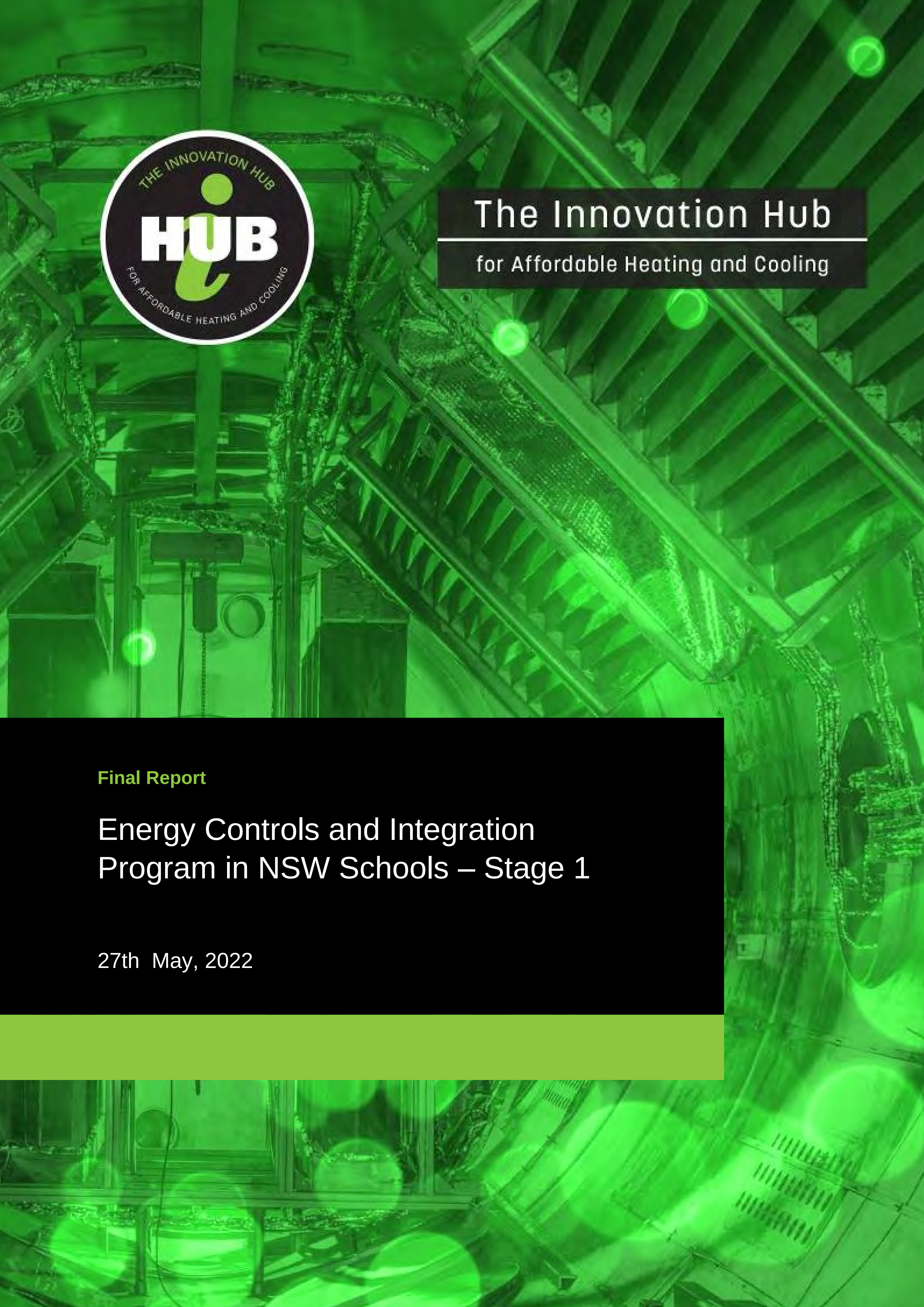

The Innovation Hub

for Affordable Heating and Cooling

Final Report

Energy Controls and Integration Program in NSW Schools – Stage 1

27th May, 2022

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

Energy Controls and Integration Program in NSW Schools – Stage 1

The DCH 6.1 project will develop a proof of concept on how to integrate and control solar PV, battery storage and air-conditioning in schools to reduce energy costs and provide a better understanding of the requirements and impacts of demand response initiatives.

The objectives are to install battery storage and control equipment in three schools, to complement the demand response enabled air-conditioning and solar already installed as part of the Department of Education's Cooler Classrooms program, and create a control application to integrate the installations at each site.

An option exists for a potential future stage 2 sub-project (participation by SINSW to be determined), for the schools to be connected to the proposed iHub Data Clearing House. This would acquire additional variables such as weather and NEM spot market prices and, taking into account data acquired from site, facilitate control algorithms to further optimise the operations and maintenance of the equipment onsite.

The DCH 6.1 project is the first stage in the wider $18.3m ARENA funded Affordable Heating and Cooling Innovation Hub (i-Hub) project.

Lead organisation

School Infrastructure NSW

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1 SUMMARY

1.1 Executive summary

As a part of i-Hub Data Clearing House (DCH) initiative, CSIRO is working with NSW Department of Education, and Buildings Evolved on a project involving the installation of battery storage and HVAC control equipment in three schools:

- Jamison High School (Penrith, Greater Sydney);
- Singleton High School (Singleton, Hunter Valley); and
- Nimbin Central School (near Lismore, Northern Rivers);

for the purpose of evaluating the opportunities to reduce energy while simultaneously improving occupant comfort and educational outcomes.

Key accomplishments include:

- Site visits & report
- Implementation & project management plan, timeline
- Comfort levels determination
- Engineering reporting
- Preliminary Business Case
- Front-end component sizing – BAU scenario evaluation using System Advisor Model (SAM)
- Control methodology for HVAC system in schools
- Import asset data from three schools into CMMS/AMS database
- Simple control methodology for battery management in schools
- Concept designs
- Financial modelling and reporting for BaU
- Control/operation strategies
- Build and test a living lab
- Compile data points list for BE Lab to DCH & documentation for tender
- Ingestion of data from local demonstrator to the Data Clearing House (DCH)
- Video introduction to BE lab for Knowledge Sharing
- DCH integration of ASHRAE 55 adaptive comfort band and PMV/PPD models
- ASHRAE comfort band-based control outputs available for managing HVAC system in demonstrator
- Development of representative Brick semantic models for 3 schools based on available equipment details
- Procurement strategy
- Detailed design to procurement stage
- System description and documentation prepared for SINSW IT Department
- Tendering, commissioning and related reporting
- Development of financial modelling database, tariff engine, scenario generator
- Production of financial report showing potential benefits from 2019 baseline and 2022 as-built

Tuning of optimisation strategies using various technology mixes is flexible, and can be achieved to favour occupant comfort over financial benefit or vice-versa dependent on the requirements of the client. In this case, NSW Department of Education has the objective of providing improved learning environments to deliver better educational outcomes while driving stronger economic outcomes for the state.

1.2 Summary of results

The modelling demonstrates HVAC controls *without battery* consistently returns the best benefit cost ratio (BCR) all three sites in DCH 6.1, of above 2x BCR. These results mirror the preliminary modelling work, undertaken prior to procurement of the batteries and additional solar PV on the three school sites covered in this report. By comparison, the modelled business case for battery storage systems for the purpose of energy arbitrage show a lower financial return, although this is improved by utilising batteries within the FCAS market (and wholesale spot pricing). The scenario with larger solar PV, without batteries or controls and using retail energy accounts, was also notable, showing an impressive BCR in its own right for two of the sites.

The results indicate that where a batteries are introduced into the mix of technologies, the BCR and NPV is often reduced. Singleton HS, the largest energy consumer, produced the best financial returns of the three schools studied, and the best BCR – when using the CCP7A scenario (solar PV + HVAC controls). Over 15 years, the modelling indicates a saving of $1.19m can be made with a spend of $0.47m at this *one school location.*

Additionally, HVAC controls have the ability to improve financial returns while *simultaneously* improving educational outcomes through strategies including the ability to:

- Set, achieve and measure thermal comfort (e.g. ASHRAE 55);
- Use night purge to provide fresh air to students at start of day;
- Provide thermal comfort models to adjust set points based on external conditions;
- Understand the thermal properties of each building and optimise against it (e.g. thermal mass of demountable buildings vs a triple brick building);
- Improve ventilation to maintain a good indoor environment quality and reduce risk of infection;
- Making sensor data available to students studying STEM subjects;
- Altering HVAC modes automatically based on external conditions & forecast, and favour fan and dry modes where possible; and
- Reduce HVAC system downtime through better maintenance methods.

The original intent of the project was to implement the infrastructure required to produce real world data from which to draw conclusions regarding the viability of the various technologies and configurations. Given the delays in installing this infrastructure, due to a number of complications including the onset of the Covid-19 pandemic, the course of this project has veered to rely on a modelled based output. Next steps include proceeding with the installation of the cabling and controls systems to enable the collection of actual data for a period of 12 months. This data will then be analysed and compared with the modelling to provide insights and inform the direction SINSW will take with regards to the technology and future viability. It should be noted that the inclusion of wholesale spot pricing (without FCAS) found in some modelling scenarios can be implemented through procuring electricity from wholesale price pass-through retailers such as Amber Electric or PowerShop – however, this may conflict with whole-of-government electricity procurement contracts. The other option: participation directly in the wholesale market, requires a virtual power plant to enable access to the FCAS markets (as modelled in scenarios labelled with FCAS); adding an additional layer of complexity for the Department of Education, and the NSW government more broadly, requiring additional consideration around the practicalities of implementation including resourcing.

Based on the outcomes of this project, there may be opportunities for further modelling focusing on the HVAC controls opportunity in concert with the demand flexibility market opportunities that are emerging adjacent to the wholesale spot price of electricity (WSP) and the frequency control and ancillary service markets (FCAS). Now that the financial modelling tool has been built, adjusting assumptions or adding scenarios can be done with relative ease.

1.3 Variations due to COVID

The start of the COVID-19 pandemic coincided with the start of the DCH 6.1 project and has brought about challenges affecting the project schedule and deliverables. The initial project plan called for rapid deployment of the cabling and additions to the Cooler Classrooms Program and the establishment of data monitoring as soon as possible. The original project plan called for installation of these components in mid-2020.

The pandemic caused issues relating to the installation of the battery energy storage systems that were required as a precursor to the installation of the communications and controls systems. It also caused issues relating to the access of schools, and a CSIRO travel ban resulted in a change of scope away from doing site visits and engineering, with this responsibility taken on by Buildings Evolved. For example, one school was unavailable to visitors for several months, necessitating double the travel than would other be required. Additionally, only one member of the BE team was able to attend site. Because of all this, and keeping project deadlines in mind, site visits, control documentation and tender schedules have been prepared by Buildings Evolved with review by CSIRO. This has also impacted upon the schedule.

The tendering was divided into two sections, both of which have had delayed deliveries.

System	**Original Schedule**	**Revised COVID Schedule**
Battery Storage System & Additional Solar PV	September 2020	September 2021-January 2022
Additional HVAC controls, connection to existing PLCs	September 2020	May-June 2022 *

* Installation will run past completion of this project.

Due to the COVID related delivery delays and the consequence of limited real-world data to use in modelling, Buildings Evolved proposed to project partners to deliver a far more accurate financial modelling tool than the spread sheet used for the preliminary costings done in 2020. The purpose of this tool would be to draw upon available data sources, including the as-installed state of the battery storage and larger solar systems to project elements that could not be completed within the time frame of the DCH 6.1 project. The objective is to provide meaningful results that can be brought forward to bring the project to the next stage should this be approved to proceed.

Once the additional HVAC controls have been installed, data will be captured for 12 months and analysed and compared with the modelling to provide insights and inform the direction SINSW will take with regards to the technology and future viability.

1.4 Engineering

Given the changed circumstances in 2020, Buildings Evolved in consultation with project partners determined it to be appropriate to extend basic bench testing of the solution prior to installation into a full demonstrator test installation.

A full living lab environment was built during 2020 and into early 2021, expanding on the limited bench testing undertaken as part of the original scope of works. It was surmised and approved that such a strategy would allow the development of the technology stack to continue despite the lock-downs and limited access to complete the schools site visits. This work includes programming and commissioning and connection to the Data Clearing House hosted by CSIRO. This was subsequently expanded to include two small buildings.

CSIRO have implemented ASHRAE 55 comfort models(adaptive comfort model and Predicted Mean Vote (PMV model) in the Senaps Data clearing House. These model outputs (upper and lower bound temperature recommendations) can be requested from DCH via the Node-RED control software and used for controlling air conditioning set points in the schools. Currently these models are delivering set point recommendations using the data provided by the living lab environment. The overall objective of the comfort model adoption is to provide enhanced learning environments for students – delivering better educational outcomes.

Significant progress has been made on the development of a battery control program for managing schools onsite energy demand. The objective of this program is to operate autonomously and provide charge/discharge control signals to the onsite battery based on a model predictive control algorithm (to be implemented in a future stage) that minimises electricity costs. Multiple battery control strategies are being developed ranging from simplistic charging to maximise self-consumption of PV generation, through to full 7 day ahead optimisation accounting for forecasting uncertainties and risk tolerance.

Deployment of control algorithms (as applications hosted in DCH) across these schools in a scalable way requires creation of semantic models to support application implementation in DCH. Semantic models for three schools have been built during this period by CSIRO for engineering modelling.

The tender specification documents consequently went into far more detail and dealt with a level of complexity not considered at the project inception. The original intent was to do a basic installation in DCH 6.1, with a more refined specification to be developed for potential future stages based on lessons learned. This process has been modified by proceeding with the more in-depth demonstrator testing, delaying the release of the tender and installation of additional components with the result of getting a specification closer to one envisaged for potential future stages. This also reduced risk that the solution as installed is not complete enough to satisfy the requirements from the project partners. CSIRO, Data 61 and SINSW have all had a chance to observe the progress of the integration of the test environment to the DCH, and to observe resultant data in the DCH.

The procurement of controls was delayed due to the late commencement date, limited access to schools due to COVID, and the demonstrator test providing challenging questions to resolve for documentation purposes. Chief amongst these was discussions around thermal comfort, the positions of temperature sensors, and understanding the relationship between the PLC, it's sensors, and the HVAC PAC's control system. This has been documented into data flow diagrams, and has led the project to be able to not affect the original CCP program to achieve the desired outcomes, further reducing risk and ensuring that the original intent of the CCP is not lost, only enhanced.

In the lead-up to writing the final report, key datasets specific to the schools include:

Source	Role	Data	Range
PlusES	Meter Data Agent	NEM12 Interval Data	Last 7 years Jamison & Singleton to 2022 Nimbin to 2019*
Shell ERM	Energy Retailer	Monthly EDI Invoice data	Last 7 years
Origin Energy	Energy Retailer	Quarterly EDI Invoice data	Last 7 years
SMA Sunny Web Portal	Solar Inverter		Limited, some on Fronius Unreliable and of limited use
Alpha ESS	Battery Management System	5 minute interval (KW instantaneous) Provides data for: • System SOC • Grid consumption • PV generation • Battery charge/discharge	Jamison since Sep 20 Nimbin since Jan 21 Singleton – not available
CSIRO	Battery Control	Simulation data	Updated to consider new solar PV system size. Battery operation removed for simulation purposes**

* Nimbin CS moved from large to small market account in 2019, terminating access to NEM12 data

1.5 Preliminary modelling

Preliminary financial modelling was undertaken by consultant Aeris Capital, under direction of project partners. The preliminary modelling was undertaken using spread sheets and consequently was limited to modelling step tariffs only. This was still extremely useful in 2020 to obtain a broad understanding of the impacts of decision making, but was not able to answer the primary question posed in the hypothesis underlying this project: that exposure to the wholesale spot price, or a wholesale price pass-through electricity retailer, such as Amber Electric – in conjunction with supporting technology – produces economic benefits that provide income to improve the educational outcomes of students in NSW.

Aeris Capital applied their own methodology used extensively in the private and public sectors to validate BCR and NPV of various scenarios in the modelling and is labelled “Rapid Cost Assessment” or RCA. Modelling in Milestone 4 focused on the existing NSW whole-of-government electricity procurement contracts, known as C776 for small market sites, and C777 for large market sites. This has shown that the benefits lie principally with a combination of Solar PV and HVAC controls in Ausgrid zones, due to their peak network tariff starting at 2pm. It also showed that the network tariff accounted for as much as 60% of the total costs incurred by the department.

The preliminary modelling showed that the NPV and BCR are particularly high for locations that require upgrades to the electrical network to support increased demand as a result of CCP HVAC roll-out. In these circumstances, the BCR can be as high as 21x by augmenting technology with additional HVAC, solar, batteries and controls and avoiding capital cost of upgrading substations and switchboards.

The biggest conclusion from the preliminary modelling was that static (stepped) retail tariffs such as C776 and C777 show a weak business case for batteries, and only a minimal installation has any reasonable payback period, and this only through tariff change and assisting with peak demand. The limitations of the existing approach were making themselves apparent.

1.6 Advanced modelling

Early in 2021, Buildings Evolved in negotiation with Aeris Capital formed a resolution that more needed to be done in order to fully test the hypothesis – namely a requirement for interval by interval dynamic pricing from the wholesale spot market. The CSIRO battery control simulation is optimised around the wholesale spot price, so therefore the financial modelling needed to be able to handle wholesale spot in order to properly model the benefits of the battery control system.

Buildings Evolved hired software development staff and reallocated existing resources towards agile software development with the aim of solving the hypothesis. This was undertaken only after market research proved existing modelling tools to either be targeted at completely different electricity markets (energyPlus, SAM), or likewise had similar limitations in only being able to model conventional retail step tariffs, or were not able to capture the complexity of the Australian energy market.

Extensive background IP was drawn upon to create a tool that could model an extensive array of what-if scenarios and deliver it in a method compatible with NSW Treasury business case guidelines. Major components of work include:

- extract, load transform scripts for NEM12, EDI retail data, BOM, AEMO & other data sources
- tariff engine to model and normalise the extreme complexity of network and retail stepped tariffs
- emissions factor calculations and repository of variables based on state, year and emissions source
- scenario and assumption generator/editor
- 50-year NPV & BCR report outputs
- software is written in Python using a PostgreSQL database back-end
- web user interface written using the React.JS framework

Undertaking this project now allows infinitely more sophisticated modelling to be undertaken, principally in being able to process each interval of data through a unique (wholesale) price. Central to the modelling effort is the ability to create infinite numbers of load profile assumptions. Buildings Evolved in conjunction with CSIRO produced over 10,000 days of unique load profiles for simulation and results generation in the advanced modelling tool.

Load profiles were largely generated by algorithm for each time period – either:

- simple mutators (remove 10% demand, for example)
- the CSIRO battery simulation outputs, and

- what would be assumed to occur if Model Predictive Controls were implemented on the HVAC systems.

2 BUILDINGS EVOLVED LIVING LAB

2.1 Overview

The living lab configuration functions to replicate controls technologies and connection method used for simulating a typical NSW air conditioning controls scenario used for testing controls strategies in the Buildings Evolved living lab.

The Buildings Evolved Laboratory had been fitted with a Daikin Sky VRV system in late October 2019 and was chosen as it was a similar type to those found in NSW Schools.

Upon agreement of change of scope, Buildings Evolved:

1. developed:
    a. single line diagrams
    b. concept design
    c. functional requirements
    d. data requirements
2. Researched and ordered:
    a. interface to the Daikin HVAC system
    b. Easy IO FS32 Programmable Logic Controller
    c. EDMI MK7C meter with Modbus Duo adaptor and Moxa media converters as required
    d. DIN relays to suit the above
    e. mechanical Control Centre (MCC) panel (with transparent lid for R&D purposes)
    f. power supplies, breakers, cabling, and accessories for the above
    g. stainless steel HVAC control panel identical to those found in NSW Schools
    h. identical temperature/humidity/CO2 sensors used in NSW schools for both indoor and outdoor use
    i. IT hardware suitable for acting as DCH Edge Server
    j. double conversion UPS to protect the above
3. added wiring to connect the system components
4. rewired and moved the Daikin control panel to an inaccessible location (but still at 1500FFL)
5. connected existing Fronius Solar PV inverter
6. installed and commissioned the system components
7. added system components to existing network infrastructure
8. programmed and commissioned Node-Red to the Data Clearing House
9. worked with CSIRO & Data 61 to get ASHRAE 55 and PMV draft workflows calculating values into the DCH
10. integrated a local time-series database (InfluxDB) & web-driven user interface (Grafana & Cronograf) to emulate typical BMS historian functionality
11. further works as described in this document

2.2 Purpose

The purpose of testing control strategies is to provide proof-of-concept testing to:

1. develop full vertical proof-of-concept of the Operational Technology and Information Technology to be used at NSW Schools in DCH 6
2. recreate and test SINSW control logic to determine baseline/BAU controls operation
3. manipulate air-conditioning set-points in response to internal and external conditions, such as:
    a. internal/external temperature, humidity and internal C02 levels,
    b. in context of ASHRAE Comfort Bands, and
    c. control signals from AEMO (simulated).
4. demonstrate control functionality in concert with solar inverter operation, energy generation and onsite consumption. Noting that testing of batteries operation and control are not available as batteries are not installed in the laboratory.

5. integrate the living lab with DCH to demonstrate operational capability and response times through various IoT integration layers, on-premise server Node RED – DCH response and latency testing.
6. for Buildings Evolved consultants and staff to “Live” the control system, meaning effective debugging of functionality and logic
7. reduce risk in the specification, tendering and commissioning phases of works
8. provide a local historian functionality with more detailed information than sent to DCH
9. allow CSIRO and Buildings Evolved teams to rapidly develop control algorithms

2.3 Architecture overview

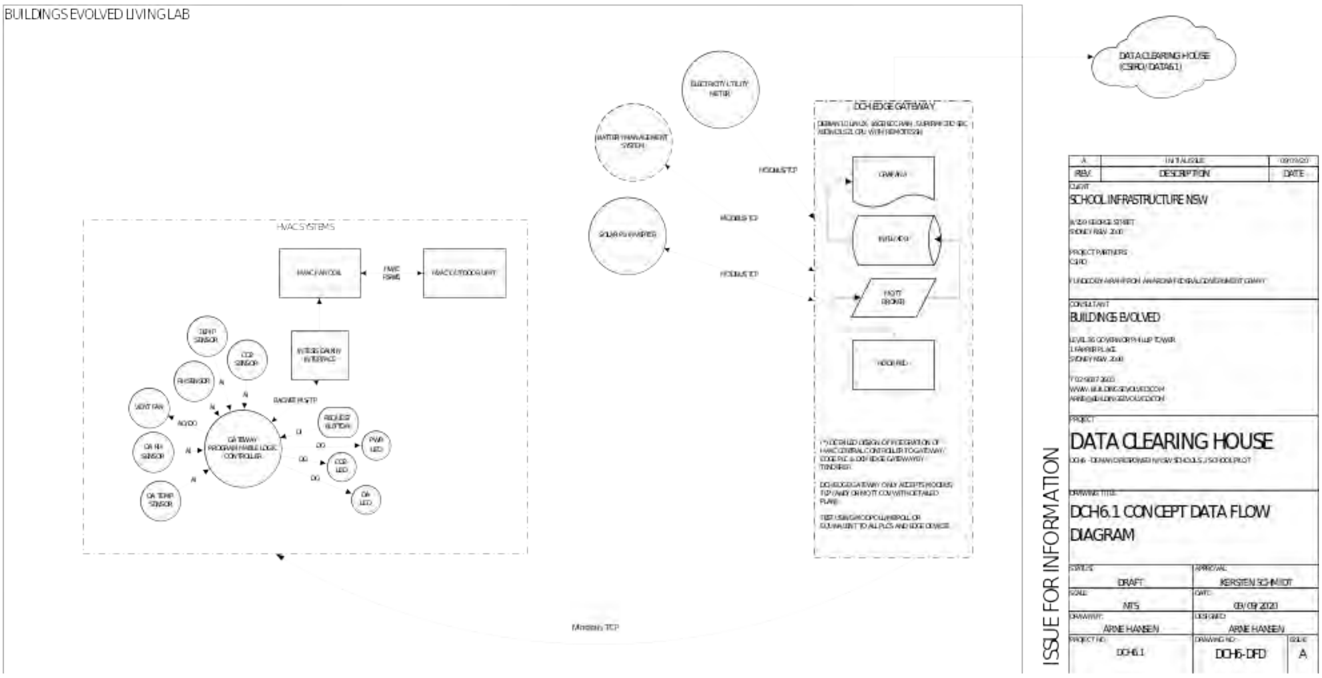


Figure 1: living lab - data flow diagram

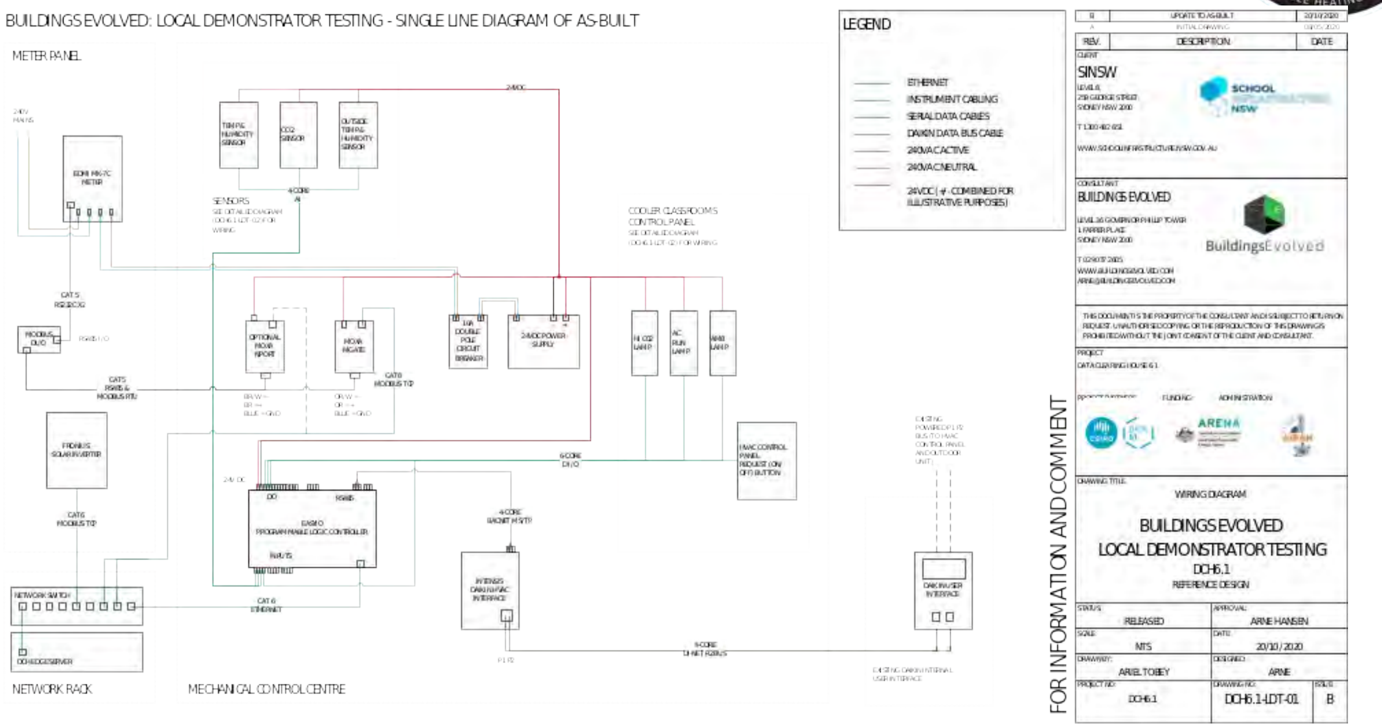


Figure 2: living lab - single line diagram

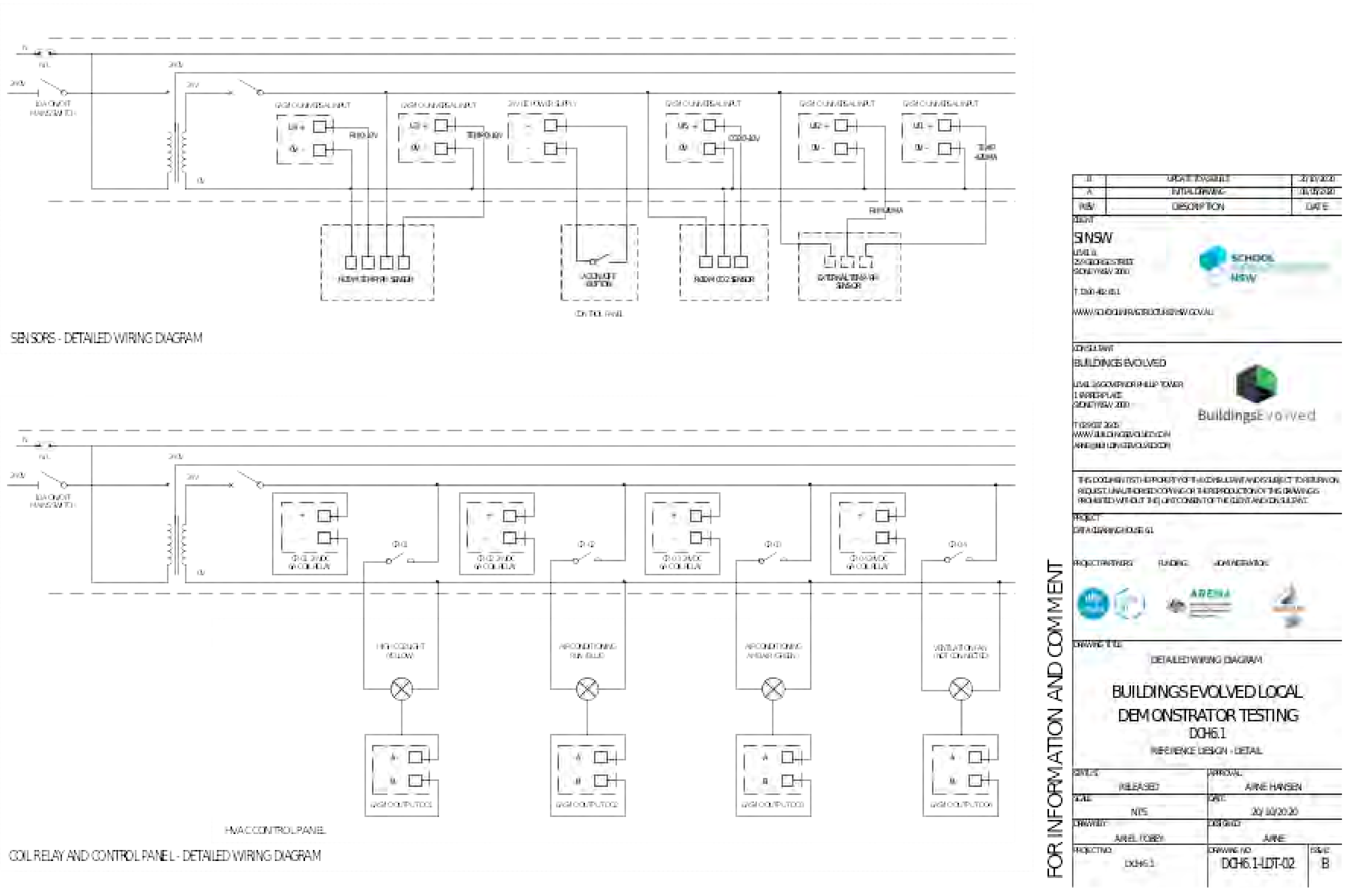


Figure 3: living lab - detailed wiring diagram - PLC I/O

2.4 Hardware stack

PLC & Mechanical Control Centre

The image in Figure 4 shows the EasyIO controller, Intesis and Moxa devices, and power supply with relays.

1. The EasyIO PLC provides the programmatic control of air-conditioning set points via the Intesis MS/TP gateway. As well inputs for sensors & request button, and outputs for the LED indicator lights.
   Note: in schools, the function of turning the PAC HVAC unit on/off is via a contact closure only. The lab opted for the high-level control to simulate functionality available from a central control module from the HVAC vendor.
2. The Intensis to BACnet gateway converts the proprietary air-conditioning protocol (Daikin RC NET) into BACnet MS/TP for use in the overarching system.
3. The Moxa mGate and nPort devices convert the electricity meter data into Modbus RTU serial data for use in the overarching system. The nPort is used for programming and debugging of the meter, and would not appear in a production environment.
4. The power supply provides 240VAC to 24VDC conversion to all applicable devices.
5. The power relays switch 24VAC for the LED lamps on the air-conditioning control panel.

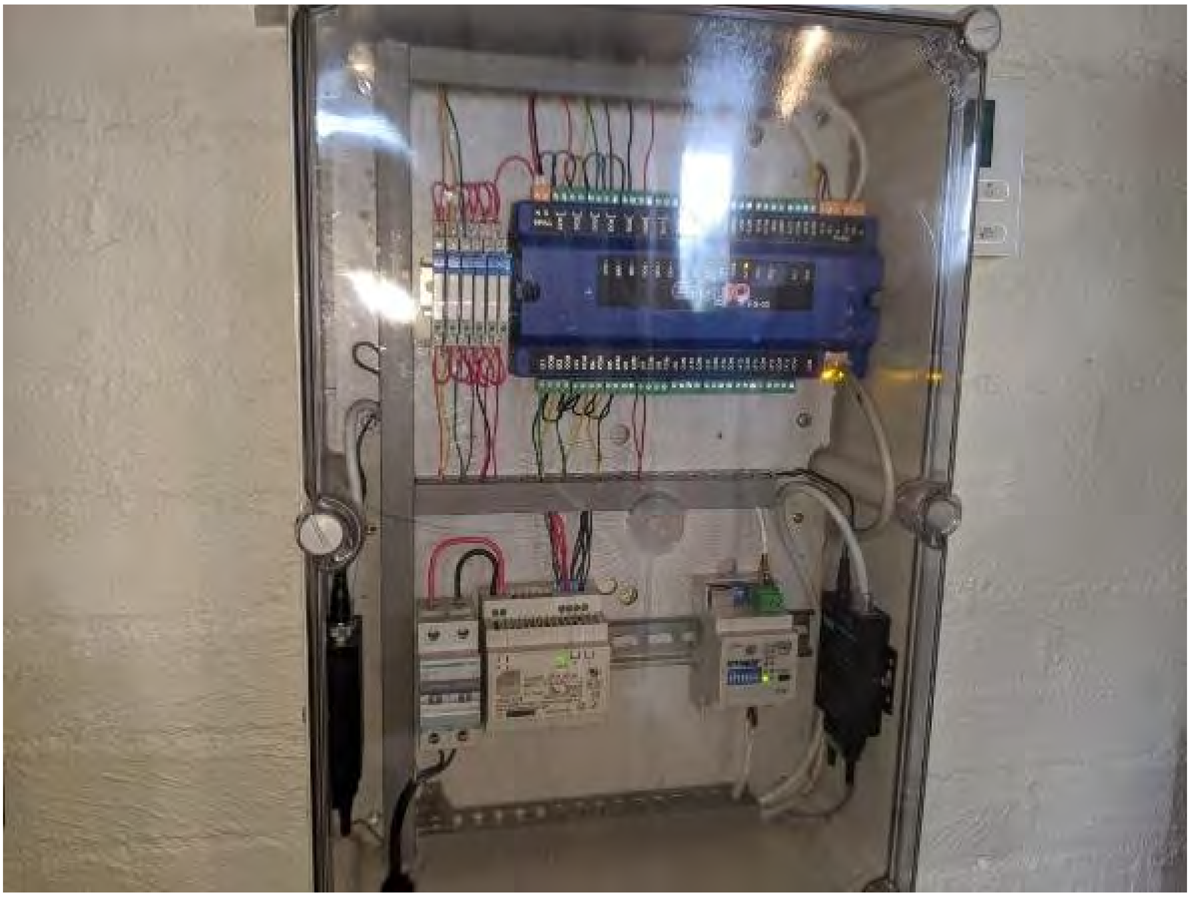


Figure 4: living lab - mechanical control centre (MCC)

The image in Figure 5 shows the EasyIO controller communication points:

1. Universal inputs,
2. Universal outputs,
3. RS485 communications, and

4. Network communications ports.

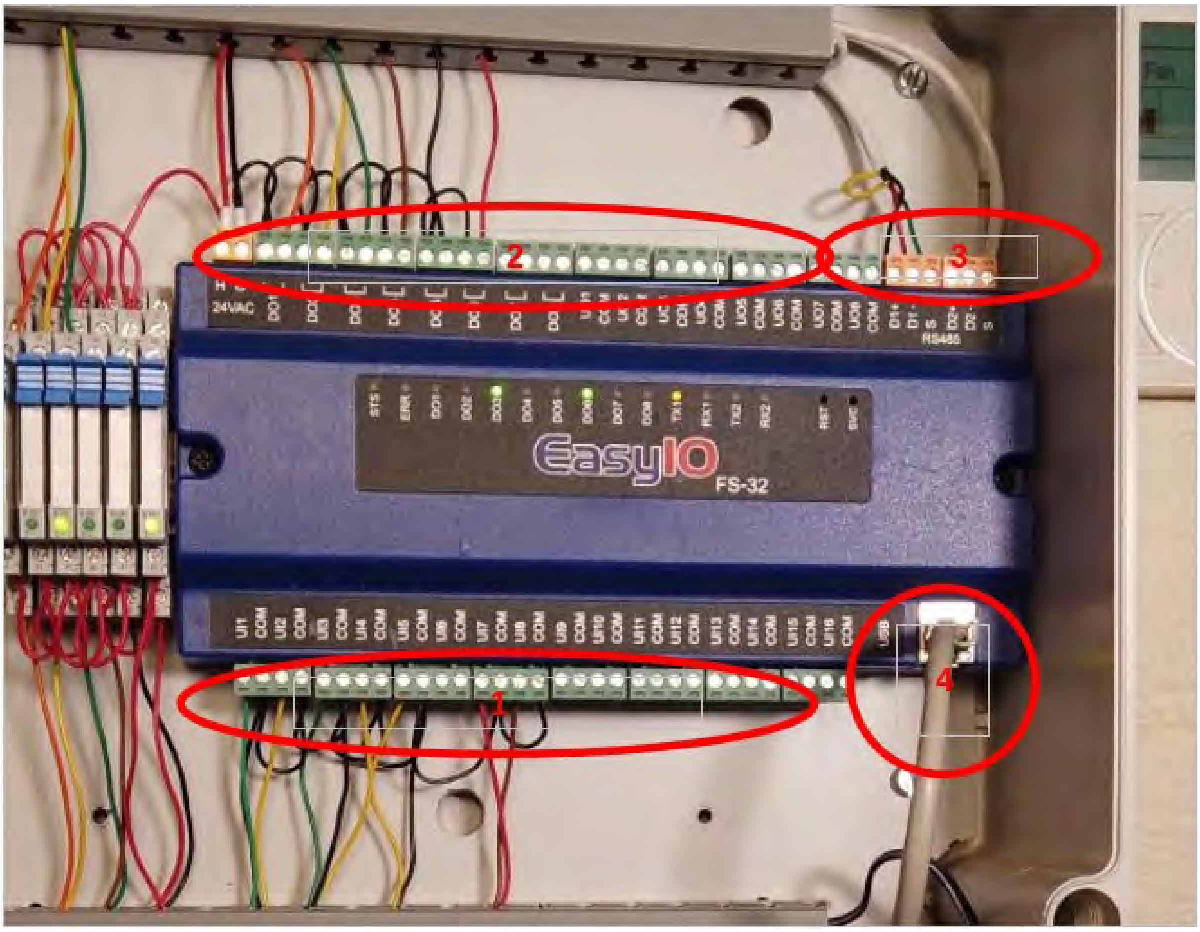


Figure 5: living lab - PLC I/O arrangement

PLC Programming

This has allowed Buildings Evolved to recreate the requirements of the schools as stipulated in the CCP design guidelines, and has further allowed the R&D team to test the interaction between components for integration.

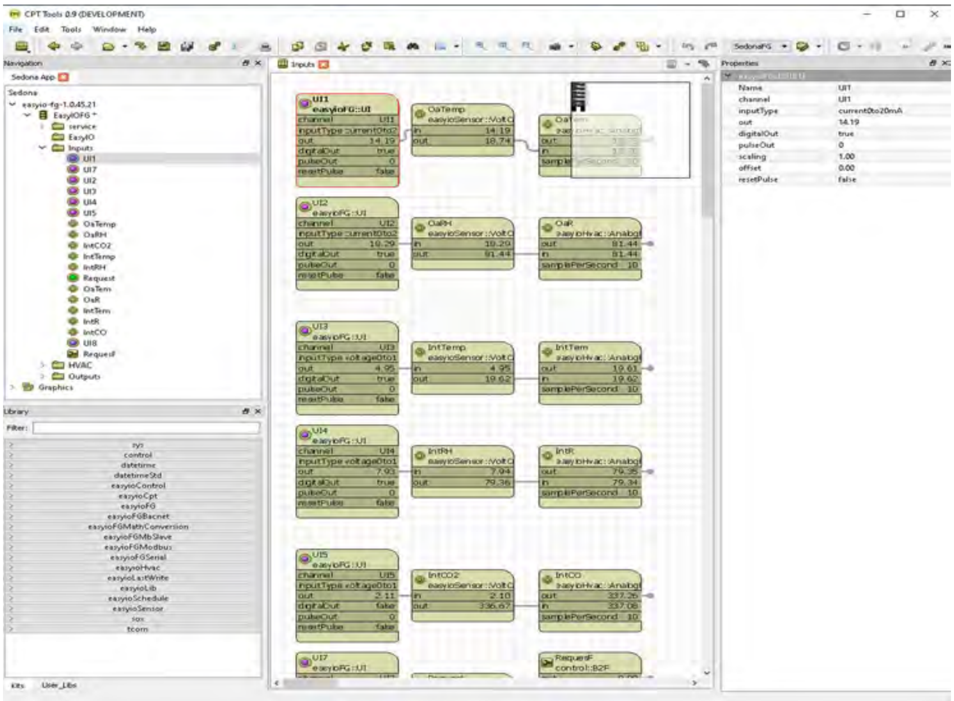


Figure 6: living lab - PLC inputs, converted to real values with analogue filters applied

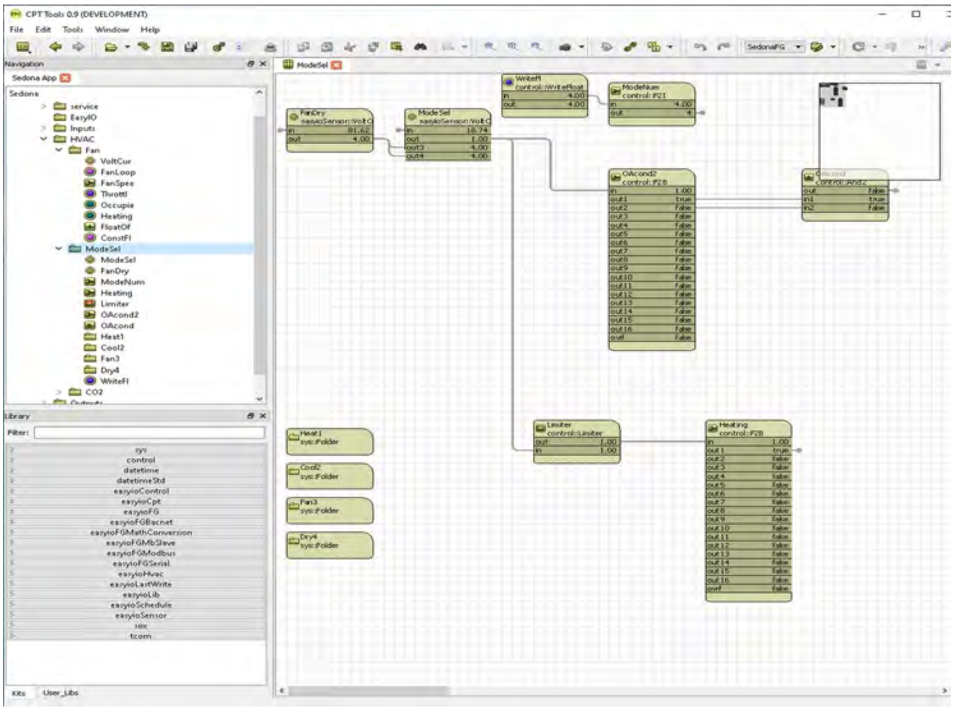


Figure 7: living lab - CPT-Tools showing auto-mode selection R&D work

Internal temperature, humidity and CO2 sensors

Air-conditioning control panel

Figure 9 is a picture of the air-conditioning control panel that has been installed internally that provided high level communications and control of the system.

Figure 9: living lab - cooler classrooms program typical control panel; blue = on/off, green = outdoor conditions OK, orange = CO2 levels high

External temperature and humidity sensor

The image in Figure 10 is of the external temperature and humidity sensor installed on the external wall of the building. The purpose of this sensor is to communicate external temperature and humidity values to the EasyIO PLC used to manage set-points, modes and communicate favourable conditions to occupants in response to external conditions. The outdoor temperature and humidity sensor was ordered as a impedance (4-20mA) output to provide diversity of sensor types into the PLC. Functionally both voltage and current sensors provide the same result/output.

Figure 10: - outdoor temperature & humidity sensor

Fronius solar PV inverter

The image in Figure 11 is of the Fronius Inverter that is networked to the controller. This provides generation data used for control functions used in the overarching system. An Ethernet cable was run to the inverter back to the central network that the DCH edge server can access. Communications is via Modbus TCP using the SunSpec schema.

Figure 11: - Fronius solar PV inverter via modbus TCP

EDMI electricity meter

The image in Figures 12 and 13 is of the EDMI electricity meter that communicates interval values from the Essential Energy electricity meter as 1:1 values. This information provides electricity consumption data used in the overarching system.

Figure 12: living lab - private EDMI meter located below main meter panel

Figure 13: living lab - EDMI utility meter and modbus RTU adaptor

DCH edge server

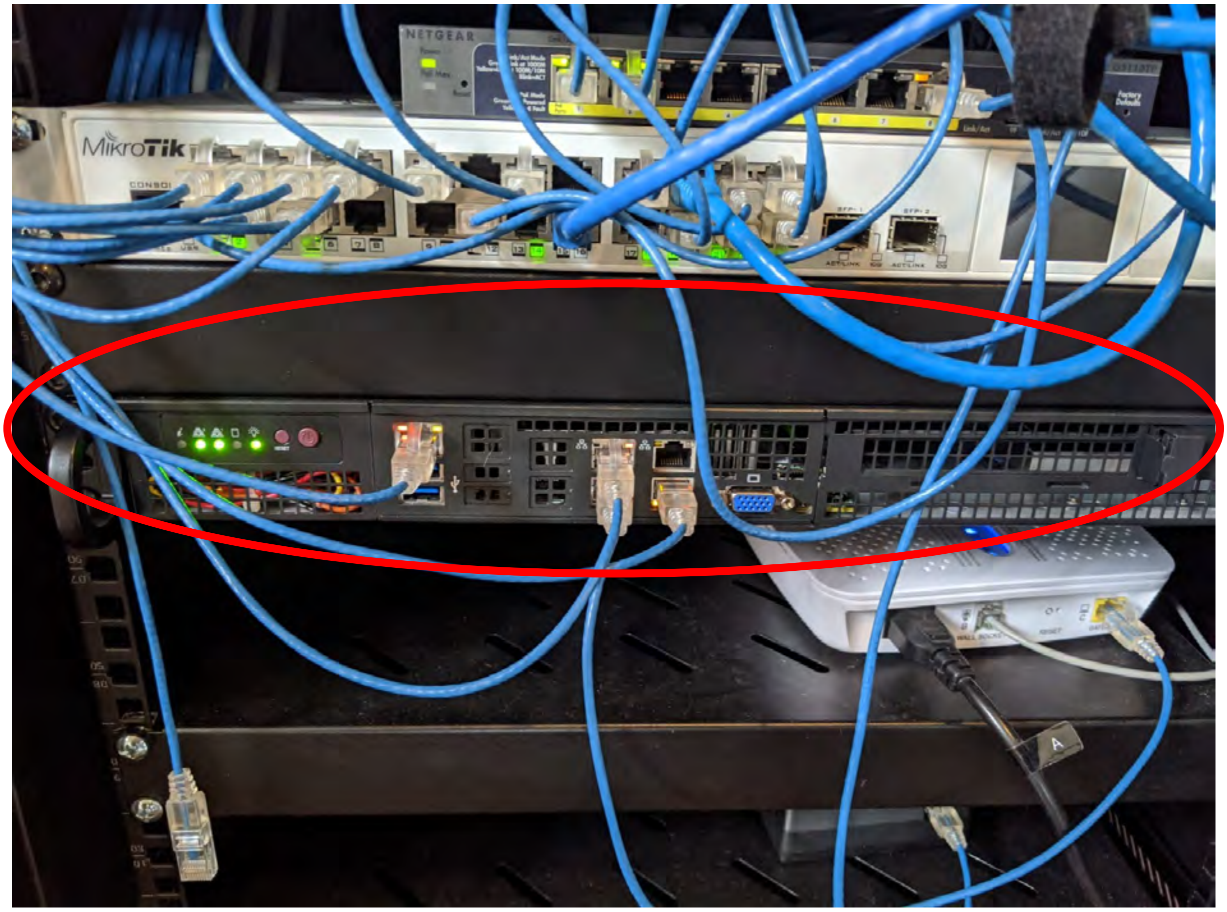
The image in Figure 14 is of the DCH Edge Server (Supermicro X10SDV-6C+-TLN4F based SuperServer). Initially, the server ran Debian 10 Linux and Docker containerisation. Docker was used to rapidly test different bundled applications and services for consideration for use in the living lab, and ultimately the software stack to be applied to the schools to provide connectivity to the DCH. Docker stacks were built using docker-compose yaml files and deployed to the server. These stacks included InfluxDB, Node-Red, Telegraf, Chronograf, Mosquitto, Grafana, Freeboard and other supporting containers.

Following the initial prototyping using Debian 10 and Docker containers, the server was migrated to Proxmox-VE, a Debian 11 based virtualisation environment (Figure 15). The VE hosts Linux eXecution Containers (LXC) and Virtual Machines (VMs) as required to execute the functions of the living lab. Ultimately, all services have been broken down into several core LXCs including:

- Time series database: InfluxDB 2.0
- Flow programming tool: Node-red 2.2
- Time-series visualisation tool: Grafana 8.4.3
- MQTT message broker (local): Mosquitto

Other elements of the TICK stack (Telegraf, Influx, Chrongraf, Kapacitor) have also been tested, but have limited utility in this application aside from telegraf extracting edge server performance and usage statistics.

Figure 14: living lab - 1RU Supermicro SuperServer acting as DCH edge server



2.5 Software stack

The DCH Edge Server can handle several R&D outcomes, the principal requirement being to support a flow-based programming tool such as Node-Red, to extract transform and load real-time data from the various components listed above.

Node-red was chosen from several options (Apache Kafka, Apache Airflow, others) due to its ease of programming and similarity to PLC programming tools that the controls industry is familiar with. Indeed, Node-red is built and maintained for Opto22 – a PLC manufacturer. Therefore many standard PLC functions can be achieved with ease using Node-red – in addition to unleashing full JavaScript capability and a vast array of IT friendly functions (or ‘nodes’ in Node-red parlance).

