optimised energy consumption. • Able to see the solution assessment in five (5) dimensions to assist users to decide whether to go ahead with the suggestion. 

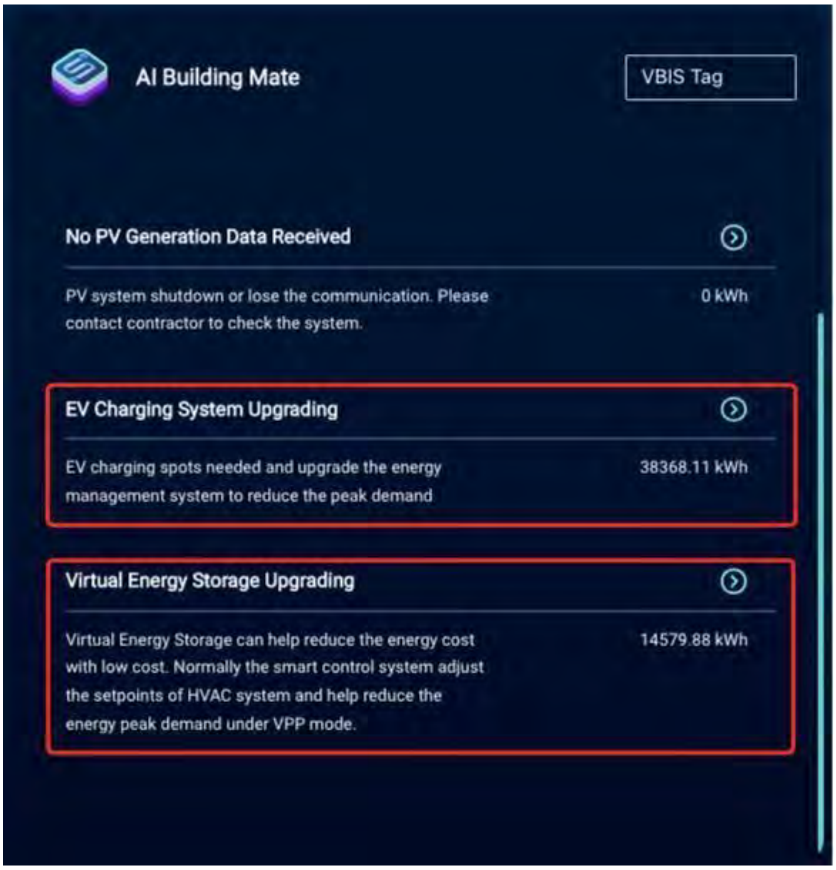


Building AI Suite
buildingaisuite.com/index.html#/energy-management-overview
EM
Energy Management
Home > Energy Management > Boyd School
Overview
VPP
Report
Last 7 Days
Last 14 Days
Last 30 Days
Last 90 Days
29/12/2021
29/03/2022
Energy Wasting From Outdoor Lighting
1963.72 kWh
Unnecessary device running discovered. Adjust control strategy with dynamice time schedule setting or enable the light when outdoor light level is too low.
Strategy Assessment
Cost
Sustainability
ROI
Tenant Impact
Difficulties of Configuration
Related Devices
OA Lighting
Related Service Provider
BMS Maintenance Team
Effectiveness of Strategy
Before
After
Analytical Forecast Saving (kWh)
Actual
Ideal
18/01/2022 19:00
Actual : 10 kWh
Ideal : 2.92 kWh

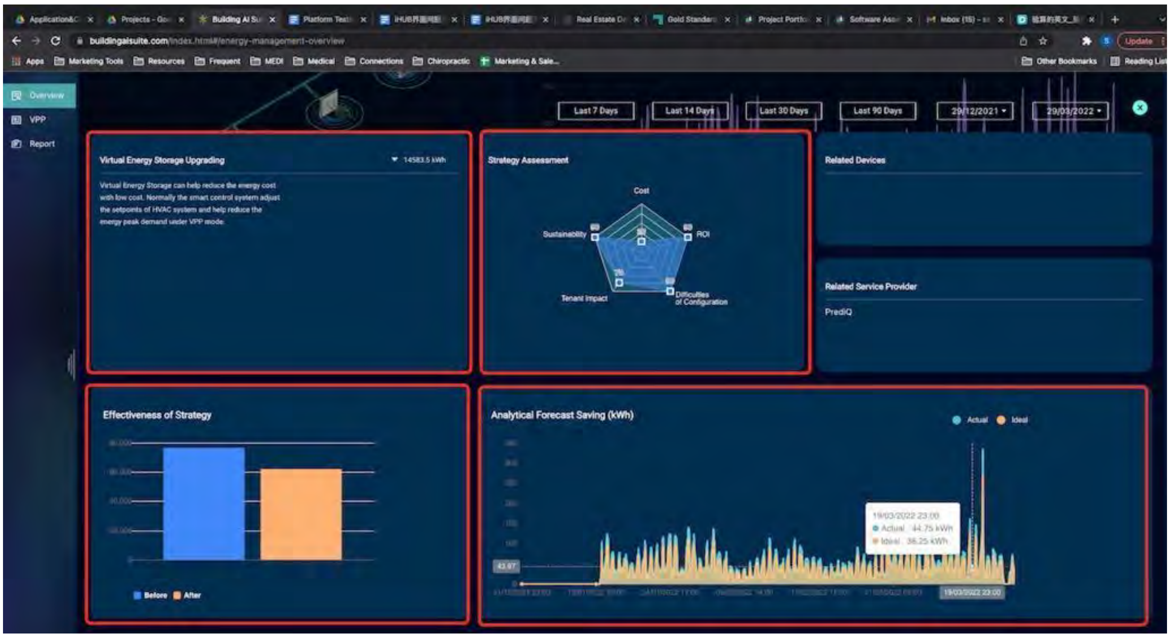
4.6 Energy Management – AI Solution – Economic Model on System Upgrading