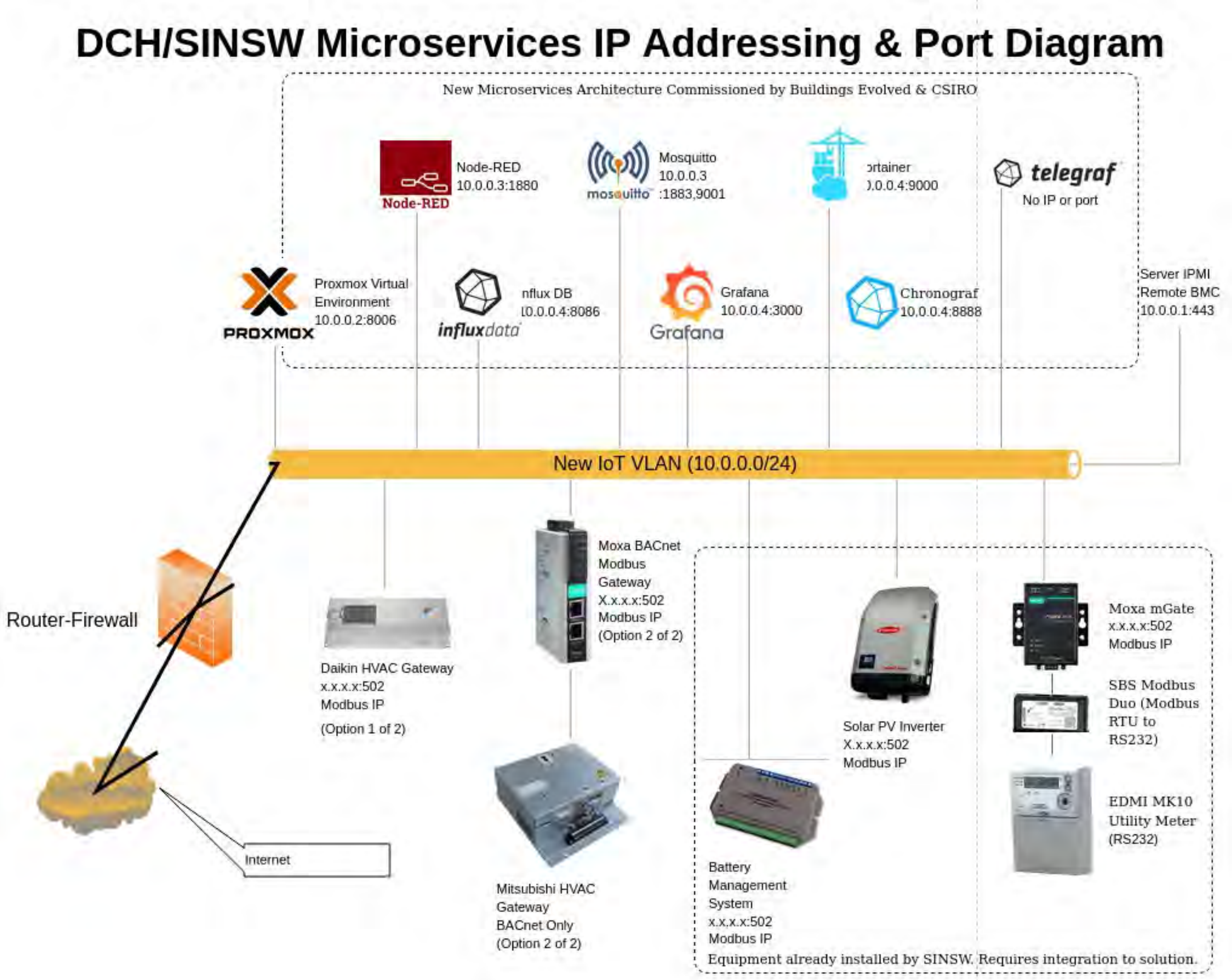


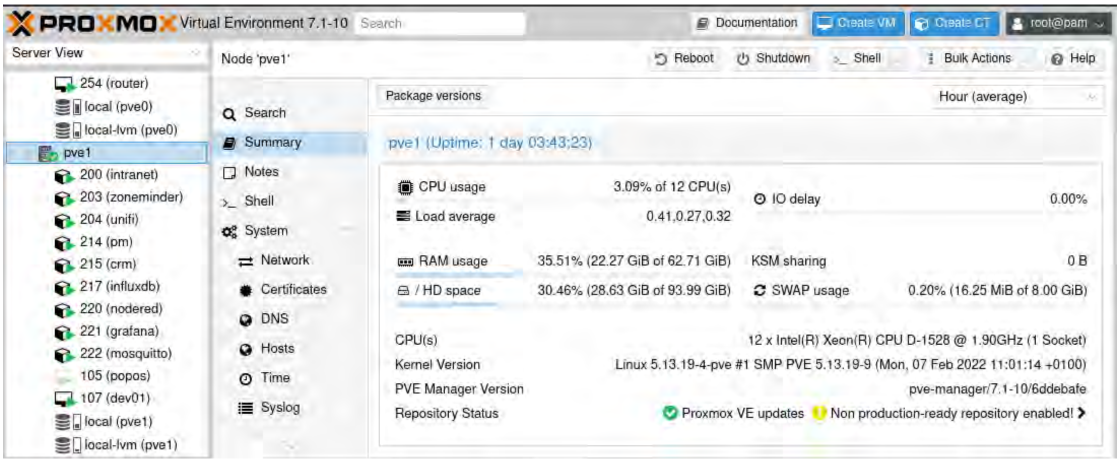
Figure 14: software stack - SINSW controls concept diagram

Our local test demonstrator, in recognition of the existing infrastructure in the schools, opted to host node-red on the gateway device connecting to remote PLCs using low-level modbus – ensuring that existing equipment could be reused regardless of age or capability. This topology was emulated with the EasyIO PLC and EDMI meter providing Modbus IP memory registers that Node-red could poll and parse in identical ways. This same capability can be extended to any similar device: solar PV inverters, battery inverters, and be scaled to any and all network connected PLCs and electricity meters/sub-meters.

The following statements explain the topology and connection methodology:

1. Node-red is hosted on premise, on a Supermicro SuperServer computer, under a Proxmox-VE hosted LXC. This could be hosted in any number of different existing virtualisation environments, like VMWare, for example, or on “direct metal” for small form-factor & low power gateway devices.
2. Node-red polls the modbus target device for a large number of consecutive memory registers, every 10 seconds. This data is parsed through an array of dead-band filters (more below) to only allow meaningful (changed) data through.
3. Node-red also polls the target modbus devices at every hour, bypassing the dead-band filters (more below).
4. The buffer parser (flow) specification is loaded into the flow on start and it specifies offset positions for each data point, along with names and other metadata that can be used usefully later.
5. The memory buffer created from the polling is placed through a buffer parser, reading the buffer parser specification. This creates JavaScript objects with attached metadata.
6. If the data is Float 32, the number is rounded to either 1 or 2 decimal places.
7. An array of dead band filters are applied to the data generated from the 10 second poll. Different steps are applied to different JavaScript objects (specified in the object catalogue), allowing different granularity (resolution) of data to be stored. Useful resolutions for the demonstrator test are 0.1, 1, 10 and 100. For example, electrical frequency sensor uses 0.1, CO2 uses 10, while apparent power (watts) uses 100.
8. A separate, on-the-hour, polling method exists to create regular time-series interval data, in this case every 1 hour. This deliberately bypasses the dead-band filters to create regular time-series data, useful for testing, but also useful for dashboards which requires data within the query window to render charts or outputs.
9. The polled data, either filtered or unfiltered, is then used to generate payloads – one for the DCH and the other for the local time series database: InfluxDB.
10. The generated payloads are sent either to the DCH MQTT broker (marked SENAPS), or to the local InfluxDB instance. In our example, we are also sending messages to a local MQTT broker (marked LOCAL)
11. Higher frequency/resolution data can be stored on premise versus sending to DCH. In our example below, we have parity between the two, but has been set differentially during the R&D phase of the project.

Proxmox-VE



pve1 (Uptime: 1 day 03:43:23)

CPU usage 3.09% of 12 CPU(s)
Load average 0.41,0.27,0.32
IO delay 0.00%
RAM usage 35.51% (22.27 GiB of 62.71 GiB)
/ HD space 30.46% (28.63 GiB of 93.99 GiB)
KSM sharing 0 B
SWAP usage 0.20% (16.25 MiB of 8.00 GiB)
CPU(s) 12 x Intel(R) Xeon(R) CPU D-1528 @ 1.90GHz (1 Socket)
Kernel Version Linux 5.13.19-4-pve #1 SMP PVE 5.13.19-9 (Mon, 07 Feb 2022 11:01:14 +0100)
PVE Manager Version pve-manager/7.1-10/6ddebafe
Repository Status Proxmox VE updates Non production-ready repository enabled!

Figure 15: software stack - Proxmox-VE web page with containers and VMs used for R&D

Node-red: Node.JS flow programming

The DCH Edge Server can handle several R&D outcomes, the principal requirement being to support a flow-based programming tool such as Node-Red, to translate data from the various components listed above.

The flow for various data streams in the BE Lab are described in this high-level way:

1. sensors → (analogue) → EasyIO PLC → (modbus TCP) → Node-red → (MQTT) → DCH
2. HVAC package unit → (BACnet MS/TP) → EasyIO PLC → (modbus TCP) → Node-red → (MQTT) → DCH
3. utility meter → (modbus TCP) → Node-red → (MQTT) → DCH
4. solar PV → (modbus TCP) → Node-red → (MQTT) → DCH

In schools, the HVAC PAC data will not flow through the PLC, but via a central controller. Therefore the overall summary for the schools is:

1. sensors → (analogue) → PLC → (modbus TCP) → Node-red → (MQTT) → DCH
2. HVAC zone → HVAC central controller → (modbus TCP) → Node-red → (MQTT) → DCH
3. utility meter → (modbus TCP) → Node-red → (MQTT) → DCH
4. solar PV → (modbus TCP) → Node-red → (MQTT) → DCH
5. battery system → (modbus TCP) → Node-red → (MQTT) → DCH

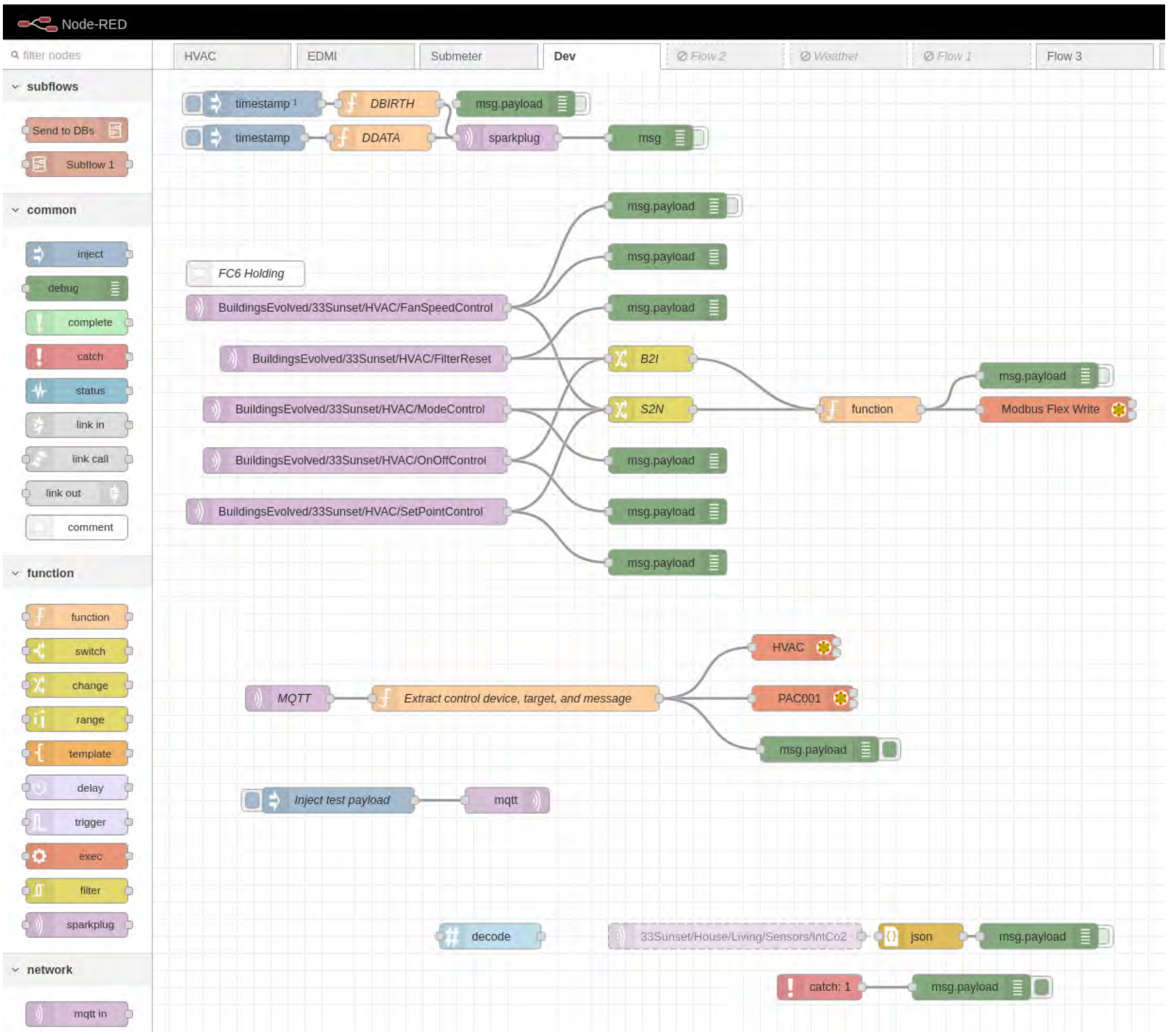


Figure 16: software stack - Node-red flow during R&D phase

Figure 16 depicts an in progress flow program for R&D purposes for HVAC and PLC data. It shows how Modbus data is acquired from the HVAC and PLC system, and converted into MQTT messages for ingestion by the DCH. Also shown are stubs for Sparkplug-B, and a group of functions to test DBIRTH and DDATA messages. Also shown is receiving MQTT payloads to set values on devices via Modbus (control in reverse).

Node-red: object catalogue

The assets need to be declared in Node-Red to provide identification to the data being received. Figure 17 shows the “object catalogue” which sets context and specifications for processing through node-red. Stubs for sparkplug names are noted.

```
flow.set(
    'spec',
    {
      "options": {
        "byteSwap": [],
        "resultType": "value",
        "singleResult": false,
        "msgProperty": "payload",
        "setTopic": true
      },
      "items": [
          {
              "type": "uint8",
              "name": "dch/Bellingen/BuildingsEvolvedB001/generic/PAC001",
              // sparkplug "name": "HVAC.ErrorActive/unit8",
              "pointname": "ErrorActive",
              "parentname": "PAC001",
              "offset": "1",
              "length": "1",
              "offsetbit": "0",
              "mask": "",
              "units": "boolean"
          },
          {
              "type": "uint8",
              "name": "dch/Bellingen/BuildingsEvolvedB001/generic/PAC001",
              // sparkplug "name": "HVAC.ErrorAddress/uint8",
              "pointname": "ErrorAddress",
              "parentname": "PAC001",
              "offset": "3",
              "length": "1",
              "offsetbit": "0",
              "mask": "",
              "units": "N/A"
          },
          {
              "type": "uint8",
              "name": "dch/Bellingen/BuildingsEvolvedB001/generic/PAC001",
              // sparkplug "name": "HVAC.ErrorCode/uint8",
              "pointname": "ErrorCode",
              "parentname": "PAC001",
```

Figure 17: software stack - Node-red object catalogue

Node-red: reading data from systems

For the living lab, and to mimic the proposed solution within schools, Node-red is hosted on premise and is used as the programming to bridge Modbus on the local network school with MQTT in the DCH. Doing so allows high-frequency and relatively high bandwidth polling of Modbus on the local network, with a filter applied to only transmit values when they have changed.

Node-red “programming” looks like this, with each node being a function in node JS, as shown in Figure 18.

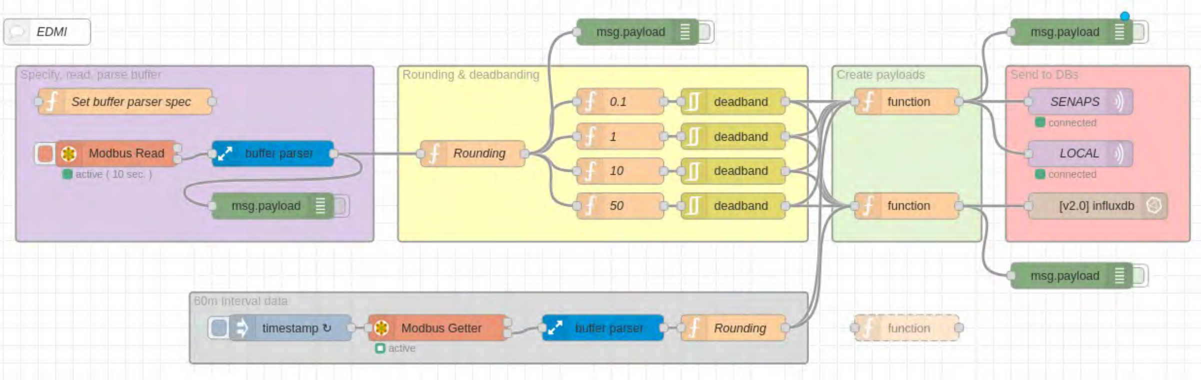


Figure 18: software stack - example flow to poll EDMI meter for data and to send to the DCH and InfluxDB

In this example, we are polling all of the Modbus registers on the EDMI meter, parsing the buffer to create JS objects, round values, dead-band filter the results (change of value), before being assembled into a JSON payload, and in this case, sent to InfluxDB, the DCH and a local MQTT broker. The “set buffer parser spec” is the object catalogue used by the buffer parser to assemble the JS objects.

This “flow” program is for an EDMI electricity meter. It is also exactly the same flow program for HVAC devices, battery inverters & solar PV inverters. Any modbus device will utilise the same essential methodology. The only difference applied to the flow is what is contained in the flow spec, and the configuration of the modbus reader (which IP address, what memory range).

Green nodes are debug output and can be inserted anywhere in the flow to assist in debugging.

It is planned to move some of these functions into their own nodes for deploying at scale.

Once a buffer has been parsed using the object catalogue specification shown in Figure 17, a JS object is created in Node-red for processing and sending to the target (DCH/local time-series db) as shown in Figure 19.

```
10/21/2020, 4:09:41 PM   node: 83123cd9.7af348
dch/Bellingen/BuildingsEvolvedB001/generic/PAC001
msg.payload : Object
 ▾object
   $schema: "http://csiro.au/dch/bms-
   json/schema-draft-05.json"
  ▾point: object
     pointName: "FanSpeed"
     timestamp:
     "2020-10-21T05:09:39.658Z"
     currentValue: 2
     parentName: "PAC001"
   ▸ facets: object
```

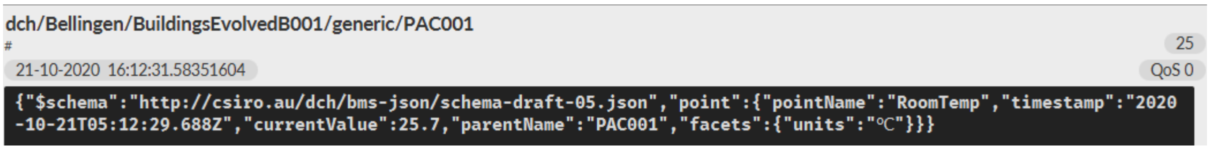
Figure 19: software stack - a single JS object in Node-Red debugging window

Node-red: OASIS Sparkplug B

During the R&D phase we experimented with sending to the DCH using the DCH JSON payload schema, and also the Sparkplug B schema to test interoperability with many other systems that utilise Sparkplug B (particularly, SCADA systems).

Sparkplug is an OASIS published protocol for payloads and transmission of operational technology data to remote servers using MQTT as transport. It describes methods of compressing data-streams using Google Protobuf, the payload contents, structure and format as well as topic structure.

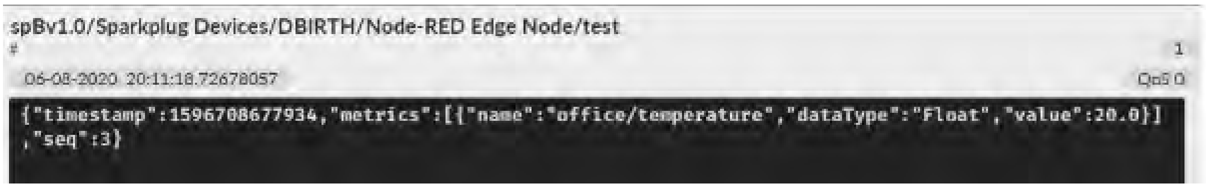
The R&D process covered testing sparkplug B schema, for comparison with that adopted by CSIRO in the DCH as shown in Figures 21, 22 and 23.



dch/Bellingen/BuildingsEvolvedB001/generic/PAC001
#
21-10-2020 16:12:31.58351604
25
QoS 0

```
{"$schema":"http://csiro.au/dch/bms-json/schema-draft-05.json","point":{"pointName":"RoomTemp","timestamp":"2020
-10-21T05:12:29.688Z","currentValue":25.7,"parentName":"PAC001","facets":{"units":"ºC"}}}
```

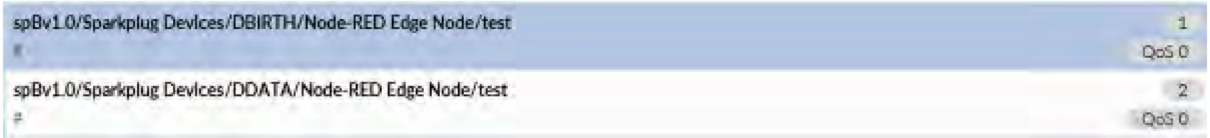
Figure 20: software stack - MQTT payload to send data to DCH using CSIRO JSON schema



spBv1.0/Sparkplug Devices/DBIRTH/Node-RED Edge Node/test
#
06-08-2020 20:11:18.72678057
1
QoS 0

```
{"timestamp":1596708677934,"metrics":[{"name":"office/temperature","dataType":"Float","value":20.0}]
,"seq":3}
```

Figure 21: software stack - MQTT Sparkplug B payload



spBv1.0/Sparkplug Devices/DBIRTH/Node-RED Edge Node/test
#
1
QoS 0

spBv1.0/Sparkplug Devices/DDATA/Node-RED Edge Node/test
#
2
QoS 0

Figure 22: software stack - testing DBIRTH and DDATA message types

The conclusion was that a standardised approach to generating and sending payloads to the DCH would be optimum, or more likely, supporting multiple methods would be the likely outcome.

Node-red: writing data to systems

The flow program in Figure 23:

1. queries datastreams contained in the DCH for the PMV Upper and PMV Lower temperatures (Predicted Mean Vote) using the DCH API to do so.
2. converts values to a rolling average,
3. forms a JSON payload consistent with the schema used to send data to the DCH.
4. payload is then sent to the local MQTT broker on the correct topic

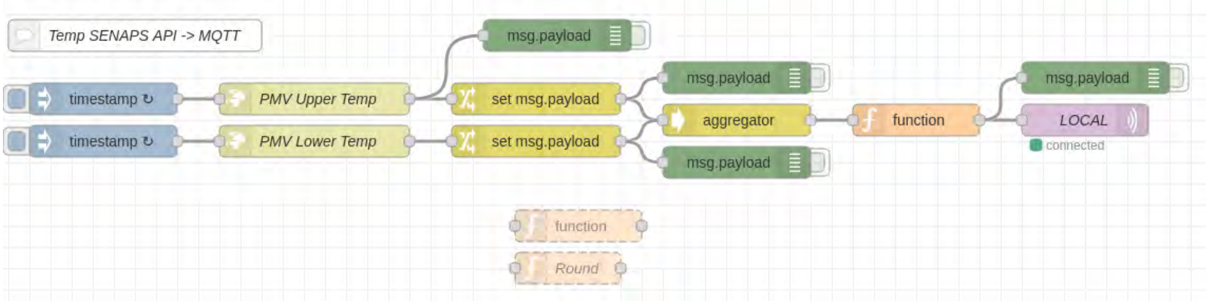


Figure 23: software stack - Node-red reading values from DCH via web API

A separate function block reads MQTT messages from the local MQTT broker, extracts metadata from the JSON payload, and then defines where to send the Modbus signals, and to what address. The value is then relayed to the correct memory register on the target device. In this case, the program affects the set point temperature in the main zone of the living lab.

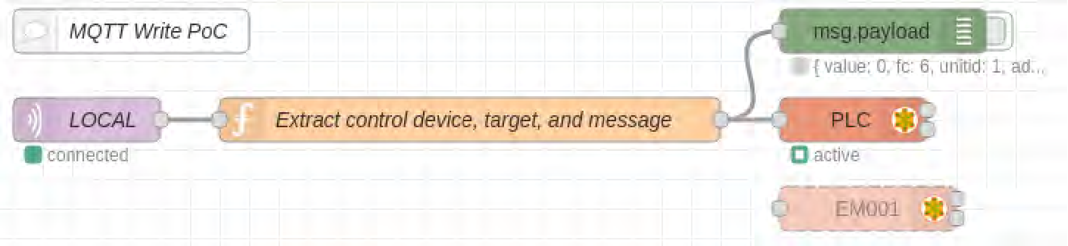


Figure 24: software stack - Node-red reading MQTT topics, generating and sending modbus commands to target device

Node-red: notes

BACnet IP has been tested during the R&D phase of this project. Indeed, BACnet MS/TP is used as a protocol between the PLC and HVAC system, and the PLC and lighting control system. However, BACnet IP support in target devices was found to be inconsistent, latency was problematic, and payload size was unmanageable. In addition, BACnet IP traversing NSW Schools IT infrastructure was far more problematic than regular TCP/IP traffic (such as Modbus TCP) which can be monitored and regulated using standard IT equipment. Latency is so problematic with BACnet (in general), that with 20:20 hindsight, the project would have used Modbus interfaces throughout simply for this reason alone. Modbus, while antiquated, is also extremely simple and reliable, as this project has once again proven.

Node-red has an immediate advantage being a flow based programming tool in that it is similar to what PLCs use, so is a familiar type of programming for industry to grasp. Opto22 maintain node red, and build a PLC using it as the programming environment (i.e. they just have additional nodes for direct I/O on the device).

For our testing purposes, HVAC and PLC sensor data are already unified prior to ingestion by Node-red. Testing of scalability has been run using the EDMI meter as an alternate device that node-red polls in the lab environment.

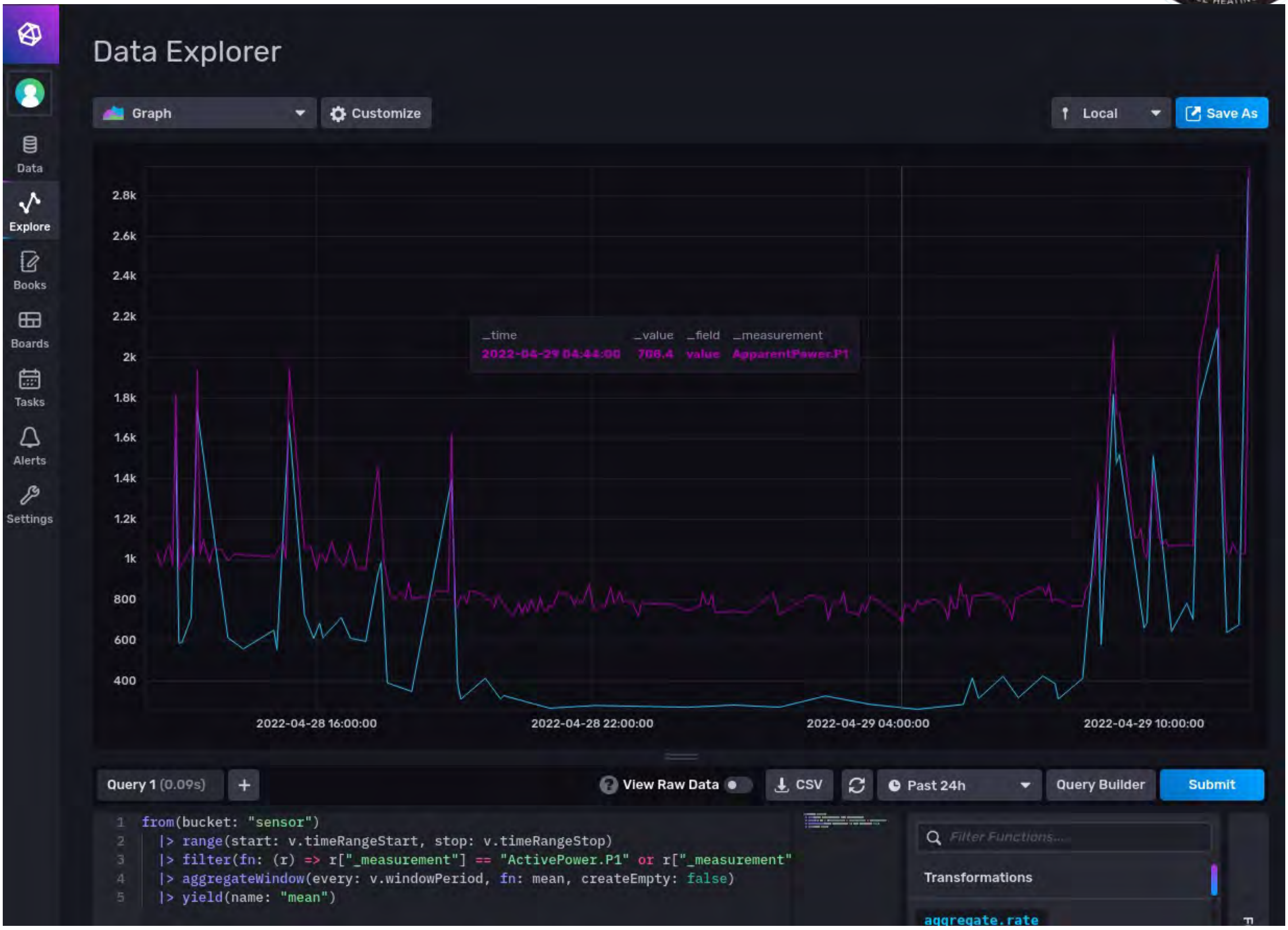
2.6 InfluxDB

InfluxDB is an open-source time-series database that competes with Prometheus, TimescaleDB amongst others. It is different from a flat file database, such as MongoDB, in that it includes a query language aimed at dealing with time series datasets. It is considered part of the “TICK” stack: Telegraf, Influx, Chronograf, Kapacitor.

A local time-series database is included in the scope as it provides a potential replacement methodology for providing a historian functionality at higher resolution than that provided to the DCH. Historians are a core part of BMS systems. As we will show, the advantage of incorporating operational technology data with an information technology workflow is that server and network performance can be monitored alongside plant and equipment.

InfluxDB inputs are typically designed to operate at a sample rate of 10 seconds – vastly more frequent than the multiple minutes seen in the electricity market or BMS industry, and vastly more than would typically be required to execute any optimisation, reporting or measurement/verification function. This data is typically consumed by engineers and contractors that are visiting site that may require more detailed information in order to diagnose a fault with more accuracy.

The default data sampling rate of 10 seconds implies massive scalability, and because that data is stored on site, has minimal cost associated with it. The database has the ability to summarise data automatically into new buckets using InfluxDB Tasks coupled with Flux queries, and purge data older than x number of days – automating the curation of the datasets as required by the project.



_time	_value	_field	_measurement
2022-04-29 04:44:00	706.4	value	ApparentPower.P1

```
from(bucket: "sensor")
  |> range(start: v.timeRangeStart, stop: v.timeRangeStop)
  |> filter(fn: (r) => r["_measurement"] == "ActivePower.P1" or r["_measurement"]
  |> aggregateWindow(every: v.windowPeriod, fn: mean, createEmpty: false)
  |> yield(name: "mean")
```

Figure 25: InfluxDB - data explorer showing Flux query language

InfluxDB uses a bespoke query language called Flux that is designed to deal with time series data, allowing on-the-fly calculations with minimal effort. Data can be aggregated into windows, difference can be calculated between intervals, and mat calculations can easily be applied.

Figure 25 shows the Influx website, spawned when running Influx as a service. The data explorer tab includes a wizard to show available data streams, and can build queries for use in graphing applications such as Grafana (see below).

Figure 26 shows the data explorer in query builder mode, with the same data as expressed in the Flux query shown in Figure 25. The query builder allows easy exploration of the database structure, tags, fields and measurements.

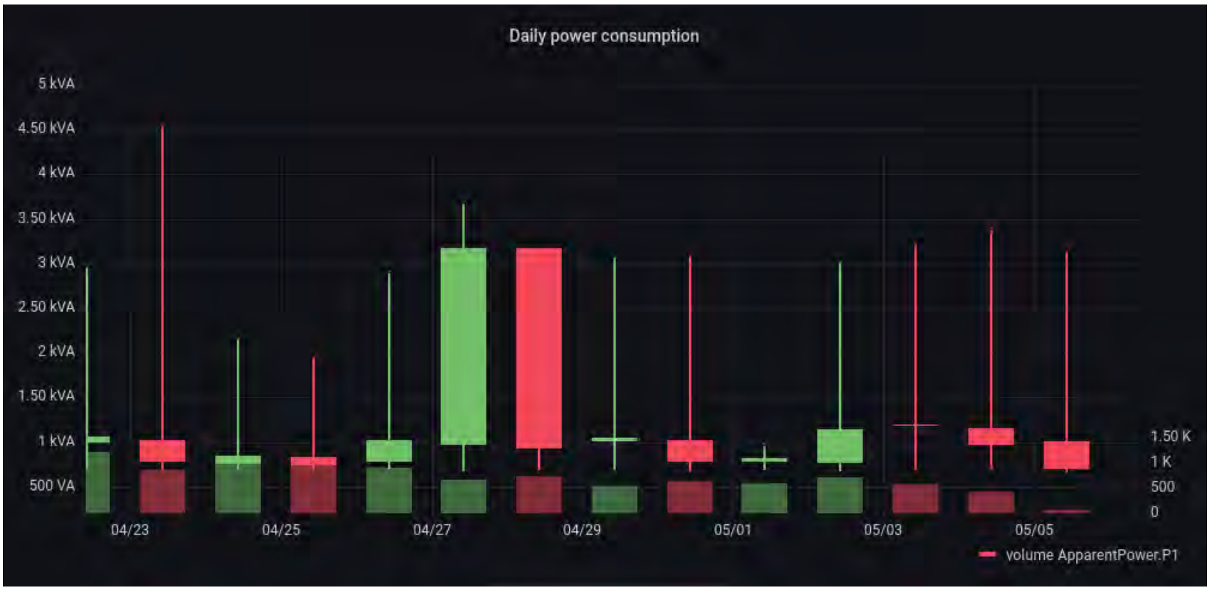


Figure 26: InfluxDB - daily summary of electricity consumption (kVA), showing peak demand and range of consumption per day (displayed in Grafana)

The testing of the software yielded best results with 30 days of detailed history, summarised into daily Open/High/Low/Close (OHLC) which is commonly used to summarise financial ‘tick’ data. Volume therefore is used as the volume of electricity consumed rather than a count of samples taken. This resultant data is then rendered in a candlestick chart (per Figure 26) to monitor range and variance at a higher level, and reducing the required amount of data storage. This can be tailored to suit the particular requirements of a any project. We found limited use for 10 second datasets beyond the 30 day time-frame, as viewing this many data points in one query is problematic, and rendering the results in any meaningful way is impossible. Therefore, InfluxDB is configured to automatically purge detailed data after 30 days, but keep daily summary data indefinitely.

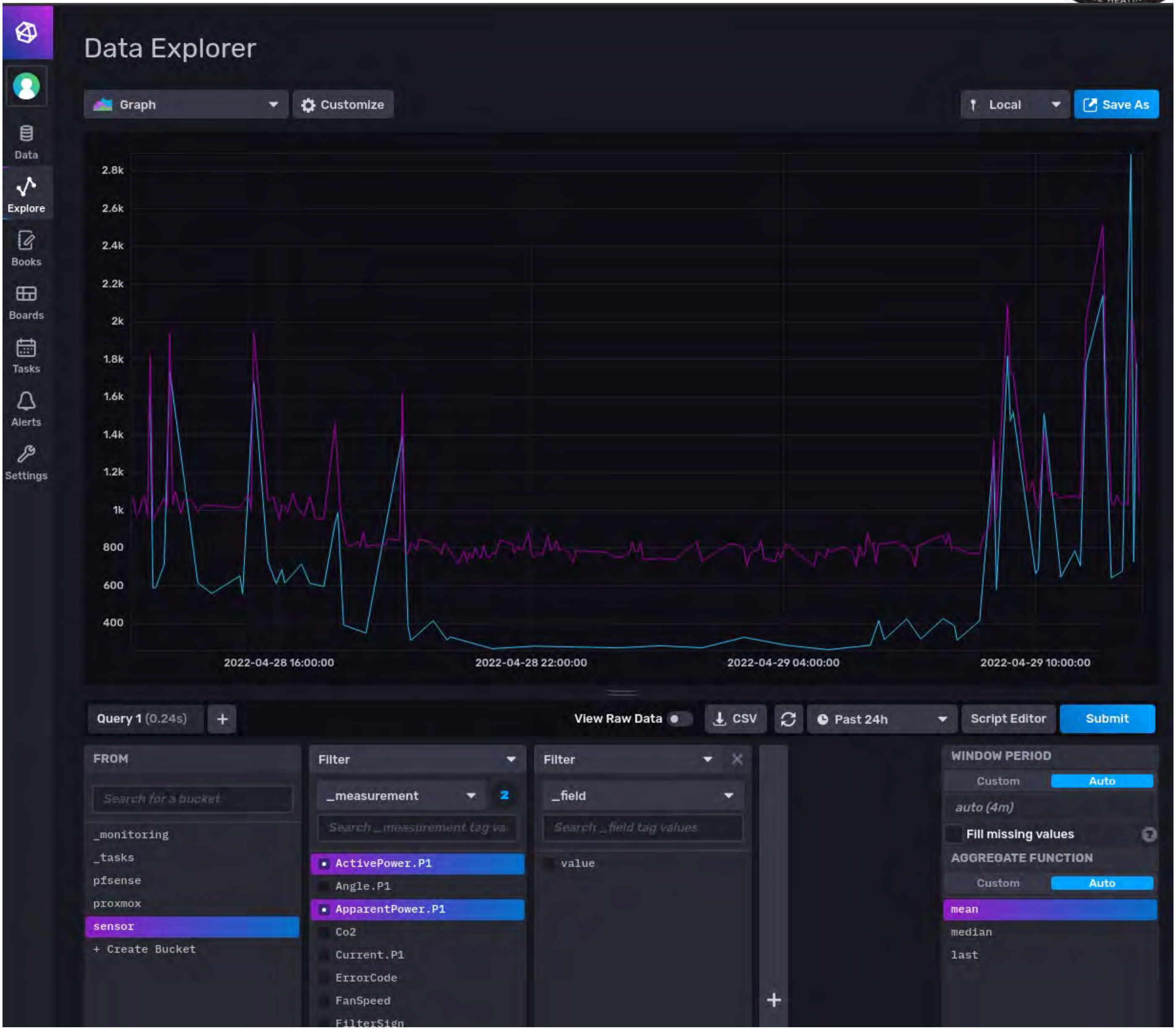


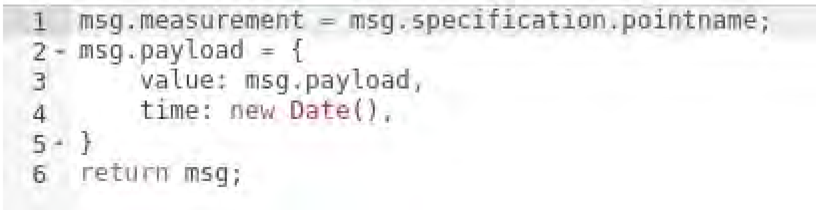
Figure 27: InfluxDB - query builder tool

It was found that building Flux queries was at first difficult, but with the query builder/script editor conversion function, became much easier over time as shown in Figure 27. Documentation for the Flux query language is excellent, but is lacking community support. This matter is confused due to two incompatible scripting languages existing for different versions of Influx DB.

InfluxDB had a major version release during the project, changing query language from InfluxQL to Flux QL, and changing the topology and design of the database quite significantly. Initially, we used v1.8 of InfluxDB, and structured a dashboard using Grafana using the now depreciated InfluxQL. Due to the uplift in performance, query capability and integration with Grafana, we shifted to InfluxDB 2.0 in early 2022. As a consequence, the dashboards in Grafana were rewritten using Flux QL.

InfluxDB: creating payloads in Node-red

Our function node in Node-red to generate the influx JSON payload appears in Figure 28.



```
msg.measurement = msg.specification.pointname;
msg.payload = {
    value: msg.payload,
    time: new Date(),
}
return msg;
```

Figure 28: InfluxDB - Node-red function to create InfluxDB payload

InfluxDB: next steps

The team created an organisation called “be” and a database bucket called “sensor” and started piping data into both DCH and InfluxDB.

Creating an instance of InfluxDB also creates an InfluxDB website (as discussed earlier). This also allows creation of the buckets and API keys required to send data from Node-red to InfluxDB.

InfluxDB 2.0 has many new features that we have no current application for in this project, such as integral alerts and alarms, summary data queries, labelling/attribution. However, these functions could be highly useful for on-site operations teams, engineers and contractors. We would prefer to use the DCH followed by Grafana for such tasks, as the DCH provides broader interoperability with applications and services using a common metadata schema.

InfluxDB: is the “I” in the “TICK” stack

InfluxDB is part of the TICK stack: Telegraf, Influx, Chronograf and Kapacitor.

This project did not use Chronograf or Kapacitor beyond assessing capability and usefulness in this project. Chronograf is equivalent to Grafana in terms of scope and capability, but without the broader interoperability with other database solutions. Grafana is more “open” in the sense that Influx could be replaced with an equivalent such as Prometheus or TimescaleDB without impacting upon the visualisation toolkit, dashboards and alarms.

Kapacitor is for real-time stream processing to generate alerts and alarms, and integrates to the main Influx management website to achieve such outcomes. Again, this functionality shows extensibility of the solution, but also duplicates functions that can be achieved in the DCH using more generalised and higher level tool kits to interrogate the data streams on a less bespoke basis.

Figure 29 shows some examples of the Telegraf plugins available.

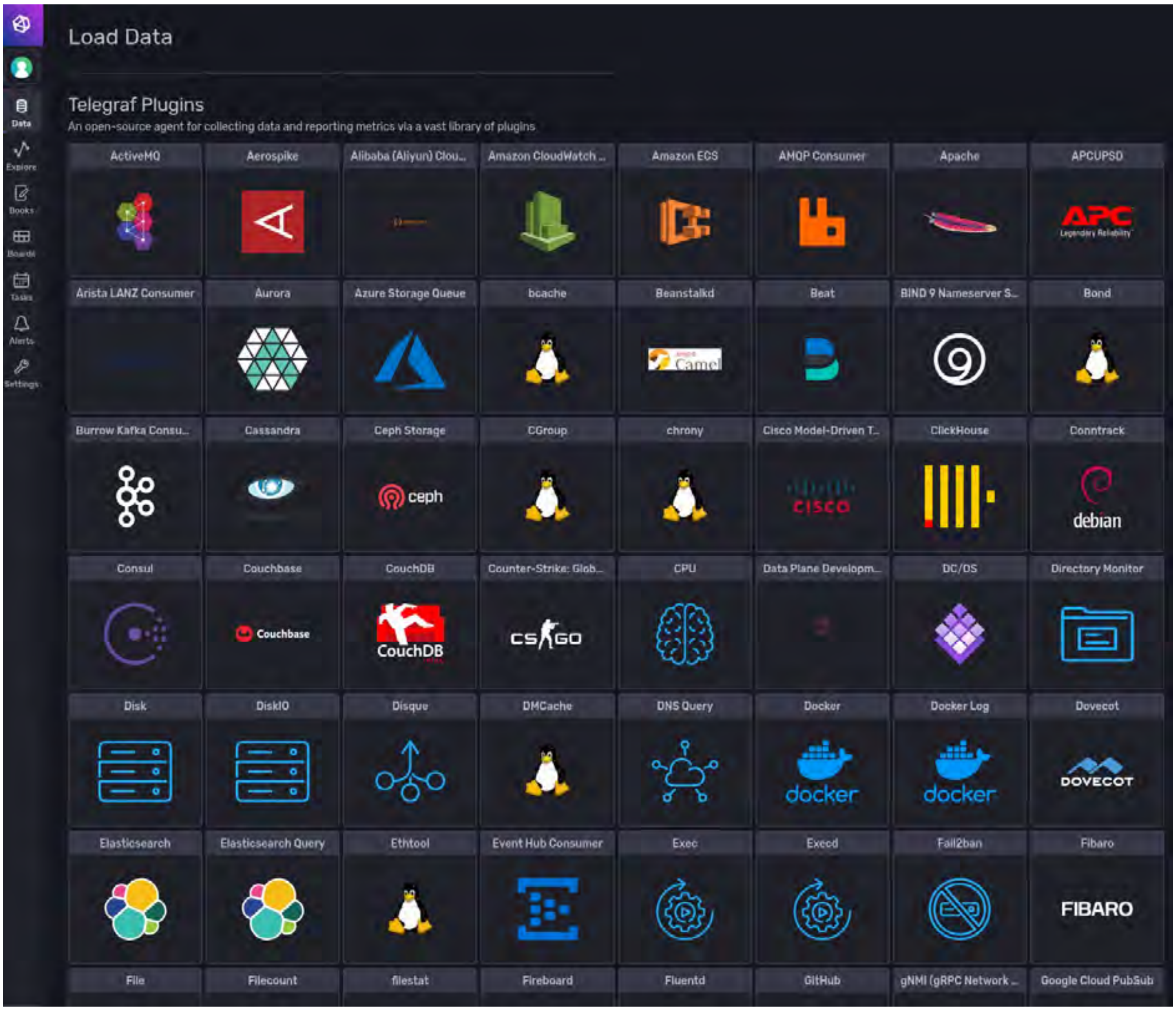


Figure 29: InfluxDB - telegraf plugins list (part of)

In order to test interoperability, the team chose to integrate statistics from Proxmox Virtual Environment (an equivalent to VMWare) & Router data from pfSense via Telegraf, as well as data from the operational equipment sent in via Node-red as shown in Figures 30 and 31.

InfluxDB is a passive entity, requiring remote applications and services to send data to the database (per the way Node-red integrates by sending data to InfluxDB). Telegraf is an application that is therefore installed on each monitored device, and with minimal configuration, sends in datasets that are similar to Simple Network Management Protocol (SNMP). This includes CPU, RAM, disk, network activity, and status of all services/applications.

This activity proves the hypothesis that open-source applications and tools can be leveraged to fully integrate operational technology and information technology datasets into a unified environment for analysis & reporting across all building services. It further proves that the siloing of data between BMS, network, access control and other building services is not done for technical reasons.

dataSource: InfluxDB; pfSense: router.bellohive.com; Disk: All; WAN: All; LAN: All; CPU: All; bucket: pfsense; Gateway: None

CPU

	Mean	Max
cpu0	2%	7%
cpu1	1%	8%
cpu2	1%	9%
cpu3	2%	8%
cpu4	1%	12%
cpu5	1%	6%

Process Information

blocked	idle	sleeping	wait
31	116	16	1

PF Information

Match	State Insert	State
32,119,918	55	1,51

Load

	Mean	Max
load1	0.2	0.5
load15	0.2	0.2
load5	0.2	0.3

Disk Utilization

	Mean	Max
Value	9.25%	9.25%

Ram

	Mean	Max
Memory Used	31.9%	33.6%
Swap Used	0%	0%

Temperature Sensors: min max avg current

WAN Traffic - vtnet1 (Bytes/sec)

	Mean	Last *	Max
Sent	1.83 MB/s	704.53 kB/s	19.32 MB/s
Received	4.72 MB/s	676.32 kB/s	11.80 MB/s

WAN Traffic - ...: Sent 704.53 kb/s; Received 676.32 kb/s

WAN vtnet1: Sent this month 4.52 GiB; Received this month 6.05 GiB

WAN Throughput - vtnet1

	Mean	Last *	Max	Min
Packets Sent	3.78 K	2.28 K	14.59 K	1.39 K
Packets Received	4.91 K	2.18 K	12.54 K	1.35 K

Figure 30: InfluxDB - Grafana dashboard, connected to the same InfluxDB instance, rendering pfSense router data

The router dashboard made use of variables that allow the user to modify the report with ease – these can be seen as drop-down boxes at the top of the screen. This would make re-usable dashboards possible. However, with further use, it was found that the use case worked well for IT equipment, where there is less diversity, than an HVAC system, where there is enormous diversity. Due to the diversity issue, generating reusable dashboards for HVAC equipment is much more problematic and difficult.

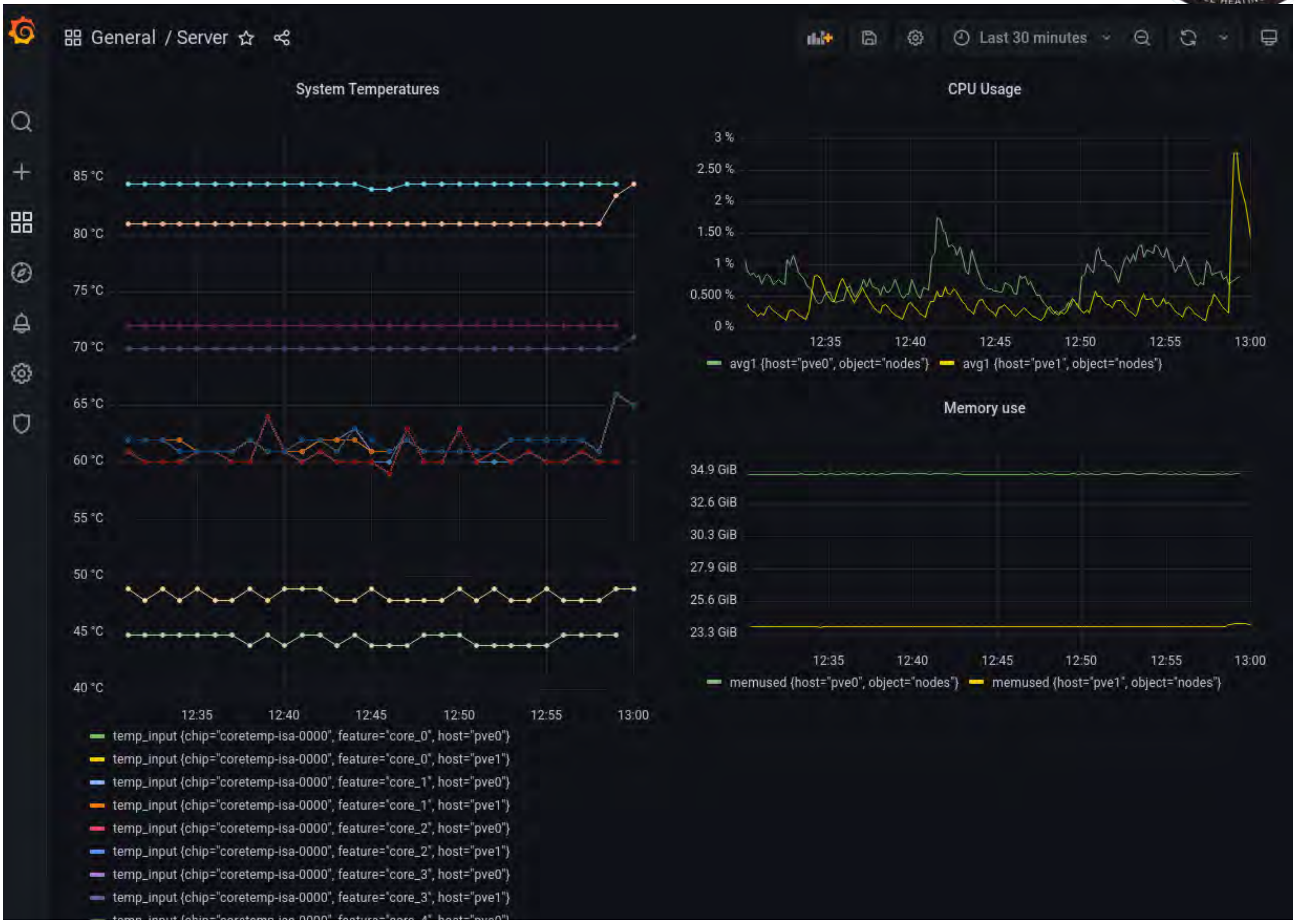


Figure 31: InfluxDB - basic server temperature, CPU & memory use statistics in Grafana via InfluxDB and Telegraf

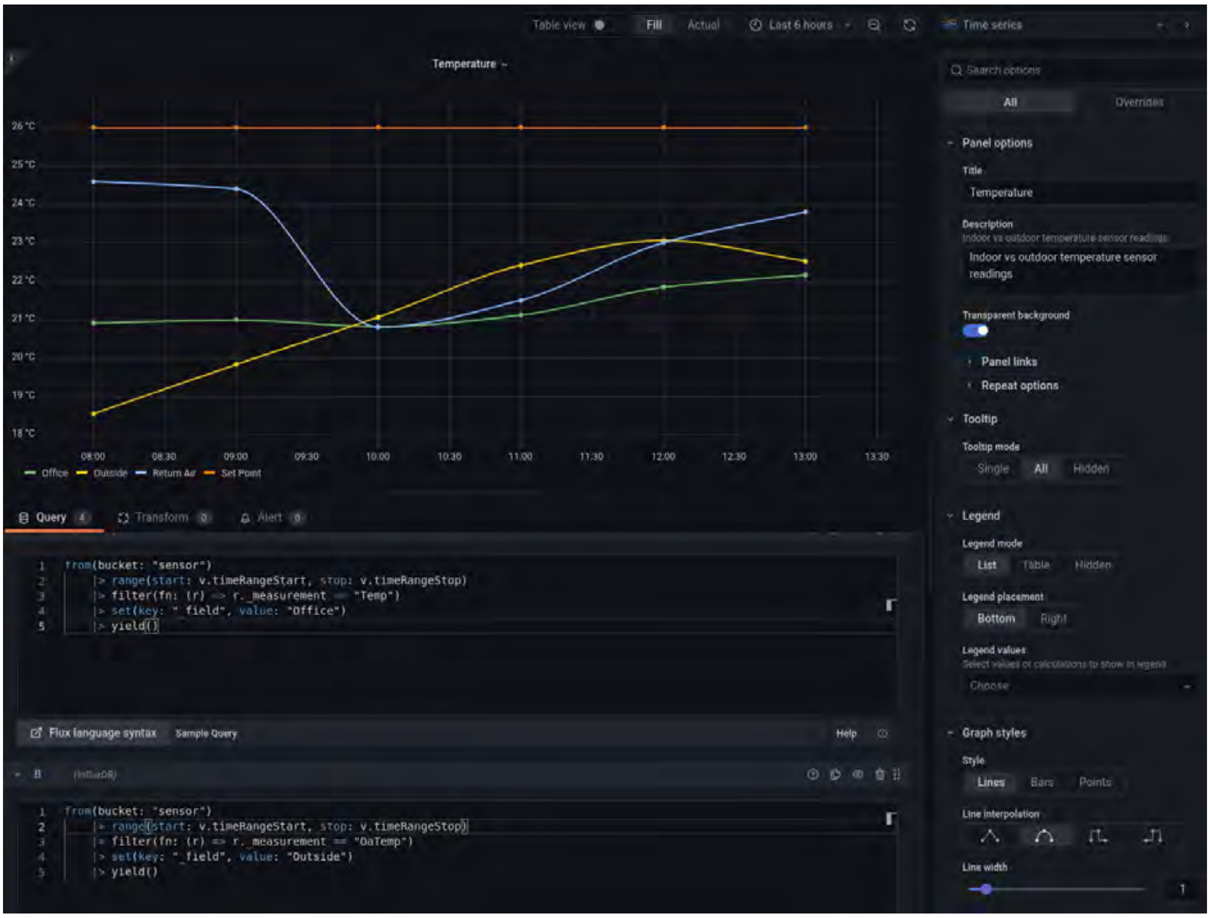
While the team sees great potential in developing further local dashboards for alerts generated in Kapacitor time-series stream processing, these would have to be done in a bespoke manner per site. This would seem to be a retrograde step against the backdrop of the DCH and a unified metadata schema given that the DCH is capable of stream processing data itself.

2.7 Grafana

Grafana is open-source charting and dash boarding software that has a vast array of connectors for existing databases, both proprietary and open source. Grafana includes a connector for InfluxDB 1.x and 2.x – the former using the depreciated InfluxQL, with the latter using Flux query language. The team opted for the former initially, and converted to the latter during the course of the project.

The implementation as documented above delivers near real-time data to the Grafana dashboards from all sensors, systems, applications and servers.

Configuring the database connector was trivial, and rapidly we could run queries to render datasets.



```
from(bucket: "sensor")
    |> range(start: v.timeRangeStart, stop: v.timeRangeStop)
    |> filter(fn: (r) => r._measurement == "Temp")
    |> set(key: "_field", value: "Office")
    |> yield()
```

```
from(bucket: "sensor")
    |> range(start: v.timeRangeStart, stop: v.timeRangeStop)
    |> filter(fn: (r) => r._measurement == "OaTemp")
    |> set(key: "_field", value: "Outside")
    |> yield()
```

Title: Temperature

Description: Indoor vs outdoor temperature sensor readings

Transparent background: ●

Tooltip mode: Single [✓ All] Hidden

Legend mode: [✓ List] Table Hidden

Legend placement: [✓ Bottom] Right

Legend values: Select values or calculations to show in legend — Choose

Style: [✓ Lines] Bars Points

Line width: 1

Figure 32: Grafana - rendering multiple temperature sensors into one report

Figure 32 shows 4 Flux QL queries rendering temperature data. The query language allows for rendering data as open/high/low/close, mean/average, and can easily aggregate data into dashboard widgets. The timescale of the query is set by variables tied to the user controls, in this case 6 hours. It can also be a fixed value, such as hours, days or weeks.

Figure 33: Grafana - rendering InfluxDB data for environment sensors

Figure 33 shows sensor data from the HVAC system and PLC sensor inputs, queried by Node-red, sent to InfluxDB, and rendered in Grafana using Flux query language.

2.8 Brick metadata schema, graph database & class-entity relationships

From the Brick Schema website[1]:

> *"Brick is an open-source effort to standardise semantic descriptions of the physical, logical and virtual assets in buildings and the relationships between them. Brick consists of an extensible dictionary of terms and concepts in and around buildings, a set of relationships for linking and composing concepts together, and a flexible data model permitting seamless integration of Brick with existing tools and databases. Through the use of powerful Semantic Web technology, Brick can describe the broad set of idiosyncratic and custom features, assets and subsystems found across the building stock in a consistent matter."*

---

[1] https://brickschema.org/

Brick is an entity-relationship or class diagram of a building, and is utilised by the DCH and other applications to build a graph database that provides foreign keys for the unique datastream name within the DCH or other time series databases[2]. This allows querying of the graph database using SPARQL to find a datastream name, or multiple datastream names. With the datastream names as a variable, a further query of the time-series database yields data from the required datastreams. A metadata schema allows a standard set of classes and naming convention to reference arbitrary names sourced from a BMS or other form of operational technology. In this way, a metadata schema simply acts as middle-ware – allowing standard database queries to reference any known arbitrary datastream name. It is envisaged that the mechanical and electrical trades will provide the relationship between the standard Brick metadata schema and the unique names that reside on their client systems.

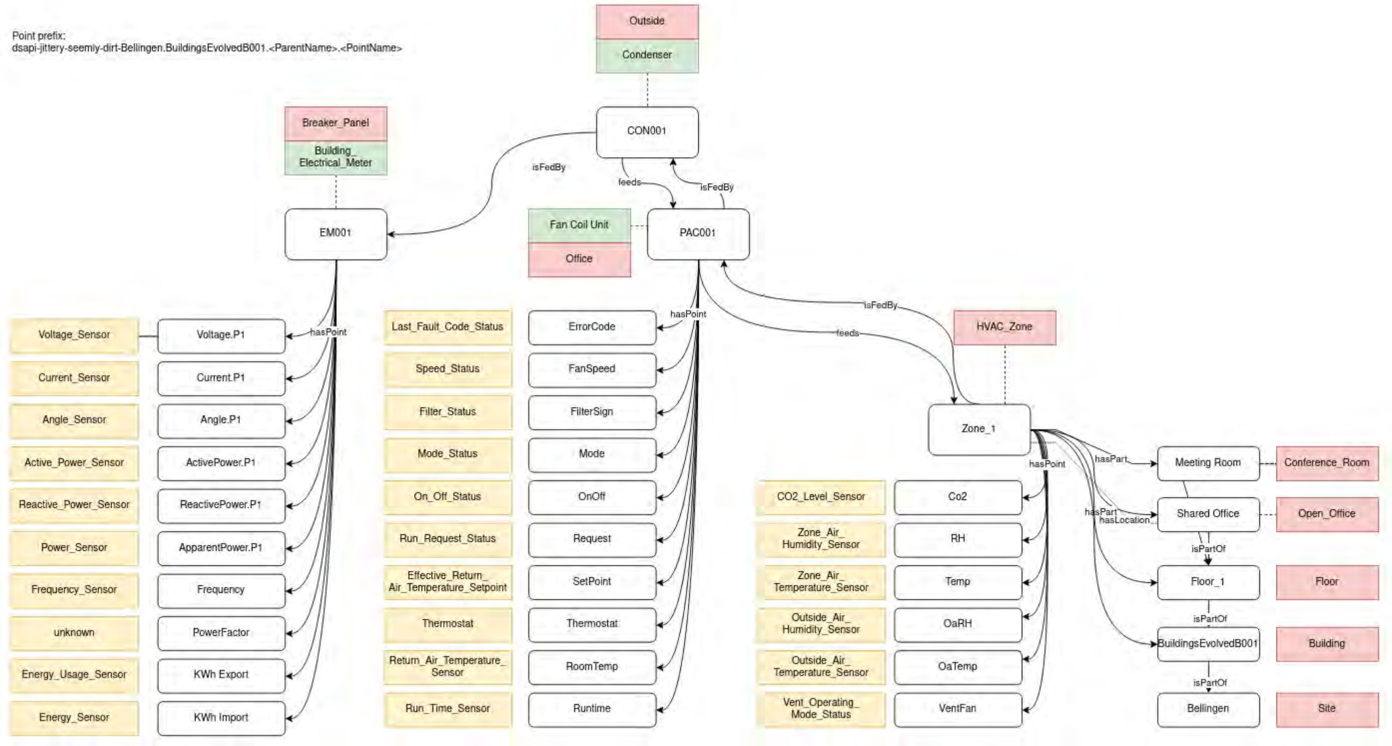


Figure 34: Brick – a diagram representing the metadata schema for the living lab

Brick uses the W3C standard "Resource Description Framework" (RDF) that describes the relationships between objects in the form subject, predicate and object. For example, a way to represent the idea that "zone 1 has point CO2 level sensor" would be expressed in RDF as "zone 1" (subject), "has point" (predicate), CO2 level sensor (object). Other examples from Figure 34 are "Fan coil 1 is fed by Condenser 1" or "Meeting room is part of Floor 1". Therefore, queries can rapidly generate a graph of the relationship between these objects so that an application developer using the metadata schema can easily find a list of what points zone 1 has, using the above example.

An excellent overview video is available which features the academics behind Brick Schema: Gabe Fierro and Jason Koh[3].

A reference schema is available at ref-schema.brickschema.org[4].

Brick: Building a metadata schema

There are a few methods available to generate Brick models, of which all were investigated during the research phase of the project.

Option 1: Using Python

---

[2] Fierro, Prakash, Mosiman et al (2020). Shepherding Metadata Through the Building Lifecycle.

[3] https://www.youtube.com/watch?v=5w3uu_vevCA

[4] https://ref-schema.brickschema.org/#hasTimeseriesReference

Brick schema is built and maintained using Python[5]. Therefore it is a natural place to start generating a Brick model for the living lab.

Being able to generate models programmatically allows transformation of existing datasets into a Brick model. For example, a CSV export of BMS object catalogue can be manually manipulated to provide the subject predicate and object for each entity that will form the class diagram. Tools such as OpenRefine[6] provide a web-driven method to clean and manipulate exported object catalogues ready for ingestion through transformation scripts.

Several examples of python code are available on the Brick Schema GitHub site that perform CSV to Brick model conversions[7]. Other conversion tool code examples in this repository include, IFC (BIM) to Brick[8] & TSV to Brick[9]. In addition, readthedocs.io has a page for brickschema python[10].

The Brick schema authors and maintainers have built a Python package py-brickschema[11] that installs via the Linux command using “pip install brickschema”. The brickschema package allows:

- management and querying of Brick models;
- simple OWL-RL, SHACL and other inference;
- conversion of Haystack models to Brick; and
- adding VBIS tags to Brick model, or getting Brick types from VBIS tags[12]

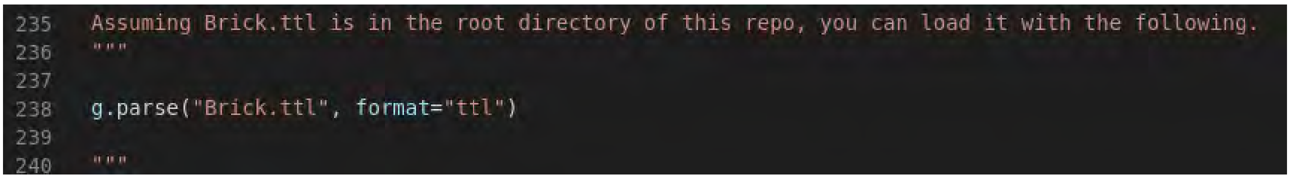
Brickschema is also used to import various python libraries as shown in Figure 35 for writing applications to generate a graph, manipulate entities, or provide parsing and inference.

```
from brickschema.namespaces import RDF, RDFS, BRICK, TAG, OWL
from brickschema.graph import Graph
from rdflib import Namespace, URIRef, Literal
```

Figure 35: Brick - using the brickschema python package to import various python libraries

In our R&D, we validated the above tools, and used the Brickschema python package to generate valid Brick models. We further used Brickschema package coupled with SHACL to parse and validate the RDF output of the python script, stored as a turtle/ttl file. An example is the BrickEntityShapeBase.ttl[13], and will likely be a method of application developers communicating their data model requirements to integrators..

To achieve a successful parse of the ttl file by SHACL, the full Brick schema ttl file needs to be parsed into the generated ttl. However, the integration of the two ttl files is not a prerequisite for loading the Brick ttl into the DCH. In this case, line 238 of the image shown in Figure 36 is commented out when writing a file with a target for the DCH, and as indicated when the target is a SHACL parser/interpreter.



```
235  Assuming Brick.ttl is in the root directory of this repo, you can load it with the following.
236  """
237
238  g.parse("Brick.ttl", format="ttl")
239
240  """
```

Figure 36: Brick - Python code to parse and add the base Brick TTL to the generated TTL

---

[5] https://github.com/BrickSchema/Brick/tree/master/bricksrc

[6] https://openrefine.org

[7] https://github.com/BrickSchema/Brick/tree/master/tools/convert

[8] https://github.com/gtfierro/brick-ifc-convert

[9] https://github.com/BrickSchema/Brick/tree/master/examples

[10] https://brickschema.readthedocs.io/en/add-brickify/source/brickschema.html

[11] https://github.com/BrickSchema/py-brickschema

[12] https://brickschema.readthedocs.io/_/downloads/en/latest/pdf/

[13] https://raw.githubusercontent.com/BrickSchema/Brick/master/shacl/BrickEntityShapeBase.ttl

Another resource provided in the Brick Schema github repository provides a “quick start” as shown in Figure 37 to generate a brick model, and provides excellent documentation as comments in code[14].

```
# (subject, predicate, object)
g.add((BLDG.AHU1A, RDF.type, BRICK.Air_Handler_Unit))
# you can use "quotes" to name entities as well
g.add((BLDG["VAV2-3"], RDF.type, BRICK.Variable_Air_Volume_Box))


"""
We can also add relationships between entities in our Brick model. The
BRICK.feeds relationship indicates a sequence between two pieces of equipment
"""

g.add((BLDG.AHU1A, BRICK.feeds, BLDG.VAV2_3))

"""
Let's add a few more entities so the graph is more interesting. We will
implement the Brick model for the "blue" entities in the sample graph at
brickschema.org
"""

# declare entities first
g.add((BLDG["VAV2-4"], RDF.type, BRICK.Variable_Air_Volume_Box))
g.add((BLDG["VAV2-4.DPR"], RDF.type, BRICK.Damper))
g.add((BLDG["VAV2-4.DPRPOS"], RDF.type, BRICK.Damper_Position_Setpoint))
g.add((BLDG["VAV2-4.ZN_T"], RDF.type, BRICK.Supply_Air_Temperature_Sensor))
g.add((BLDG["VAV2-4.SUPFLOW"], RDF.type, BRICK.Supply_Air_Flow_Sensor))
g.add((BLDG["VAV2-4.SUPFLSP"], RDF.type, BRICK.Supply_Air_Flow_Setpoint))
g.add((BLDG["VAV2-3Zone"], RDF.type, BRICK.HVAC_Zone))
g.add((BLDG["Room-410"], RDF.type, BRICK.Room))
g.add((BLDG["Room-411"], RDF.type, BRICK.Room))
g.add((BLDG["Room-412"], RDF.type, BRICK.Room))

# declare edges
g.add((BLDG["AHU1A"], BRICK.feeds, BLDG["VAV2-4"]))
g.add((BLDG["VAV2-4"], BRICK.hasPart, BLDG["VAV2-4.DPR"]))
g.add((BLDG["VAV2-4.DPR"], BRICK.hasPoint, BLDG["VAV2-4.DPRPOS"]))
g.add((BLDG["VAV2-4"], BRICK.hasPoint, BLDG["VAV2-4.SUPFLOW"]))
g.add((BLDG["VAV2-4"], BRICK.hasPoint, BLDG["VAV2-4.SUPFLSP"]))
g.add((BLDG["VAV2-3"], BRICK.feeds, BLDG["VAV2-3Zone"]))
g.add((BLDG["VAV2-3Zone"], BRICK.hasPart, BLDG["Room-410"]))
g.add((BLDG["VAV2-3Zone"], BRICK.hasPart, BLDG["Room-411"]))
g.add((BLDG["VAV2-3Zone"], BRICK.hasPart, BLDG["Room-412"]))

"""
We can "serialize" this model to a file if we want to load it into another program.
"""
with open("example.ttl", "wb") as f:
    # the Turtle format strikes a balance beteween being compact and easy to read
    f.write(g.serialize(format="ttl"))
```

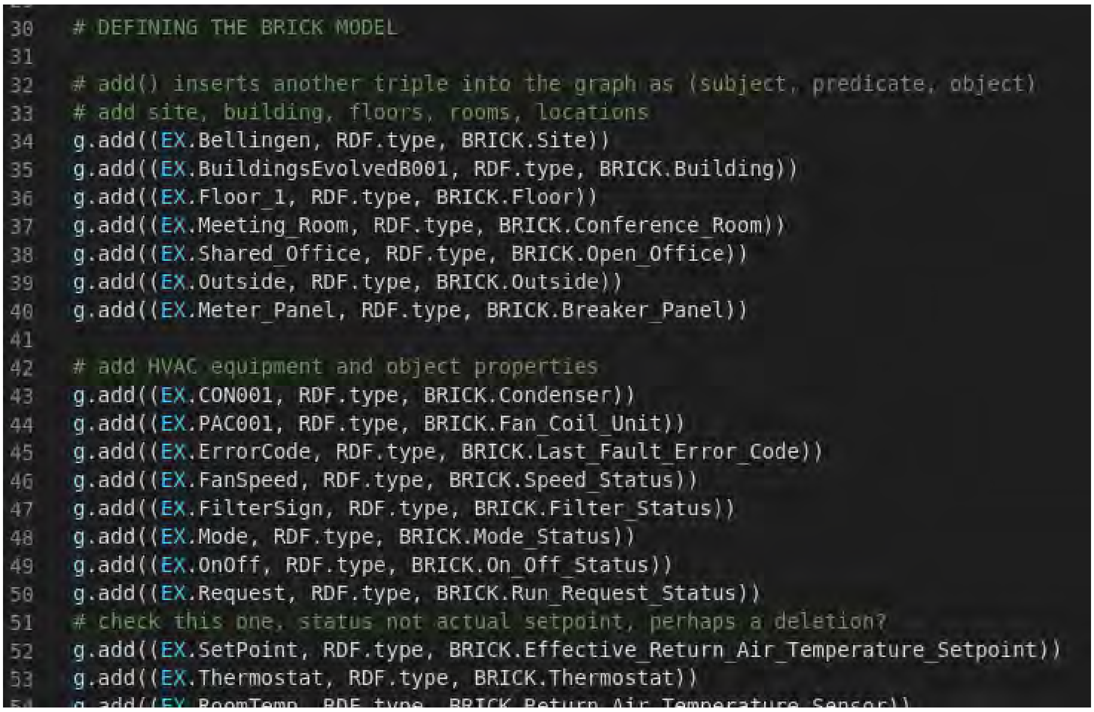
Figure 37: Brick - Python code example to generate a Brick model

The graph represented in Figure 34 was converted into python using the template shown in Figure 37, and was then used to generate a valid Brick model for the DCH.

The main steps in creating a Brick model from raw Python are represented in the Figures 38, 39, 40 and 41.

---

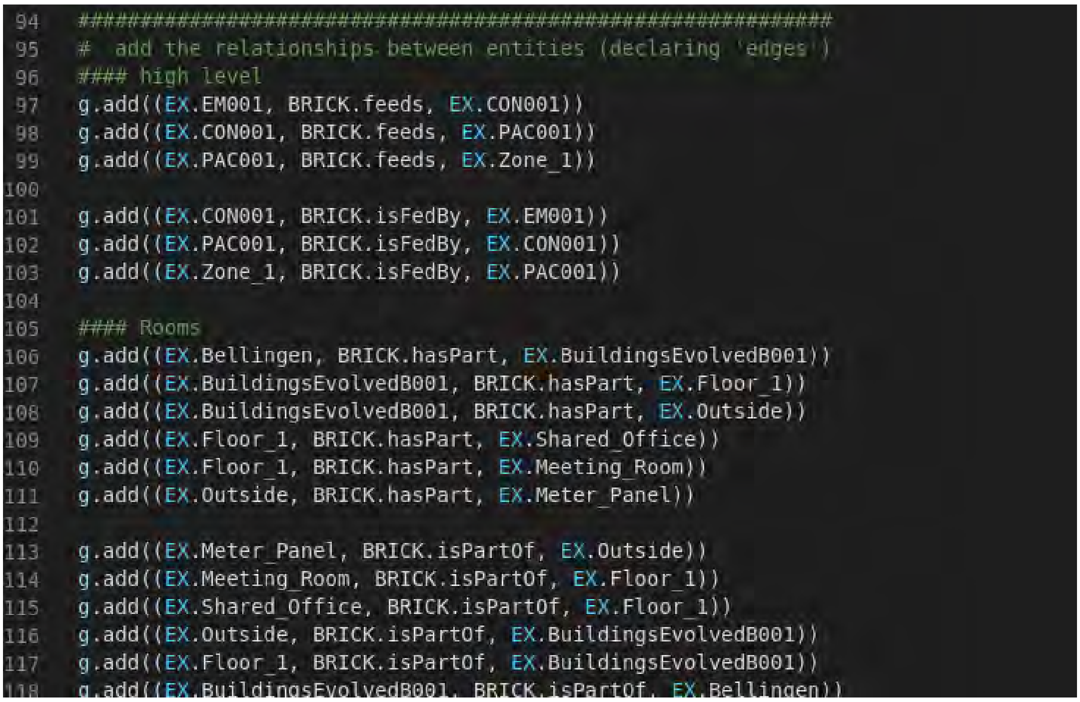
[14] https://github.com/BrickSchema/Brick/blob/master/examples/example1/generate.py



```
# DEFINING THE BRICK MODEL

# add() inserts another triple into the graph as (subject, predicate, object)
# add site, building, floors, rooms, locations
g.add((EX.Bellingen, RDF.type, BRICK.Site))
g.add((EX.BuildingsEvolvedB001, RDF.type, BRICK.Building))
g.add((EX.Floor_1, RDF.type, BRICK.Floor))
g.add((EX.Meeting_Room, RDF.type, BRICK.Conference_Room))
g.add((EX.Shared_Office, RDF.type, BRICK.Open_Office))
g.add((EX.Outside, RDF.type, BRICK.Outside))
g.add((EX.Meter_Panel, RDF.type, BRICK.Breaker_Panel))

# add HVAC equipment and object properties
g.add((EX.CON001, RDF.type, BRICK.Condenser))
g.add((EX.PAC001, RDF.type, BRICK.Fan_Coil_Unit))
g.add((EX.ErrorCode, RDF.type, BRICK.Last_Fault_Error_Code))
g.add((EX.FanSpeed, RDF.type, BRICK.Speed_Status))
g.add((EX.FilterSign, RDF.type, BRICK.Filter_Status))
g.add((EX.Mode, RDF.type, BRICK.Mode_Status))
g.add((EX.OnOff, RDF.type, BRICK.On_Off_Status))
g.add((EX.Request, RDF.type, BRICK.Run_Request_Status))
# check this one, status not actual setpoint, perhaps a deletion?
g.add((EX.SetPoint, RDF.type, BRICK.Effective_Return_Air_Temperature_Setpoint))
g.add((EX.Thermostat, RDF.type, BRICK.Thermostat))
g.add((EX.RoomTemp, RDF.type, BRICK.Return_Air_Temperature_Sensor))
```

Figure 38: Brick - defining RDF types in Python to generate a Brick model

In Figure 39, if each triple in each line is read consecutively, it describes the subject, predicate & object. Both directions are declared: for example, the relationship ‘feeds’ is matched with ‘isFedBy’. This allows the query to travel in both directions, querying entities upstream or downstream of the target object.



```
###################################################################
#  add the relationships between entities (declaring 'edges')
#### high level
g.add((EX.EM001, BRICK.feeds, EX.CON001))
g.add((EX.CON001, BRICK.feeds, EX.PAC001))
g.add((EX.PAC001, BRICK.feeds, EX.Zone_1))

g.add((EX.CON001, BRICK.isFedBy, EX.EM001))
g.add((EX.PAC001, BRICK.isFedBy, EX.CON001))
g.add((EX.Zone_1, BRICK.isFedBy, EX.PAC001))

#### Rooms
g.add((EX.Bellingen, BRICK.hasPart, EX.BuildingsEvolvedB001))
g.add((EX.BuildingsEvolvedB001, BRICK.hasPart, EX.Floor_1))
g.add((EX.BuildingsEvolvedB001, BRICK.hasPart, EX.Outside))
g.add((EX.Floor_1, BRICK.hasPart, EX.Shared_Office))
g.add((EX.Floor_1, BRICK.hasPart, EX.Meeting_Room))
g.add((EX.Outside, BRICK.hasPart, EX.Meter_Panel))

g.add((EX.Meter_Panel, BRICK.isPartOf, EX.Outside))
g.add((EX.Meeting_Room, BRICK.isPartOf, EX.Floor_1))
g.add((EX.Shared_Office, BRICK.isPartOf, EX.Floor_1))
g.add((EX.Outside, BRICK.isPartOf, EX.BuildingsEvolvedB001))
g.add((EX.Floor_1, BRICK.isPartOf, EX.BuildingsEvolvedB001))
g.add((EX.BuildingsEvolvedB001, BRICK.isPartOf, EX.Bellingen))
```

Figure 39: Brick - defining relationships between entities in python for a Brick model

In Figure 40, each data point is then attached to a unique id for the target time series database, in this case the DCH. Brick/Mortar, in contrast, use the relationship “hasTimeSeriesId” coupled with a UUID linking to an ID contained within

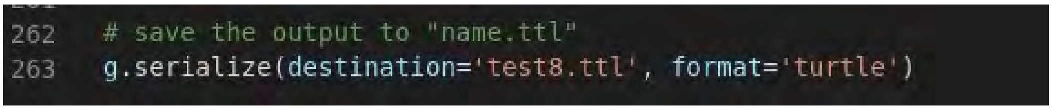
Postgres TimescaleDB. It has not been tested in this project, but it is logically deduced that the same approach would work with InfluxDB, Prometheus or other time series databases.

While the sting following the Literal is arbitrary, that that proceeds it is standardised around the Brick schema. Hence a standardised SPARQL query to an RDF graph will allow the return of a single or an array of unique IDs for the time series database.

```python
# This is a fork from new Brick functionality, which uses BRICK.hasTimeseriesId rather than SENAPS.stream
# Have to store a string rather than UUID as intended with Brick/Mortar AFAIK
# g.add((EX.ErrorCode, BRICK.hasTimeseriesId, Literal("bd65600d-8669-4903-8a14-af88203add38")))
g.add((EX.ErrorCode, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.
g.add((EX.FanSpeed, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.P
g.add((EX.FilterSign, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001
g.add((EX.Mode, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.PAC00
g.add((EX.OnOff, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.PAC0
g.add((EX.Request, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.EM
g.add((EX.SetPoint, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.P
g.add((EX.Thermostat, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001
g.add((EX.RoomTemp, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.P
g.add((EX.RunTime, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.PA
```

Figure 40: Brick - providing external references to DCH datastream names in python for a Brick model

Brick therefore allows for discovery of entities in the class-relationship diagram/metadata graph, both upstream or downstream, and further provides a foreign key to a timeseries database. Application developers, knowing the target database, can then perform queries across the resultant datastream names returned from a query against the metadata graph.



```python
# save the output to "name.ttl"
g.serialize(destination='test8.ttl', format='turtle')
```

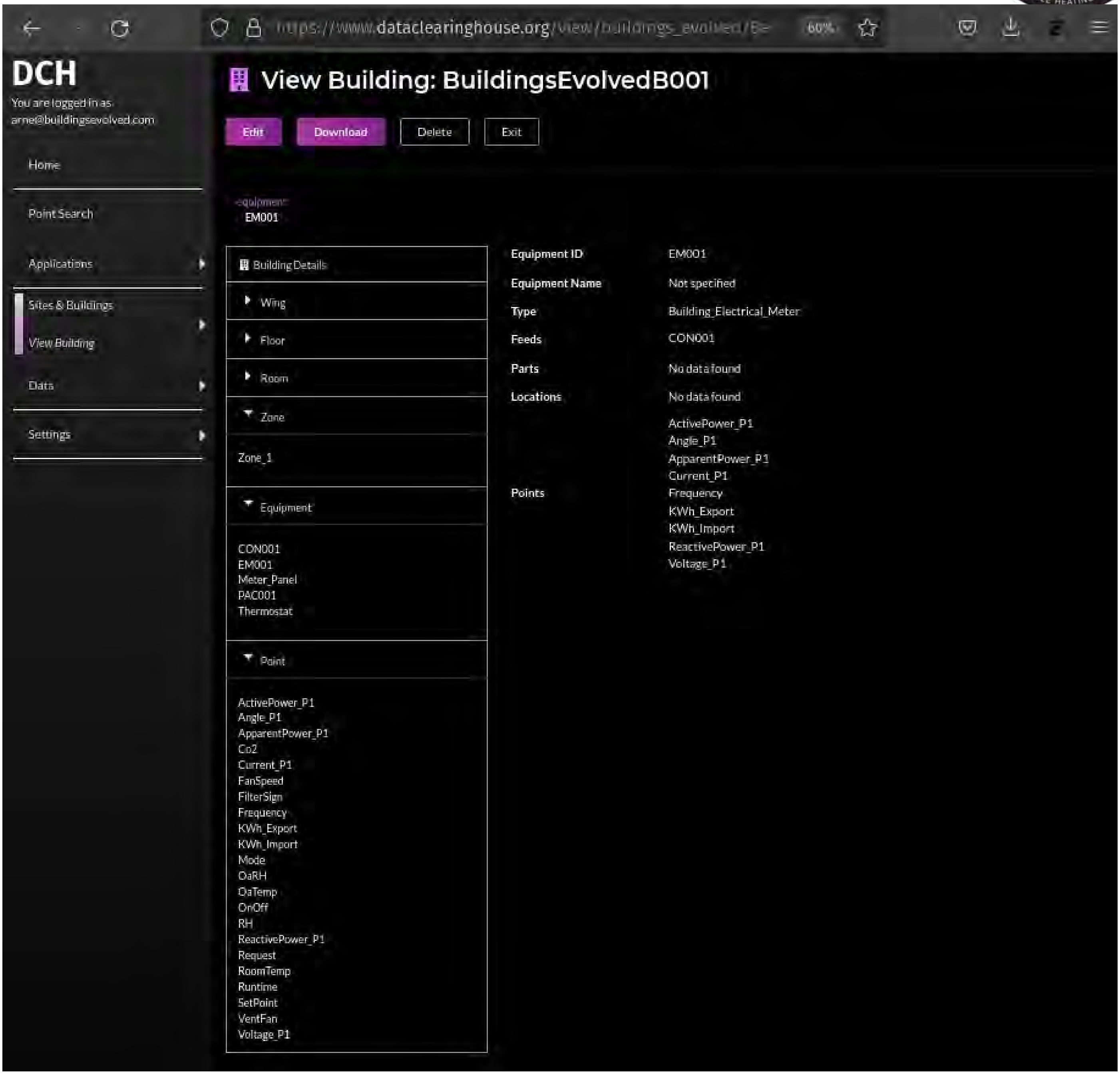
Figure 41: Brick - Python serialising the output to a TTL file

In Figure 42, a simple Brick model is represented, generated by the above code examples. This ttl file was subsequently uploaded successfully to the DCH as shown in Figure 43.

```
@prefix brick: <https://brickschema.org/schema/Brick#> .
@prefix senaps: <http://senaps.io/schema/1.0/senaps#> .

<dch:org/buildings_evolved/site/Bellingen/building/BuildingsEvolvedB001#Runtim

<dch:org/buildings_evolved/site/Bellingen/building/BuildingsEvolvedB001#Active
    senaps:stream_id "dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001
    brick:isPointOf <dch:org/buildings_evolved/site/Bellingen/building/Buildin

<dch:org/buildings_evolved/site/Bellingen/building/BuildingsEvolvedB001#Angle_
    senaps:stream_id "dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001
    brick:isPointOf <dch:org/buildings_evolved/site/Bellingen/building/Buildin

<dch:org/buildings_evolved/site/Bellingen/building/BuildingsEvolvedB001#Apparen
    senaps:stream_id "dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001
    brick:isPointOf <dch:org/buildings_evolved/site/Bellingen/building/Buildin

<dch:org/buildings_evolved/site/Bellingen/building/BuildingsEvolvedB001#Bellin
    brick:hasPart <dch:org/buildings_evolved/site/Bellingen/building/Buildings

<dch:org/buildings_evolved/site/Bellingen/building/BuildingsEvolvedB001#Co2> a
    senaps:stream_id "dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001
    brick:isPointOf <dch:org/buildings_evolved/site/Bellingen/building/Buildin

<dch:org/buildings_evolved/site/Bellingen/building/BuildingsEvolvedB001#Curren
    senaps:stream_id "dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001
    brick:isPointOf <dch:org/buildings_evolved/site/Bellingen/building/Buildin

<dch:org/buildings_evolved/site/Bellingen/building/BuildingsEvolvedB001#ErrorC
    senaps:stream_id "dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001
```

Figure 42: Brick - simple Brick schema represented in TTL format. This example is not merged with the main Brick Schema TTL.

TTL files can then be uploaded to the DCH or used to power queries of local time series databases. It is worth noting that when using the **senaps:stream_id** or **brick:hasTimeseriesId**, the TTL file is then targeted towards a particular platform or environment, but could possess multiple external references – i.e. both **senaps:stream_id** and **brick:hasTimeseriesId** could co-exist.



View Building: BuildingsEvolvedB001

equipment
EM001

Zone_1

CON001
EM001
Meter_Panel
PAC001
Thermostat

ActivePower_P1
Angle_P1
ApparentPower_P1
Co2
Current_P1
FanSpeed
FilterSign
Frequency
KWh_Export
KWh_Import
Mode
OaRH
OaTemp
OnOff
RH
ReactivePower_P1
Request
RoomTemp
Runtime
SetPoint
VentFan
Voltage_P1

Equipment ID	EM001
Equipment Name	Not specified
Type	Building_Electrical_Meter
Feeds	CON001
Parts	No data found
Locations	No data found
Points	ActivePower_P1 Angle_P1 ApparentPower_P1 Current_P1 Frequency KWh_Export KWh_Import ReactivePower_P1 Voltage_P1

Figure 43: Brick - Python generated Brick TTL file, parsed and loaded successfully into DCH

Option 2: using a UI driven tool (Protege/WebProtege)

While it is possible to generate a brick model within a UI driven tool such as webprotege[15], as shown in Figure 44 or Protege and equivalent generalised RDF tools were found to be more useful to view and edit a generated brick model rather than generation itself.

---

[15] https://webprotege.stanford.edu/

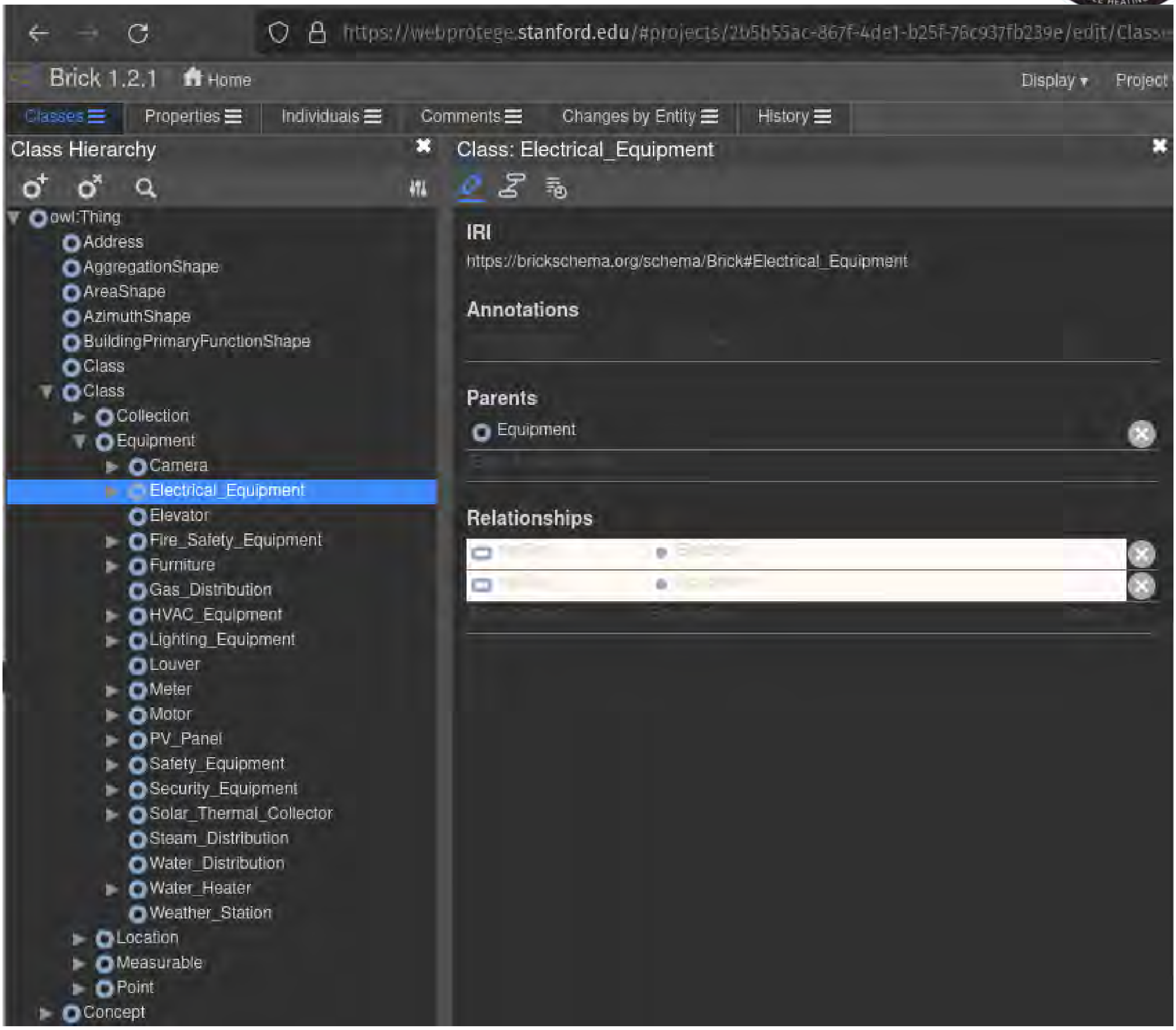


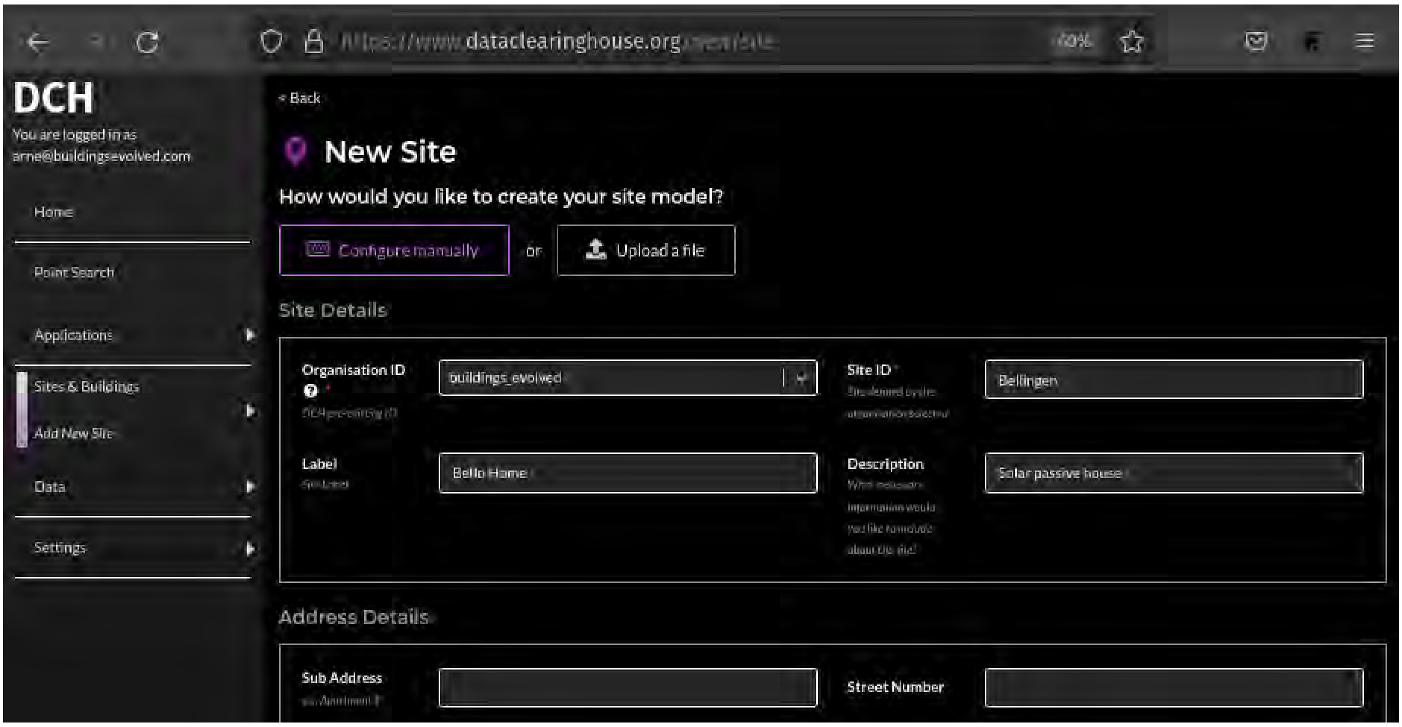
Figure 44: Brick - Stanford University WebProtege RDF viewing tool rendering the Brick 1.2.1 reference ttl graph database

Protege/Webprotege were found to not have great utility in generating a brick model. As there are over 180 lines of code in our simple 1 zone living lab site, this would mean 180 or more interactions with the webpage or user interface to generate a single model. The model generated from the tool could not be iterated, tested or improved upon without going back to the beginning each time. Throughout the development of our Python-based solution to Brick model generation, we had 8 major iterations, reinforcing that presently a Brick model is best generated in a declarative manner, or (more likely) converted from a flat file such as CSV or TSV using Python.

Option 3: Using the DCH web-based Brick generation wizard

The DCH has a unique web-based wizard specifically targeted towards generation of a Brick model. While protege/webprotege are difficult to use, this could be attributed to the general nature of the tool for RDF, rather than an RDF based tool designed specifically for generating Brick/building models. Consequently, the wizard performs well compared to the general RDF tools, but would still likely be difficult to use if onboarding a large or complex building.

First step is to create a site via the DCH website as shown in Figure 45.



You are logged in as arne@buildingsevolved.com

New Site

How would you like to create your site model?

Site Details

Organisation ID: buildings_evolved

Site ID: Bellingen

Label: Bello Home

Description: Solar passive house

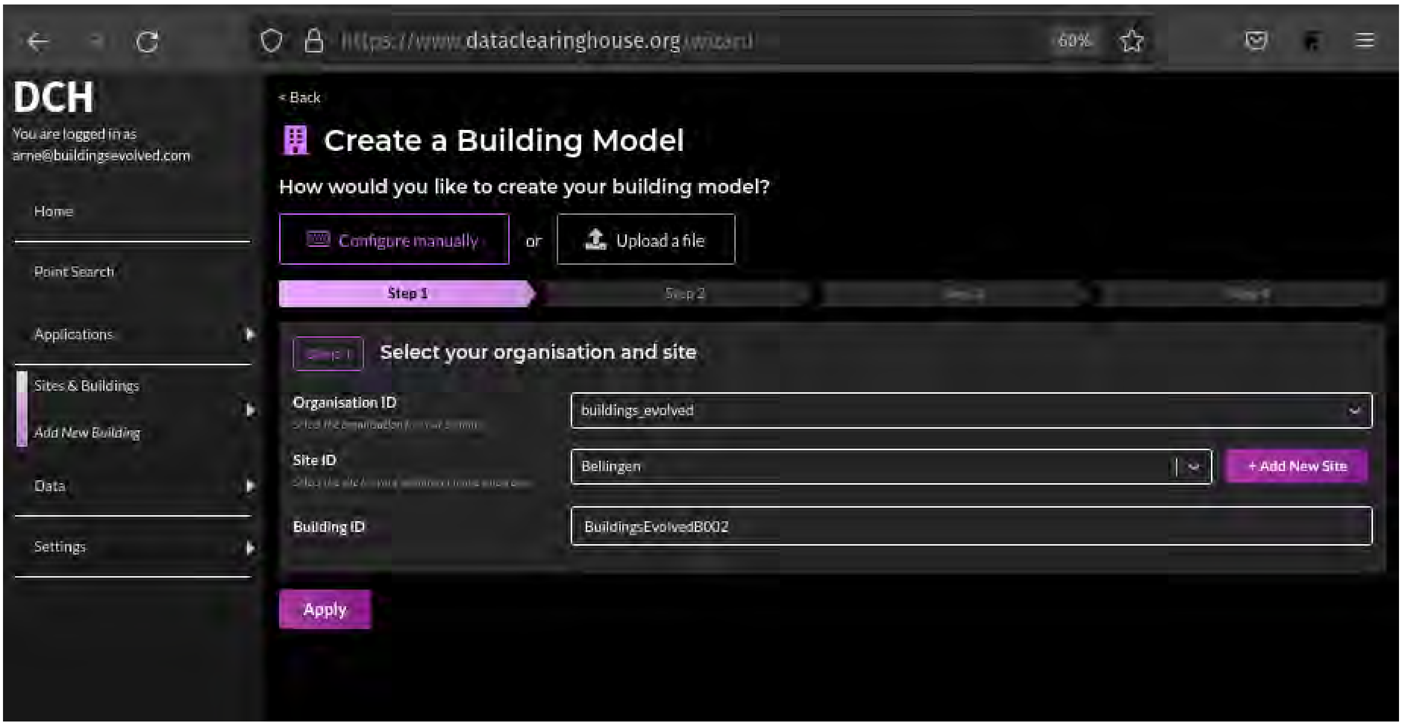
Address Details

Sub Address:

Street Number:

Figure 45: Brick - DCH wizard: creating a site

After a site is created, a building model generation wizard can be launched, or a programatically generated model can be uploaded (as a ttl file) as shown in Figure 46.



You are logged in as arne@buildingsevolved.com

Create a Building Model

How would you like to create your building model?