<table>
<tr><td>Brief of Functionality</td><td>Formulated and optimised economic model that calculates the return on EV Charging System and VESS (Virtual Energy Storage System) usage in the energy market to provide feedback and recommendations on the way of using energy to maximise the return of investment of using renewable energy systems.</td></tr>
<tr><td>Functionality Output</td><td>

- Able to find recommendations for reducing energy consumption and maximising ROI from the “AI Building Mate” box.
- Detailed page pops-up when clicking on the specific alert.
- Able to see full savings from taking the action suggested.
- Able to compare the actual energy consumption with optimised energy consumption.
- Able to see the solution assessment in five (5) dimensions to assist users to decide whether to go ahead with the suggestion.



</td></tr>
</table>

buildingaisuite.com/index.html#/energy-management-overview
Overview
VPP
Report
Last 7 Days
Last 14 Days
Last 30 Days
Last 90 Days
29/12/2021
29/03/2022
Virtual Energy Storage Upgrading
14583.5 kWh
Virtual Energy Storage can help reduce the energy cost with low cost. Normally the smart control system adjust the setpoints of HVAC system and help reduce the energy peak demand under VPP mode.
Strategy Assessment
Cost
ROI
Sustainability
Tenant Impact
Difficulties of Configuration
Related Devices
Related Service Provider
PrediQ
Effectiveness of Strategy
Before
After
Analytical Forecast Saving (kWh)
Actual
Ideal

5. FORECAST SAVINGS THROUGH USE CASE APPLICATIONS

5.1 Energy Savings

While this project developed an M&V application which is also mass redeployable, site constraints limited the project team's ability to verify the implementation of the application recommendations.

Through the application building modelling and forecasting undertaken, it was possible to model the predicted savings across each site with the 20+ application solutions developed for this project.

The prediction from the modelling shows between 5% and 20% savings can be achieved depending on site complexity, with the greatest savings coming from established sites which are complex HVAC services.

A summary of these savings is provided below. Please refer to Knowledge Share Report 3 - Application Implementation in Trial Buildings for application development details

Lady Huntingfield	Boyd Community Hub	East Melbourne Library	Fitzroy Garden	Library at the Dock
8% Energy Saving by PV Optimisation + BMS Optimisation + Virtual ESS	17% Energy Saving by PV Optimisation + BMS Optimisation + Virtual ESS	12% Energy Saving by PV Optimisation + BMS Optimisation + Virtual ESS	5% Energy Saving by PV Optimisation + BMS Optimisation	20% Energy Saving by PV Optimisation + BMS Optimisation + Virtual ESS

Table 3: Overview structure of utilising VBIS tags and brick models for analytics modelling

A number of assumptions were also used to when providing recommendations within the user interface covered above.

5.2 Assumption 1 – Agreed Utility Rates

The utility rates refer to rate agreed and established during the baseline period from 2016 to 2020. The utility rates shown in the figure below refer to the agreed rates in City of Melbourne's bills that will be used to determine the project's cost savings over the term of the analytics period.

peak price (Mon-Sun 3pm-9pm)	Electricity	10.2336	Off-peak price	7.4459	cent/kWh
	SRECs	0.883		0.883	cent/kWh
	VEECs	0.4384		0.4384	cent/kWh
	LRECs	1.4312		1.4312	cent/kWh
	CLLV Peak	3.46		2.12	cent/kWh
	Ancillary fee	0.0389		0.0389	cent/kWh
	Market Fee	0.0401		0.0401	cent/kWh
PV feed-in tariff	12 cent/kWh	Demand Charge	105.74	$/KVA/pa	

Table 4: Utility Rates

5.3 Assumption 2 – Agreed annual hours of operation

Site operation hours are as provided in the table below.