Select your organisation and site

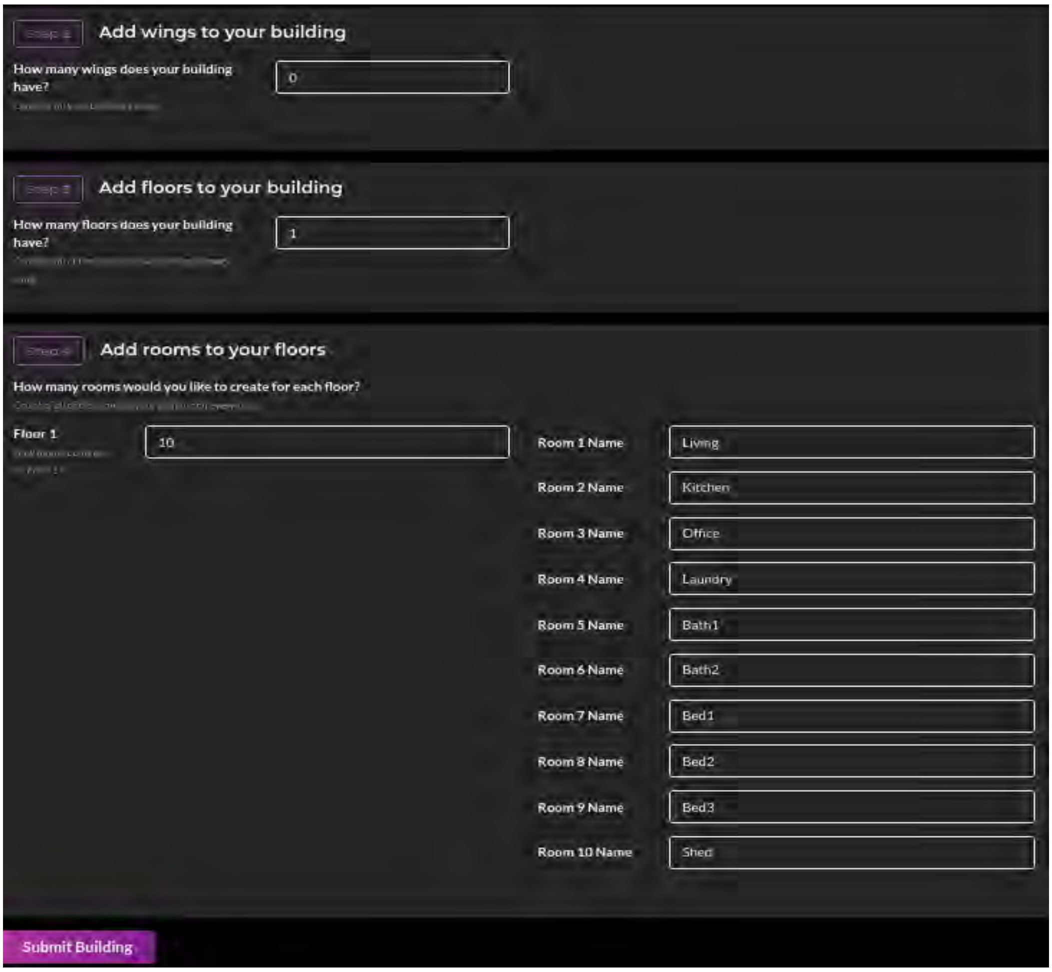
Organisation ID: buildings_evolved

Site ID: Bellingen

Building ID: BuildingsEvolvedB002

Figure 46: Brick – DCH wizard: step 1

Step 2-4 are dynamic, with fields expanding depending on number of wings/floors/rooms specified as shown in Figure 47.



Add wings to your building

How many wings does your building have? 0

Add floors to your building

How many floors does your building have? 1

Add rooms to your floors

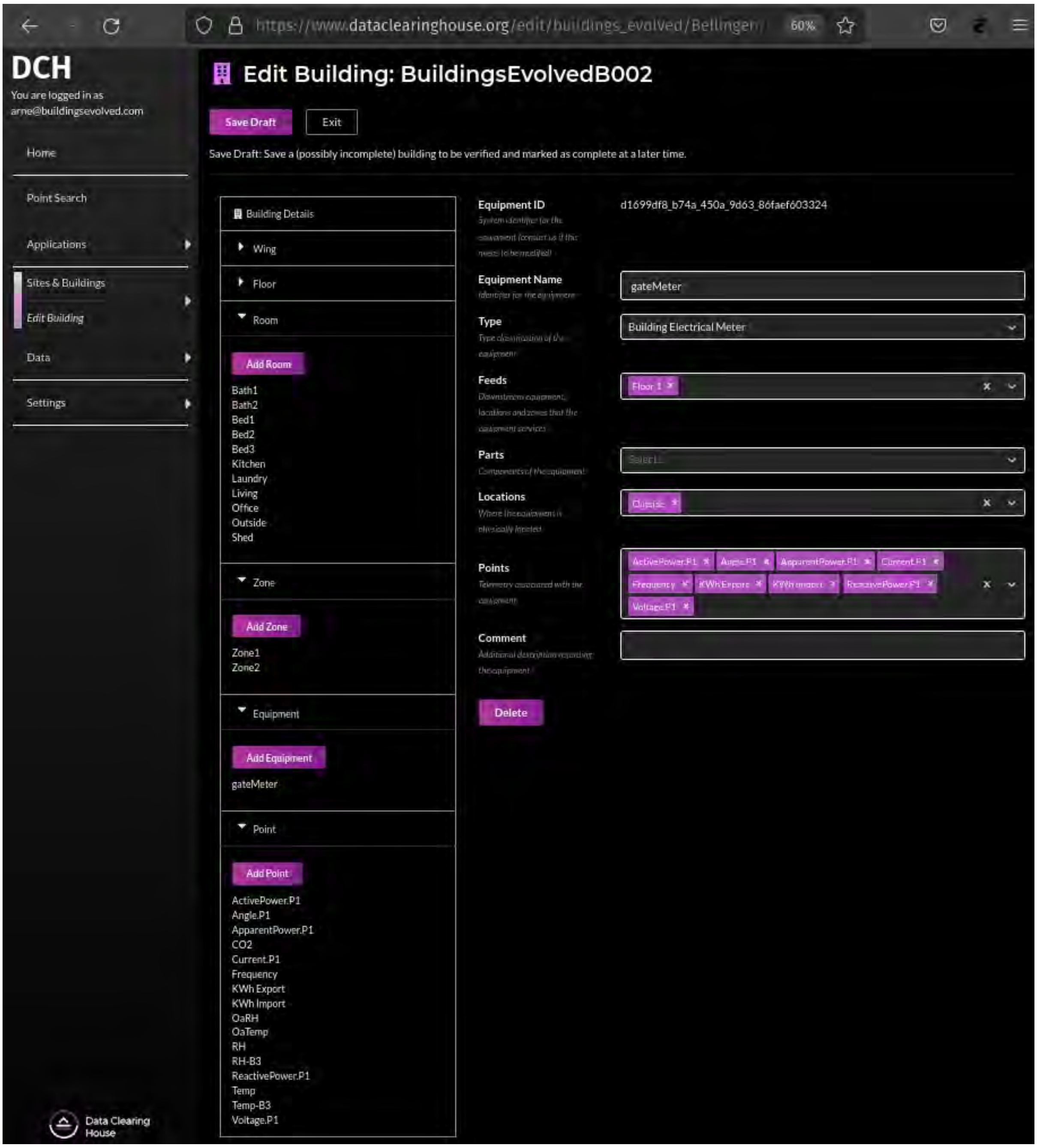
How many rooms would you like to create for each floor?

Floor 1: 10

Room 1 Name: Living
Room 2 Name: Kitchen
Room 3 Name: Office
Room 4 Name: Laundry
Room 5 Name: Bath1
Room 6 Name: Bath2
Room 7 Name: Bed1
Room 8 Name: Bed2
Room 9 Name: Bed3
Room 10 Name: Shed

Figure 47: Brick - DCH wizard steps 2-4

Following the basic setup providing the structure of the building into wings/floors and rooms, the user is brought to an editing screen that allows further addition of zones, equipment and points. From there the user is prompted to create the relationships between objects, with the user interface using look-ups on type to enforce consistency with the brick schema, as shown in Figure 48.



https://www.dataclearinghouse.org/edit/buildings_evolved/Bellingen

DCH

You are logged in as arne@buildingsevolved.com

Edit Building: BuildingsEvolvedB002

Save Draft: Save a (possibly incomplete) building to be verified and marked as complete at a later time.

Building Details
- Wing
- Floor
- Room
  - Bath1
  - Bath2
  - Bed1
  - Bed2
  - Bed3
  - Kitchen
  - Laundry
  - Living
  - Office
  - Outside
  - Shed
- Zone
  - Zone1
  - Zone2
- Equipment
  - gateMeter
- Point
  - ActivePower.P1
  - Angle.P1
  - ApparentPower.P1
  - CO2
  - Current.P1
  - Frequency
  - KWh Export
  - KWh Import
  - OaRH
  - OaTemp
  - RH
  - RH-B3
  - ReactivePower.P1
  - Temp
  - Temp-B3
  - Voltage.P1

Equipment ID (System identifier for the equipment (contact us if this needs to be modified)): d1699df8_b74a_450a_9d63_86faef603324

Equipment Name (Identifier for the equipment): gateMeter

Type (Type classification of the equipment): Building Electrical Meter

Feeds (Downstream equipment, locations and zones that the equipment services): Floor 1

Parts (Components of the equipment): Select...

Locations (Where the equipment is physically located): Outside

Points (Telemetry associated with the equipment): ActivePower.P1, Angle.P1, ApparentPower.P1, Current.P1, Frequency, KWh Export, KWh Import, ReactivePower.P1, Voltage.P1

Comment (Additional description regarding the equipment):

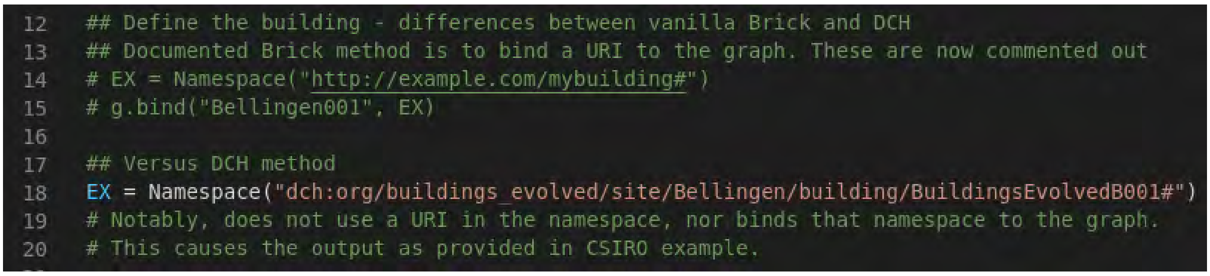
Figure 48: Brick - adding data points in the DCH wizard and creating relationships between entities. Type is a lookup to the Brick schema to enforce consistency.

Brick: DCH model variations

While the Brick model is intended to be used in a standard way, there were subtle differences with how the DCH implemented a Brick model compared with updated versions of the Brick schema. This is due to the rapidly developing capability of the Brick schema: indication of this is that two versions of Brick have been released since the commencement of the iHub project.

The variations from the code example provided by the Brick schema github repository include:

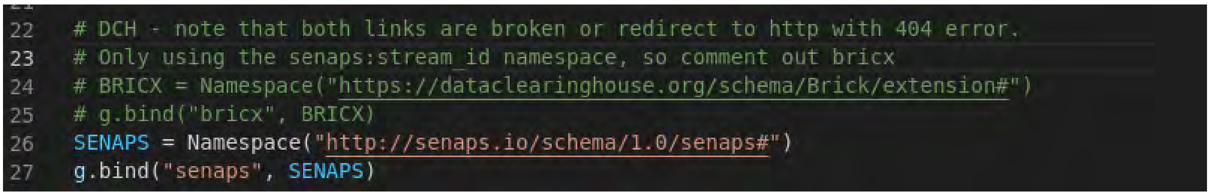
Do not bind a URI to the building namespace, bind to a DCH reference comprised of **“dch:org/<orgName>/site/<siteName>/building/<buildingName>”** as shown in Figure 49.



```
## Define the building - differences between vanilla Brick and DCH
## Documented Brick method is to bind a URI to the graph. These are now commented out
# EX = Namespace("http://example.com/mybuilding#")
# g.bind("Bellingen001", EX)

## Versus DCH method
EX = Namespace("dch:org/buildings_evolved/site/Bellingen/building/BuildingsEvolvedB001#")
# Notably, does not use a URI in the namespace, nor binds that namespace to the graph.
# This causes the output as provided in CSIRO example.
```

Figure 49: Brick - DCH variation: URI reference

Custom DCH extensions “Bricx” were not required but were noted. The Senaps (DCH) namespace was bound to the graph to support custom RDF type stream_id as shown in Figure 50.



```
# DCH - note that both links are broken or redirect to http with 404 error.
# Only using the senaps:stream_id namespace, so comment out bricx
# BRICX = Namespace("https://dataclearinghouse.org/schema/Brick/extension#")
# g.bind("bricx", BRICX)
SENAPS = Namespace("http://senaps.io/schema/1.0/senaps#")
g.bind("senaps", SENAPS)
```

Figure 50: Brick - DCH variation: SENAPS namespace, unused BRICX namespace

SENAPS (DCH) had already defined their own predicate “stream_id” to provide a foreign key store in the metadata schema prior to the adoption of BRICK.hasTimeseriesId. As such, we took note of the variation and made our code compatible with DCH. There was the option to add both, but as one would be unused, this becomes a stub, as shown in Figure 51,

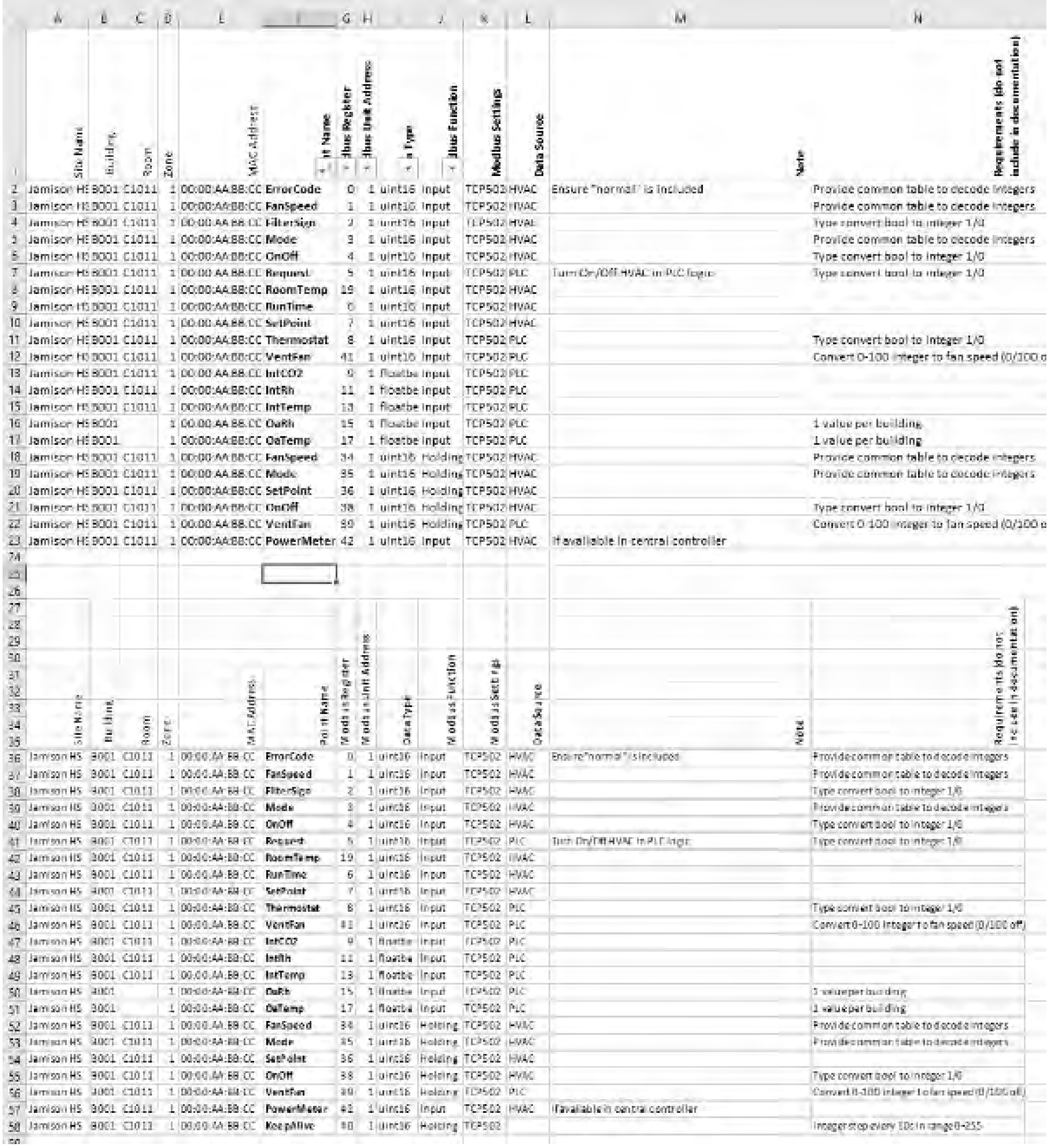
```
# This is a fork from new Brick functionality, which uses BRICK.hasTimeseriesId rather than SENAPS.stream
# Have to store a string rather than UUID as intended with Brick/Mortar AFAIK
# g.add((EX.ErrorCode, BRICK.hasTimeseriesId, Literal("bd65600d-8669-4903-8a14-af88203add38")))
g.add((EX.ErrorCode, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.
g.add((EX.FanSpeed, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.P
g.add((EX.FilterSign, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001
g.add((EX.Mode, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.PAC00
g.add((EX.OnOff, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.PAC0
g.add((EX.Request, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.EM
g.add((EX.SetPoint, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.P
g.add((EX.Thermostat, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001
g.add((EX.RoomTemp, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.P
g.add((EX.RunTime, SENAPS.stream_id, Literal("dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.PA
```

Figure 51: Brick - DCH variation: SENAPS.stream_id vs BRICK.hasTimeseriesId

The Brick model does not provide a method on how to interpret data. As such, CSIRO have authored their own specification dealing with energy metering which incorporates a few extensions to the brick model (many of which have subsequently been backported into the Brick schema). This documentation is available upon request from the DCH team at CSIRO, but should form part of iHub DCH 1 reporting.

2.9 Data requirements

Through the R&D process, and in consultation with CSIRO & Data 61, the following list of data points as shown in Figure 52 was derived as being the functional requirements for a proof-of-concept project, with a view to rationalising this for future projects once data value had been evaluated. This schedule has been included in the tender documentation for commissioning by the appointed contractor.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Site Name	Building	Room	Zone	MAC Address	t Name	dbus Register	dbus Unit Address	a Type	dbus Function	Modbus Settings	Data Source	Note	Requirements (do not include in documentation)
2	Jamison H	3001	C1011	1	00:00:AA:BB:CC	ErrorCode	0	1	uint16	Input	TCP502	HVAC	Ensure "normal" is included	Provide common table to decode integers
3	Jamison H	3001	C1011	1	00:00:AA:BB:CC	FanSpeed	1	1	uint16	Input	TCP502	HVAC		Provide common table to decode integers
4	Jamison H	3001	C1011	1	00:00:AA:BB:CC	FilterSign	2	1	uint16	Input	TCP502	HVAC		Type convert bool to integer 1/0
5	Jamison H	3001	C1011	1	00:00:AA:BB:CC	Mode	3	1	uint16	Input	TCP502	HVAC		Provide common table to decode integers
6	Jamison H	3001	C1011	1	00:00:AA:BB:CC	OnOff	4	1	uint16	Input	TCP502	HVAC		Type convert bool to integer 1/0
7	Jamison H	3001	C1011	1	00:00:AA:BB:CC	Request	5	1	uint16	Input	TCP502	PLC	Turn On/Off HVAC in PLC logic	Type convert bool to integer 1/0
8	Jamison H	3001	C1011	1	00:00:AA:BB:CC	RoomTemp	19	1	uint16	Input	TCP502	HVAC		
9	Jamison H	3001	C1011	1	00:00:AA:BB:CC	RunTime	6	1	uint16	Input	TCP502	HVAC		
10	Jamison H	3001	C1011	1	00:00:AA:BB:CC	SetPoint	7	1	uint16	Input	TCP502	HVAC		
11	Jamison H	3001	C1011	1	00:00:AA:BB:CC	Thermostat	8	1	uint16	Input	TCP502	PLC		Type convert bool to integer 1/0
12	Jamison H	3001	C1011	1	00:00:AA:BB:CC	VentFan	41	1	uint16	Input	TCP502	PLC		Convert 0-100 integer to fan speed (0/100 o
13	Jamison H	3001	C1011	1	00:00:AA:BB:CC	IntCO2	9	1	floatbe	Input	TCP502	PLC		
14	Jamison H	3001	C1011	1	00:00:AA:BB:CC	IntRh	11	1	floatbe	Input	TCP502	PLC		
15	Jamison H	3001	C1011	1	00:00:AA:BB:CC	IntTemp	13	1	floatbe	Input	TCP502	PLC		
16	Jamison H	3001		1	00:00:AA:BB:CC	OaRh	15	1	floatbe	Input	TCP502	PLC		1 value per building
17	Jamison H	3001		1	00:00:AA:BB:CC	OaTemp	17	1	floatbe	Input	TCP502	PLC		1 value per building
18	Jamison H	3001	C1011	1	00:00:AA:BB:CC	FanSpeed	34	1	uint16	Holding	TCP502	HVAC		Provide common table to decode integers
19	Jamison H	3001	C1011	1	00:00:AA:BB:CC	Mode	35	1	uint16	Holding	TCP502	HVAC		Provide common table to decode integers
20	Jamison H	3001	C1011	1	00:00:AA:BB:CC	SetPoint	36	1	uint16	Holding	TCP502	HVAC		
21	Jamison H	3001	C1011	1	00:00:AA:BB:CC	OnOff	38	1	uint16	Holding	TCP502	HVAC		Type convert bool to integer 1/0
22	Jamison H	3001	C1011	1	00:00:AA:BB:CC	VentFan	39	1	uint16	Holding	TCP502	PLC		Convert 0-100 integer to fan speed (0/100 o
23	Jamison H	3001	C1011	1	00:00:AA:BB:CC	PowerMeter	42	1	uint16	Input	TCP502	HVAC	If available in central controller	

35	Site Name	Building	Room	Zone	MAC Address	Point Name	Modbus Register	Modbus Unit Address	Data Type	Modbus Function	Modbus Settings	Data Source	Note	Requirements (do not include in documentation only)
36	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	ErrorCode	0	1	uint16	Input	TCP502	HVAC	Ensure "normal" is included	Provide common table to decode integers
37	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	FanSpeed	1	1	uint16	Input	TCP502	HVAC		Provide common table to decode integers
38	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	FilterSign	2	1	uint16	Input	TCP502	HVAC		Type convert bool to integer 1/0
39	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	Mode	3	1	uint16	Input	TCP502	HVAC		Provide common table to decode integers
40	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	OnOff	4	1	uint16	Input	TCP502	HVAC		Type convert bool to integer 1/0
41	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	Request	5	1	uint16	Input	TCP502	PLC	Turn On/Off HVAC in PLC logic	Type convert bool to integer 1/0
42	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	RoomTemp	19	1	uint16	Input	TCP502	HVAC		
43	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	RunTime	6	1	uint16	Input	TCP502	HVAC		
44	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	SetPoint	7	1	uint16	Input	TCP502	HVAC		
45	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	Thermostat	8	1	uint16	Input	TCP502	PLC		Type convert bool to integer 1/0
46	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	VentFan	41	1	uint16	Input	TCP502	PLC		Convert 0-100 integer to fan speed (0/100 off)
47	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	IntCO2	9	1	floatbe	Input	TCP502	PLC		
48	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	IntRh	11	1	floatbe	Input	TCP502	PLC		
49	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	IntTemp	13	1	floatbe	Input	TCP502	PLC		
50	Jamison HS	3001		1	00:00:AA:BB:CC	OaRh	15	1	floatbe	Input	TCP502	PLC		1 value per building
51	Jamison HS	3001		1	00:00:AA:BB:CC	OaTemp	17	1	floatbe	Input	TCP502	PLC		1 value per building
52	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	FanSpeed	34	1	uint16	Holding	TCP502	HVAC		Provide common table to decode integers
53	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	Mode	35	1	uint16	Holding	TCP502	HVAC		Provide common table to decode integers
54	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	SetPoint	36	1	uint16	Holding	TCP502	HVAC		
55	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	OnOff	38	1	uint16	Holding	TCP502	HVAC		Type convert bool to integer 1/0
56	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	VentFan	39	1	uint16	Holding	TCP502	PLC		Convert 0-100 integer to fan speed (0/100 off)
57	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	PowerMeter	42	1	uint16	Input	TCP502	HVAC	If available in central controller	
58	Jamison HS	3001	C1011	1	00:00:AA:BB:CC	KeepAlive	40	1	uint16	Holding	TCP502			Integer step every 10s in range 0-255

Figure 52: data requirements - data point schedule per classroom

2.10 CSIRO Senaps/DCH cloud

From modbus target, to buffer parser, to dead-band filtering, to payload creation, to sending via MQTT, the data then resides in the DCH, stored in the time series database as shown in Figures 53 and 54.

The image in Figure 53 shows temperature and humidity values transmitting from the living lab environment to the CSIRO DCH analytics cloud platform in near real-time.

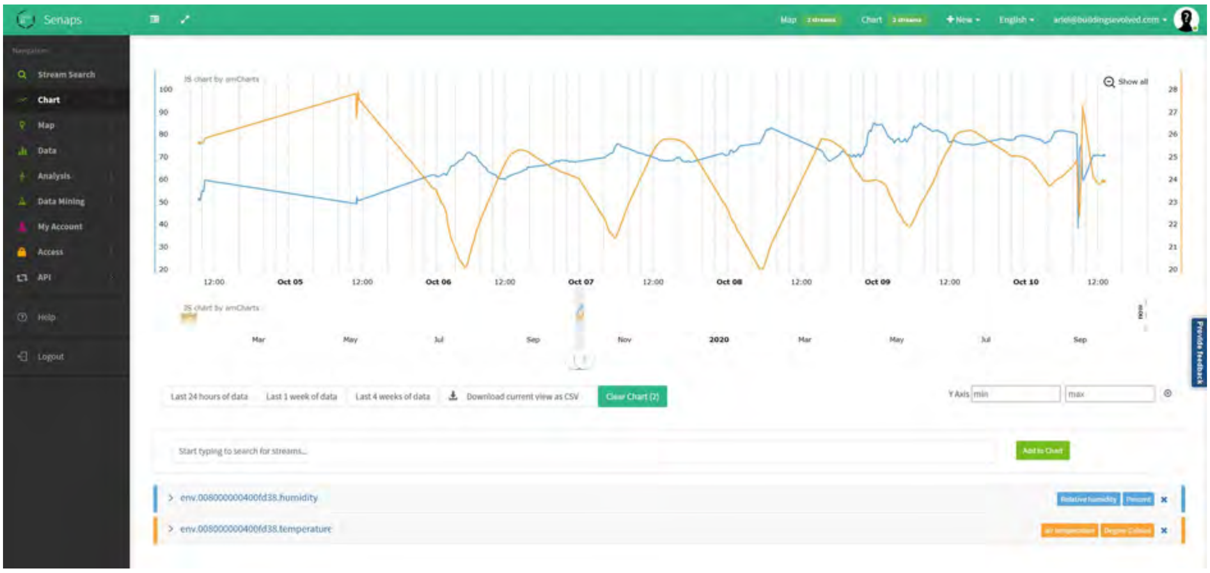
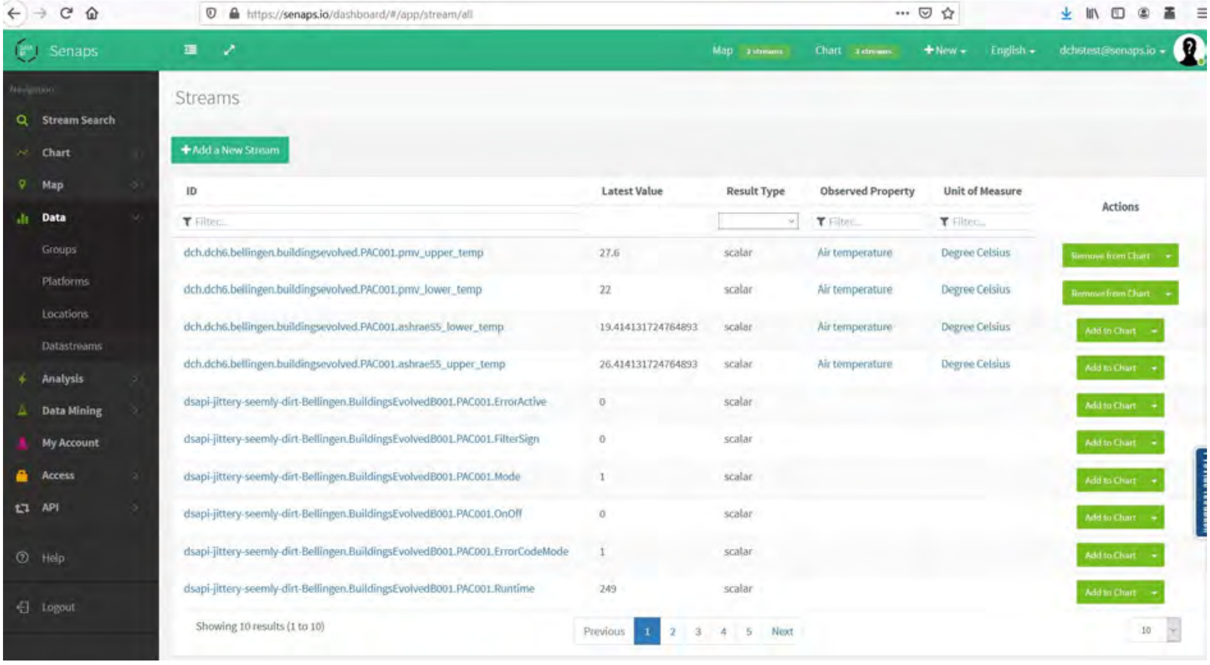


Figure 53: DCH cloud - displaying simple query of real-time datastreams sourced from the living lab site in near real-time

The image in Figure 54 shows how the Predictive Mean Vote (PMV) is determined in the CSIRO DCH analytics cloud platform. PMV metrics are used for determining acceptable thermal conditions in occupant-controlled air-conditioned spaces in accordance with the ANSI/ASHRAE 55 Standard. These values are polled on an interval of 15 minutes to update the set point in the living lab.



Streams

ID	Latest Value	Result Type	Observed Property	Unit of Measure	Actions
dch.dch6.bellingen.buildingsevolved.PAC001.pmv_upper_temp	27.6	scalar	Air temperature	Degree Celsius	Remove from Chart
dch.dch6.bellingen.buildingsevolved.PAC001.pmv_lower_temp	22	scalar	Air temperature	Degree Celsius	Remove from Chart
dch.dch6.bellingen.buildingsevolved.PAC001.ashrae55_lower_temp	19.414131724764893	scalar	Air temperature	Degree Celsius	Add to Chart
dch.dch6.bellingen.buildingsevolved.PAC001.ashrae55_upper_temp	26.414131724764893	scalar	Air temperature	Degree Celsius	Add to Chart
dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.PAC001.ErrorActive	0	scalar			Add to Chart
dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.PAC001.FilterSign	0	scalar			Add to Chart
dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.PAC001.Mode	1	scalar			Add to Chart
dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.PAC001.OnOff	0	scalar			Add to Chart
dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.PAC001.ErrorCodeMode	1	scalar			Add to Chart
dsapi-jittery-seemly-dirt-Bellingen.BuildingsEvolvedB001.PAC001.Runtime	249	scalar			Add to Chart

Showing 10 results (1 to 10)

Figure 54: DCH cloud - displaying latest PMV and ASHRAE55 upper and lower values for set-point temperature setting

It should be noted that the data clearing house back-end is being provided in the initial phase by the Senaps team within CSIRO – therefore images showing Senaps are interchangeable with functionality found within the dataclearinghouse.org website.

2.11 Integration of ‘demonstrator’ data onto DCH & Implementation of comfort model in DCH

HVAC systems serve as flexible loads offering additional opportunities for demand management and participation in the VPP market. Temperature set point control is seen as a viable method that can assist in reducing HVAC load usage during peak summer days. However, this load reduction is often traded-off with indoor thermal comfort conditions.

In order to identify the potential for set-point based HVAC control in pilot schools, the team had developed two comfort calculators based on the widely recognised ANSI/ASHRAE Standard 55: Thermal Environmental Conditions for Human Occupancy. These models were developed during the last milestone period.

The Predicted Mean Vote (PMV) method uses four environmental factors and two physiological factors to estimate the occupant satisfaction rate. These factors are the dry bulb temperature, mean radiant temperature, air velocity, and relative humidity. Additionally, the model uses metabolic rate and clothing insulation level details as inputs. It should also be noted that cultural, national, and geographical differences may also influence thermal comfort. Once PMV is predicted, PPD (Predicted Percentage Dissatisfied) is calculated and it provides the percentage of people dissatisfied. ASHRAE 55 stipulates that thermal comfort can be achieved based on 80% occupant satisfaction rate, translating to a PMV in the range of -0.5 to +0.5 and PPD of 20%. More details about the PMV/PPD method estimations can be found elsewhere[16]. The implemented PMV/PPD model allows users to dynamically input these parameters and determine the temperature range required to be within the prescribed comfort band limits.

By adjusting the temperature set point towards the upper and lower bounds of the comfort band (depending on whether heating or cooling is required), energy efficiency and cost savings can be achieved, whilst maintaining thermal comfort conditions according to this internationally recognised thermal comfort standard.

During this project, this model has been deployed as part of a Senaps (DCH1) workflow delivering 15-minute interval updates on upper and lower comfort band temperature recommendations. In order for the model to use relevant inputs from the NSW schools, the NSW school control system ‘demonstrator’ built by project partner Buildings Evolved was onboarded to DCH. This demonstrator represents a typical classroom in a school. Data from the demonstrator sensors are published to DCH using a MQTT client available through the Node-RED software stack. As a result, 27 data points from the demonstrator are being ingested to DCH in near real-time. This includes indoor temperature, humidity data and outdoor temperature sensor and humidity data. Additional input parameters required by the MPV/PPD model were configured to the following values tailored for a classroom setting with spring/summer seasonal conditions:

- Clo (clothing insulation) - a unit used to express the thermal insulation provided by garments and clothing ensembles. For spring/summer type conditions, clo = 0.555 (being average of these clothing ensembles: Trousers, short-sleeve shirt 0.57; Knee-length skirt, short-sleeve shirt, sandals 0.54) was used.
- Met (metabolic rate). For a classroom setting, met = 1.0 (being for seated office activities - I.e. writing) was used.
- Vel (average air velocity). For a classroom setting, vel = 0.2 (In many indoor situations the indoor air velocity conforms to the still air conditions of the PMV comfort zone i.e. 0.2 m/s) was used.

ASHRAE comfort model outputs (upper and lower bound temperature recommendations) can be requested from DCH via the Node-RED control software and used for controlling air conditioning set points in the schools.

Typical outputs from the PMV/PPD model are shown in Figure 55. Room temperature data from NSW schools control system ‘demonstrator’ has been included in this plot (green trend line). As shown in the plot, the comfort band upper limit (blue trend line) is consistently higher than the indoor room temperature, thus there is considerable opportunity to

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[16] https://escholarship.org/content/qt2m34683k/qt2m34683k.pdf

increase the room temperature (e.g. by raising air conditioner temperature set points) to more energy efficient levels and still have indoor conditions within the temperature band deemed comfortable by the PMV/PPD comfort model.

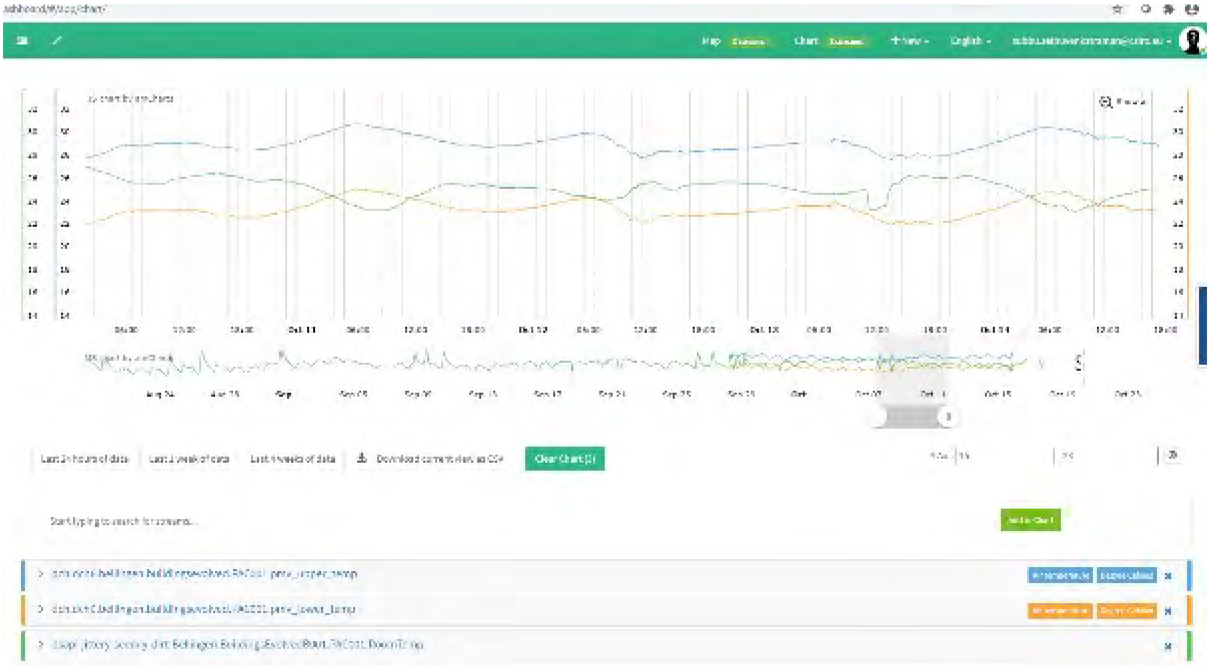


Figure 55: PMV/PPD comfort model outputs over a 2 day window showing upper and lower bounds of comfort conditions

As HVAC systems and sensors were not available in the schools at the time of this report being compiled, no thermal models were able to be developed for the schools. The above work on the BE living lab shows the concept in operation as an analogue for one classroom, and how it could be applied to the three schools when the HVAC systems and sensors are available in the DCH.

2.12 Semantic model development for schools

CSIRO has been developing the semantic model for schools to support control algorithm deployment across multiple schools in a scalable way. DCH’s Building Services Layer supports handling of semantic models of buildings so that hosted applications can be easily implemented across the buildings without building specific customisation. Creation of the models involved a staged approach, first collating relevant metadata into a skeleton Brick model (spreadsheet) and then running a script to translate that spreadsheet into the semantic models.

Firstly, the building floor-plan/layout was broken down into the relevant Brick classes. For example, building location information is broken down to Building > Wing > Floor > Room and connected with ‘hasLocation’ Brick relationship. After the layout of the building is described in the spreadsheet, major equipment of the building is then added in a similar fashion, using information sources from site visits and documentation. Major equipment details including Air Handling Units, Fan Coil Units, Chillers, Condensers and energy meters at the site are included in the model. Details of an equipment and its location or relation to other pieces of equipment is captured at this stage.

A software script was written that translates this spreadsheet into a semantic Brick Model. With the schools models this script is tailored to the spreadsheet design and produces a 1:1 mapping of information in the spreadsheet to entities and relationships in the model. The output of the script is an RDF model of each building (semantic data model), stored as a TTL file (i.e. Turtle: Terse RDF triple language file). An RDF model of the whole site referencing all the individual buildings is also created for each school. The Table below provides a summary of Brick relationships currently available in these models.

	Nimbin	**Jamison**	**Singleton**
Number of locations in brick model (incl: city, building, floor, rooms)	220	59	453
Number of BMS points	1103	1131	1530
Number of equipment points (FCUs, Condensers, OAF)	146	99	227
Total Points	**1469**	**1289**	**2210**

The final part process is to link the time-series information from the BMS points to the equipment in the models. This is yet to be done for the School's models as equipment and data sources to feed the Schools' BMS systems into DCH platform are yet to be set up.

These models can be easily visualised using RDF viewers available at the Brick website[17] or open source tools such as Protege[18]. A sample of output from Protégé viewer for one of the blocks in Singleton High school is shown in Figure 56.

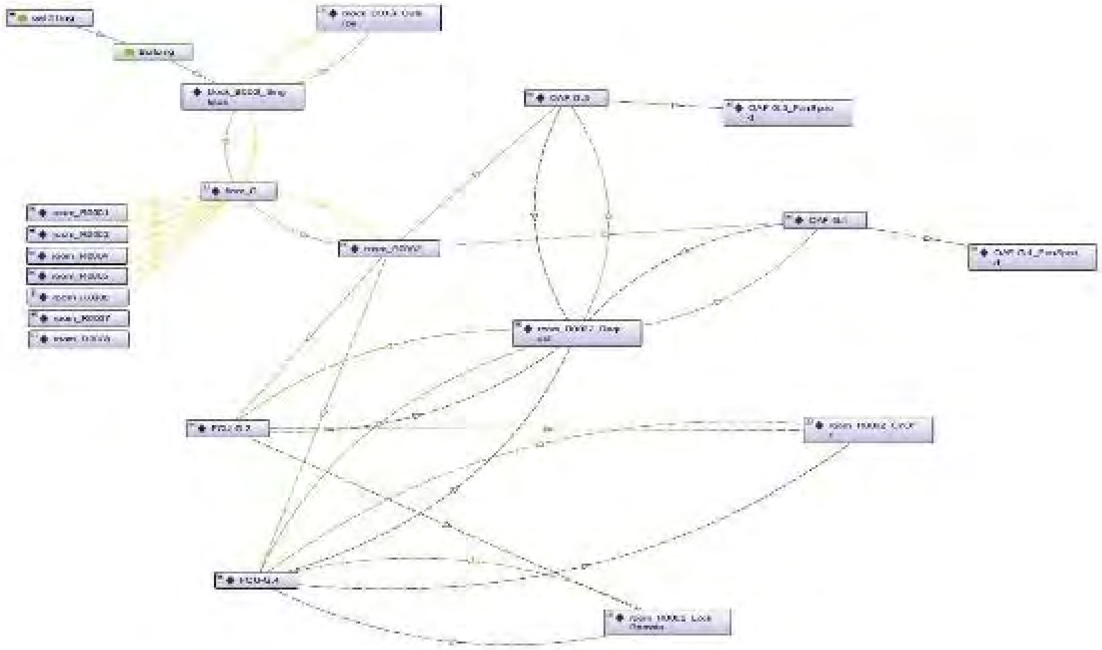


Figure 56: Brick - Protégé RDF viewer for one of the blocks in Singleton High School

2.13 Procurement specification

Below is a specification for Singleton HS, but is similar in many respects to the other two schools in this proof-of-concept testing. This was developed by Kersten Schmidt (BE) with input from others in BE and review and input from CSIRO. SINSW have used this specification for tender of the additional controls for the proof-of-concept test.

Scope of Works

General

---

[17] https://brickschema.github.io/brick-studio/

[18] https://protege.stanford.edu/

The scope of the work is the

- design, supply, installation, and warranty provision of communications and control cabling
- design, supply, installation, and warranty provision of additional monitoring, control and communications system modules
- programming, commissioning and verification of the entire monitoring, control and communications system as a whole

Purpose

The school has already received HVAC systems from the NSW Department of Education Cooler Classroom Program (CCP).

Additional solar and battery systems have been or are in the process of being installed.

The purpose of the proposed control and communication systems under this project is to:

- Enable centralised control of air conditioning units and other devices
- Gather various data from existing devices and sensors
- Improve occupant comfort via the adjustment of the thermostat setpoints and fan speed
- Enable advanced maintenance regimes, pre-heat/cool, night purge
- Control air conditioning units and other devices in such a way that certain market mechanisms on the current and future National Electricity Market (NEM) can be accessed for financial benefit

Design Concept

The following design concept underpins this project to achieve the purpose:

- To enable centralised HVAC control via the HVAC vendor centralised control system module, communicating via communications cabling to all HVAC outdoor units
- To make all HVAC data available on the School LAN
- To enable improvements to HVAC and ventilation fan controls
- To enable centralised HVAC control via other applications and processes over the School LAN

Design Scope

- The design is based on a modular topology, comprising of the following general distributed I/O control modules and associated sensors and controlled devices:
  - New:
    - Central HVAC controller (one or a few per school/location depending on design)
    - Central DCH Edge Server
    - PLC to connect to a block of existing PLC’s (already inter-connected via MS/TP cabling) to allow for connection to the School LAN
  - Existing:
    - PLC controlling HVAC FCU’s and related functions (one per learning space)
    - Indoor ambient air temperature
    - Outdoor ambient relative humidity sensor
    - Outdoor ambient air temperature
    - Indoor CO2 level sensor
- Site survey, interaction with client and analysis of existing infrastructure and topology and its adequacy for the purpose
- Overall design of system
- Communications and control cabling design
- Communications and control hardware selection
- Communication and control programming for the entire system
- Network security consideration
- Safety in design principles

- Detailed design including, but not limited to:
  - Control design
  - Communication and Network design
  - Programming
  - Physical layouts
  - Cable selection
  - Cabling run design
  - Electrical power supply design
  - Hardware mounting design
  - Software/programming/configuration design

Construct and Install Scope

- Construction of controllers, sensors, communication devices and related hardware
- Installation of above
- Installation of communications cabling system as required
- Connection of communications and control system to electricity supply as required

Programming Scope

- Connect and configure HVAC central controller
- Program HVAC central controller and PLCs to make select datapoints available on the School LAN
- Test Modbus TCP communications to the HVAC central controller and PLCs from the DCH Edge Server, either directly and/or via gateways
- As a contractual option: Provide variable fan speed control output out of controllers for ventilation fans (currently either on or off)

Commissioning and Verification Scope

Commissioning and verification report, including:

- Verification of correct data communications, programming and integration across entire system
- Creation of a detailed Inspection and Test Plan (ITP) prior to commissioning for review by and input from the client
- Commissioning of entire system including all subsystems

Warranty Scope

Warranty provision for all products, installation workmanship and the overall system, with a minimum period of 5 years

Specific Scope of Works Details

<u>For entire school:</u>

- Provide, install and program DCH Edge Server to be the central control module
- Provide Mitsubishi Electric Central Controller AE-200E (and slave controllers AE-50E as required)
  - Mount in appropriate secure location, preferably the server room
  - If mounted elsewhere, mount in a secure lockable enclosure using the same key as the existing CCP enclosures
  - Connect up to 50 indoor FCU's to the AE-200E as per contractor's design and below, using AE-50Es for expansion beyond 50 FCUs, or as required by design
  - Connect each to school communications School LAN

The following applies to all 36 new HVAC indoor FCU units as installed under the CCP program. It does not apply to older HVAC units that were not installed under the CCP program.

<u>Per cooler classroom block and/or per learning space:</u>

- Provide communications cabling between all Mitsubishi City Multi VRF HVAC outdoor units across all relevant buildings
- Provide communications cabling between all buildings required to allow for connection of all outdoor units as per above (with up to 50 indoor FCU's connected in one chain of outdoor units) to connect to one Mitsubishi Central Controller (use space in existing conduits between buildings or use breezeways to install new conduit runs)
- Provide communications cabling between the CCP PLCs in each block to the School LAN (in the comms room of that building block or another appropriate location)
- Please provide this as a contractual option in your response: Check that existing on/off control wiring at ventilation fan is using the analogue 0-10V control input of the fans, if not, rewire to use this input
- Please also provide this as a contractual option in your response: Move the existing HVAC wall controller or add external temp sensor for the PAC FCU at 1500FFL and ensure there is mechanical protection and serviceability
- If installed, disable any DRED control of HVAC units
- Recommission and test all CCP PLCs controllers to achieve:
  - sensor data available to the DCH Edge Server via Modbus TCP
  - communications to the School LAN/configure DHCP/supply MAC address
  - Control of ventilation fan via Modbus from DCH Edge Server
  - As a contractual option: Implement stepless control of ventilation fan via 0-10V analogue output from digital on off/control
- Publish all relevant BACnet points from the HVAC central controller to the DCH Edge Server via Modbus TCP

Detailed Specification

Compliance

The latest versions as applicable of all applicable standards, rules, regulations, codes and requirements shall be followed for all work. This includes, but is not limited to:

- Relevant EFSG guidelines
- Relevant Australian Standards, other standards, codes, rules and other requirements
- SINSW procurement guidelines
- ITD Structured Cabling System Specification
- ITD Network Security guidelines
- Equipment from list of approved vendors (particular for network security purposes)
- Manufacturer's requirements
- Industry best practice
- WHS Act, Regulations, guidelines, best practice
- SINSW Health and Safety (including COVID-safety) guidelines for external contractors
- Working With Children Check WWCC
- Site Inductions

Cable specifications and installation details should follow communication devices and cable manufacturer's recommendation and requirements, industry standards and best industry practice.

Concealment: Generally, reticulated services; pipework, conduits etc. are to be concealed from view, where possible within existing building elements. Where visible in occupied areas internally or externally, cover all services:

- External Services: Provide proprietary protective and decorative ducting, Colorbond or galvanised steel to house all pipework and conduits and the like. Match Colorbond colours or paint steel to match the associated surfaces.
- Internal Services: Provide proprietary extruded aluminium ducting with clip on aluminium covers. For small runs of control cabling, rectangular plastic ducting with removable covers is acceptable.

HVAC System Communications

- Current Control: via individual PAC wall controllers for each Fan Coil Unit FCU

Provide centralised HVAC control via Mitsubishi Electric central controller(s) (amount as per contractor’s design pending manufacturers requirements etc) for all CCP HVAC units.

Provide communications cabling between all Mitsubishi City Multi VRF HVAC outdoor units to the new Mitsubishi Electric Central controller(s) as per manufacturers requirements.

Provide error and status codes and filter alerts from the Mitsubishi Central Controller to the DCH Edge Server using Modbus TCP for later integration by SINSW to an existing SINSW CMMS.

The communications network connecting HVAC outdoor units enables the control of the indoor FCU’s.

DCH Edge Server

Supply a SuperMicro Edge Server with the following specifications (or approved equivalent) for integration to the School LAN:

- Xeon-D 1521 mITX SBC
- 1RU micro chassis with front I/O
- 1TB NVME Storage
- 16GB ECC RAM
- Example vendor: mitxpc.com p/n: RS-SMX104C2N-FIO

Notes for 1RU micro server commissioning:

- Mount in central school server room
- Install Debian 10 Linux
- Connect ethernet and IPMI ports to School LAN.
- Provide DHCP, MAC address, connected network switch ports and IPMI username/password to the client prior to commissioning/testing
- Test Modbus connectivity using modpoll/mbpoll to all devices
- Configure SSH for later access by SINSW
- Handover user and root accounts as requested or as part of documentation
- Check Modbus TCP connectivity to all PLCs, controllers, inverters and utility meter
- Note: No cellular modems to be installed, no VPNs or remote access outside of the specification above is allowed

PLC Communications

Network and test all CCP PLCs controllers to achieve the following:

- Connect all existing PLC’s from the CCP program to the School LAN (directly or via chains of PLCs connected via a serial communications bus) enabling DHCP, and supplying MAC addresses & network switch ports to the client
- Provide additional gateway PLC’s per MS/TP network for conversion between BACnet MS/TP and BACnet IP and Modbus TCP
- Relay the MS/TP network internal classroom sensor data to the gateway PLC for ingestion by the DCH Edge Server
- Relay all specified data points from the PLCs into Modbus TCP for connection by the DCH Edge Server including outside air sensors, where available
- Must preserve current CCP functionality in order for the systems to continue to operate as designed and intended under the CCP program*
- As a contractual option: Enable status and control of the ventilation fan via Modbus TCP
- Test Modbus polling of all PLCs from the DCH Edge Server
- Ensure all FCU settings can be modified by the HVAC central controller without impediment from PLC (on/off, mode, fan speed, set point).

* Note on CCP functionality: The only programming changes to the PLC that are required relate to the publishing of sensor data to, and allowing control of the ventilation fan from, the DCH Edge Server. The contact closures, LED

indicators and other CCP functions remain intact, with the exception being to price an option for variable fan speed control. The intent is that the CCP should operate per design guidelines regardless of connectivity of the central controller, DCH Edge Server or other additional equipment related to this project.

Ventilation Fan Speed Control

As a contractual option:

- Fans installed: Pacific HVAC FSW190-VEE model with 0-10V input to allow variable fan speed control
- PLCs installed: Innotech Omni C40 family of PLC as installed
- Current control: digital start/stop, using a digital output of the PLC via relay/contactor

Implement the following variable speed control for the fan speed via a 0-10V signal from an analogue PLC output depending on actual measured CO2 levels in the room (see figure 80). This analogue speed signal should use the existing digital control cable where possible.

Tenderer to provide line item costing for this item

Data Points

- Provide all data points as per table in the appendix
- Provide a data point naming convention for review and approval, following a standard naming scheme along the lines:
    - Site Name
    - Building
    - Room
    - MAC address
    - Point Name
    - Modbus Register
    - Modbus Unit Address
    - Data Type (uint16, floatbe, or similar)
    - Modbus Settings
    - Modbus Function (input or holding register)
    - Notes
- Refer to the data point list in the appendix for an example
- Provide data to the client or their representatives during the design stage as well as on demand and as required to complete commissioning

Documentation and Training

The following documentation and data must be provided both in hard copies (one copy) as well as electronically via a USB stick.

Inspection and Test Plans (ITP) and Commissioning Checklists with the minimum content of:

- Any commissioning requirements from the manufacturer,
- Provide test results (return value) from data point testing for every data point
- Screenshots of successful polling/writing of sample data points from/to end point devices
- Provide results from edge server testing to all Modbus devices incl PLCs and connected downstream BACnet devices
- Provide complete data point list with all configuration details as per naming convention

Programming Details

- Software programs as files
- Documentation of HVAC controller settings

Drawings

- AutoCAD drawings in pdf and AutoCAD format of all cabling and connections
- As designed
- As constructed

Manuals

- Complete set of all manuals for each site
- All relevant warranty, maintenance, specification, data information etc applicable to the goods/services/materials used in the project
- System operation manuals
- Maintenance manuals
- Provision of detailed information for any alarm features included in the system
- Clear information on contact details for provision of assistance
- Information pertaining to the access to specific data or hosted system information including user logins, and available apps or programs
- Basic operation and design principals
- Periodic inspection and maintenance requirements

Specifications

- Equipment specifications
- Purchase sources of all products used

Sign Off (at both the stages of the finalised design and the project handover)

- Record of sign off from the Project Manager
- Record of sign off meeting with school & Asset Management Unit (AMU)
- Record of any uncompleted works and associated completion programme
- Record of all defect works and associated completion programme

Training

- A training session with relevant client stakeholders or nominated representatives shall be provided, including;
- Introduction to the system
- Maintenance requirements
- Fault finding
- Provide overview of manuals

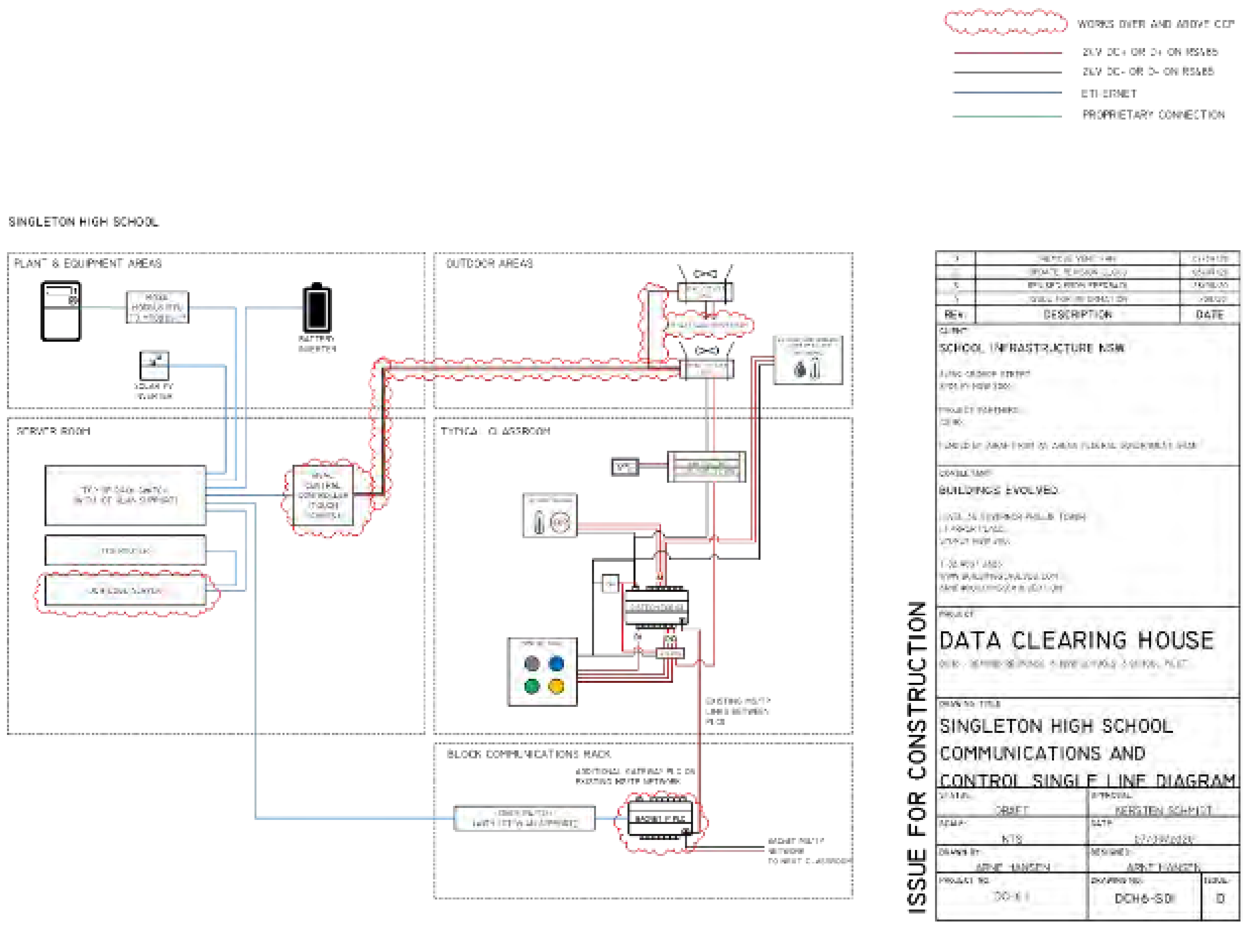


Figure 57: tender - Singleton HS single line diagram

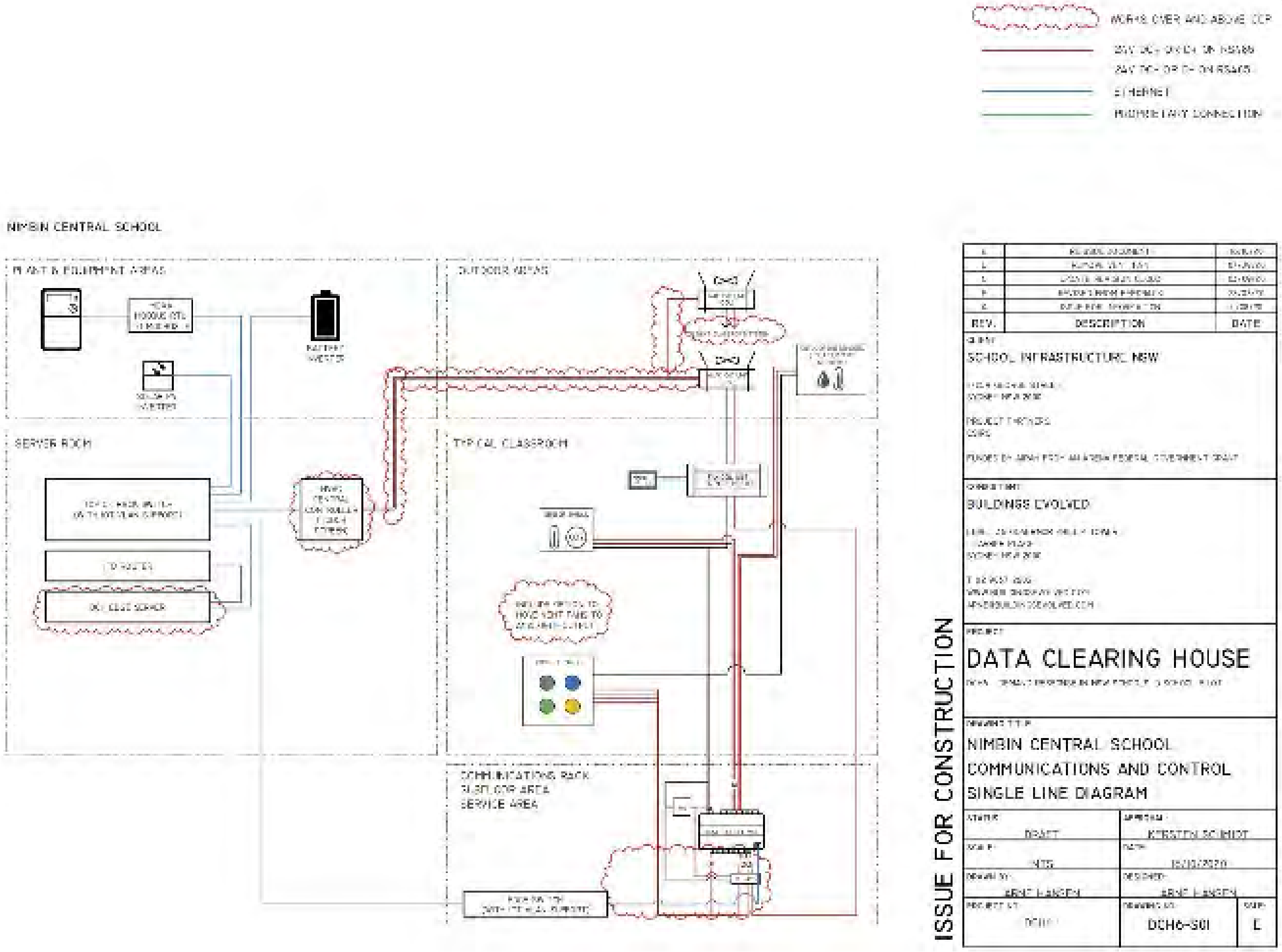


Figure 58: tender - Nimbin single line diagram

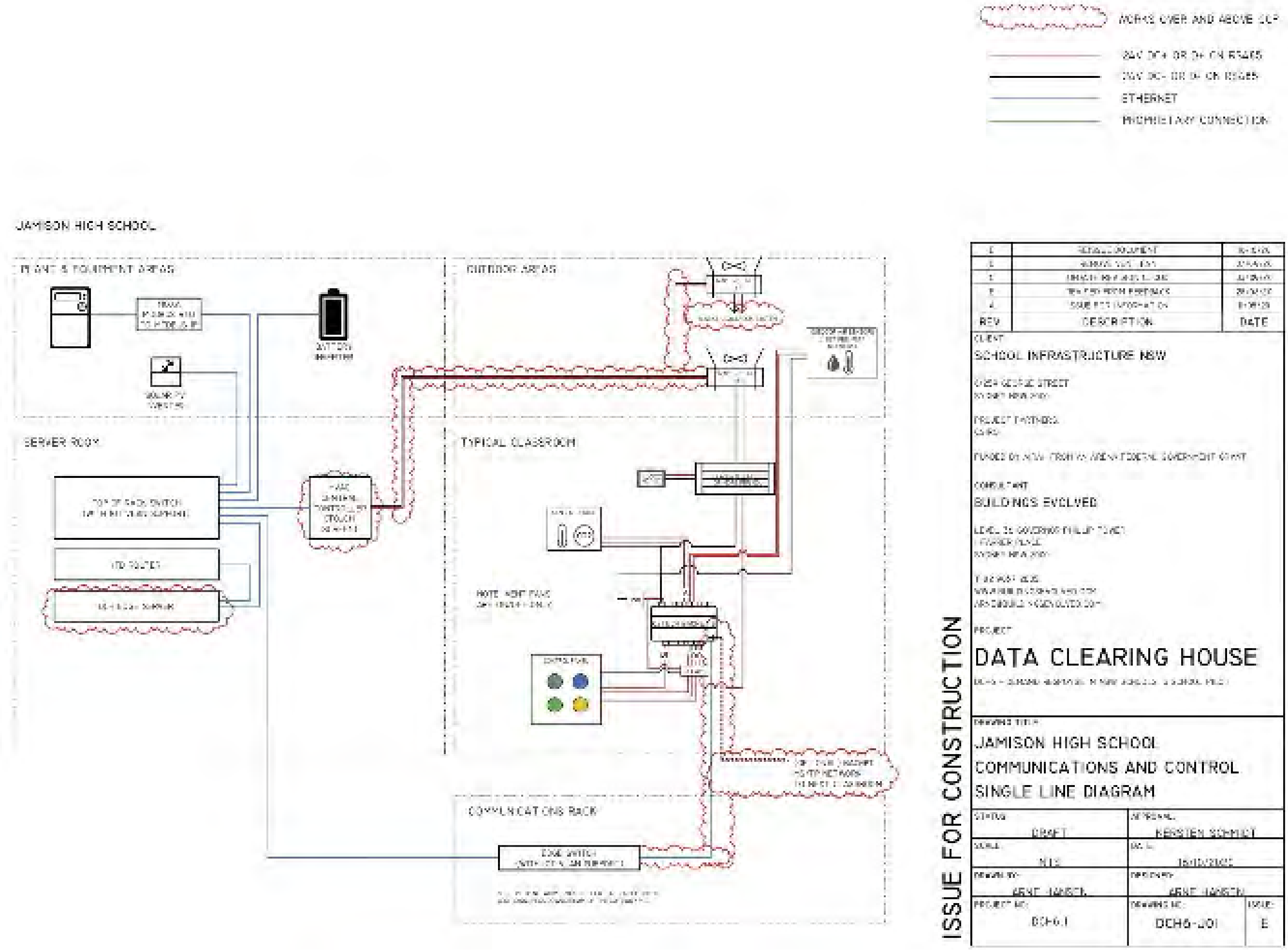
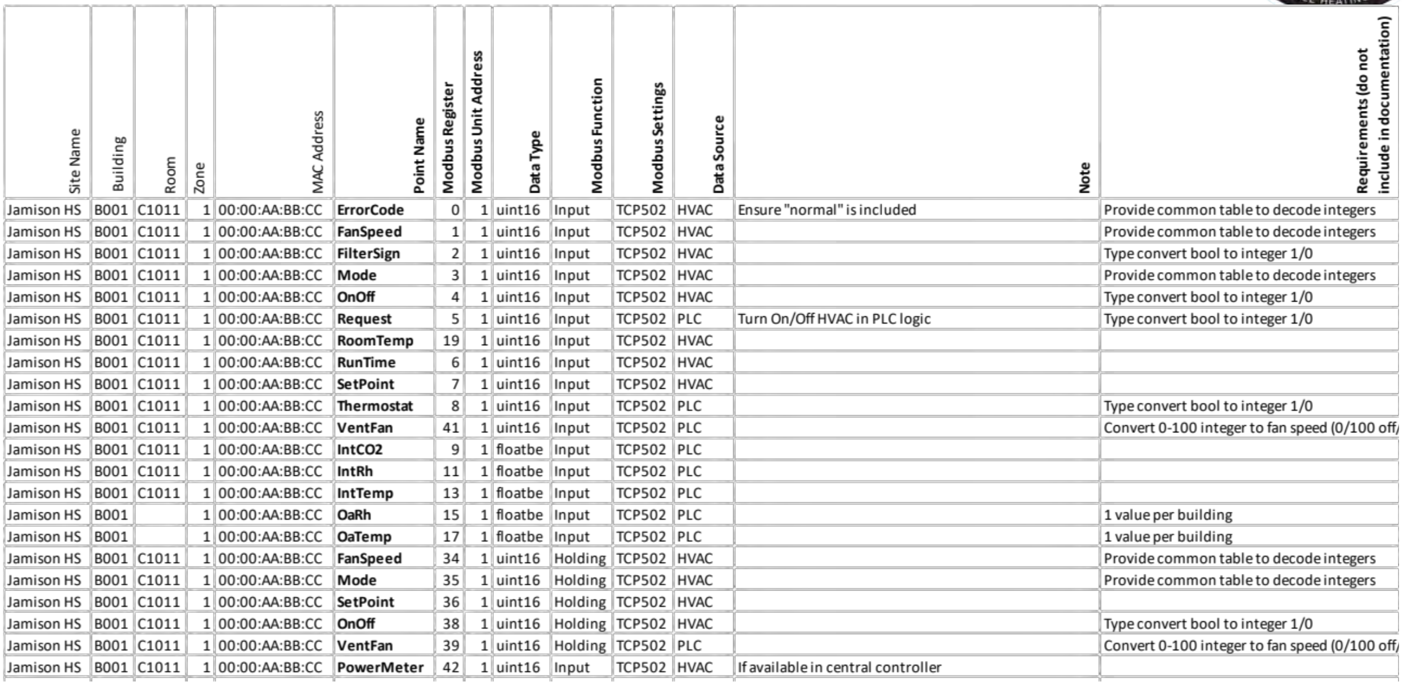
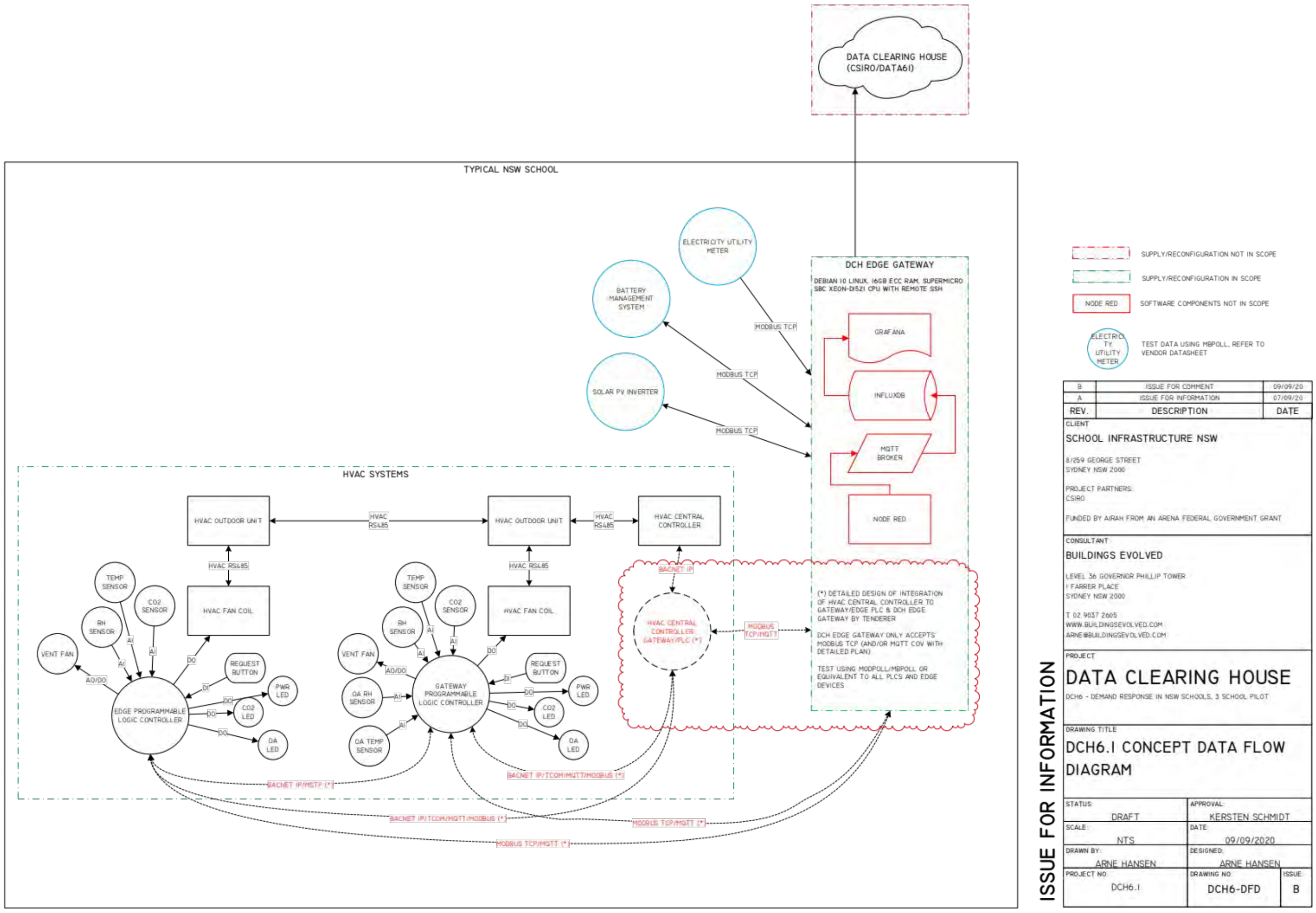


Figure 59: tender - Jamison single line diagram



Site Name	Building	Room	Zone	MAC Address	Point Name	Modbus Register	Modbus Unit Address	Data Type	Modbus Function	Modbus Settings	Data Source	Note	Requirements (do not include in documentation)
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**ErrorCode**	0	1	uint16	Input	TCP502	HVAC	Ensure "normal" is included	Provide common table to decode integers
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**FanSpeed**	1	1	uint16	Input	TCP502	HVAC		Provide common table to decode integers
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**FilterSign**	2	1	uint16	Input	TCP502	HVAC		Type convert bool to integer 1/0
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**Mode**	3	1	uint16	Input	TCP502	HVAC		Provide common table to decode integers
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**OnOff**	4	1	uint16	Input	TCP502	HVAC		Type convert bool to integer 1/0
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**Request**	5	1	uint16	Input	TCP502	PLC	Turn On/Off HVAC in PLC logic	Type convert bool to integer 1/0
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**RoomTemp**	19	1	uint16	Input	TCP502	HVAC		
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**RunTime**	6	1	uint16	Input	TCP502	HVAC		
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**SetPoint**	7	1	uint16	Input	TCP502	HVAC		
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**Thermostat**	8	1	uint16	Input	TCP502	PLC		Type convert bool to integer 1/0
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**VentFan**	41	1	uint16	Input	TCP502	PLC		Convert 0-100 integer to fan speed (0/100 off/
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**IntCO2**	9	1	floatbe	Input	TCP502	PLC		
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**IntRh**	11	1	floatbe	Input	TCP502	PLC		
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**IntTemp**	13	1	floatbe	Input	TCP502	PLC		
Jamison HS	B001		1	00:00:AA:BB:CC	**OaRh**	15	1	floatbe	Input	TCP502	PLC		1 value per building
Jamison HS	B001		1	00:00:AA:BB:CC	**OaTemp**	17	1	floatbe	Input	TCP502	PLC		1 value per building
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**FanSpeed**	34	1	uint16	Holding	TCP502	HVAC		Provide common table to decode integers
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**Mode**	35	1	uint16	Holding	TCP502	HVAC		Provide common table to decode integers
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**SetPoint**	36	1	uint16	Holding	TCP502	HVAC		
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**OnOff**	38	1	uint16	Holding	TCP502	HVAC		Type convert bool to integer 1/0
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**VentFan**	39	1	uint16	Holding	TCP502	PLC		Convert 0-100 integer to fan speed (0/100 off/
Jamison HS	B001	C1011	1	00:00:AA:BB:CC	**PowerMeter**	42	1	uint16	Input	TCP502	HVAC	If available in central controller	

Figure 60: tender - data point requirements for each classroom



(*) DETAILED DESIGN OF INTEGRATION OF HVAC CENTRAL CONTROLLER TO GATEWAY/EDGE PLC & DCH EDGE GATEWAY BY TENDERER

DCH EDGE GATEWAY ONLY ACCEPTS MODBUS TCP (AND/OR MQTT COV WITH DETAILED PLAN)

TEST USING MODPOLL/MBPOLL OR EQUIVALENT TO ALL PLCS AND EDGE DEVICES

REV.	DESCRIPTION	DATE
B	ISSUE FOR COMMENT	09/09/20
A	ISSUE FOR INFORMATION	07/09/20

CLIENT
SCHOOL INFRASTRUCTURE NSW
8/259 GEORGE STREET
SYDNEY NSW 2000

PROJECT PARTNERS:
CSIRO

FUNDED BY AIRAH FROM AN ARENA FEDERAL GOVERNMENT GRANT

CONSULTANT
BUILDINGS EVOLVED
LEVEL 36 GOVERNOR PHILLIP TOWER
1 FARRER PLACE
SYDNEY NSW 2000

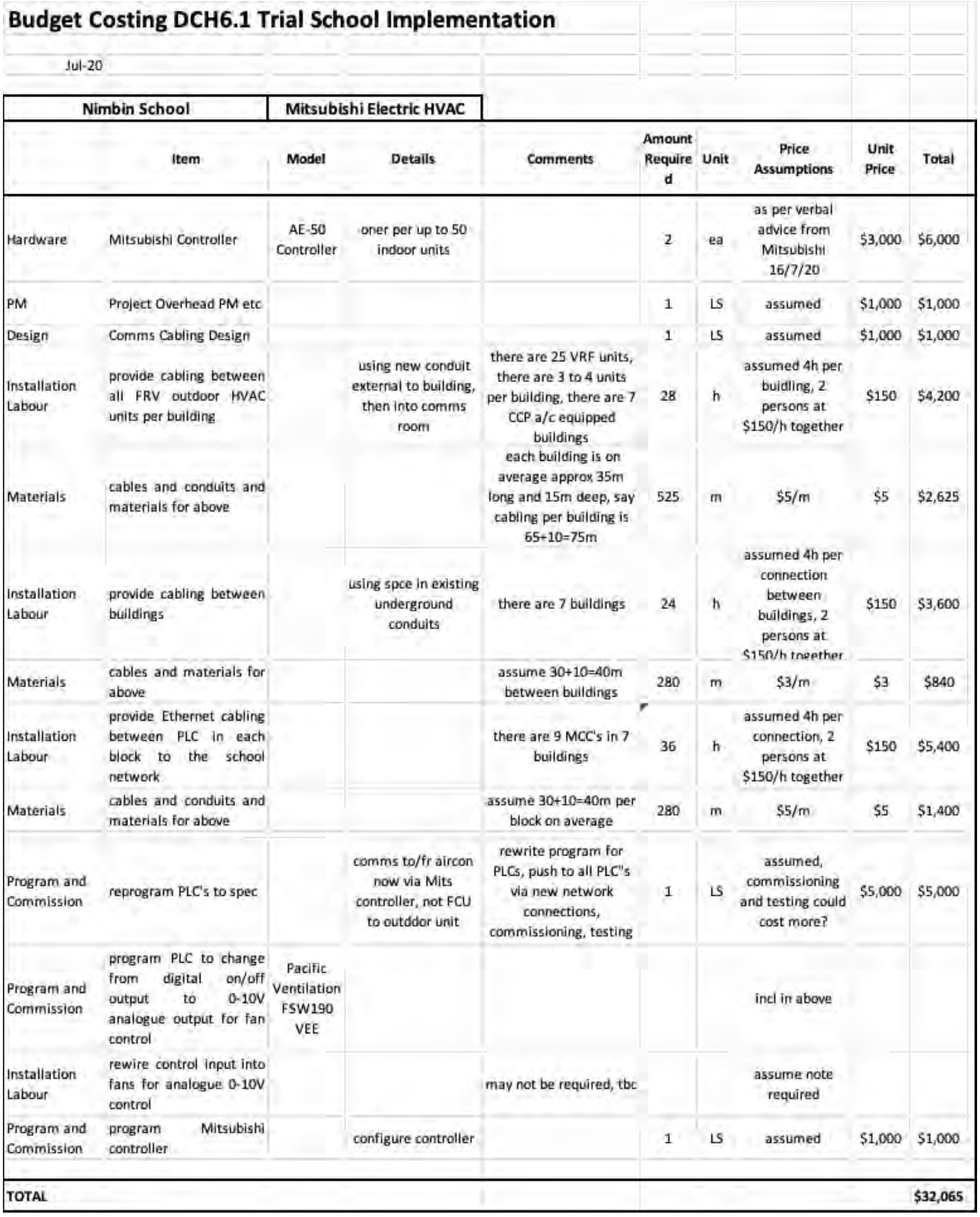
T 02 9037 2605
WWW.BUILDINGSEVOLVED.COM
ARNE@BUILDINGSEVOLVED.COM

PROJECT
DATA CLEARING HOUSE
DCH6 - DEMAND RESPONSE IN NSW SCHOOLS, 3 SCHOOL PILOT

DRAWING TITLE
DCH6.1 CONCEPT DATA FLOW DIAGRAM

STATUS: DRAFT	APPROVAL: KERSTEN SCHMIDT
SCALE: NTS	DATE: 09/09/2020
DRAWN BY: ARNE HANSEN	DESIGNED: ARNE HANSEN
PROJECT NO: DCH6.1	DRAWING NO: DCH6-DFD ISSUE: B

Figure 61: tender - data flow diagram



Budget Costing DCH6.1 Trial School Implementation

Jul-20

Nimbin School | **Mitsubishi Electric HVAC**

	Item	Model	Details	Comments	Amount Required	Unit	Price Assumptions	Unit Price	Total
Hardware	Mitsubishi Controller	AE-50 Controller	oner per up to 50 indoor units		2	ea	as per verbal advice from Mitsubishi 16/7/20	$3,000	$6,000
PM	Project Overhead PM etc				1	LS	assumed	$1,000	$1,000
Design	Comms Cabling Design				1	LS	assumed	$1,000	$1,000
Installation Labour	provide cabling between all FRV outdoor HVAC units per building		using new conduit external to building, then into comms room	there are 25 VRF units, there are 3 to 4 units per building, there are 7 CCP a/c equipped buildings	28	h	assumed 4h per buidling, 2 persons at $150/h together	$150	$4,200
Materials	cables and conduits and materials for above			each building is on average approx 35m long and 15m deep, say cabling per building is 65+10=75m	525	m	$5/m	$5	$2,625
Installation Labour	provide cabling between buildings		using spce in existing underground conduits	there are 7 buildings	24	h	assumed 4h per connection between buildings, 2 persons at $150/h together	$150	$3,600
Materials	cables and materials for above			assume 30+10=40m between buildings	280	m	$3/m	$3	$840
Installation Labour	provide Ethernet cabling between PLC in each block to the school network			there are 9 MCC's in 7 buildings	36	h	assumed 4h per connection, 2 persons at $150/h together	$150	$5,400
Materials	cables and conduits and materials for above			assume 30+10=40m per block on average	280	m	$5/m	$5	$1,400
Program and Commission	reprogram PLC's to spec		comms to/fr aircon now via Mits controller, not FCU to outddor unit	rewrite program for PLCs, push to all PLC"s via new network connections, commissioning, testing	1	LS	assumed, commissioning and testing could cost more?	$5,000	$5,000
Program and Commission	program PLC to change from digital on/off output to 0-10V analogue output for fan control	Pacific Ventilation FSW190 VEE					incl in above		
Installation Labour	rewire control input into fans for analogue 0-10V control			may not be required, tbc			assume note required		
Program and Commission	program Mitsubishi controller		configure controller		1	LS	assumed	$1,000	$1,000
TOTAL									$32,065

Figure 62: tender - typical costing document for Nimbin CS (only in internal Procurement Strategy Document)

Conclusion

As a proof-of-concept, the project attracted higher prices than the assumed prices within the tender strategy. They would more accurately reflect the price as an addition to the CCP rather than a retrofit, which is what this project involved. Retrofit, plus the relative over-engineering involved with a proof-of-concept, coupled that the work it is new to the market (attracting risk as cost from the perspective of the contractor) equates to inflated prices. The results of the proof-of-concept are intended to inform what data and controls provide value, allowing value engineering to occur in hindsight. Regardless, the modelled capex for the HVAC controls scenarios remains set at $100,000, or $125,000 where batteries and HVAC controls occur.

3 2020 SCHOOL SITE VISIT & RECOMMENDATIONS

This is a revision to the initial site visit report by BE with input by CSIRO and SINSW. This work was used to understand the requirements for the modelling and control system and was completed in May of 2020. Due to constraints outlined above in relation to COVID, a subsequent site visit was not completed by this project team in the project timeline.

3.1 Site details – Jamison HS

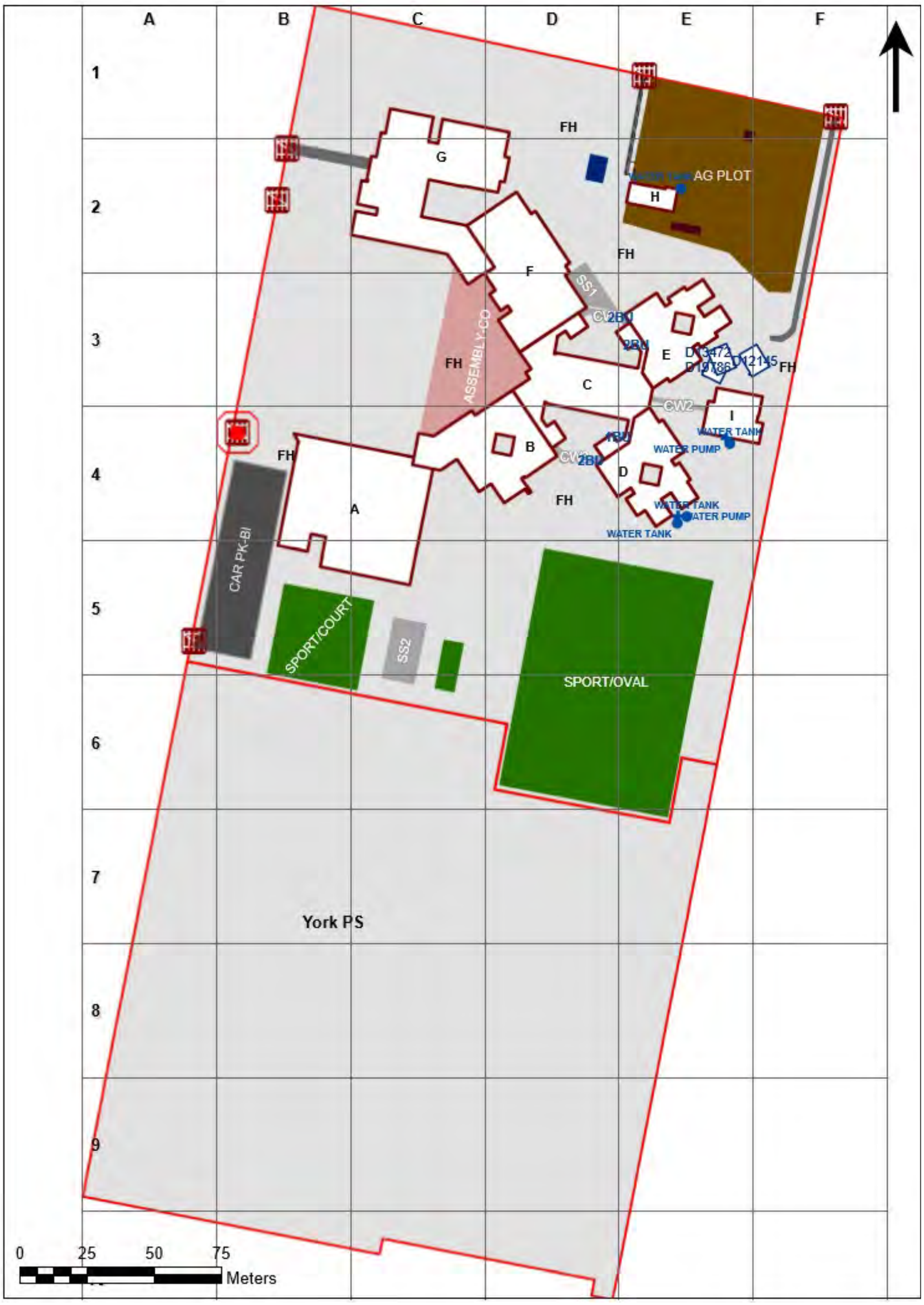


Figure 63: site report - Jamison HS site layout

Drawing 1: site report - Jamison HS drone photography taken during 2020 site visit

Figure 64: site report - Jamison HS typical Daikin FCU

Figure 65: site report - Jamison HS typical Daikin condenser unit (with return air)

Figure 66: site report - Jamison HS typical CCP HVAC control panel

Figure 67: site report - Jamison HS typical CCP HVAC control panel

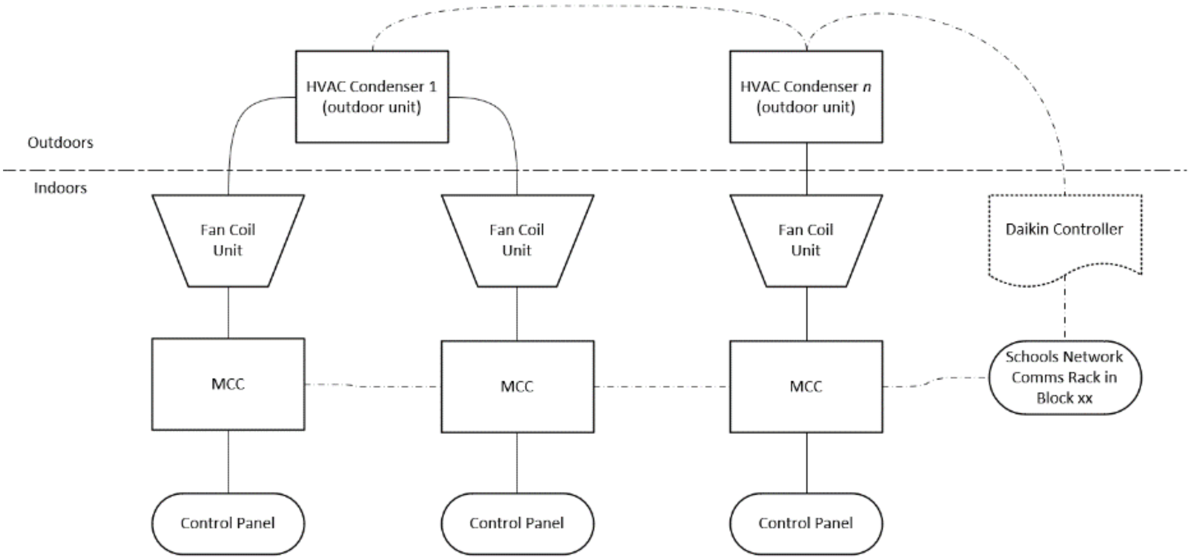


Figure 68: site report - Jamison HS concept communications diagram

3.2 Site details - Singleton HS

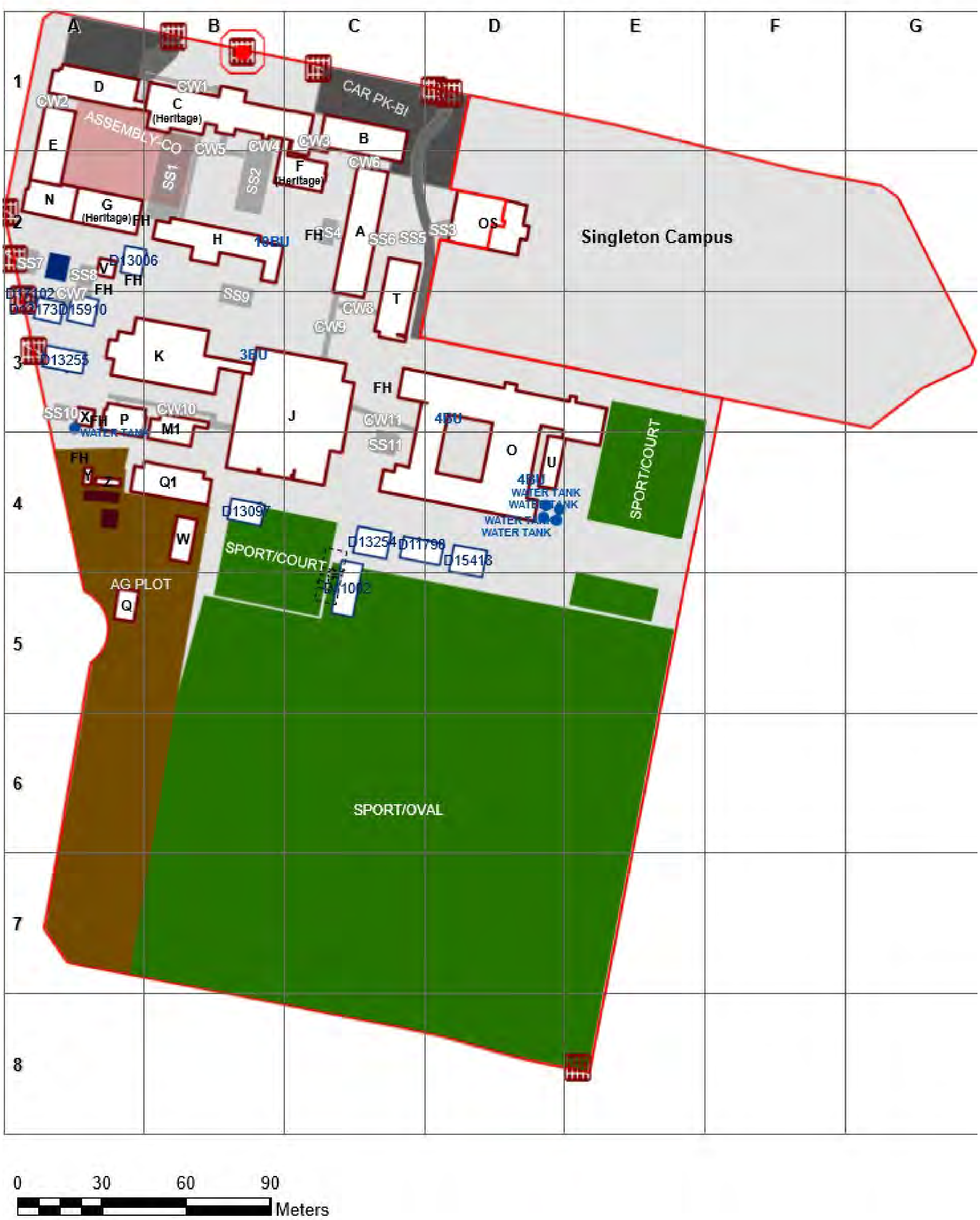
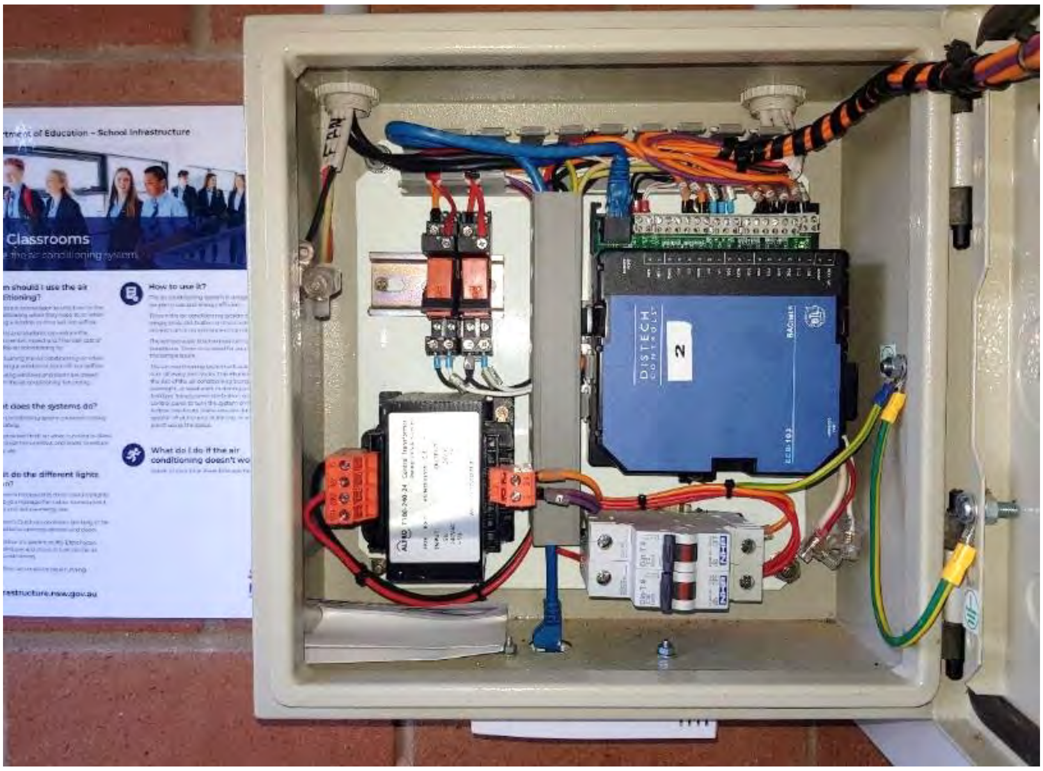


Figure 69: site report - Singleton HS layout

Drawing 2: site visit - drone photography of Singleton HS taken in 2020 site visit

Figure 70: site report - Singleton HS typical HVAC system



Drawing 3: site report - Singleton HS typical CCP HVAC control panel

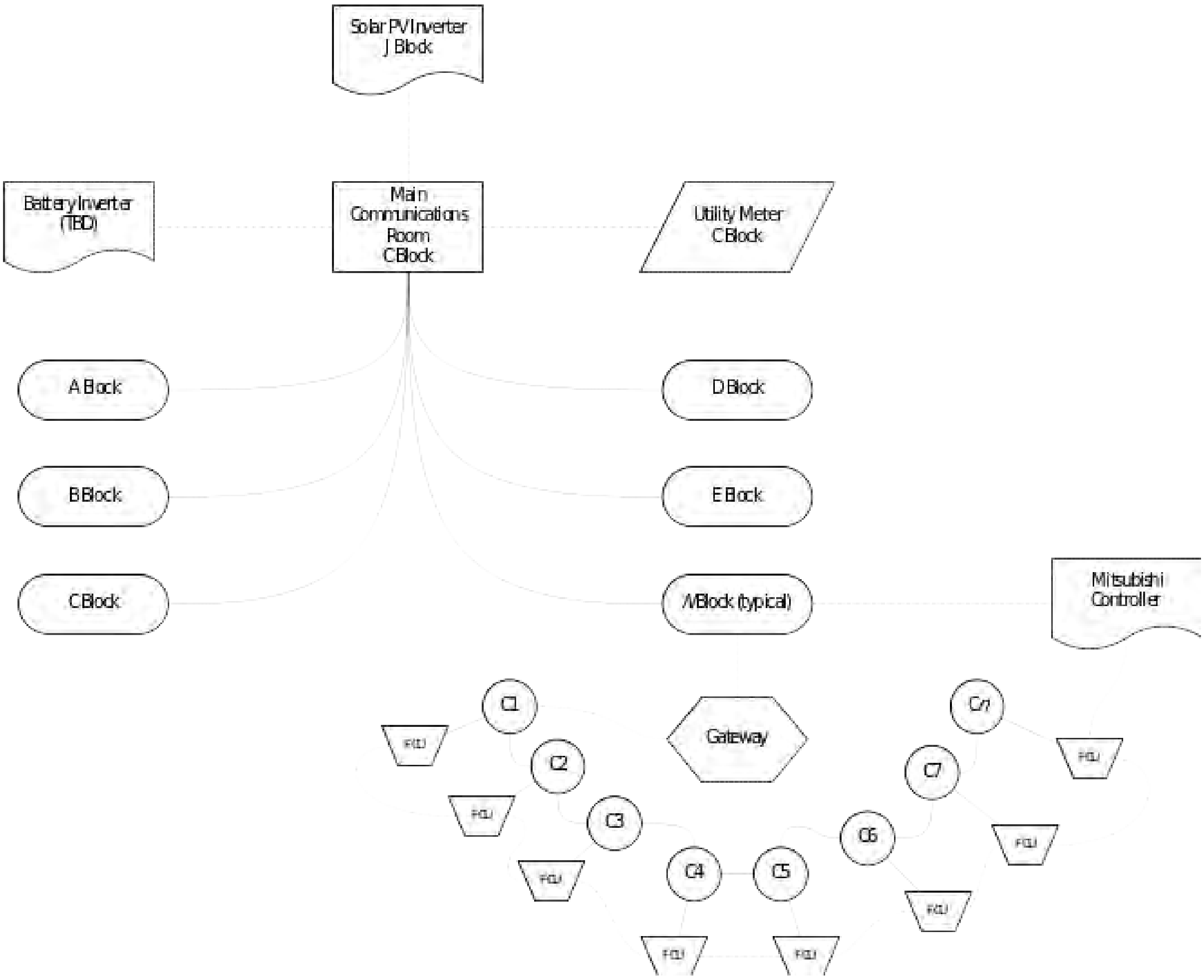


Figure 71: site report - Singleton HS concept diagram of systems to monitor

3.3 Site details - Nimbin CS

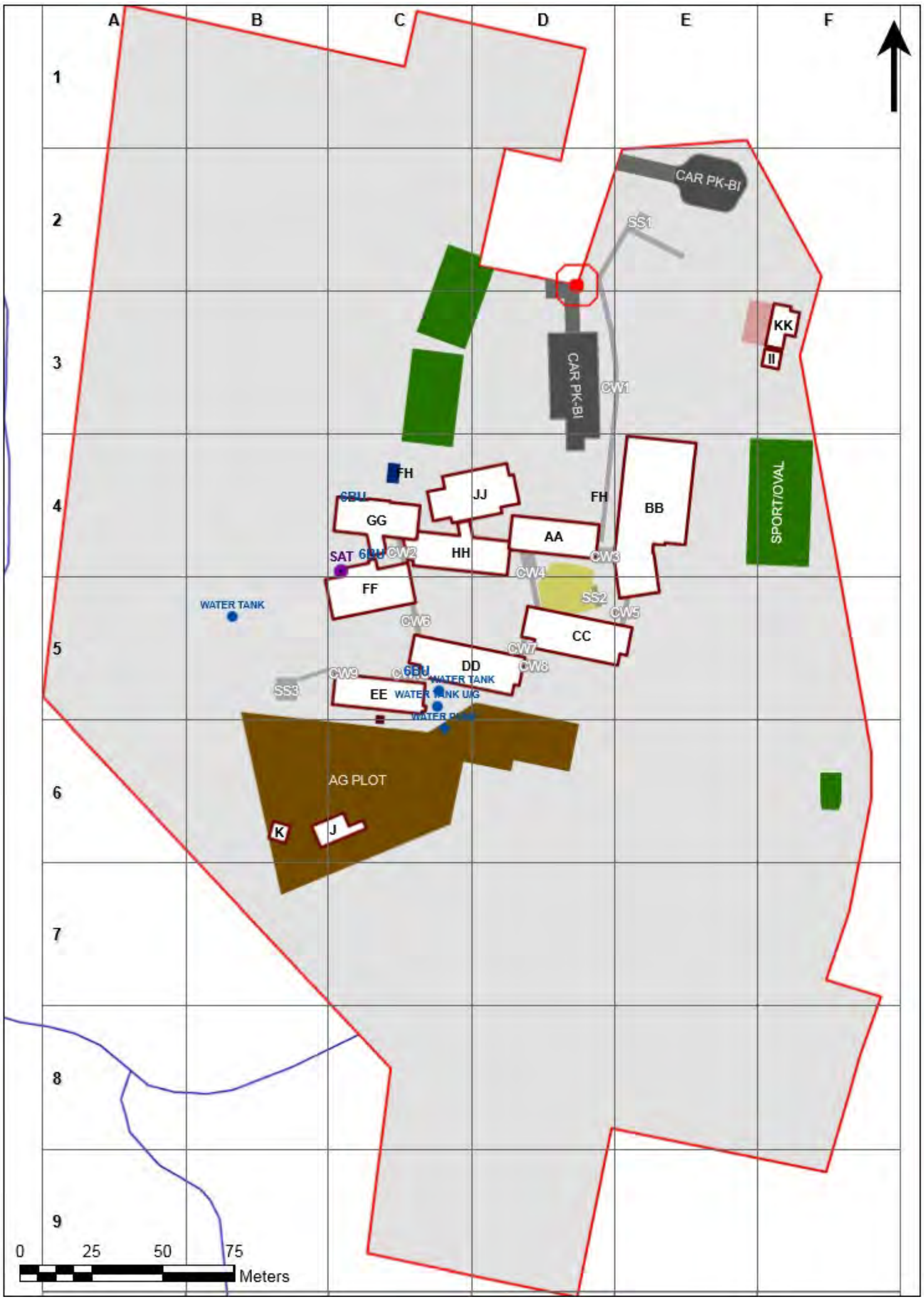


Figure 72: site report - Nimbin CS site layout


Figure 73: site report - Nimbin CS drone photography taken during 2020 site visit

Figure 74: site report - Nimbin CS typical Mitsubishi 'city multi' FCU

Figure 75: site visit - Nimbin CS typical CCP HVAC control panel, and temp/CO2 sensor

Drawing 4: site report - Nimbin CS library showing FCU, control panel and ventilation fan

Drawing 5: site report - Nimbin CS typical CCP HVAC control panel

NSW Department of Education – School Infrastructure

Cooler Classrooms

How to use the air conditioning system

When should I use the air conditioning?