	Weekdays	Saturday	Sunday
Boyd Community Hub	Mon-Thu 10:00-18:00 Fri 13:00-18:00	10:00-13:00	-
Lady Huntingfield	7:00-18:00	-	-
East Melbourne Library	Mon-Thu 10:00-18:00 Fri 13:00-18:00	10:00-13:00	-
Fitzroy Garden Visitor Centre	10:00-16:00	10:00-16:00	10:00-16:00
Library at the Dockland	Mon-Thu 10:00-18:00 Fri 13:00-18:00	10:00-13:00	12:00-16:00

Table 5: Building hours of operation

5.4 Deployment Savings

In past projects, it is common that the benefits of data analytics do not outweigh the cost of it, or the revenue is not allocated to data analytic services due to business models. To overcome this, this project focused on data value by developing replicable data model used in applications to minimise implementation costs.

The project was able to demonstrate savings achievable through the development of mass redeployable applications. Through the various applications developed, PrediQ was able to quantify labour savings between 20% and 90%. For the 8 applications that could obtain all required information from within the VBIS enhanced DCH data model, savings in the order of 90% was achievable. The remaining 10% labour was attributed to review of the deployed application to ensure no errors appeared.

For applications where manual configuration was still required, savings in the order of 20% to 35% is still achievable through the use of standardised, structured relational data within the DCH BRICK environment and the equipment information available within the VBIS asset classification structure.

It is anticipated however that the building data model and the applications improves with each iteration, the labour required to review the deployment will also decrease, further reducing the initial implementation cost to deploy.

6. FURTHER DEVELOPMENT AND NEXT STEPS.

This project has already been able to demonstrate through its various applications that it is possible to create applications that improve on site renewable generation and HVAC performance while also reducing initial implementation and on-boarding costs through re-useable applications.

Currently, the user interface provides a visual representation of the various application outputs, with data primarily travelling from site to DCH to the applications. For any changes to site, users will still need access to the individual sites and multiple operating systems. It is understood from CSIRO that information however can flow in both directions, i.e. back out to site. It is suggested that a further development would be to develop the ability to automate applications recommendations so that applications can send commands back into DCH which can then control equipment back on site.

This type of automation would ensure savings are maximised while inefficiencies from equipment detected are quickly addressed. Applications will however then need to be developed to further improve robustness for redeployability as each application will then have an ability to directly impact the environment it is monitoring.

The value of data can only be measured by the impact it has through the ability to communicate the correct information when necessary. Through the implementation workshops, City of Melbourne also provided feedback for the user interface based on information that would be useful to them. Another area for further development would be to incorporate the feedback received from City of Melbourne and develop end user customisable interfaces that can automatically display information from each background application.

7. CONCLUSIONS.

This project set out with the goal of developing an integrated semantic model utilising VBIS asset classification and BRICK within the DCH environment to develop mass redeployable applications to focus on on-site renewable energy generation and HVAC system performance, which it has achieved.

While this project experienced challenges delays to the on-boarding process resulting from COVID, DCH7 was still able to develop 20+ applications which make use of the DCH BRICK model and VBIS asset classification information, with 8 applications being fully redeployable with all data being sourced from the DCH model.

The applications and models developed can be grouped broadly into the following categories:

- PV analytics: the performance and optimisation of renewable energy
- Building decarbonisation: Mainly on discovering buildings' non-electricity energy consumption, driving the process of getting to net-zero.
- Energy audits: Based on traditional energy audits and carry out upgrades. Using the long-term building operation data to identify the possible energy-saving strategies and precisely predict the results. (It also includes the innovative analytical concept of virtual energy storage)
- Carbon Neutral: Precise carbon emission data in one minute granularity, giving suggestions on achieving carbon neutrality.
- Occupancy Experience: Provide the basic models of occupancy experience that constructed from the existing indoor sensors.
- Critical Equipment Health: Aiming to reduce the critical equipment's failure rate.

The CSIRO M&V application was also developed to be re-deployable and provide a means of validating energy performance changes within each building. With site constraints on implementation of application recommendations, the project team was unable to use the M&V application to validate the energy and carbon savings however the modelling developed based on historical performance, the project was able to demonstrate potential energy savings of between 5% and 20%.

By using the "common vocabulary" from the DCH BRICK semantic model and the VBIS asset classification standard, the developed applications were also shown to be capable of being easily redeployable. Overall, this will provide savings of between 20% and 90% of the initial deployment time, depending on the complexity of the applications being deployed and the information available within the DCH model.