How to use it?

What does the systems do?

What do the different lights mean?

What do I do if the air conditioning doesn't work?

REPORT FAULT TO
GA OR HEAD TEACHER

schoolinfrastructure.nsw.gov.au

Figure 76: site report - Nimbin CS education around HVAC system use (found in all three schools visited)

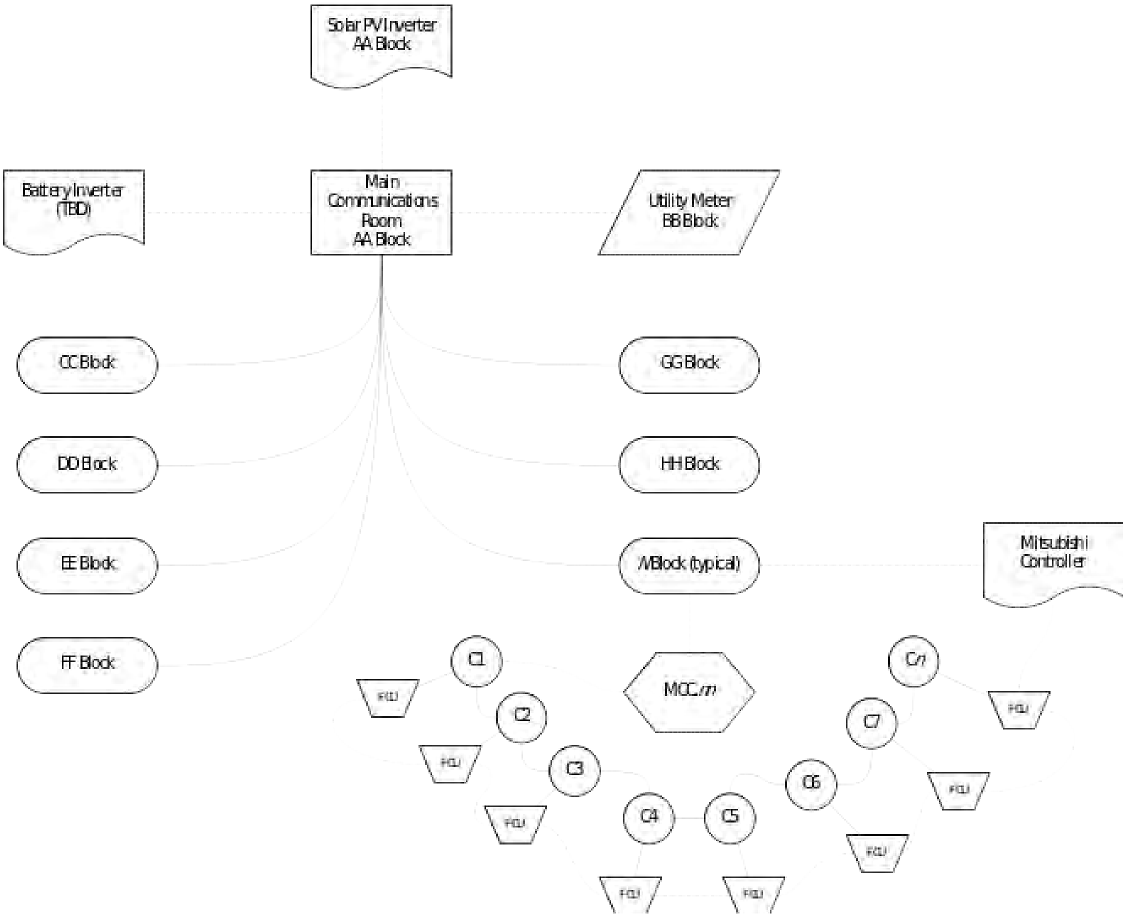


Figure 77: site report - Nimbin CS concept communications diagram

3.4 Planned architecture

Report objectives include:

- Review as installed Cooler Classrooms plant and equipment, control systems and communications.
- Review existing communications infrastructure.
- Review any existing metering or sub-metering equipment and communications.
- Inform stakeholders about site network infrastructure and processes required to fulfill the technical requirements of the DCH6.1 project.

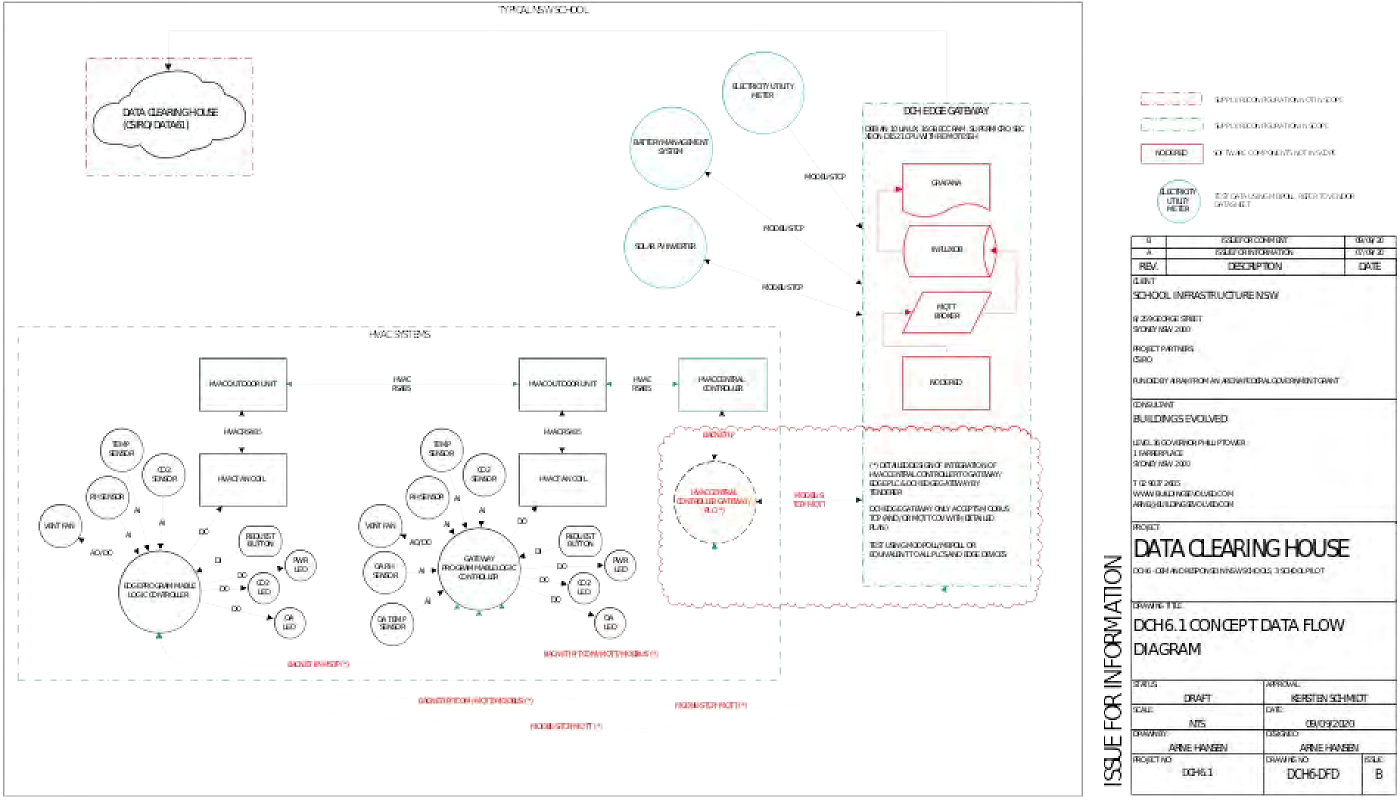


Figure 78: site visits - network architecture data flow diagram

The future state system involves:

- HVAC systems communication via Modbus to the nominated gateway PLC on each school network
- PLC communication via BACnet IP/Modbus IP/MQTT to the central edge controller gateway PLC
- Output from the edge controller to the nominated data/analytics platform (Grafana).

3.5 Typical cooler classroom

The type, characteristics and location of mechanical control centres (MCC) varies between school sites. Likewise, the controllers used to operate MCCs also varies. Typically, controllers are networked using BACnet MS/TP over a two-wire RS485 serial bus. The extent and topology of networking between classrooms is generally unknown as this is not often documented. To meet the control performance specification, each classroom will need to be networked to gather external sensor data (common to each block).

To uplift the MCCs, the following is required:

- Addition of a BACnet MS/TP communications gateway or PLC (by Mech contactor)
- Connection to the existing MS/TP RS485 network
- Connected to an SINSW network switch in each of the block’s communication racks
- Commissioning of BACnet MS/TP gateway or PLC to configure IP addresses/supply MAC address to ITD
- Configuration of an IOT Virtual LAN on the ITD infrastructure
- High-level interface to HVAC systems implemented via BACnet IP
- Possible recommissioning of MCC PLC to publish Modbus points if not already configured to do so
- Publishing of Modbus registers for polling by the central communications gateway
- Configuration of an IOT Virtual LAN on the ITD infrastructure
- High-level interface to HVAC systems implemented via BACnet IP
- Possible recommissioning of MCC PLC to publish Modbus points if not already configured to do so

- Publishing of Modbus registers for polling by the central communications gateway

3.6 Recommendations - Singleton HS

Recommendations – Nil additional equipment

That the control systems are remediated in part through the following actions:

1. **Change ventilation fan from on/off to variable speed** – no additional equipment required

   The Distech ECB-103 family of PLC as installed provides 4x digital outputs and 2x analogue outputs. Each of the fans are connected as specified, using a relay (from the digital output) to control the fan operation. Figure 79, a photograph of a document found on site shows the wiring to each of these channels and how they are configured for operation

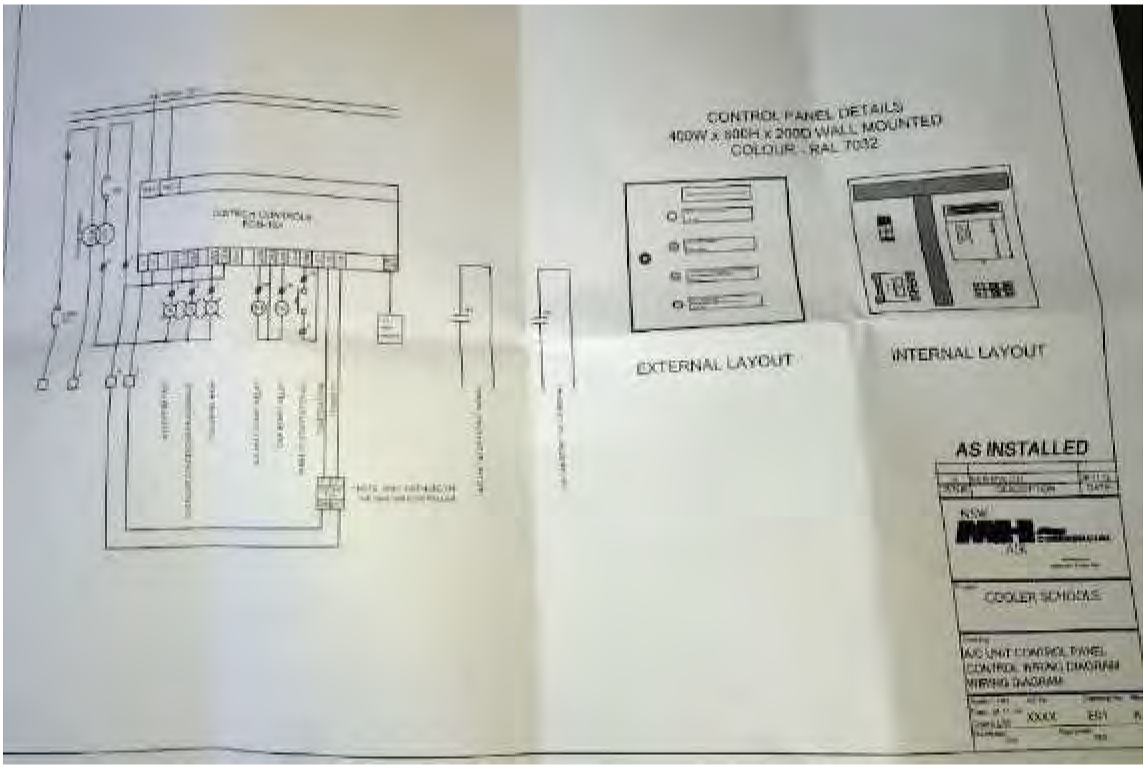


Figure 79: wiring diagram for a typical PLC (from a photograph taken of site documentation)

   The ventilation fans, a Pacific HVAC FSW190-VEE model, provides a 0-10V input to allow variable EC fan speed control from a PLC such as the Distech ECB-103 series.

   The recommendation is to a) rewire the fan output from digital output to analogue output; and b) modify the programming of the PLC to provide a 0-10V signal to the fans and ramp the fans on depending on CO2 concentrations per Figure 80.

   It is recommended that the fan begin operating at lower concentration levels, and that the fan continue to ramp in speed as it approaches 1200ppm CO2 (Figure 80). Not only does this better manage CO2 levels, it ensures that noise is minimised.

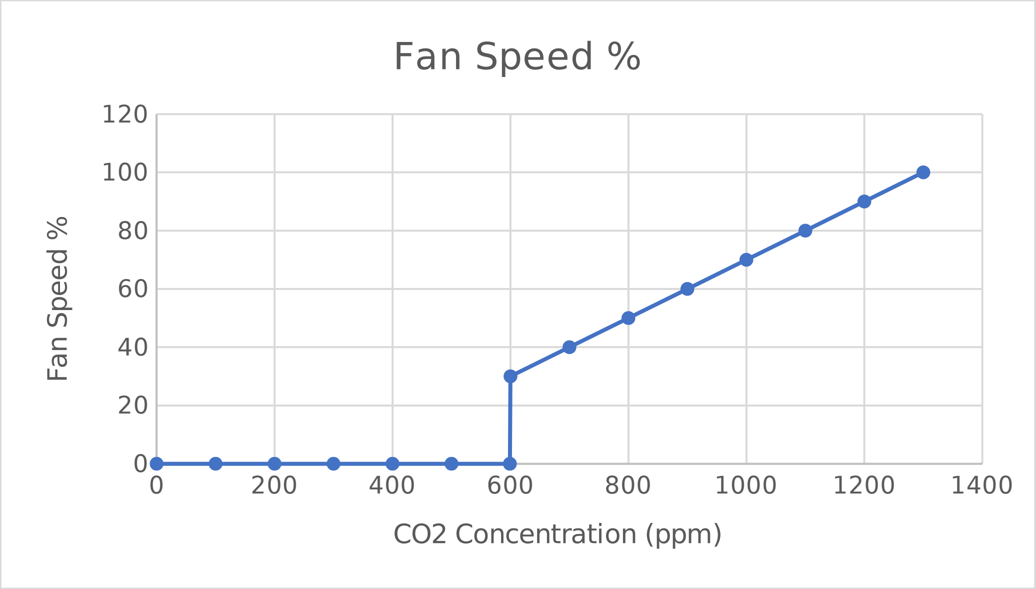


Figure 80: site report – typical fan speed based on CO2 concentration

The present situation as specified yields the following fan speed diagram (Figure 81) – producing a very noticeable sound for occupants.

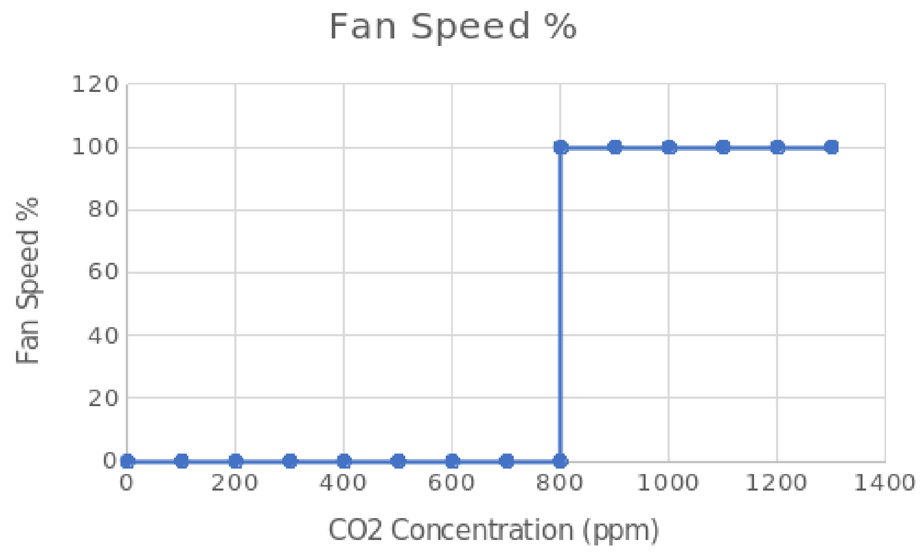


Figure 81: site report - current fan speed control scenario

2. **HVAC systems appear to be oversized** – Review of HVAC systems shows 11kW of cooling being installed in a room of 14.3m2 (BR0007)

Recommendations – Additional equipment

3. ~~**Add additional HVAC system temperature sensor (PAC-SE41TS-E) wired at 1500 FFL to each system** – The HVAC system relies either on the return air or the wall controller temperature sensor to provide the control for the system thermostat. This control logic sits external of the PLC and is part of the stand-alone operation of the HVAC system itself. In many locations, FCUs and their return air are mounted at high locations, and the CCP design guideline calls for wall controllers to be mounted at height or in locked boxes to~~

~~avoid vandalism issues. Therefore, there are many circumstances where the delta-T from 1500 FFL to the return air temperature sensor will vary wildly, making set point control of the space impossible without application of a manual offset. We would question how this is being done by the service technicians, whether they apply a manual offset to the manual set point control on each unit based on these height variances in order to achieve the stated goal of ASHRAE 55. In some instances, the FCUs were mounted at 4000 FFL with the corresponding wall controller mounted alongside. In other locations, the FCU and wall controller was at 2200 FFL.~~

~~It is important to note that the temperature sensor connected to the PLC has no bearing on the operation of the HVAC system. The temperature sensor data from the PLC cannot be used by the proprietary HVAC system. This sensor is only used to vary the operation of the ventilation fans based on internal temperature.~~

~~It is recommended that this sensor be added to the sensor cluster containing the PLC connected internal Temp and CO2 Sensor. It is then required to reprogram the HVAC unit to use this new sensor as room temperature reference for internal thermostat control.~~

~~Achieving the above will allow for accurate thermostat and refrigerant flow control by the HVAC system, improving occupant comfort, predictability of comfort, system lifespan, and energy consumption through optimised internal control.~~

Negated by HVAC controls in subsequent system design work.

4. **PLCs to be connected to the SINSW network** – PLCs should be wired to the Schools Network per the scope of works, and that Modbus control functionality is tested by the contractor at a central point on the school’s network.

   It is suggested that in each of blocks O, A, B, C, D, E, N and G that an additional PLC be could be added as a gateway to each of the existing BACnet MS/TP networks, or a quantity of PLCs factoring in cost of interconnecting blocks with MS/TP cabling. Given that we are uncertain as to the exact MS/TP cabling, there may already be many classrooms interconnected to avoid the OA sensor costs being repeated on each block.

   These PLCs will gateway BACnet MS/TP to BACnet IP and Modbus TCP (slave) to service the requirements of the Mitsubishi Central Controller and the DCH Edge Server. While the MS/TP network could replace the on/off contact closure, it is recommended this is retained because it is zero cost and adds redundancy. While no error lamp exists in the present CCP guidelines, this could easily be added using this control methodology. The MS/TP network will relay internal classroom sensor data to the PLC gateway for ingestion by the DCH Edge Server.

   The gateway PLC will then relay all other relevant HVAC system information into a Modbus Slave for connection to the DCH Edge Server. Modbus TCP is selected for this transport as it is the same used by all other equipment: PV inverter, battery inverter and electricity meter.

   Ultimately, the scope of which blocks were to be installed with controls were based on price from market: blocks with a small number of classrooms were deemed non-material compared with the outcomes and impact of focusing spending on blocks with a high classroom density. Jamison HS and Nimbin CS fit this profile: Singleton did not.

5. **Wire Mitsubishi outdoor units together and add Mitsubishi Central Controller** – The Mitsubishi HVAC system as installed is predominantly the “City Multi” model variant which features central control capability. Vendor control panels can be removed in large part, or replaced in some instances with a vendor temperature sensor (no user input). Modes can be selected from a central point, as can system status, fault reports and operational control. The Data Clearing House can connect to the existing on/off PLC functionality but would provide a better outcome with setpoint control. The above vendor details has been confirmed with the Technical Director at Mitsubishi Heavy Industry, Australia on 14th April, 2020.

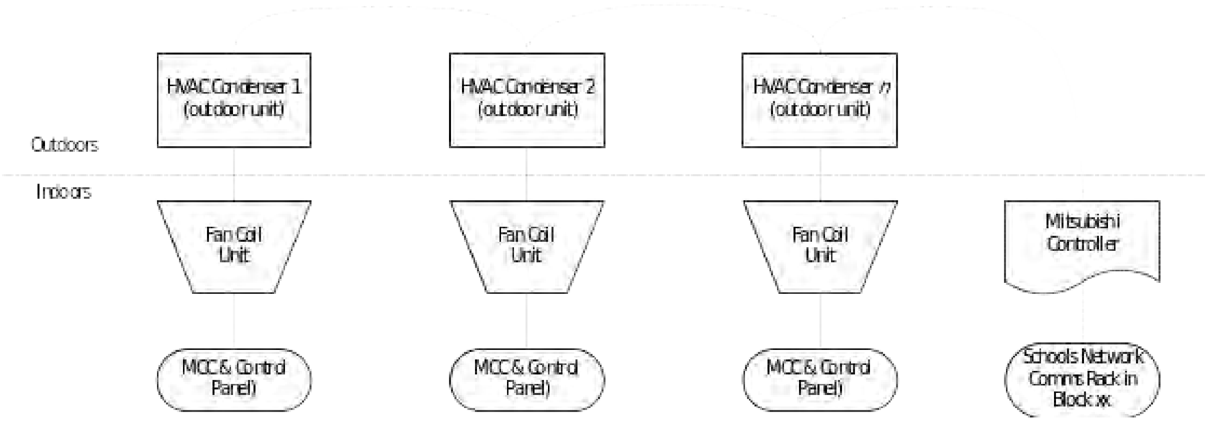


Figure 82: site visit - upgrading Mitsubishi outdoor units with control system

6. **Add fault reporting for reactive and preventive maintenance** – Faults are not reported as each system is stand-alone. Faults should be rectified in a timely manner to ensure a long lifespan of the equipment. This has a material financial impact upon the Cooler Classrooms project in the operational phase.

   Using the Mitsubishi Central Controller as gateway, provide error codes and filter alerts to the Computerised Maintenance Management System (CMMS) or Asset Management System (AMS) for automated fault resolution and optimised maintenance regimes. Introduce preventive maintenance through algorithmic analysis of system runtime and fault history. See section on AMS simulation for further information.

7. **Add automated mode selection** – Using data from the outdoor air sensors, automatically select system mode. In testing in our lab, we have found that selecting fan mode when the outdoor conditions light is active is a simple upgrade that will undoubtedly save energy. In addition, we have created a logic scenario whereby the system shifts to “dry” mode when the outdoor temperature condition is met, but the humidity condition is not. This upgrade also removes the need for bi-annual scheduled maintenance to coincide with manual mode selection of the individual units throughout the portfolio.

8. **Add IoT VLAN to ITD network for transit of insecure BACnet IP traffic** – This network VLAN would encompass all BACnet IP related traffic to and from the Mitsubishi Controller and the gateway PLCs.

9. **Add network access via the ITD router and internet connection** – Utilise a second network adaptor on the DCH Edge Server to connect to the DCH hosted at Data61 and allow remote access capability.

10. **Allow SSH access to the DCH Edge Server via VPN or other method** – ITD to supply a method of remotely monitoring and controlling the DCH Edge Server for remote monitoring and updates during the development phase into operational phase.

11. **Add DCH Edge Server to Server Room** – Supply a SuperMicro Edge Server in a 1RU chassis for integration to the ITD network. The lab environment uses a Xeon D 1528 based board with 4x network adaptors. It is likely that a minimum of 2 of these adaptors will be used for the DCH project: 1x for BACnet IP and Modbus TCP connected to the internal IoT VLAN and the other for connection to the outbound internet connection. There is the possibility of requiring the separation of the BACnet IP traffic into another VLAN to the Modbus, and if this eventuates, the unit provides expansion capabilities in this regard.

    Recommend that the contractor supply and install the server, pre-install it with Debian Linux and test Modbus connectivity using mbpoll. Remote access shall be provided using SSH, along with outbound DNS. Results should be included in the commissioning report.

12. **Provide redundancy in the edge PLC** – Use a keep alive from the DCH Edge Server via Modbus to the edge PLC to engage DCH connected mode. Should the keep alive fail, the PLC will revert to a redundant mode complying with the general requirements of the CCP.

13. **Lock out wall control panels via the central controller** – Due to interference with the operation of the HVAC systems in classrooms from staff and students, it is recommended that the keypad lock function be enabled on all wall controllers from the central controller.
14. **Add Modbus IP to the Electricity Utility Meter** – Per the network monitoring trial at 20 schools including Jamison HS, arrange for PlusES (metering provider) to add modbus IP to the school, and arrange cabling to suit.

3.7 Recommendations - Nimbin CS

Recommendations – Nil additional equipment

That the control systems are remediated in part through the following actions:

2. **Change ventilation fan from on/off to variable speed** – no additional equipment required

   The Innotech Omni C40 family of PLC as installed provides “universal input/output” meaning that each of the 40 channels can be tasked to analogue or digital/input or output. Each of the fans are connected as specified, using a relay or digital output to control the fan operation. Figure 41, a photograph of a document found on site shows the wiring to each of these channels and how they are configured for operation.

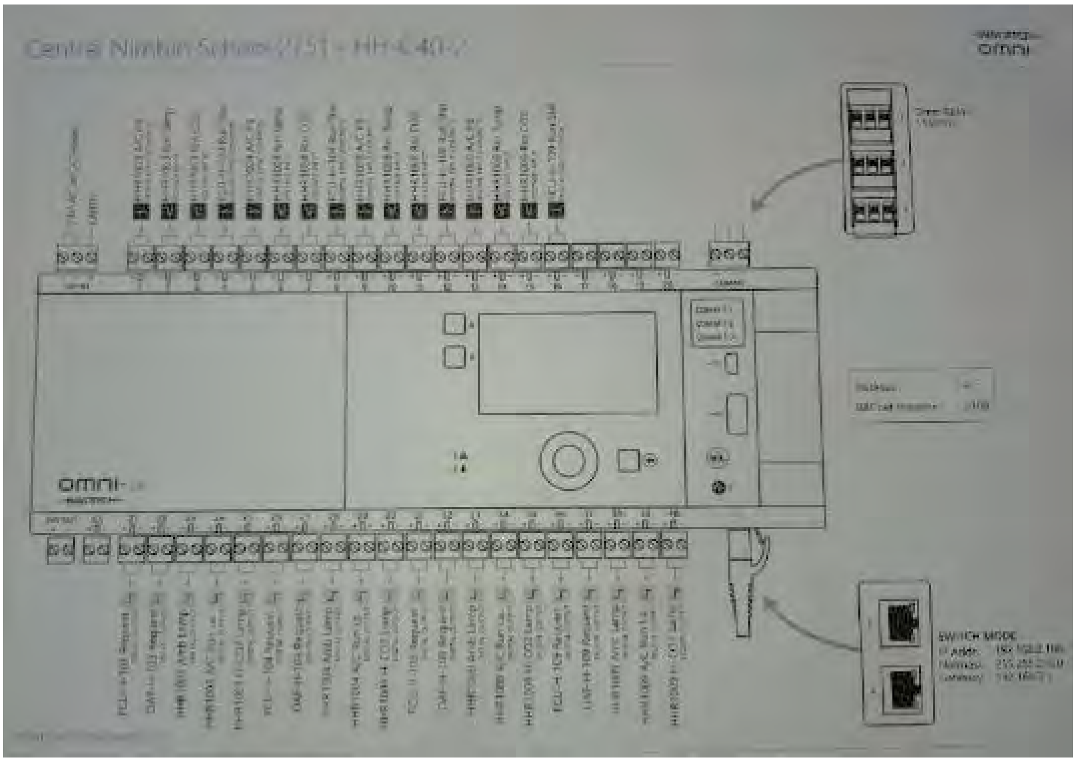


Figure 83: Wiring diagram for a typical PLC from a photograph taken of site documentation

   Other recommendations on this topic mirror that of Singleton HS.

3. Point 3-12; Follow recommendations from Singleton

3.8 Recommendations - Jamison HS

1. Follow recommendations from Singleton
2. as above

3. **Wire Daikin outdoor units together and add a Daikin Central Controller (DMS502B7)** – Jamison has very few outdoor units, and those that exist are large units. This makes the wiring to connect the outdoor units together relatively straight-forward compared to other locations and topologies of systems. The VRF solution from Daikin as installed in Jamison HS provides the capability for a central controller and BACnet gateway that this school would require 1x quantity.

   Modes can be selected from a central point, as can system status, fault reports and operational control. The Data Clearing House would primarily use setpoint control via the central controller, while user input would be from the existing contact closure from the edge PLC.

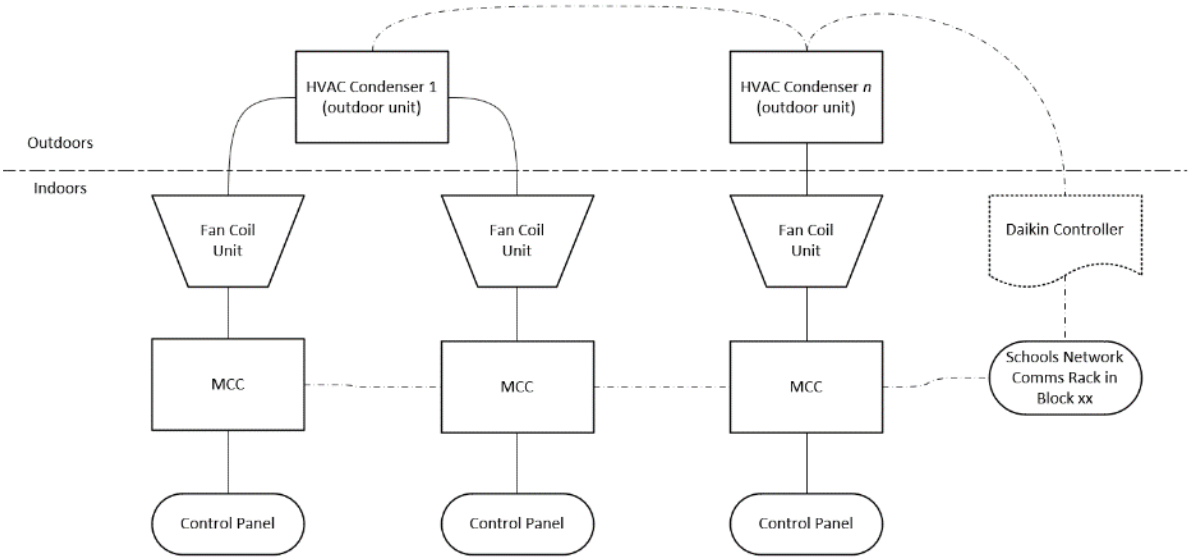
   

   Figure 84: upgrading Daikin outdoor units with control system

   This upgrade does not require any additional cabling to be run through internal areas of the school to the FCU or PLC. The wiring runs between the outdoor condenser units in a “daisy chain” methodology.

   All outdoor units can be wired together in one contiguous RS485 bus using covered walkways as conduit paths between non-connected blocks. Due to the cost of the Daikin controllers, and the requirement of external cabling, we have estimated this to be the most cost effective approach for gaining central control of the systems. It is recommended that this central controller be mounted on the wall of the server room, with location by agreement with ITD, AMS and other interested parties.

   The Daikin Central Controller will require to be connected to the IoT VLAN.

4. Points 4-11, Follow recommendations from Singleton

4 2020 ENGINEERING MODELLING

4.1 CSIRO system sizing – preliminary assessment

Solar PV & battery storage system benefits evaluation using System Advisor Model (SAM)

This modelling work has been completed by CSIRO with input from BE and SINSW prior to system installation in the three schools.

Summary of results for System Advisor Model (SAM) evaluation of solar PV & battery storage system sizing:

The team carried out case studies using 2019 interval electricity consumption data available for Nimbin and Jamison schools. Models for different scenarios were developed for Nimbin CS and Jamison HS and simulations were conducted to determine the optimum sizing of solar PV and battery storage systems for both schools, using different battery dispatch algorithms and existing tariffs that the schools are on. Results from this study show:

- For Nimbin CS, the addition of larger solar PV systems results in higher net present value (NPV), although this trend seems to flatten for solar PV system sizes larger than about 70kW. The same applies for system payback, where the shortest payback period was found to be for a 70kW solar PV system. The addition of larger battery storage systems does not offer higher NPV or shorter payback period. This is due to the combination of high battery prices and the solar PV generation and load demand profile of the school being well correlated. Similar results were obtained when two different peak shaving algorithms were used for the battery dispatch.
- For Jamison HS, the addition of both larger solar PV and battery storage systems resulted in decreasing NPV even though larger electricity bill savings was observed. This is most likely because of the very low peak electricity rates across the year for the current electricity tariff (Endeavour Energy N19) that the school is on and the demand charges only apply between 4pm and 8pm on weekdays, which fall after school hours, together with the high battery cost. This leads to the capital cost of the system outweighing the bill savings, and hence to negative NPV. Similar results were obtained when two different peak shaving algorithms were used for the battery dispatch.

Details:

The System Advisor Model (SAM) is a techno-economic software model that facilitates decision-making for people in the renewable energy industry. SAM has been developed and maintained by the National Renewable Energy Laboratory (NREL) of USA. The model is used to evaluate different system configurations to maximise earnings and savings from electricity sales and consumption. It can also be used to experiment with different incentive structures. SAM was chosen as one of the modelling software to assist in the sizing of solar PV and battery storage systems for the “Energy Control and Integration Program in NSW Schools – Stage 1 (DCH6.1)” project.

Models for different scenarios were developed for Nimbin CS and Jamison HS and simulations were conducted to determine the optimum sizing of solar PV and battery storage systems for both schools.

All scenarios were based on a 25-year analysis period with NPV and payback period used as the measures of comparison. Additional modelling parameters are listed in the table below.

Summary of SAM modelling parameters for all scenarios

Component	Details
PV – inverter system	SunPower SPR-E19-310-COM modules. Efficiency 19.0%. Max power 310Wdc. Fixed ground or rack mounted one story or lower. 28deg tilt (Nimbin), North facing. Inverter: SMA America STP 33-US-41 (480V). CEC efficiency 97.5% PV array 5% losses due to soiling, DC power loss 4.4%, AC wiring loss 1%. Annual

	degradation 0.5%/year. NOCT temperature correction. No shading. Array AC capacity as per scenarios.
Battery storage	Lithium Ion: Nickel Manganese Cobalt Oxide (NMC/Graphite) chemistry. AC connected 500V. 2.25Ah cells. State of charge limits: 15%, 95%. Initial charge 50%. 96% AC-to-DC and DC-AC efficiency. 4% capacity drop due to temperature (assumed fixed at 20C) Linear cycling-based decay: 60% capacity @ 10000 cycles with 20% DoD or 2000 cycles with 80% DoD. Battery replacement at 50% capacity. Battery capacity, power and dispatch as per scenarios.
System costs	PV module: \$0.91/ W. Inverter: \$0.27/W. Battery \$300/kWh+ \$600/kW Balance of equipment: \$4445. Permitting & environmental: \$635. Engineering: \$10795. Grid connection: \$635. Annual cost \$16/kW/year. Battery replacement cost: \$300/kWh
Financial parameters	25 year analysis, 5% loan rate, 2.5% inflation, 6.4% real discount rate 21% federal income tax. 7% state income tax. 0.585 \$/W capacity based direct cash incentive (taxable). 5 year MACRS depreciation. Net salvage value 0%
Electricity rates	Net energy metering with \$ credits. Monthly charge \$192. ToU and demand charges as per scenarios.

4.2 Modelling for Site 1: Nimbin CS

A model was developed in SAM for Nimbin CS to simulate various scenarios – to understand the impact of PV and battery sizing on the economic parameters. These details and results or Nimbin CS are summarised in this section.

Hourly load demand data for Nimbin CS across 2019 was used for the model - the profile is shown in Figure 85.

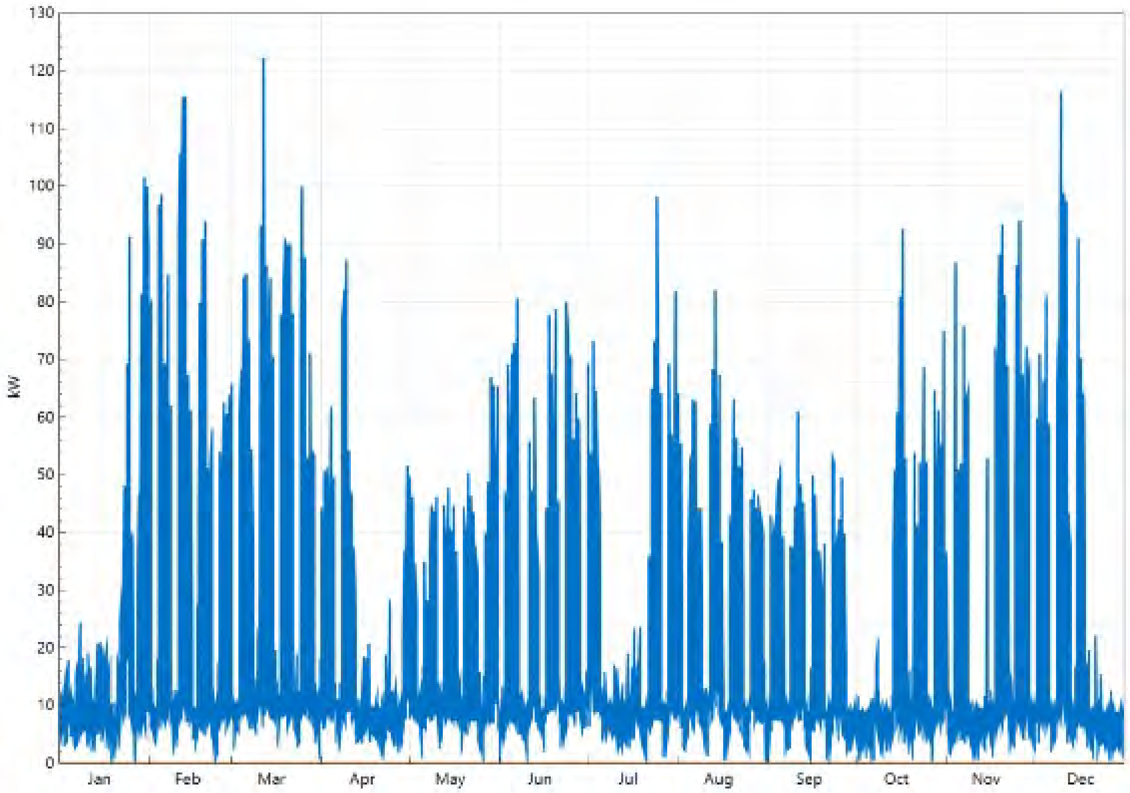


Figure 85: engineering modelling - load demand profile of Nimbin CS for 2019 (hourly resolution)

Scenario 1.1

Scenario description: Optimum system (PV and battery storage) sizes for highest NPV and lowest payback (using current tariff and manual battery dispatch where we allow battery to charge only from excess PV generation)

Modelling inputs and assumptions:

- Solar resource data used was from typical meteorological year (TMY) data from the Lismore airport weather station and this was used as the estimate for solar power output.
- Note: electricity tariff changed from flat to time-of-use on 1st March 2019. The electricity tariffs used for modelling purposes were obtained from the school's Origin Energy bill issued on 5th November 2019, and these are as follows (all incl GST):
  - Solar feed-in: 9 c/kWh
  - Peak tariff: 28.9432 c/kWh
  - Off-peak tariff: 16.918 c/kWh
  - Shoulder tariff: 27.3922 c/kWh
  - Supply charge: 640.585 c/day
- The ToU rates apply as follows: Peak: 7 am-9 am and 5 pm-8 pm weekdays | Shoulder: 9 am-5 pm and 8 pm-10 pm weekdays | Off peak: all other times.

The ranges of sizes considered were:

- Solar PV: 10kW up to 100kW in steps of 15kW
- Battery storage: 10kW up to 100kW in steps of 15kW, and 10kWh up to 100kWh in steps of 15kWh

The system costs for solar PV and battery storage used in the model are:

- Solar PV (incl STCs of $600/kW): $1400/kW
- Battery storage: $1450/kWh

The Net Present Value (NPV) and payback period for various solar PV and battery storage system size scenarios were investigated. A summary of results for NPV for different solar PV system sizes can be seen in the plot in Figure 86. The vertical lines at each of the different solar PV system sizes represent the range of NPV for different battery storage system sizes – an example is the NPV for a 85kW solar PV system ranges from -$60,482 for a 100kW/100kWh battery (indicated by the green dot) to $113,617 for a 10kW/10kWh battery storage system (indicated by the red dot). Similarly, a summary of results for payback for different solar PV system sizes is plotted in Figure 87. For a 85kW solar PV system at the school, the payback ranges from 4.8 years for a 10kW/10kWh battery storage system to 9 years for a 100kW/100kWh battery storage system. These results are for a set up where the battery is only allowed to charge from solar PV output at any time and not from the grid. The battery is allowed to discharge at any time.

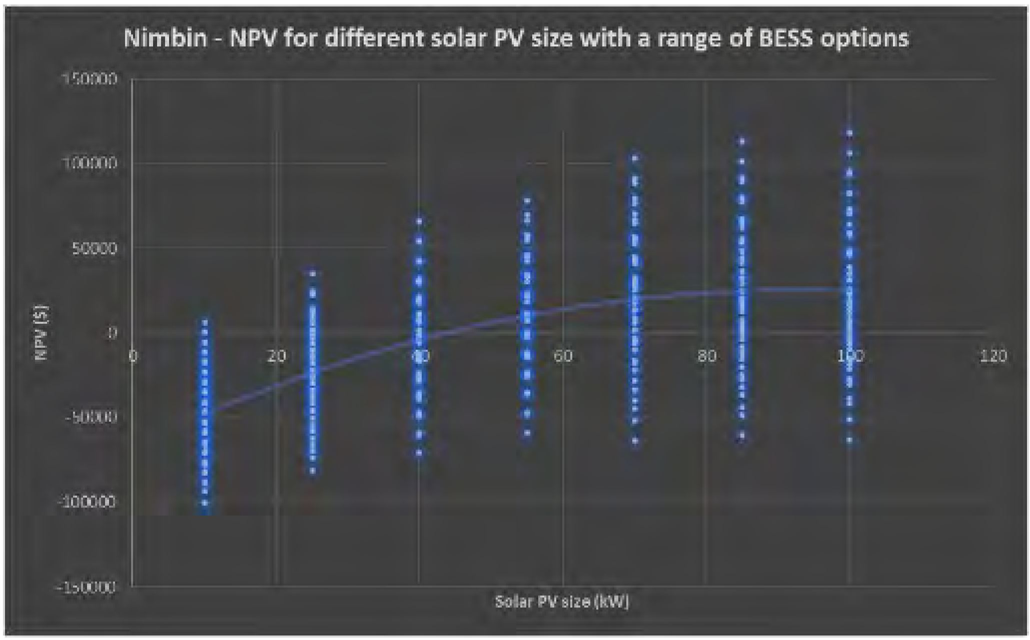


Figure 86: engineering modelling - NPV for various solar PV and battery storage system size combinations for Nimbin CS

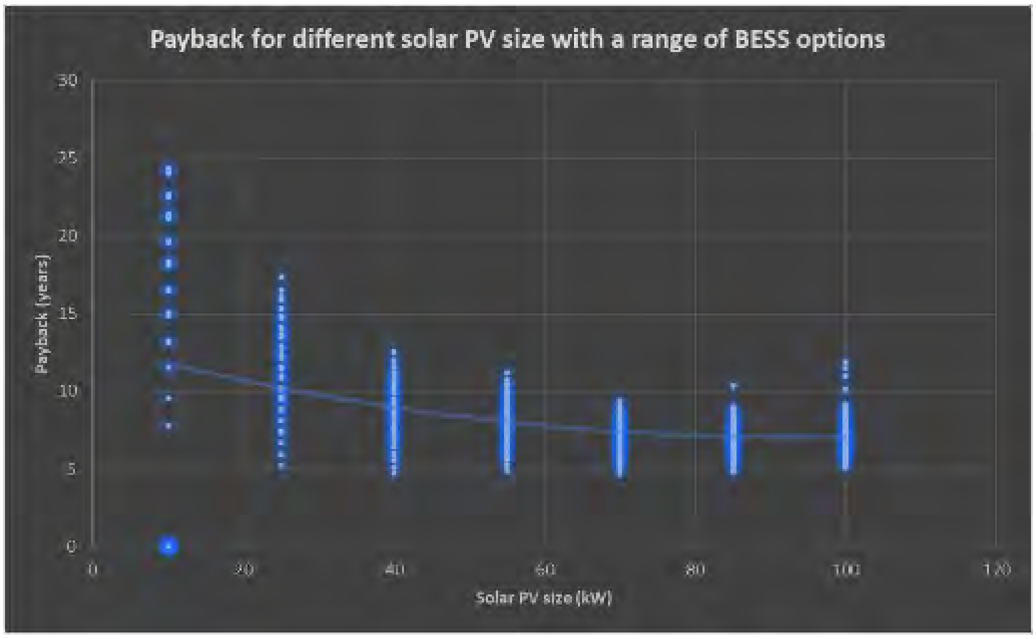


Figure 87: engineering modelling - payback for various solar PV and battery storage system size combinations for Nimbin CS

A summary of results using these financial parameters are as follows:

- Largest net present value (NPV) of $118,403 was obtained for the combination of 100kW solar PV and 10kW/10kWh battery storage system. Bill savings in year 1 of $30,914 and payback period of 5.1 years.
- Smallest payback period of 4.7 years was obtained for 70kW solar PV and 10kW/10kWh battery storage system, with bill savings in year 1 of $25,357 and NPV of $103,396. These results are summarised in Table 2 for the top two largest NPV and payback combinations.

Table 1 - Top two combinations of solar PV and battery systems for largest NPV and smallest payback (Nimbin CS)

	Solar PV (kW)	**Battery (kW)**	**Battery (kWh)**	**NPV ($)**	**Payback (years)**	**Elec bill savings in Year 1 ($)**
Largest NPV (1)	100	10	10	$118,403	5.1	$30,914
Largest NPV (2)	85	10	10	$113,617	4.8	$28,384
Shortest payback (1)	70	10	10	$103,396	4.7	$25,357
Shortest payback (2)	40	10	10	$66,176	4.7	$15,679

Note: Electricity bill without system is $33,921

Results showed that while the addition of larger solar PV systems leads to higher NPV, the addition of larger battery storage systems does not lead to higher NPV or shorter payback period. This is most likely due to the following factors:

- The solar PV generation and load demand profile of the school are well correlated;
- The electricity tariff of the school does not have a demand/capacity charge, hence there is no incentive to reduce peak demand or electricity import of electricity from the grid.
- Peak and shoulder time-of-use tariffs are almost the same. Hence there is minimal financial incentive to use the batteries to shift the load.

In addition to the above cost data, it was also assumed that there is no debt incurred in the project. Note that the NPV was calculated for an analysis period of 25 years with an inflation rate of 2.5% per year.

Scenario 1.2

- Scenario description: Different battery dispatch method, options limited by availability in SAM
- Battery dispatch: Peak shaving (look ahead)
- Definition in SAM of peak-shaving 1-day look ahead: For each day, look ahead to the next day's solar resource and load data, and operate system to minimise grid power consumption.
- The Net Present Value (NPV) and payback period for various solar PV and battery storage system size scenarios were investigated – results shown in Table 3.

Table 2 - Top two combinations of solar PV and battery systems for largest NPV and smallest payback (battery dispatch algorithm based on peak shaving (look ahead)

	Solar PV (kW)	Battery (kW)	Battery (kWh)	NPV ($)	Payback (years)	Elec bill savings in Year 1 ($)
Largest NPV (1)	100	10	10	$132,670	5.1	$30,994
Largest NPV (2)	85	10	10	$127,599	4.8	$28,490
Shortest payback (1)	70	10	10	$116,536	4.7	$25,451
Shortest payback (2)	40	10	10	$70,674	4.7	$15,729

- Note: Electricity bill without system is $33,921
- Battery dispatch: *Peak shaving (look behind)*
- Definition in SAM of peak-shaving 1-day look ahead: For each day, look behind to the previous day's solar resource and load data, and operate system to minimise grid power consumption.
- The Net Present Value (NPV) and payback period for various solar PV and battery storage system size scenarios were investigated – results shown in the table above.

Table 3 - Top two combinations of solar PV and battery systems for largest NPV and smallest payback (battery dispatch algorithm based on peak shaving (look behind)

	Solar PV (kW)	Battery (kW)	Battery (kWh)	NPV ($)	Payback (years)	Elec bill savings in Year 1 ($)
Largest NPV (1)	70	10	10	$109,226	4.9	$23,616
Largest NPV (2)	85	10	10	$106,354	5.3	$25,410
Shortest payback (1)	55	10	10	$94,534	4.8	$19,831
Shortest payback (2)	40	10	10	$69,567	4.9	$14,881

Note: Electricity bill without system is $33,921

Results obtained using the different peak shaving battery dispatch algorithms in SAM in this scenario showed similar results to the previous scenario where the addition of larger battery storage systems does not offer higher NPV or shorter payback period.

4.3 Modelling for Site 2: Jamison HS

A model was developed in SAM for Jamison HS to simulate various scenarios – to understand the impact of PV and battery sizing on the economic parameters. These details and results or Jamison HS are summarised in this section.

Hourly load demand data for Jamison HS across 2019 was used for the model - the profile is shown in Figure 88.

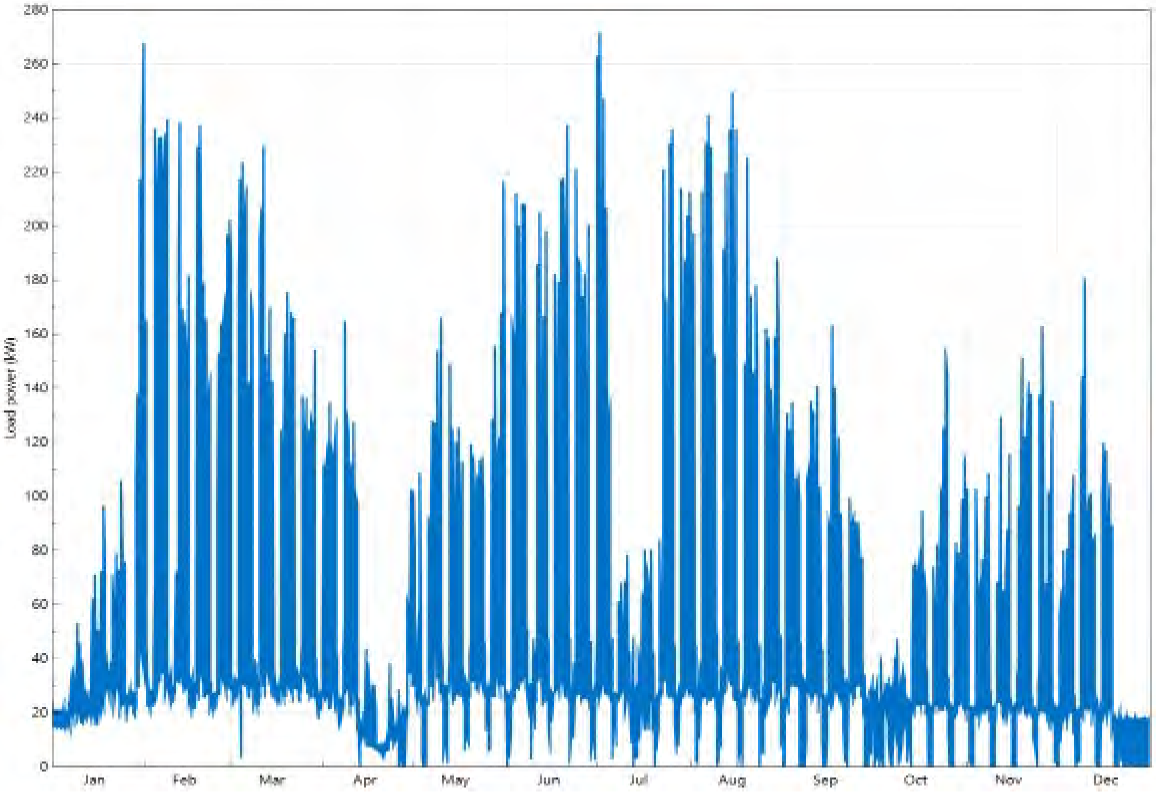


Figure 88: engineering modelling - load demand profile of Jamison HS for 2019 (hourly resolution)

Scenario 2.1

Scenario description: Optimum system (PV and battery storage) sizes for highest NPV and lowest payback (using current tariff and manual battery dispatch where we allow battery to charge only from excess PV generation)

Endeavour Energy tariff N19 (Service Rate EN19) standard time-of-use (STOU) applies to the Jamison HS and this includes demand charges.

Tariff N19 consists of the following pricing components:·

- Network Access Charge ($/day);
- High-season Peak, Low-season Peak and Off Peak energy consumption charges (c/kWh); and
- High-season and Low-season demand charges ($/kVA/month).

Tariff N19 structure:

- Network access charge (incl GST): $8,269.40 per annum ($689.12 per month)
- Energy charge:
    - High-season peak (Nov-Mar): 4.34951 c/kWh
    - Low-season peak (Apr-Oct): 3.71151 c/kWh
    - Off-peak: 2.18361 c/kWh

- Demand charge ($(kVA or kW)/mth):
  - High-season (Nov-Mar): $11.03795
  - Low-season (Apr-Oct): $9.42755

Peak' and 'Off Peak' periods are based on the following time periods and apply during both Eastern Standard Time (EST) and Daylight Saving Time (DST):

- Business Days
  - Peak:16:00 – 20:00
  - Off Peak: All other times.
- Non-business Days
  - Off Peak: All times.

Demand charges apply to 'Peak' periods only. The following seasons apply to 'Peak' energy and demand charges:

- High-season: November to March
- Low-season: April to October

The ranges of sizes considered were:

- Solar PV: 10kW up to 100kW in steps of 15kW
- Battery storage: 10kW up to 100kW in steps of 15kW, and 10kWh up to 100kWh in steps of 15kWh

The system costs for solar PV and battery storage used in the model are:

- Solar PV (incl STCs of $600/kW): $1400/kW
- Battery storage: $1450/kWh

The Net Present Value (NPV) and payback period for various solar PV and battery storage system size scenarios were investigated. A summary of results for NPV for different solar PV system sizes can be seen in the plot in Figure 80. Similarly, a summary of results for payback for different solar PV system sizes is plotted in Figure 81. These results are for a set up where the battery is only allowed to charge from solar PV output at any time and not from the grid. The battery is allowed to discharge at any time.

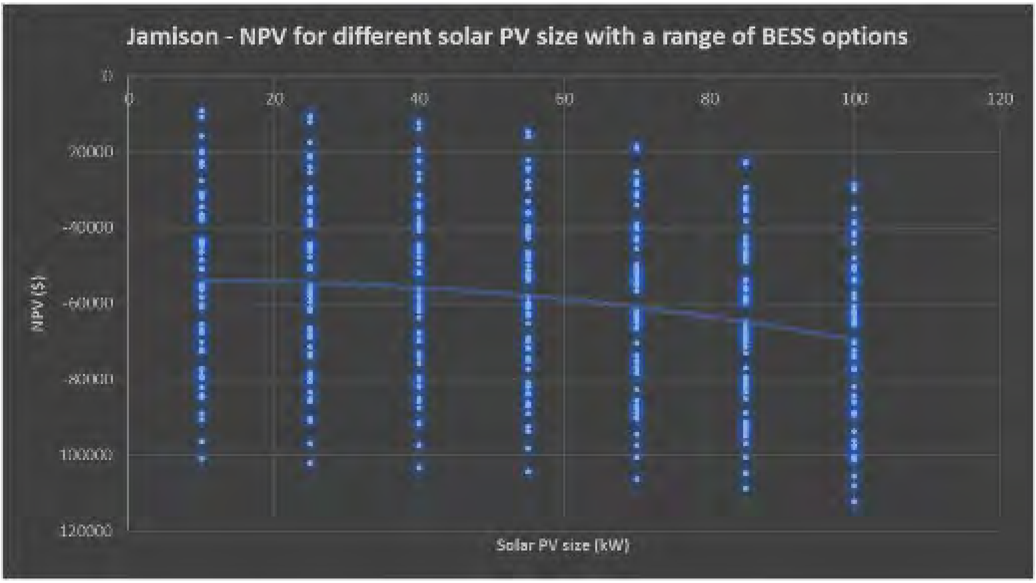


Figure 89: engineering modelling - NPV for various solar PV and battery storage system size combinations for Jamison HS

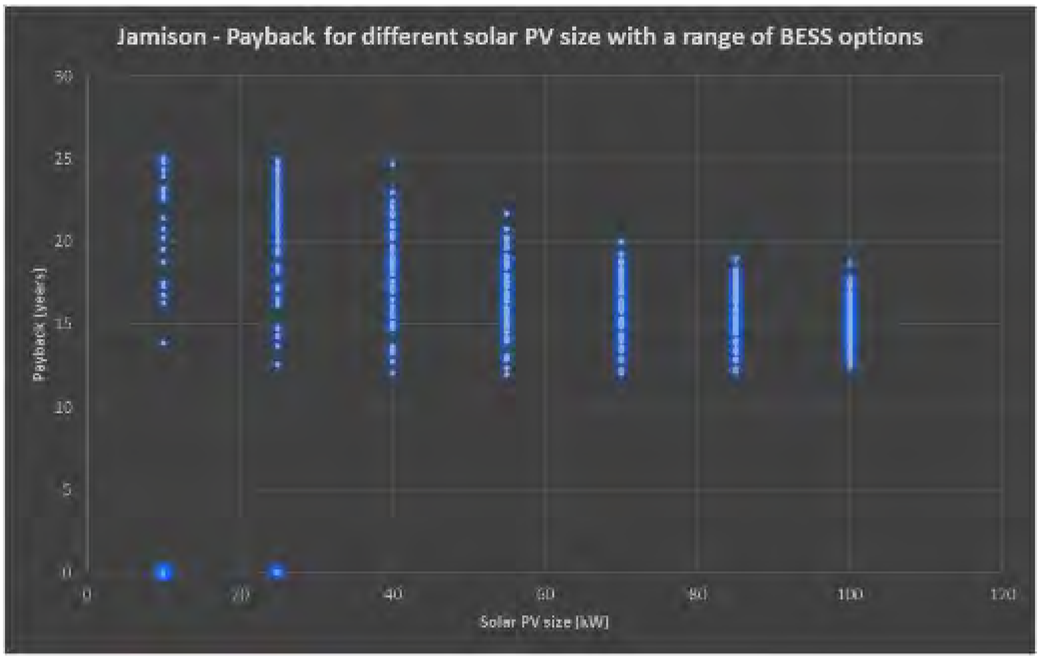


Figure 90: engineering modelling - payback for various solar PV and battery storage system size combinations for Jamison HS

A summary of results using these financial parameters are as follows:

- Largest net present value (NPV) of -$9,145 was obtained for the combination of 10kW solar PV and 10kW/25kWh battery storage system. Bill savings in year 1 of $2,392 and payback period of 13.9 years.
- Smallest payback period of 12 years was obtained for 55kW solar PV and 10kW/25kWh battery storage system, with bill savings in year 1 of $8,115 and NPV of -$14,777. These results are summarised in Table 4 for the top two largest NPV and payback combinations.

Table 4 - Top two combinations of solar PV and battery systems for largest NPV and smallest payback (Jamison HS)

	Solar PV (kW)	**Battery (kW)**	**Battery (kWh)**	**NPV ($)**	**Payback (years)**	**Elec bill savings in Year 1 ($)**
Largest NPV (1)	10	10	25	-$9,145	13.9	$2,392
Largest NPV (2)	25	10	25	-$10,723	12.6	$4,334
Shortest payback (1)	55	10	25	-$14,777	12	$8,115
Shortest payback (2)	70	10	25	-$18,490	12	$9,815

Note: Electricity bill without system is $53,138 (annual)

Results showed that the addition of larger solar PV and battery storage systems does not result in higher NPV, although larger electricity bill savings are apparent. This is most likely because of the very low peak electricity rates across the year for the current electricity tariff (Endeavour Energy N19) that the school is on and the demand charges only apply between 4pm and 8pm on weekdays, which fall after school hours. Even though larger solar PV and battery storage systems result in larger electricity bill savings, the NPV for such systems become more negative with increasing system sizes, likely due to the capital cost of the system being significantly higher than the savings obtained.

In addition to the above cost data, it was also assumed that there is no debt incurred in the project. Note that the NPV was calculated for an analysis period of 25 years with an inflation rate of 2.5% per year.

Scenario 2.2

Scenario description: Different battery dispatch method, options limited by availability in SAM

Battery dispatch: Peak shaving (look ahead)

Definition in SAM of peak-shaving 1-day look ahead: For each day, look ahead to the next day's solar resource and load data, and operate system to minimise grid power consumption.

The Net Present Value (NPV) and payback period for various solar PV and battery storage system size scenarios were investigated – results shown in Table 5.

Table 5 - Top two combinations of solar PV and battery systems for largest NPV and smallest payback (battery dispatch algorithm based on peak shaving (look ahead)

	Solar PV (kW)	**Battery (kW)**	**Battery (kWh)**	**NPV ($)**	**Payback (years)**	**Elec bill savings in Year 1 ($)**
Largest NPV (1)	100	10	10	-$9,145	13.9	$2,392
Largest NPV (2)	85	10	10	-$10,723	12.6	$4,334
Shortest payback (1)	70	10	10	-$14,777	12	$8,115
Shortest payback (2)	40	10	10	-$18,490	12	$9,815

Note: Electricity bill without system is $53,138 (annual)

Battery dispatch: Peak shaving (look behind)

Definition in SAM of peak-shaving 1-day look ahead: For each day, look behind to the previous day's solar resource and load data, and operate system to minimise grid power consumption.

The Net Present Value (NPV) and payback period for various solar PV and battery storage system size scenarios were investigated – results shown in Table 6.

Table 6 - Top two combinations of solar PV and battery systems for largest NPV and smallest payback (battery dispatch algorithm based on peak shaving (look behind)

	Solar PV (kW)	Battery (kW)	Battery (kWh)	NPV ($)	Payback (years)	Elec bill savings in Year 1 ($)
Largest NPV (1)	10	10	10	-$12,472	19.3	$1,343
Largest NPV (2)	25	10	10	-$14,003	14.6	$3,290
Shortest payback (1)	70	10	10	-$21,323	12.7	$8,822
Shortest payback (2)	85	10	10	-$25,609	12.7	$10,457

Note: Electricity bill without system is $53,138 (annual)

Results obtained using the different peak shaving battery dispatch algorithms in SAM in this scenario showed similar results to the previous scenario where the addition of larger battery storage systems does not offer higher NPV or shorter payback period.

Next steps

Future SAM modelling work can be undertaken based on NSW school's requirement. Suggestions of potential focus areas are:

- Sensitivity analysis to explore the impact of financial assumptions
  - Capital costs
  - Model assumptions (Analysis period, loan, inflation and tax rates)
  - Electricity ToU rates
- Sensitivity analysis to explore the impact of system parameters
  - PV array orientation
- Analysis of wholesale price scenario (a.k.a. Amber tariff)

5 ASSET MANAGEMENT SYSTEM SIMULATION

The following work has been completed by Buildings Evolved with input from CSIRO and SINSW.

Purpose

The purpose of this paper is to explore the benefits of relational data models and functions used to manage and control assets in the built environment over traditional linear data models and functions.

The two basic premises; relational and linear will be described and understood, the differences will be conveyed, and pros and cons will be explored in evaluating the benefits based on their composition, location, and functional relations in a unified, overarching system.

Presently, buildings have haphazard, and bespoke metadata naming conventions incorporated into bespoke organisational systems that makes operating and acquiring/onboarding new buildings into an overarching system costly and problematic. This reality has created a vast legacy of global building stock that is incompatible with modern web applications and systems solutions designed for efficiency management and innovation.

Whereas a unified and standardised approach to metadata design and management in the built environment would enable the worlds building stock to easily onboard standardised applications and systems solutions designed for efficiency management and innovation. Leading to a unified asset register, facilities maintenance, finance, logistics and asset management applications. And the ability and flexibility to adopt and trial applications and systems solutions without significant onboarding and development costs.

There are two elements to operational control and management of modern buildings: a machine focused metadata schema (such as Brick schema) coupled with an operational asset management system (such as OpenMaint or commercial solutions from vendors such as SISfm/Archibus). This section focuses on the latter.

Overview

The Brick ontology leverages the Resource Descriptor Framework (RDF) is one such semantic model that is currently being developed as an improvement to traditional naming ontologies for physical systems. The Brick model functions in multiple dimensions – subject, predicate, and object to describe physical, logical and virtual assets in buildings and the relationships between them.

Rather than a ‘this belongs to that, but also belongs to this’ linear model. The Brick metadata ontology consists of an extensible dictionary of terms and concepts in and around buildings, a set of relationships for linking and composing concepts together, and a flexible data model permitting seamless integration of Brick with existing tools and databases.

Ontologies are not functional however until they are able to be applied to physical systems in a practical way – through an asset register or documentation library. This paper explores how three-dimensional semantic models can be applied to manage and control assets in the built environment based on their composition, location, and functional relations in an overarching system – a configuration management database (CMDB).

A Configuration Management Data Base (CMDB) stores asset information as classes in a relational ontological structure. The data model, configurations, workflows and report functions are handled within the core CMDBuild architecture. Whereas the presentation layer, user interface, user profiles, access controls, specific metadata, and other business logics are handled in a configuration layer or ‘engine’ represented in Figure 91.

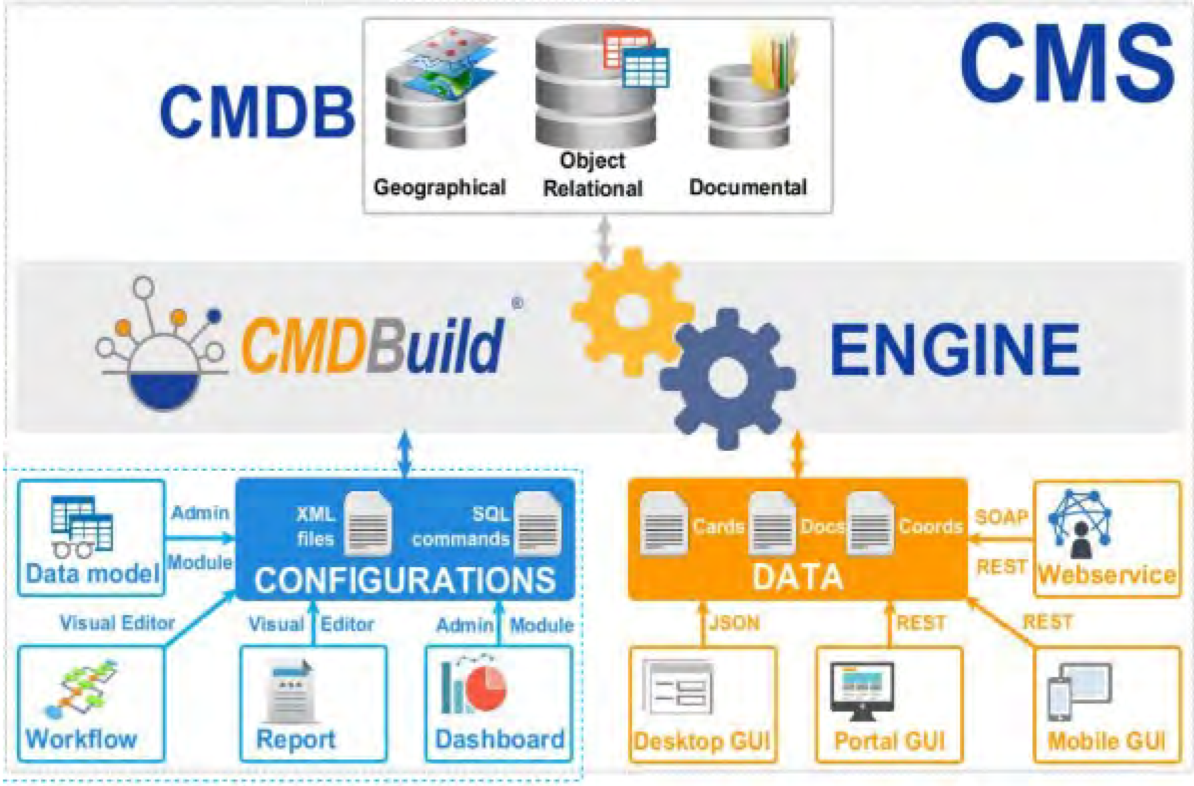


Figure 91: asset management - CMDB database and configuration layer

Case Study of a relational content management system

openMAINT is an Italian developed, open-source technology platform. Open source essentially means free, the technology is free to use, develop and extend for private and/or commercial end uses. Open source generally equates to reduced cost, increased flexibility and extensibility as the platform build, database, tables, and classes that comprise the system are fully visible for deployment and development purposes. Like any technology system, it requires commitment to implement, use and maintain the solution, and/or employ certified personnel or contractors to do so. It does not require active maintenance of source code, as with a custom solution, but it does require more skills on hand than a proprietary solution.

Platform configuration

For the purposes of proof-of-concept testing, we downloaded and configured an openMAINT demo on our servers to test and demonstrate its functionality.

Upon login, the user is presented with two modules: 1) the user module, and 2) the administration module. The user module (pictured in Figure 91) is the main application interface that end-users of the system will use to view and manage assets. The examples below show asset reporting workflows but the same methodology can be applied to time-series, energy data sets.

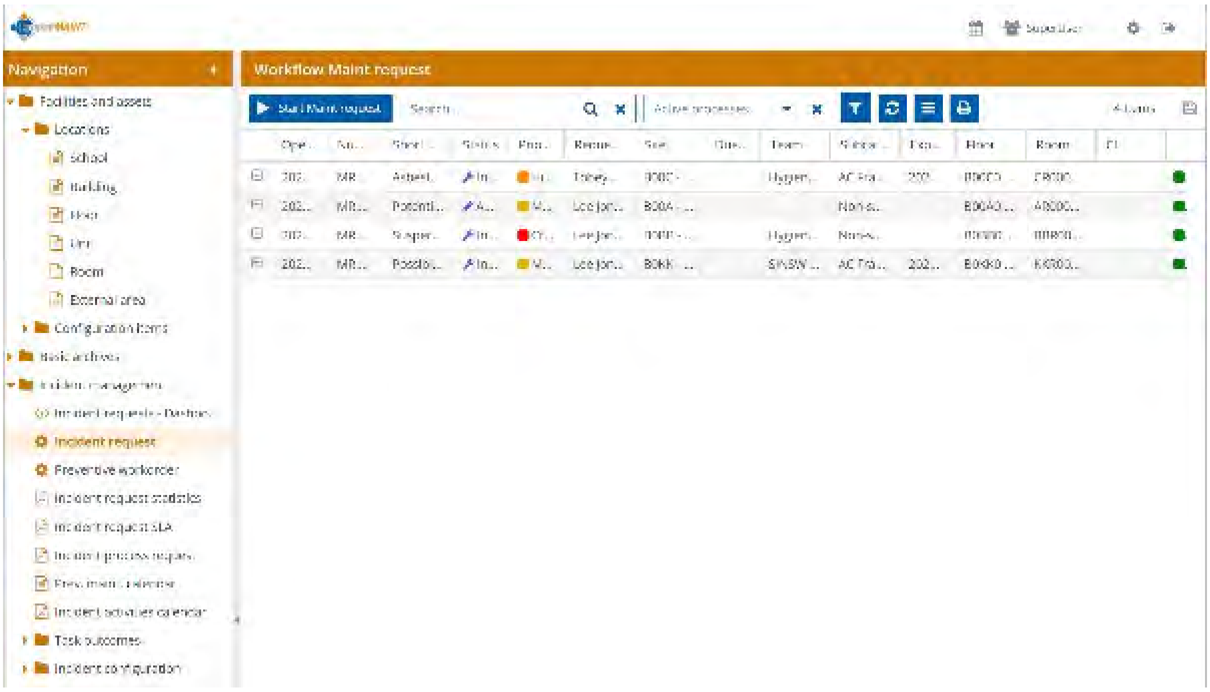


Figure 92: asset management – workflow maintenance request

Whereas the administration module (Figure 93) is where users with administrative privileges will configure the system, add users, define permissions, add semantic elements such as classes of assets, configuration items, set locations of schools, import Geo-location attributes (GIS) and BIM models. Amongst other functions.

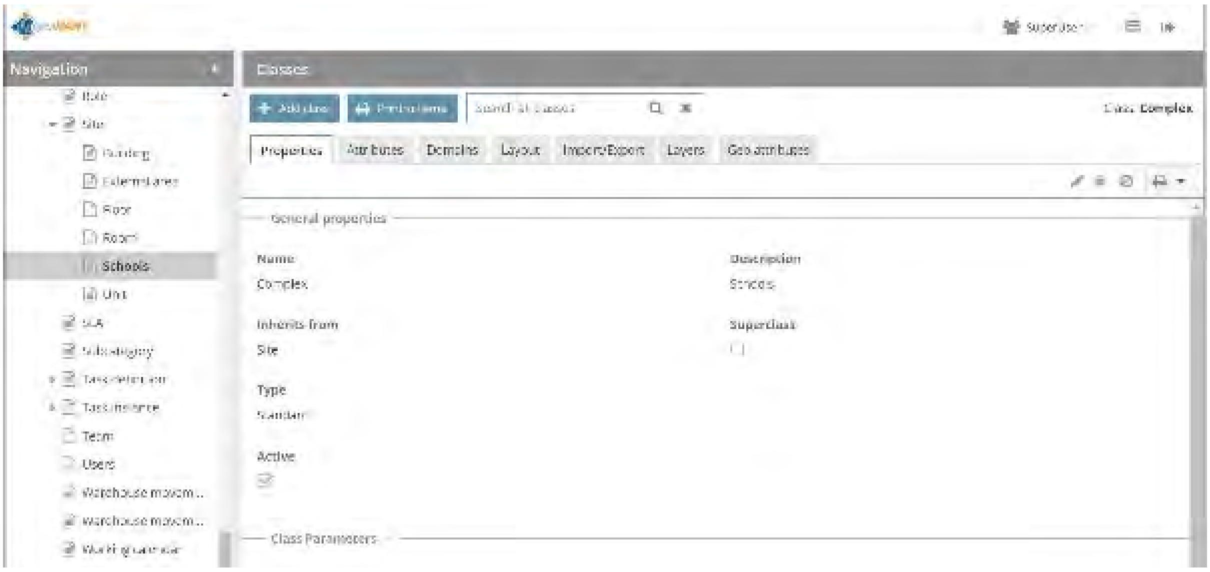


Figure 93: asset management - administration module configuration

The Data Model

The following diagram represents the class to asset and relational context of CMBD.

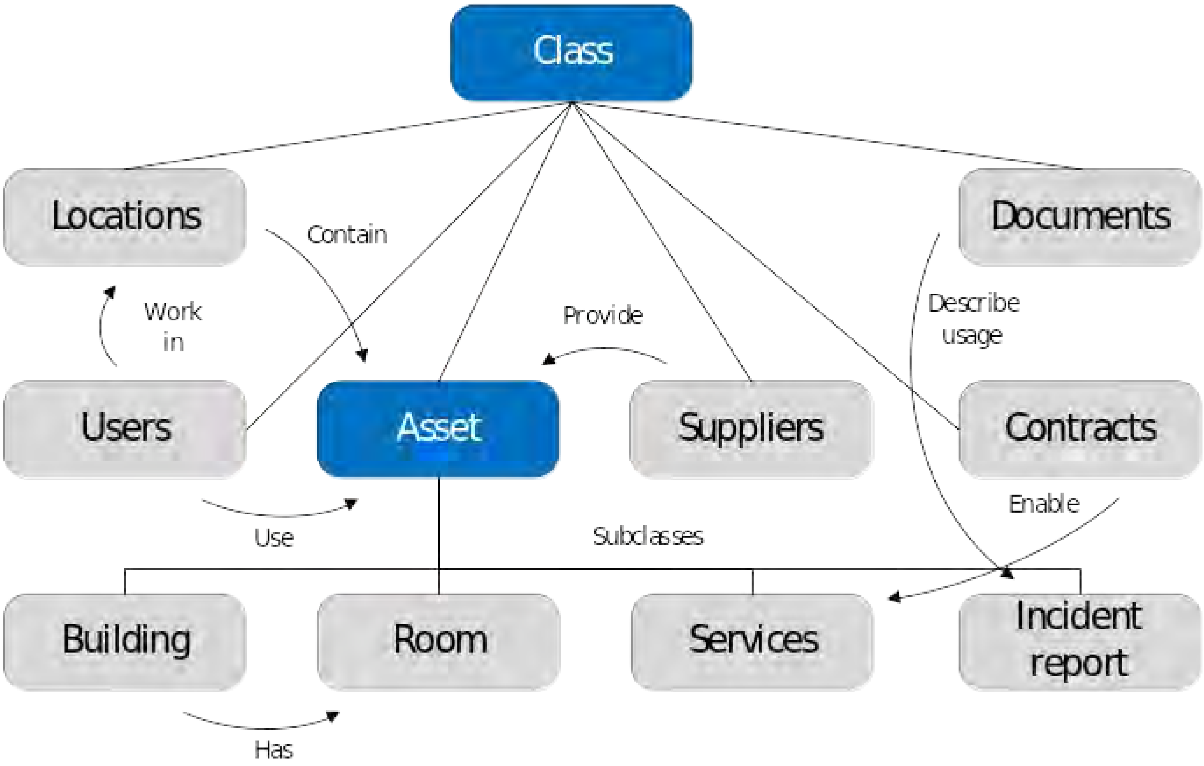


Figure 94: asset management - class based semantic modelling

A relational ontology will enable SINSW to manage assets in the context of the physical environment, its information and relationship between other elements. For example, a user can quickly investigate an asset class or element in the system and view its:

- Metadata – relevant contextual information of the asset.
- Location – where the asset is located, internal, external, and topographically via maps, GIS, and BIM.
- Relations – what other semantic elements have a relationship with the asset. For example,
    - Asset has equipment,
    - Asset is a subclass of another asset,
    - The location contains other assets,
    - Users and suppliers are associated with this asset.

The relational ontology is different to traditional asset related data whereby an asset can exist in isolation and contain only directly related metadata. For example, a traditional system may describe an asset in a linear way, as: a class > that has a location > that contains assets. This linear relational model may often fail to deliver contextual information relevant for investigation, appraisal, remediation, and thus reduce the effectiveness of reporting processes.

The relational model utilised by openMAINT is highly configurable, flexible, and extensible. The relational structure lends itself to capabilities in many other areas of asset management beyond asset reporting, such as financial, logistics and energy management. The system can cover any asset related ontology or business unit or process in the physical environment. Such a system enables business insights and intelligence by providing answers to questions such as:

- What are the highest energy consuming sites?
- Which are the poorest performing sites?
- What is the status of assets within sites?

- What are the physical areas that require frequent maintenance/monitoring?
- What service level agreements (SLAs) apply to each site?
- What are the KPIs for asset reporting performance?

Or for specific information of individual assets:

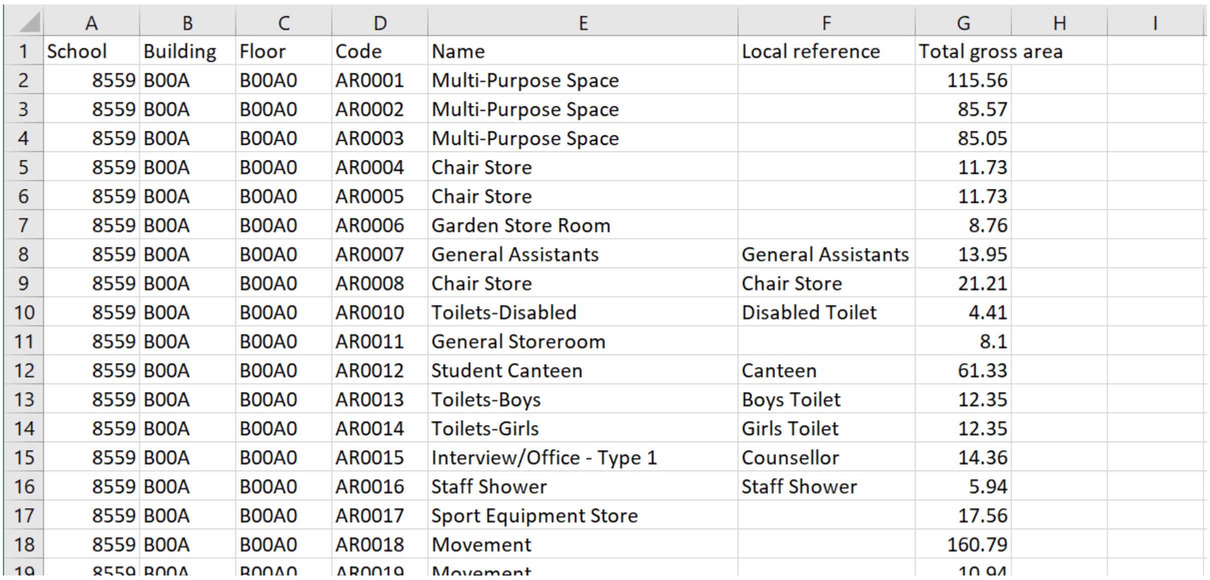
- Where is an asset?
- Who uses it?
- What does it belong to?
- What is it made up of?
- What and where are other similar assets?
- What has happened in the asset's life-cycle?
- What other assets does a possible change influence?
- How much does asset management and/or maintenance cost?
- What other information/metadata do we have for this asset?
- And others.

Importing SINSW Data

For the purposes of proof-of-concept testing, we requested access to the SINSW AMS database. In response, we were provided with a PDF flat file for three schools: Jamison, Singleton and Nimbin. Rather than manually enter the data which would be very time consuming and labour intensive, we used a PDF scraping tool to extract the data in a usable CSV format for input into the openMAINT platform.

This scraping process required some manual data cleaning. The cleaned file then required segmentation to create the view tables required to match each school's data with the openMAINT postGres data base structure. The following image is an example of how the data is structured for rooms class/asset, where:

- School code used as the unique key to establish the school>room relationship,
- Building code used as the unique key to establish the building>room relationship,
- Floor code used as the unique key to establish the floor>room relationship,
- The unique code and name of the room, and
- The contextual data for each room as applicable.



	A	B	C	D	E	F	G	H	I
1	School	Building	Floor	Code	Name	Local reference	Total gross area		
2	8559	B00A	B00A0	AR0001	Multi-Purpose Space		115.56		
3	8559	B00A	B00A0	AR0002	Multi-Purpose Space		85.57		
4	8559	B00A	B00A0	AR0003	Multi-Purpose Space		85.05		
5	8559	B00A	B00A0	AR0004	Chair Store		11.73		
6	8559	B00A	B00A0	AR0005	Chair Store		11.73		
7	8559	B00A	B00A0	AR0006	Garden Store Room		8.76		
8	8559	B00A	B00A0	AR0007	General Assistants	General Assistants	13.95		
9	8559	B00A	B00A0	AR0008	Chair Store	Chair Store	21.21		
10	8559	B00A	B00A0	AR0010	Toilets-Disabled	Disabled Toilet	4.41		
11	8559	B00A	B00A0	AR0011	General Storeroom		8.1		
12	8559	B00A	B00A0	AR0012	Student Canteen	Canteen	61.33		
13	8559	B00A	B00A0	AR0013	Toilets-Boys	Boys Toilet	12.35		
14	8559	B00A	B00A0	AR0014	Toilets-Girls	Girls Toilet	12.35		
15	8559	B00A	B00A0	AR0015	Interview/Office - Type 1	Counsellor	14.36		
16	8559	B00A	B00A0	AR0016	Staff Shower	Staff Shower	5.94		
17	8559	B00A	B00A0	AR0017	Sport Equipment Store		17.56		
18	8559	B00A	B00A0	AR0018	Movement		160.79		
19	8559	B00A	B00A0	AR0019	Movement		10.94		

Figure 95: asset management - import data schema

Considering the 2,300 SINSW school sites, manually procuring/gathering data from AMS, cleaning and structuring for input into openMAINT presents a significant undertaking – likely to incur significant development costs if this solution were taken into production. However, by automating this process via an extract, load and transform (ELT) procedure, for example, the cost of development required to onboard schools would be significantly reduced. It is proposed that further proof-of-concept testing is conducted involving testing of ELT procedures with the AMS team. Furthermore, this ELT script could be run at a regular interval to synchronise slow-changing data between AMS and openMAINT.

Workflows

Workflows, ticketing, and automation events are another significant feature of the openMAINT system. Workflows can be designed in a visual way and deployed to satisfy SINSW user stories/reporting tasks and processes identified in the functional requirements. For example, a workflow is defined in the system as:

- Classes or assets, their related attributes, and relationships.
- User roles with authorisation to perform each interactive step of the workflow.
- The sequence of activity and automation events.
- Information and widgets to be displayed or to be filled by a user on each step, such as, upload picture/document or print report etc.

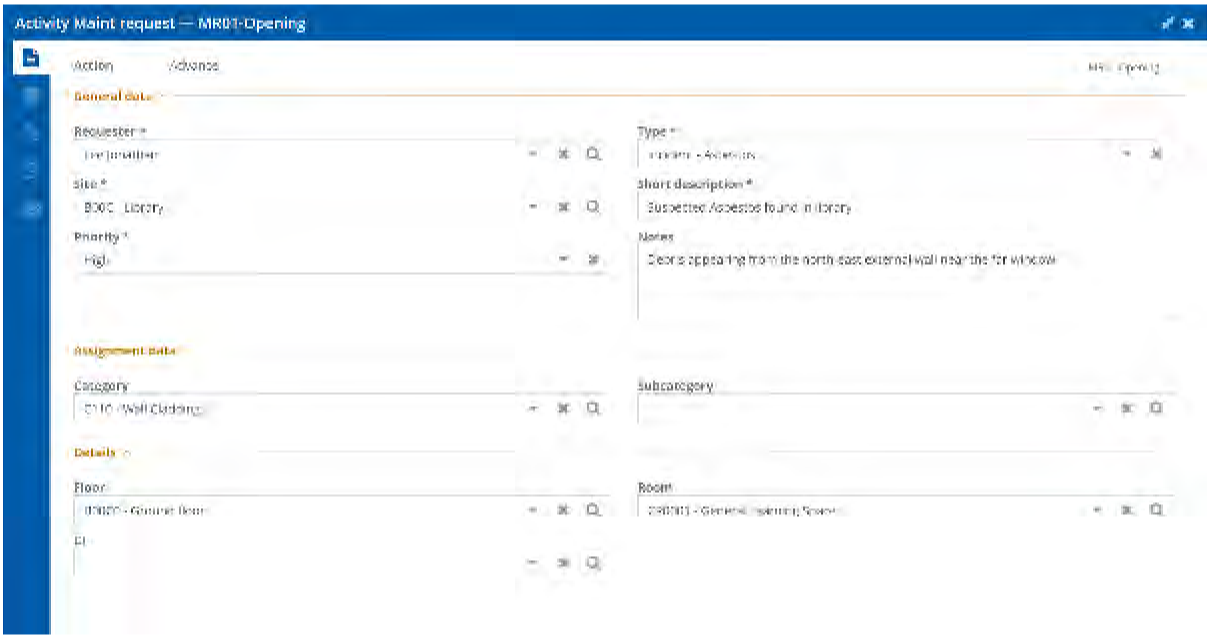
Automation tasks performed when the flow completes. For example,

- Start sub-processes,
- CMDB update,
- Send e-mail,
- Report generation,
- An interaction with external application. And others.

Workflows for Asset Reporting

Figures 96 and 97 show a basic workflow involving:

Operations staff reporting an asset, adding site related and contextual information (metadata).



Activity Maint request — MR01-Opening

Action	Advance

General data

Requester *

Site *

Priority *
High

Type *

Short description *
Suspected Asbestos found in library

Notes
Debris appearing from the north east external wall near the window

Assignment data

Category
Wall Cladding

Subcategory

Details

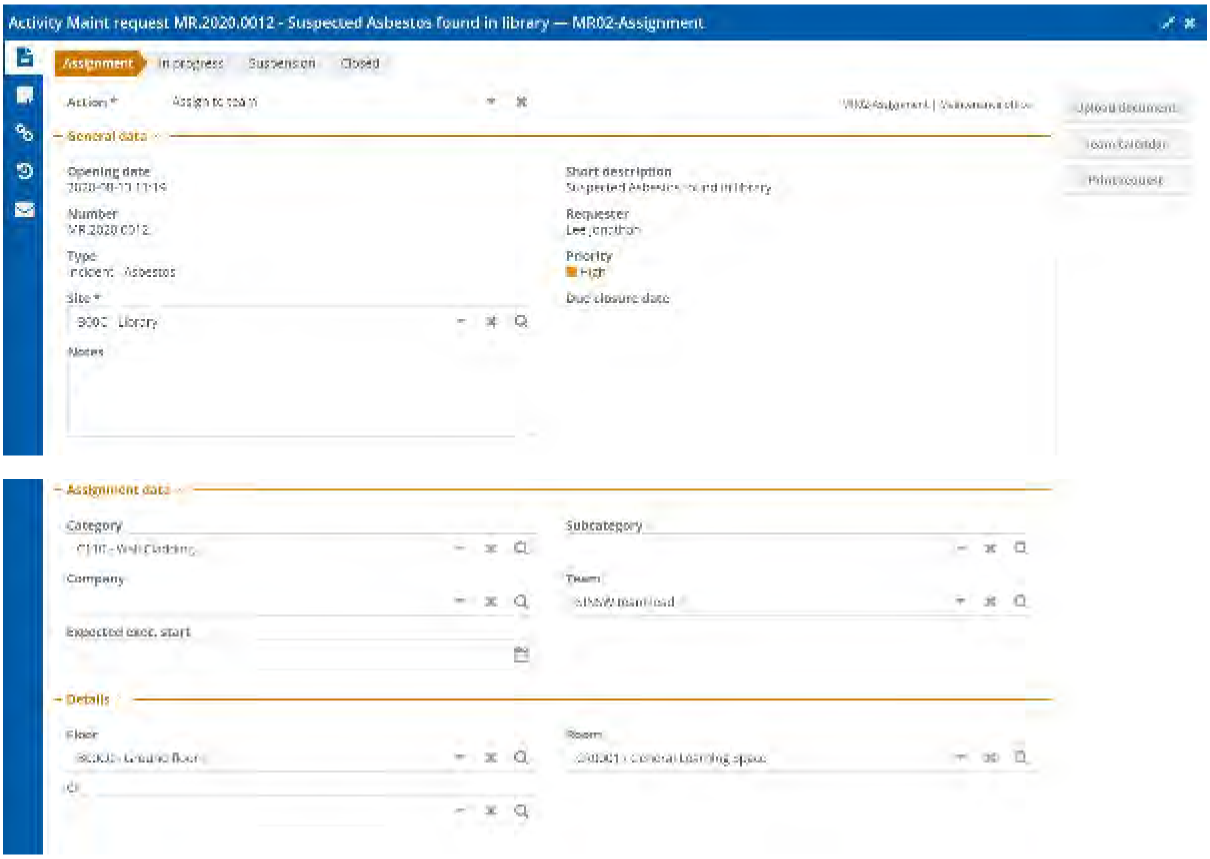
Floor

Room

CI

Figure 96: asset management - asset reporting form

Operations team lead receives an email with a link to the asset created, as a result they can assign the asset to a company for remediation or reject and close the asset.


Activity Maint request MR.2020.0012 - Suspected Asbestos found in library — MR02-Assignment

Action * Assign to team

General data

Opening date

Number MR.2020.0012

Type Incident - Asbestos

Site * Library

Short description Suspected Asbestos found in library

Requester Lee, Jonathan

Priority High

Due closure date

Notes

Assignment data

Category Wall Cladding

Subcategory

Company

Team

Expected exec. start

Details

Floor Ground floor

Room General Learning space

Figure 97: asset management - asset assignment form

In the case that the asset is assigned to a company for inspection, an email is sent to the relevant company, an asset is recorded in the system and then appears in the list (highlighted in yellow) of assets for SINSW team staff.

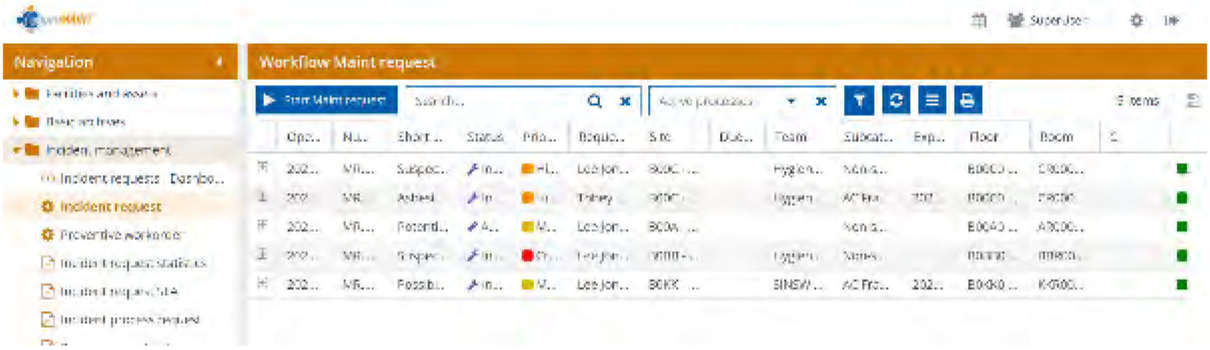

Workflow Maint request

Figure 98: asset management - user asset list

Each asset in the list can be opened, viewed, and edited to provide relevant information and other tasks required in the asset reporting process, such as, uploading documents, viewing notes, relations, history of actions, email correspondence, and more…

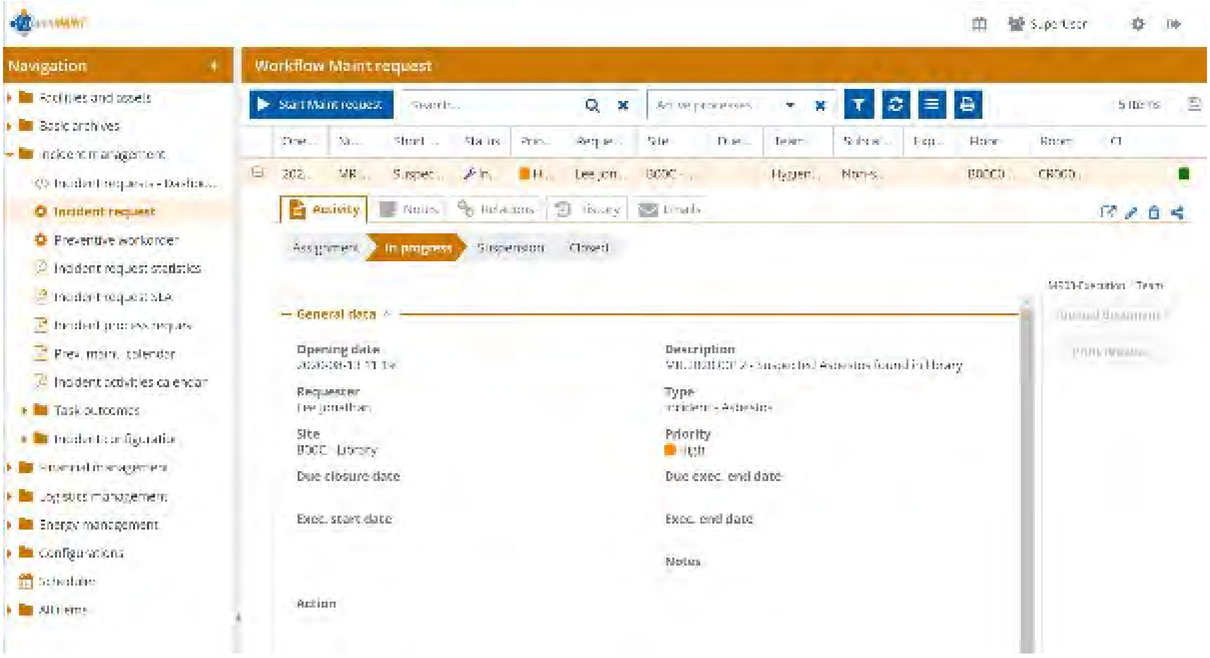


Figure 99: asset management - user asset drill-down

Editing Workflows

openMAINT comes configured with several workflows used for demonstration processes. A separate visual workflow editor – Together Workflow Editor (TWE) can be used to build out workflows/user stories defined in the functional requirements document to meet client needs.

Figure 100 shows how the previous workflow example can be edited in the visual TWE program in a drag and drop fashion.

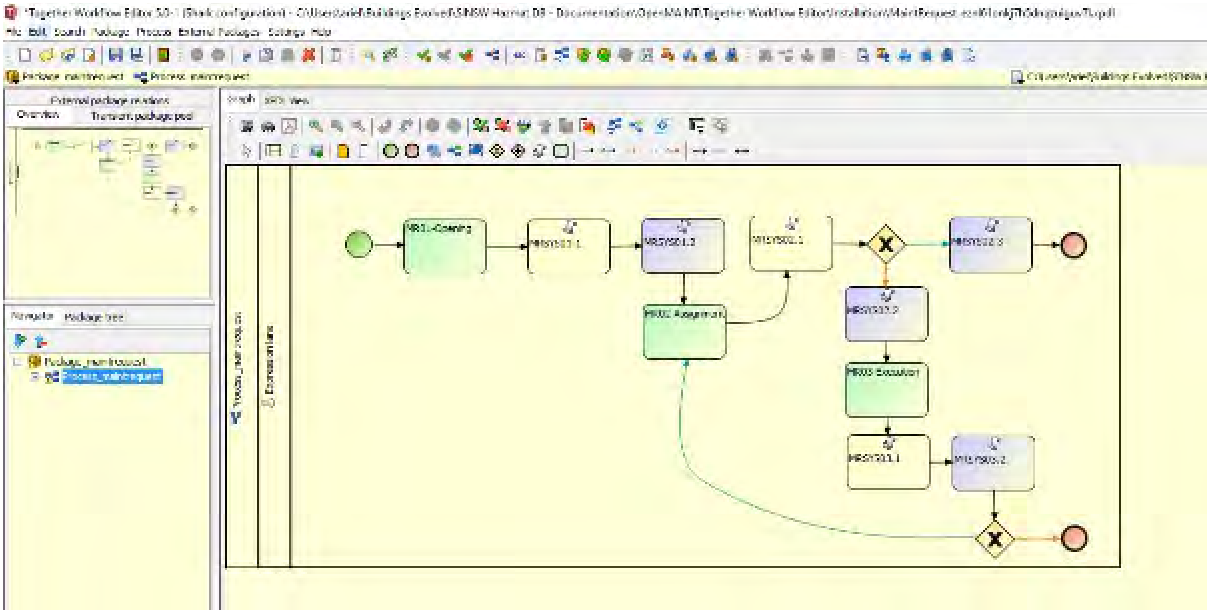
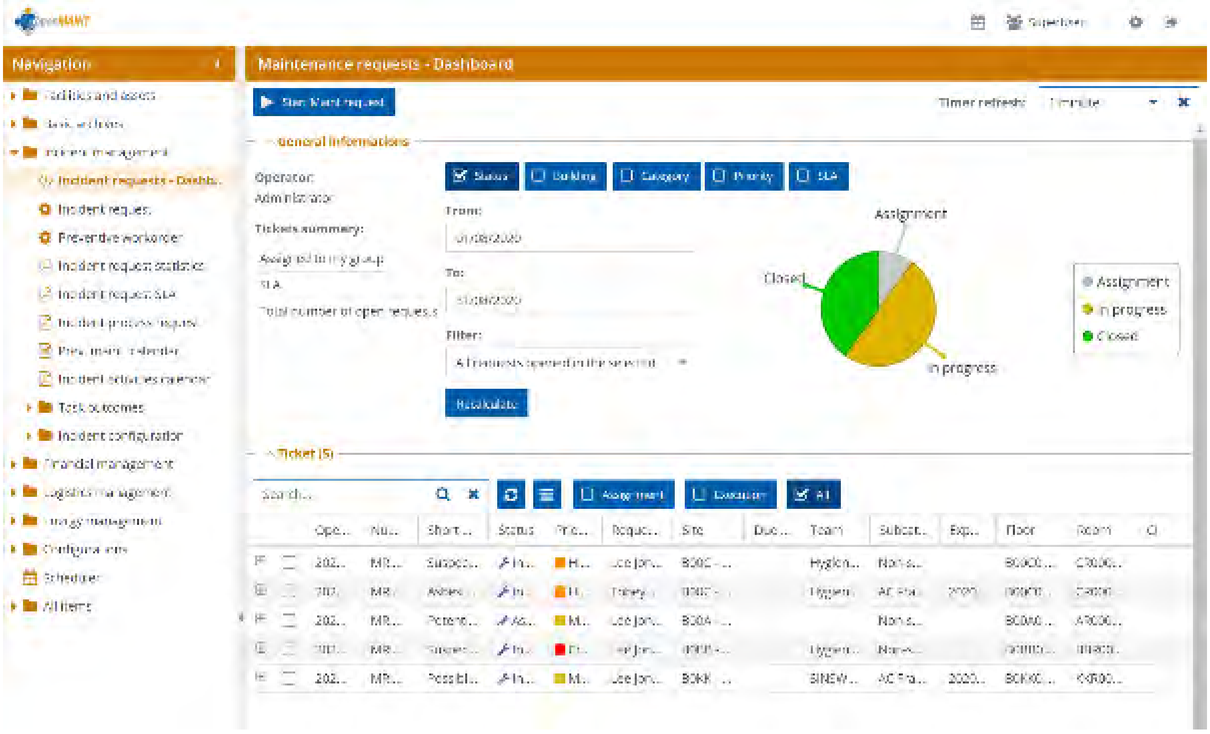


Figure 100: asset management - workflow design and configuration program

More and complex workflows can be defined using the TWE program and imported into the openMAINT platform as per user stories and SINSW functional requirements. Further proof-of-concept testing will demonstrate how the TWE can be used to build out end-to-end demonstrations of asset reporting workflows to satisfy business need.

Asset reporting KPI’s & customised dashboards

Custom dashboards, reports and KPIs can be configured in the openMAINT system that automate relevant information used to demonstrate performance and compliance. An example dashboard with user configurable KPI metrics is shown in Figure 101.



Operator: Administrator

Tickets summary:

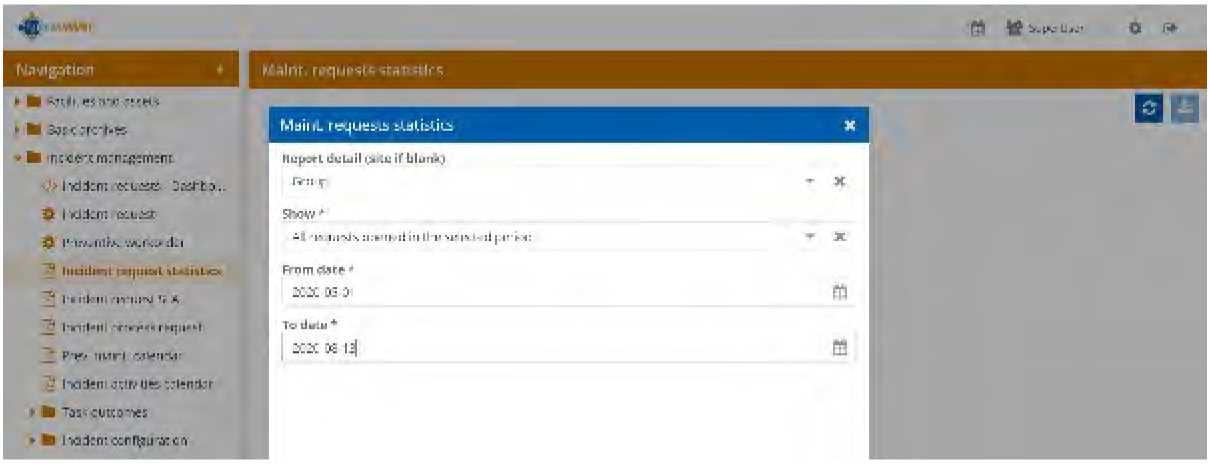
Assigned to my group

SLA

Total number of open requests

Figure 101: asset management - user dashboard and KPIs

User configurable reports can be run according to variables outlined in the Figure 102.



Report detail (site if blank): Group

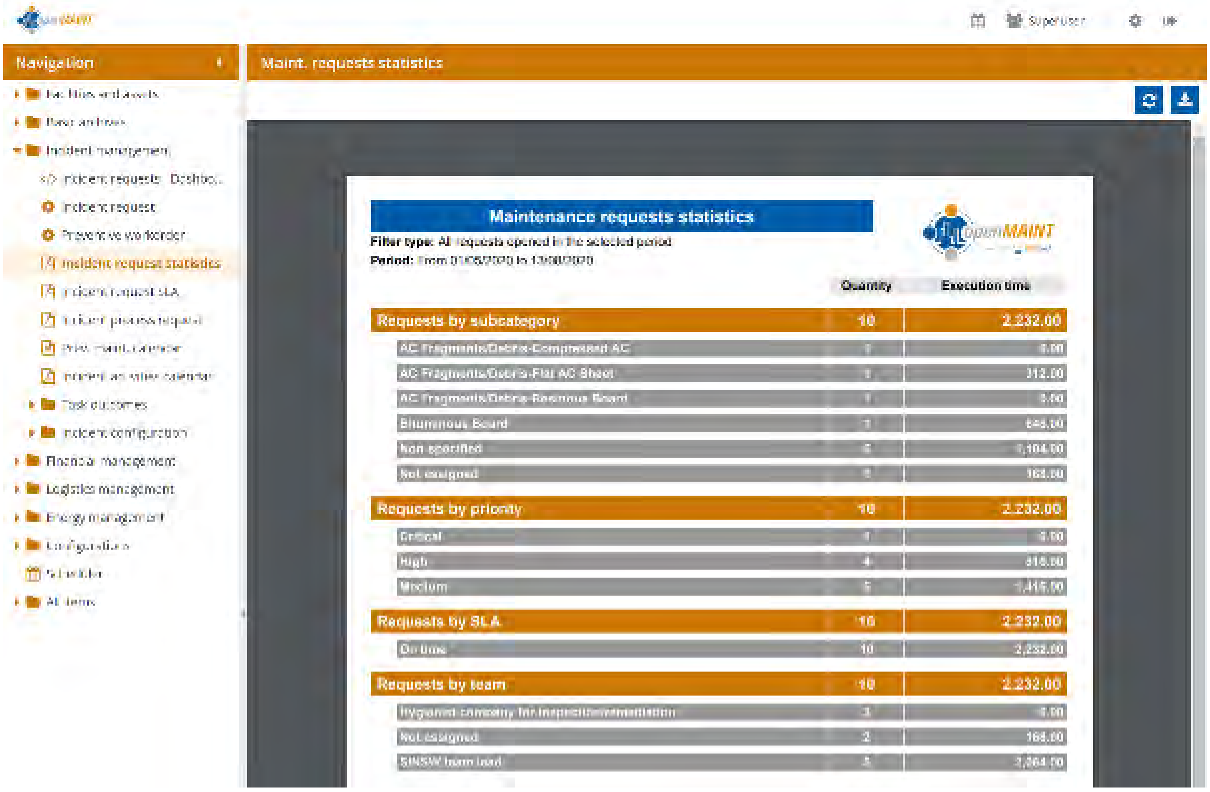
Show *: All requests opened in the selected period

From date *

To date *

Figure 102: asset management - user report form

The selected input fields above results in a database query to be run according to input fields in the form. The resulting output of the report is shown in Figure 103.



Maintenance requests statistics

Filter type: All requests opened in the selected period

Period: From [illegible] to [illegible]

	Quantity	Execution time
Requests by subcategory	10	2,232.00
AC Fragments/Debris-Compressed AC	[illegible]	0.00
AC Fragments/Debris-Flat AC Sheet	[illegible]	312.00
AC Fragments/Debris-Resinous Board	[illegible]	0.00
Bituminous Board	1	648.00
Non specified	6	1,104.00
Not assigned	[illegible]	168.00
Requests by priority	10	2,232.00
Critical	[illegible]	0.00
High	4	816.00
Medium	5	1,416.00
Requests by SLA	10	2,232.00
On time	10	2,232.00
Requests by team	10	2,232.00
Hygienist company for inspection/remediation	3	0.00
Not assigned	2	168.00
SINSW team lead	5	2,064.00

Figure 103: asset management - user report generation

This is an example of how user configurable reports can be run and automated within the system to provide timely performance metrics and satisfy statutory reporting obligations.

User interface & access controls

CMDBuild has a flexible user access control/data protection system which manages access permissions in a consistent and granular way (role-based permissions) with the following core functionality:

Consistency of access irrespective of the request source channel, desktop, tablet or mobile app.

Permissions provide a high level of granular control. Users access permissions can be defined on classes (also restricted to rows or columns), processes, views, search filters, reports and or dashboards/reports, amongst other fields and functions.

Permissions are assigned to user groups (roles) and every user can belong to one or more roles.

The flexibility of access permissions ensures that each internal/external user, group, team, or company will have access to exactly the information they require to do their job, and no more. This functionality combined with password policy rules provides the framework for an industry standard security and data protection system.

Spatial data, BIM & the visualisation layer

The ability to integrate spatial data Geographical GIS and Building Information Modelling (BIM) provides a far more flexible and intuitive method for interacting with complex and often unrelated datasets. For example, fire risk assessed by looking at vegetation density or class in a spread sheet or data grid is far less intuitive than looking at the same data visually on a map. Additionally, a map will not only display the vegetation on site, but also vegetation on neighbouring sites, proximity to buildings, fuel stores and gardening supplies. In addition, openMAINT facilitates external datasets, such as, prevailing weather conditions, seasons, elevation data (LiDAR), soil conditions amongst other data that could easily be included for analysis. Spatial data provides an intuitive method for consuming large complex datasets and is congruous with modernised trends in geo-spatial analysis relevant to SINSW.

openMAINT is built to be flexible in the input and visualisation of common GIS data formats including KML/KMZ and SHP files. Both being consistent with formats utilised by SINSW and SpatialNSW more broadly. Input methods includes geoSERV, openlayers, WMS and postGIS.

In the absence of BIM data, the following figure shows how spatial shapes can be drawn within the system. A room in the Nimbin school site is defined by a polygon, users can select the room and view contextual information as shown in Figure 104.

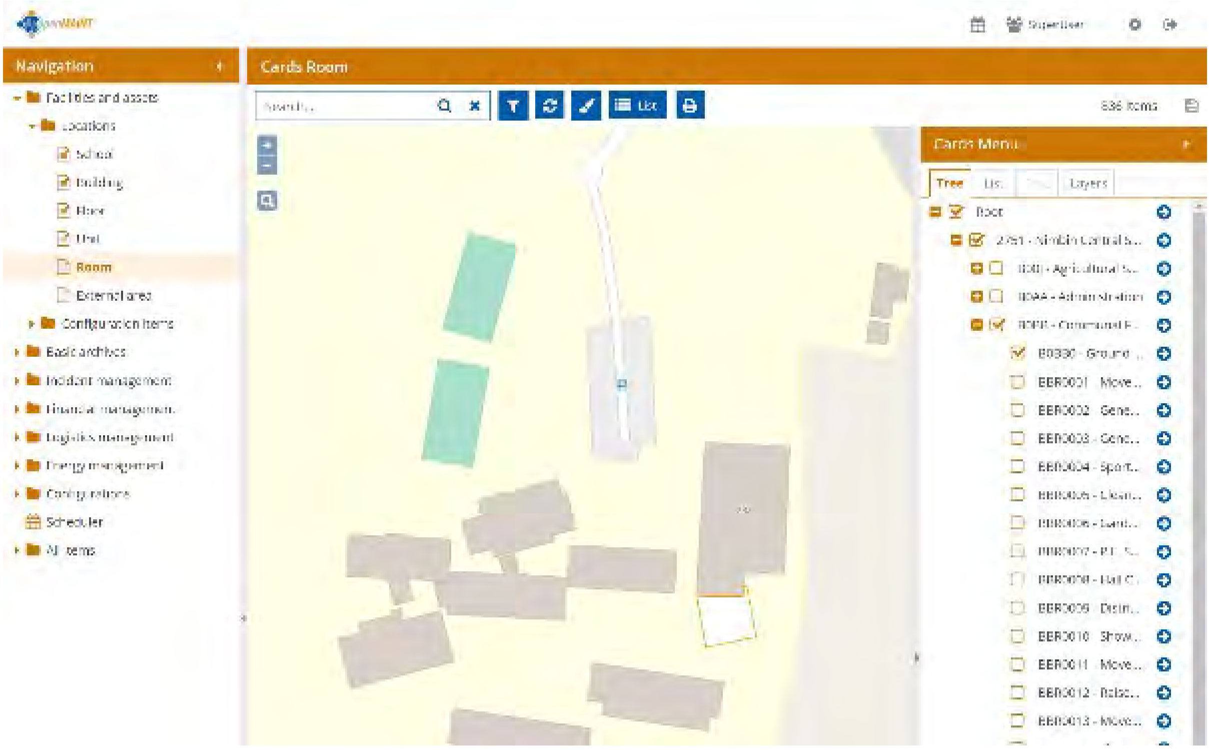
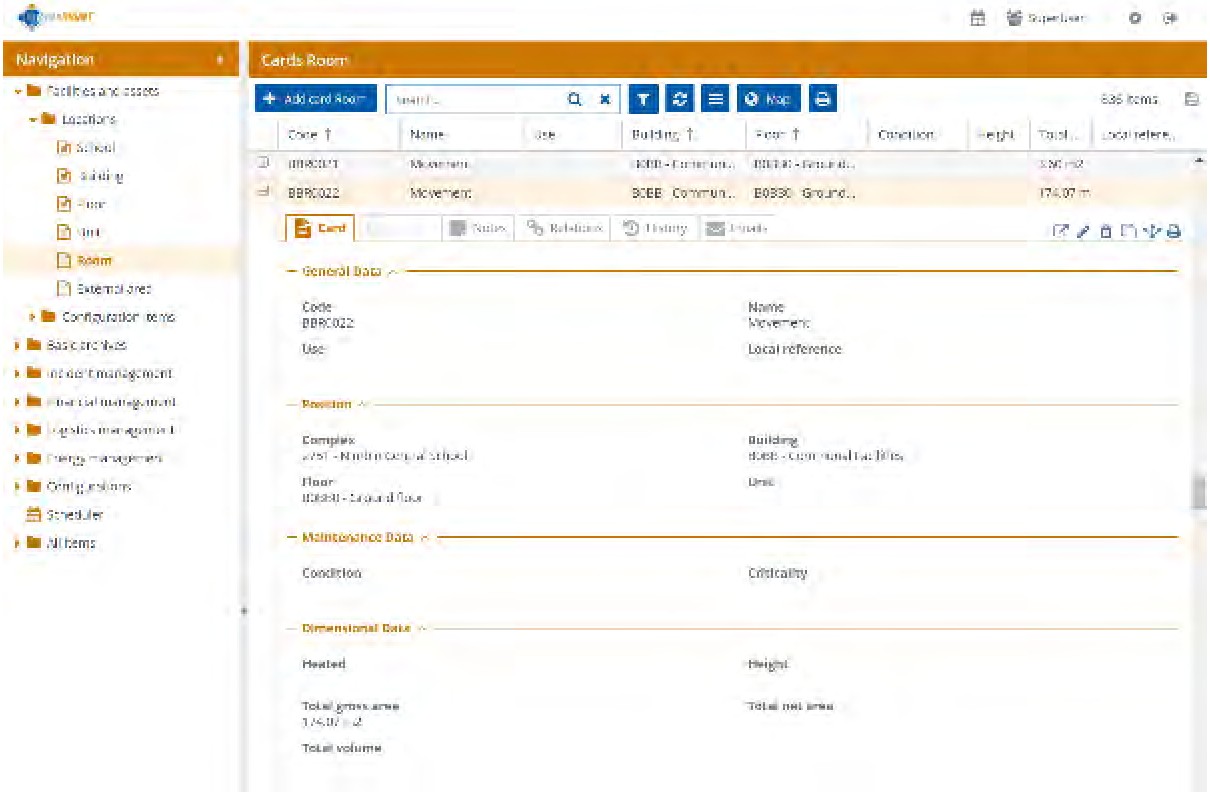


Figure 104: asset management - Geo location mapping, polygon of physical room

Users can ‘drill’ into the room to view contextual information and metadata about the room’s physical and relational properties as well as history and communications relating to this room as outlined in Figure 105.



Code	Name	Use	Building	Floor	Condition	Height	Total...	Local refere...
BBRC022	Movement		BOBB Commun...	B0S30 Ground...			174.07 m	

General Data

Code: BBRC022

Name: Movement

Use:

Local reference:

Position

Complex:

Building:

Floor:

Unit:

Maintenance Data

Condition:

Criticality:

Dimensional Data

Heated:

Height:

Total gross area:

Total net area:

Total volume:

Figure 105: asset management - 'drill down' into room metadata

In this way, operational staff can view two-dimensional spatial data in schools to more effectively convey information and provide context to asset reporting beyond text, static images and documents.

Building Information Modelling (BIM)

Functionally, the openMAINT system can import shape files and other formats made from external tools such as Autodesk AutoCAD. As well as supporting the BIM paradigm1. Supporting BIM designs in IFC file format automatically inherits all the contextual information and assigns it to an asset/class. The BIM model is rendered in 3D, each item of the BIM can be selected, and its contextual information viewed in the openMAINT system.

The widespread acceptance and use of BIM during the construction of infrastructure presents value that can be recapitalised by the client to add an entirely new linage of data to support digital asset management. The immediate use case for BIM data would be an advantage in an assessment of contaminated assets. In the occurrence where buried building material was found, BIM data could be utilised to assess the construction materials utilised on site or in geotechnical reports, environmental assessment and soil conditions reports generated during construction to assess the risk and ascertain the actual and potential contamination impacts at the site. In the longer term, BIM data is indispensable for ongoing and efficient asset management, future use simulations and expansion or contraction of assets.

Linking to financial modelling

Due to the nature of openMaint, the underlying database is PostgreSQL rather than a closed/proprietary solution. The data contained within the asset management system is a logical place to query a well maintained database, capturing slow changes within the building fabric as they happen. An example of this might be the electricity supply authority swapping/replacing their meter – the updated meter serial number can be entered and then queried by external systems. In our example, we integrated to the OpenMaint database to query for electricity NMIs and associated meter serial numbers, and gas supply authority MIRN numbers (both NMI and MIRN being unique numbers).

Figure 106: asset management - openMAINT BIM viewer

Figure 107 shows how the CMDBuild framework exists and integrates with the external BIM ecosystem.

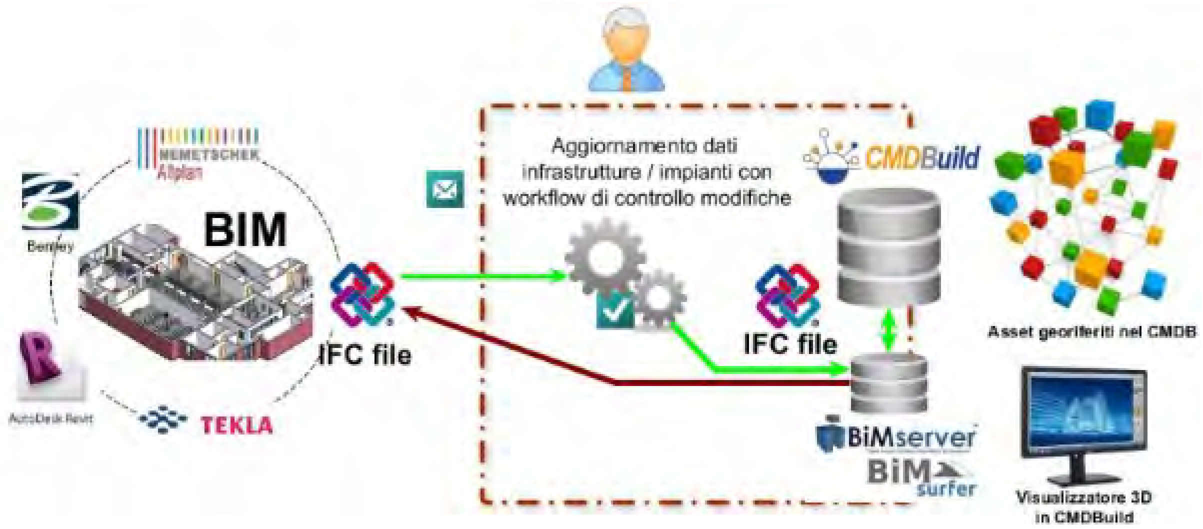


Figure 107: asset management - openMAINT BIM integrations

6 2020 PRELIMINARY BUSINESS CASE

Commercial Comparison (WIP)

The following work is by Building Evolved for completion in milestone 5 to answer the question: what is the scope of the market, and what obstacles exist in the path of adoption of open data platforms and metadata standards?

6.1 Market overview

The global building energy management systems (BEMS) market is growing at a compounded annual growth rate (CAGR) of between 9% and 13.5% and is expected to reach $62.3b by 2023 from $25.9b in 2016[19]. Strict government mandates and regulations with the objective to reduce carbon footprint along with increasing demand for electricity, efficiency and cost savings will stimulate investment in BEMS.

The following BEMS industry statistics are summarised from Global Market Insights report on the BEMS landscape[20].

The key focus and value areas for BEMS systems is expected to be motivated by the collection and usage of energy data to:

- monitor, visualise and understand energy data, and equipment performance, and
- autonomous, operational control of plant and equipment, without the need for human intervention.

BEMS systems commonly provide the following value streams:

- increase productivity,
- provide new income streams,
- reduce energy costs, and
- act as a mechanism for competitive advantage.

Whilst technology is moving rapidly, the uptake of sophisticated BEMS systems is generally lagging in the commercial and industrial sectors due to the following barriers to adoption[21]:

- financial (capital costs),
- limited expertise,
- fragmented stakeholder viewpoints and conflicting agendas.

High capital costs, in conjunction with rising cost of finance with longer payback periods is anticipated to hinder BEMS adoption especially amongst small-medium enterprises (SMEs).

- key growth drivers for the BEMS is forecast in:
- industrial sector for energy efficiency,
- energy consciousness in the residential sector, and
- efficiency and occupant comfort in organisational, office, and commercial sites.

Technological advancements and efficiency capabilities is expected to drive market growth. In addition, rising energy prices is driving the need for energy efficiency and productivity, especially in the industrial space.

The BEMS commercial marketplace is diverse and competitive. The market is dominated by major players such as:

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[19] Allied Market Research, 2018, Energy Management Systems Market, https://www.alliedmarketresearch.com/energy-management-systems-market

[20] Global Market Insights, 2017, Energy Management System Market, https://www.gminsights.com/industry-analysis/energy-management-system-EMS-market

[21] Allied Market Research, 2018

- Honeywell,
- Johnson Controls,
- Schneider Electric,
- Siemens,
- C3 Energy,
- Delta Electronics,
- DEXMA,
- General Electric,
- GridPoint, amongst others.
- In the Australian market, in addition to the larger commercial players, the market consists of:
- Bueno Systems,
- Switch Automation,
- Envizi, amongst others who have established themselves as SMEs in the BEMS space.

These vendors typically compete in areas of expertise and consulting to address barriers and roadblocks to adoption which typically results in BEMS market segmentation and increased complexity for customer decision making processes.

6.2 Market characteristics

Research from industry studies[22], white-papers and benchmark reports and an evaluation of existing vendor services has resulted in the identification of key BEMS marketplace characteristics:

- The market is immature with customers largely aware of but remain resistant to market offerings, thus there is significant competition amongst BEMS providers to gain market share[23].
- Customers' ability to afford the capital and operational expense of BEMS solutions largely confines the market to top-tier operators of built assets[24], which increases competition for BEMS vendors.
- Customer expectations and demands for business solutions are shifting as they become more reliant on software and services to support their corporate objectives. This awareness is congruous with a shift from early to more mainstream adoption indicating strong growth in the sector[25],
- Technology advancements and innovation in sensors, standardised protocols and increased interoperability of previously disparate systems is set to drive growth in the sector[26].
- The rate of technological change[27] coupled with the many and varied vendor solutions add to the complexity and confusion for organisations seeking effective and holistic BEMS solutions[28].

6.3 Market Weaknesses

Vendor research suggests[29] that the current BEMS marketplace consists of vertically integrated proprietary platforms that function to commodify data and analytic products and services. The result of BEMS commercialisation leads to the following characteristics:

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[22] CSIRO, 2018, Considering the Building Energy Management Systems Marketplace Report [B]

[23] Navigant 2016, Navigant Research Leaderboard Report: Building Energy Management Systems: Assessment of Strategy and Execution for 15 Intelligent Building Software Solutions Providers, Navigant Research Inc, p. 6.

[24] EY 2016, Mid-tier commercial office buildings in Australia: Research into improving energy productivity, EY, P. 4.

[25] Navigant 2015, Next Generation Building Energy Management Systems: New Opportunities and Experiences Enabled by Intelligent Equipment, Navigant Research Inc, p. 5.

[26] Navigant 2016, Navigant Research Leaderboard Report: Building Energy Management Systems: Assessment of Strategy and Execution for 15 Intelligent Building Software Solutions Providers, Navigant Research Inc, p. 5

[27] Deliotte 2018, Real Estate Outlook: Optimize opportunities in an ever-changing environment, Deliotte Centre for Financial Services, p. 1.

[28] Navigant 2016, Navigant Research Leaderboard Report: Building Energy Management Systems: Assessment of Strategy and Execution for 15 Intelligent Building Software Solutions Providers, Navigant Research Inc, p. 1.

[29] Global Market Insights, 2017

- Data is commonly contained within the vendor’s system.
- Data and platforms are commonly built upon proprietary formats, types and protocols presumably to protect the vendor’s intellectual property.
- The technology solution offered commonly results in an enclosed, segregated data ecosystem.
- The complexity of the built environment and perceived ability of the operator to pay commonly results in bespoke development, service and maintenance agreements.
- Despite vendor claims, top-tier operators state a lack of capability in BEMS systems.
- BEMS providers mainly focus on passive load control and load shifting activities separately to active components such as renewable energy sources.

These characteristics lead to the following market weaknesses:

- BEMS providers commonly rely on reactive rather than proactive mechanisms to derive value for customers.
- Data is often limited to a set of predefined solutions and is unable to be utilised outside of the vendors system without significant effort/cost.
- Proprietary formats, types and protocols adds to the cost, barriers and complexity of systems for future development in-house, by the vendor or third party.
- Proprietary data ecosystems lead to a legacy of vertically integrated building data silos - where building data is segregated from analysis with that of other buildings, this commonly:
    - Creates barriers to freely share building data between organisations due to the cost and resources required to de-code non-standardised building data.
    - Creates stranded or legacy systems if a building asset is sold/acquired or vendor ceases operations.
    - Limits the development of codes, standards and benchmarks used to drive industry wide BEMS outcomes.
- The costs of development, products, services and maintenance agreements act as entry barriers for adoption, especially for smaller operators.
- The complexity of the built environment coupled with the competition in the marketplace often results in a divergence in an operators’ expectations versus reality. This may result in a lack of trust/risk in ability of BEMS vendors to deliver on claims and often leads larger organisations to pursue multiple vendor solutions to diversify risk which adds to data complexity.

6.4 Market Opportunities

Key growth areas for BEMS are forecast in technological advancements.

The wireless segment is anticipated to lead a major revenue share in the building energy management system market of Australia owing to efficiency, easy installation, flexibility, and advanced technology.

Technologies that reduce barriers to entry, reduction in capital expenditure resulting from integration and hardware requirements for easier deployment, interoperability and user-friendly user interfaces are fuelling adoption rates amongst BEMS.

There have been some advancements in building optimisation and advanced control systems that BEMS systems commonly exploit. For example, DR activities can be used for reducing the peak demand across a site based on load shifting activities - managing HVAC set points programmatically, preheating, and cooling spaces in conjunction with solar PV and charge/discharge of batteries. More advanced control strategies consider control function in conjunction with external factors, weather forecast data and energy market pricing forecasts, for example, as a proactive strategy. Further to this, it is posited that more mature and relevant control strategies function to consider the network conditions and fluctuations – voltage, frequency, and power quality issues for a holistic energy management solution.

Whereas, a more sophisticated control strategy may seek to incorporate real time control (RTC) with active network infrastructure such as solar PV and batteries in conjunction with external environmental, network and market conditions, dynamically, as a continual process of iteration. For example, a research paper by Kang et al. proposes a strategy for prediction, long-term scheduling, and RTC of components. During a modelled period[30]:

> *'the process from prediction to RTC is iterated in every time unit when the system status is changed by a dynamic environment. The scheduler determines the optimal energy flows based on the prediction, and RTC utilizes the scheduling result so that the energy flow can be adaptively controlled in a dynamic environment. Finally, the system status change information is fed back for the next iteration. Simulation results indicate potential cost savings that are approximately 10–20% compared to a typical BEMS with a conventional RTC scheme.*

From a controls viewpoint, it is posited that opportunity may exist for BEMS to incorporate active components in a dynamic environment - considering internal and external factors, iterating controls on-the-fly for prediction, long-term scheduling and RTC as a path to competitive advantage.

The algorithm currently under development by the CSIRO for use in the DCH6.1 project is a reinforced learning algorithm (RLA) similar to the one in the above example.

6.5 Vendor market evaluation

This desktop research study evaluates several BEMS in the context of the DCH6.1 project and its objective to provide DR for SINSW in a dynamic, two-way electricity system and market. Considering this, the following criteria has been used to identify potential commercial competitors comparable to DCH6.1 technologies.

Internal factors	**External factors**	**Platform**
• tariffs, • local generation, predefined control goals, • device setpoints, • alerts and alarms and other real-time conditions	• weather forecasts, • wholesale energy prices, • current and emerging network conditions, • peak demand and network fluctuations, • voltage, • frequency, and power quality	• Ability to integrate and normalise data for output into any application. • Use of standardised data formats, types and protocols. • Ability to reduce entry barriers and development costs through prebuilt data connectors, application interfaces and advanced programming tools.

BEMS inputs, data and platform characteristics will be considered in context of achieving common outcomes in energy management and against SINSW business objectives:

- Increase energy productivity and efficiency.
- Reduce energy costs and provide new income streams.
- Maintaining occupancy comfort.
- Provide opportunities to improve power quality, energy security with reduced emissions.

Whilst in some cases it is difficult to gauge and evaluate the ability of vendor solutions to meet the aforementioned criteria from secondary research, assumptions and implied functionality will be reconciled against evaluated criteria where possible.

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[30] Kang et al. 2014, Scheduling-based real time energy flow control strategy for building energy management system, Energy and Buildings, Volume 75, June 2014, Pages 239-248.

6.6 BEMS Providers and Commercial Comparison

C3.ai

- C3 was founded in 2009 by technology entrepreneur and former Oracle executive Tom Siebel. The company was originally focused on providing software for managing electrical grids but was re-branded to C3 IoT in 2016 and shifted its core business to providing AI and IoT software for digital transformation, along with data analysis solutions for sensors.
- The company develops and delivers enterprise software solutions that enable organisations in data-intensive industries to use real-time performance monitoring and predictive analytics to optimise business processes, differentiate products and services, and create new revenue streams.
- C3 IoT began working with Origin in mid-2016 before establishing its direct Australian presence. The company set up its Asia-Pacific office based in Sydney in January 2017.
- C3.ai Energy Management™ uses machine learning to help customers gain visibility into their energy expenditure and reduce their operational costs. The platform leverages artificial intelligence (AI) and machine learning (ML) algorithms to model building operations, detect anomalies, predict energy savings opportunities, and help facilities managers manage energy operations in near real-time.
- The platform features peak demand forecasting and prediction algorithms on energy streaming data to dis-aggregate consumption and identify and optimise energy usage, detect anomalies and outliers, data issues and billing errors. Streaming datasets can also be combined with on-site generation, utility tariffs and market pricing to identify cost reduction opportunities.
- The strength of the company offering is in the ability to create analytics and ML modules quickly without the technical ‘know-how’. This implies the company has prebuilt modules that can be deployed on an ad-hoc basis.
- The system boasts the ability to integrate data from any system or source via a common API and data integrations. The interoperability for two-way information out of the systems architecture is unclear. However, C3 is an official Amazon Web Services (AWS) partner, therefor, standardised data systems and technologies are implied.
- It is posited that this is a top-tier offering, the cost of on-boarding buildings would likely be prohibitive to many mid-tier customers. The strength of the offering comes from the presumed maturity of optimisation and forecasting algorithms. However, the system is likely to be limited to building optimisation and energy forecasting. Not suited to managing equipment in response to two-way energy flows and markets.

Dex (GreenSync)

- Greensync is an energy management company that focuses on demand-side management. GreenSync was founded in 2010 focusing on energy efficiency and reduction for private sector clients. The company has diversified, providing data related services for distribution network providers, market operators as well as tech-vendors and private sector offerings.
- Greensync has developed their deX technology platform to provide different functions and applications.
- For distribution network service providers (DNSPs), deX provides real-time visibility into distributed energy resources (DER) registered on the network to realise capability, telemetry and impact of DER. Enabling DNSPs to adjust DER behaviour, or contract services from them, to keep the network protected at critical times.
- For energy market operators, deX provides a platform for automated digital contracting and bid evaluation to facilitate DER markets.
- For technology vendors, deX facilitates an integration layer via a single application interface (API) connection.
- For commercial and industrial customers, deX provides a platform for energy efficiency of plant and equipment via:
- Peak demand management via the automation of equipment.
- Energy storage/load shifting based on market and environmental conditions.
- Integration of DER to improve power quality and optimise/monetise generation based on internal and external conditions.

- In summary, from a commercial comparison, deX and Greensync have positioned themselves as a data layer to bridge and enable the transition to dynamic, two-way energy systems to enable DER visibility and operability through market and technological infrastructure. The deX platform has an energy management component that addresses the capability of DER utilised onsite in response to internal and external demand, supply and operating conditions.
- Criticisms of the platform would be that it is a proprietary platform, likely to not be based open-source infrastructure, or employ standardised data types and protocols. This would likely present issues for accessing/using data and developing custom modules outside of the vendors system.

Evergen

- Evergen is a provider of solar and battery energy infrastructure solutions to help manage the procurement and optimise usage based on internal and external operating conditions.
- Evergen systems are hardware agnostic, facilitate real-time communications and operational functions from energy generation and storage devices in concert with operational plant and equipment for efficiencies, demand response programs and power quality opportunities.
- It is implied that the Evergen system has some hardware controls capability that forms the intellectual property of the offering. It is implied also that the system employs standardised technologies, data formats and protocols to deliver a systems and hardware agnostic technology stack.
- In evaluation, the method of data analysis and user interface is unclear, however, it is assumed that output of solutions could integrate with standardised reporting tools such as Microsoft's PowerBI, Tableau etc.
- It is of note that the CSIRO assisted in the technology development for the commercial offering, presumably in development of control strategies.

EnergyOS

- EnergyOS provides energy management services and equipment such as meters and switches to consumers and portfolio services to electricity companies and other portfolio managers.
- EnergyOS has a data analytics platform eOS featuring real-time data, alerts and alarms, energy management automation and billing management functionality. The company has developed algorithms for load shaping and demand response with the ability to aggregate sites and manage plant and equipment in response to internal and external conditions, tariffs, local generation and predefined control goals for energy efficiency and frequency/voltage control for improved power quality.
- The system incorporates internal conditions, tariffs, local generation, control parameters in conjunction with external conditions such as wholesale energy prices, peak demand and network voltage fluctuations for an integrated wholistic energy solution.
- The company posits a technologically agnostic offering, and data analysis can be performed inside and outside of the vendors eOS system implying the use of common data types, formats and protocols. The system is scalable, designed to incorporate and aggregate data and controls from multiple sites or loads within a single site.
- EnergyOS presents a scalable and dynamic BEMS solution in eOS. The company posits a mix of hardware, data ingestion and control logic with the capability to respond to internal and external conditions. It is implied that the eOS system's infrastructure is standardised, or at least facilitates two-way data flows with the ability to incorporate external devices and systems.

6.7 Market Change, Innovation & Diversification

The Australian electricity market and network is undergoing significant transformation. AEMO has found that there is a substantial need and benefit to consumers of a timely, regulated integration of DER into an energy system that promotes reliability, innovation and competition. The Productivity Commission, Finkel Review, ACCC and Energy Security Board have all recognised the essential role of open, real-time data energy platforms in the successful integration of DER and reform of the NEM.

Advancements in data science and information technology have made federated, scalable data platforms available. These data platforms can ingest, analyse and respond to diverse energy, socioeconomic, environmental and Geo-spatial datasets. In conjunction with smart meters and edge devices, purpose-built programs and algorithms can now facilitate a two-way distribution network and elicit operational control over entire energy networks in real time, including DR capability for behind the meter infrastructure like solar PV and HVAC.

In response to these issues COAG's Energy Council, the Australian Competition and Consumer Commission (ACCC) and AEMO are guiding energy network and data reform and proposing a range of actions to improve network and market function. However, the energy data reform process in Australia has been slow, and compared to other jurisdictions, the focus has narrowed over time. There is a real risk that these measures may act to entrench data silos, limit interoperability and innovation, miss the full opportunity of DER, create an iniquitous market such as 'first in, best dressed' static export limitations for PV owners and lock-in unnecessary network upgrade costs borne by governments and all energy consumers.

The full gamut of technological capability is not wholly supported by current regulation and business models. From a market perspective, the disruption inherent in the shift from coal fired generation to intermittent renewable energy sources is concerning policymakers despite technology capability and private sector investment dollars clearly showing the path forward.

The changing landscape is likely to result in a diversified and evolving energy landscape. New products and services will likely result from network and market reform. For example, The Australian Energy Market Commission (AEMC) has released a final determination setting out a series of changes to the National Electricity Rules (NER) to facilitate wholesale demand response in the national electricity market (NEM), principally through implementing a wholesale demand response mechanism (WDRM).

Large market customers will be able to enter into contracts with (Demand Response Service Providers) DRSPs, or become DRSPs themselves and provide DR by either:

- reducing load, or
- exporting electricity generated onsite.

Retailers are well placed to take advantage of changes to the market as they have the market know-how and relationships with AEMO. Retailers can register with AEMO as demand response service provider (DRSP) and enter into contracts with large market customers whereby:

- a baseline is determined for each large market customer whereby a DR unit or maximum load reduction cap is calculated.
- likewise, a market cap for generated electricity is implied.
- each unit is settled into the wholesale market at the prevailing spot price.
- the DRSP is paid at the spot price and in turn pays the customer for demand response.

Whilst most of the technical requirements for the WDRM have been specified[31], there are two main areas which require stipulation in modelling the WDRM for schools in DCH6.1. Namely:

- Region network capacity constraints which dictate the amount of WDRUs that can be dispatched in each region of the NEM.
- Frequency of WDRUs for dispatch.

Until the amount (MWh) and frequency of WDRUs have been specified, the business case and modelling of the WDRM remains an unknown. However, the controls strategies developed in DCH6.1 will demonstrate the technological capability necessary to participate in the WDRM when available. Namely, the near real-time operation and co-ordination of DER.

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[31] AEMC, 2020, Wholesale demand response mechanism, https://www.aemc.gov.au/rule-changes/wholesale-demand-response-mechanism

The WDRM derives technical requirements from Frequency Control Ancillary Services (FCAS) market; involving the scheduling of electrical load abatement or provision from smart controlled assets to balance frequency on the network. Thus, systems with adequate capabilities could receive remuneration for services in both WDRM and FCAS markets. These markets are likely to grow over the mid to long term due to the increasingly intermittent supply of electricity, the retirement of coal-fired power and the variations in power and frequency that result from increasing solar PV.

The technological advancements of DER are also disrupting traditional retail supply models. Owners of smart controlled equipment such as solar PV inverters, batteries and HVAC can effectively choose when to dispatch electricity and/or reduce consumption based on pricing signals from the electricity market. This reduces the need for the retailer price hedge; fixed price contracts that function to protect customers from extreme price events on the electricity market. Wholesale electricity market exposure is available through contracts from agile retailers such as Amber Electric[32] whereby customers:

- gain exposure to the wholesale spot price without becoming a market participant,
- avoid the flat feed-in tariff provided by traditional retail arrangements,and
- can capitalise on over-sizing solar PV, effectively being remunerated for the value of excess electricity produced from solar PV via arbitrage on the wholesale electricity market.

However, wholesale market pricing is likely to stabilise as DER technologies become more effective. The ability to co-ordinate and control onsite devices such as HVAC and solar, in concert with external conditions on the network and energy market ensures electrical demand and onsite generation complements supply, creating a balanced network, flattening of the duck-curve and subsequently less benefit for arbitrage over the long term.

Summary

It is posited that the co-optimisation of HVAC in concert with DER in response to internal and external operating conditions and internal requirements, centrally controlled from a cloud environment is not currently available in the BEMS market. As such, the DCH6.1 project appears to be new research.

Whilst electricity market equilibrium and stable pricing will likely lead to less benefits over the short term, network services such as the WDRM and FCAS market will provide benefit over the mid to long term for owners and operators of DER.

Key findings from financial modelling outlined in further chapters will demonstrate a business case for the development and integration of DER for the energy system of the future.

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[32] Amber Electric, 2022, ‘How it works’, https://www.amber.com.au/how-it-works

7 2020 PRELIMINARY FINANCIAL MODELLING

Rapid cost assessment – financial modelling

The following modelling has been completed by Buildings Evolved contractor Aeris Capital with input from SINSW and CSIRO. It was first published in July 2020, prior to system installation by School Infrastructure NSW. This work was used to inform SINSW decision on battery and additional solar PV system size. Therefore it is not representative of the as-built in May 2022.

7.1 Summary

The rapid cost assessment methodology was developed from 2017, and deployed across a selection of schools to validate the hypothesis that control of electrical demand and energy storage would provide a BCR and NPV far in excess of simply placing solar PV on the rooftop, which is current policy under the NSW Government's *Cooler Classrooms Program*.

The results from the repeat of the rapid cost assessment methodology for

- Jamison High School;
- Singleton High School; and
- Nimbin Central School;

has produced some very positive and interestingly some non-linear outcomes.

The outcomes overall show excellent investment returns are available to SINSW if it progresses down a pathway of solar plus controls and batteries (conservatively sized).

Jamison high school – 85KW PV; 80KWh battery

Figure 108 shows the result of the 50-year NPV financial analysis for Jamison High School. The results show that CCP3 (solar + controls) delivers the highest financial returns which is primarily due to how cost-effective controls are for the benefits delivered.

Jamison suffered also from having the lowest starting, blended supply tariff of 14.4 ¢/kWh versus 20.6 ¢/kWh for Singleton.

Notably batteries in cases CCP2A, CCP2B CCP2C and CCP4 generate lower returns. Essentially this because there is a limited ability to reduce peak demand at Jamison and that the initial cost of the battery is comparably high and weighs down the financial results. CCP2B is the best of the battery and solar cases. This one aims to use the battery to reduce peak demand charges.

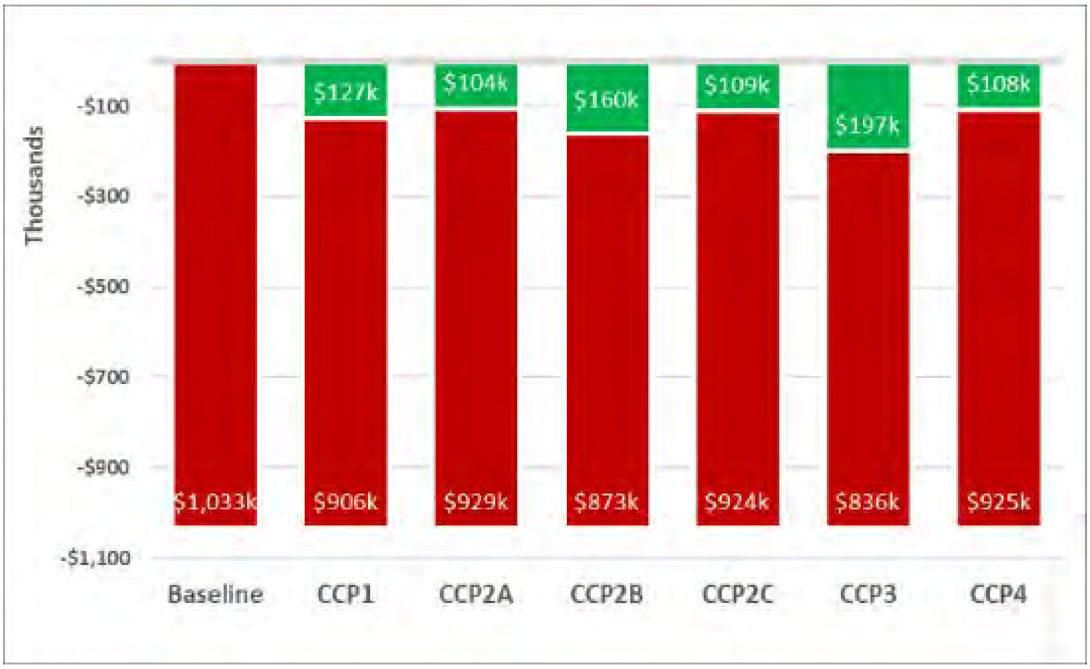


Figure 108: preliminary finance - Jamison HS 50-year NPV results

Singleton high school – 100kW PV; 100KWh battery

Figure 109 shows the result of the 50-year NPV financial analysis for Singleton High School. The results show that CCP3 (solar + controls) delivers the highest financial returns which is primarily due to how cost-effective controls are for the benefits delivered.

Notably CCP4 (solar + controls + battery) generated only marginally lower returns than CCP3. Essentially this because of Singleton high schools enormous peak demand charges and the capability the battery has to reduce these.

The financial returns for Singleton are dramatically higher than for Jamison. These were driven by:

- the substantial reduction in peak demand charges. Notable in the Baseline analysis it showed that demand charges comprised a surprising 44.1% of Singleton's Baseline energy costs.
- the relatively high blended starting energy tariff for Singleton at 20.6¢/kWh versus Jamison's starting blended tariff of 14.4 ¢/kWh.

Importantly Singleton's peak demand at 351 kW is nearly 5x higher than Jamison's at 61 kW. Further the peak demand charges in Ausgrid's network patch are 15% higher than in Jamison's Endeavour Energy network area. As a result, the capacity to make savings from the modelled initiatives is most pronounced in the case of Singleton and most subdued in the case of Jamison.

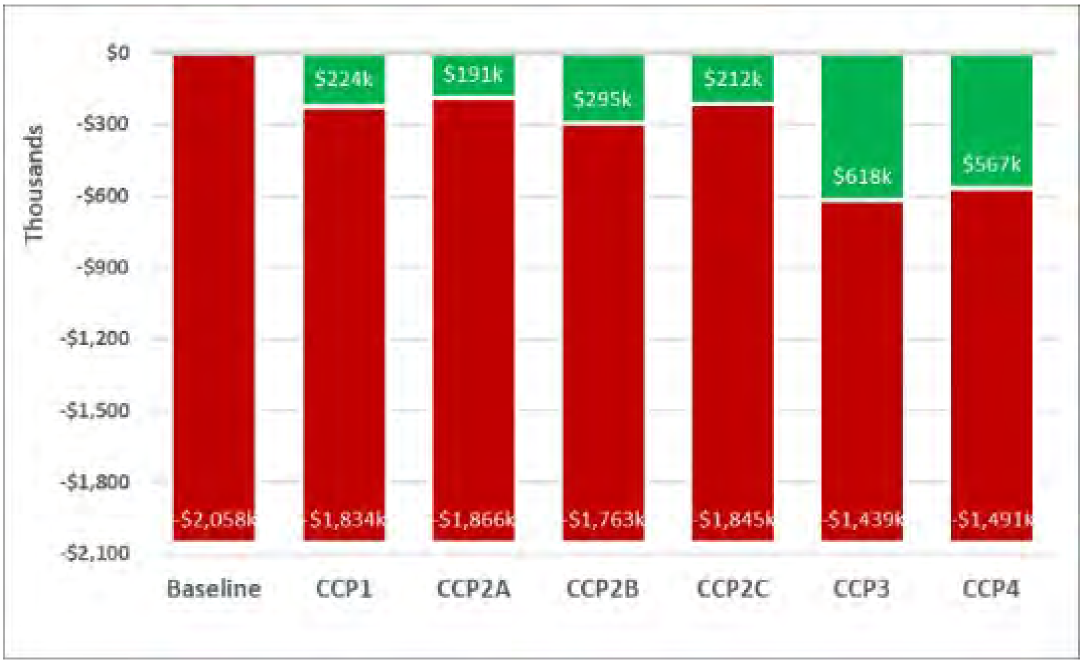


Figure 109: preliminary finance - Singleton HS 50-year NPV results

Nimbin central school – 65KW PV; 60KWh battery

Figure 110 shows the result of the 50-year NPV financial analysis for Nimbin Central School. The results show that CCP3 (solar + controls) delivers the highest financial returns which is primarily due to how cost-effective controls are for the benefits delivered. Nimbin also benefits from having high starting tariffs. In each of these cases the returns come from avoided costs. The higher starting tariffs the greater the returns from avoided cost.

Notably CCP4 (solar + controls + battery) generated only marginally lower returns than CCP3. Essentially this because of the substantial arbitrage between Nimbin's bundled-peak versus bundled-off-peak energy tariffs which over-came the financial burden of the high upfront expense of the battery.

Additionally, Nimbin showed an exceptional fit with the solar PV day including lower baseline consumption in winter months.

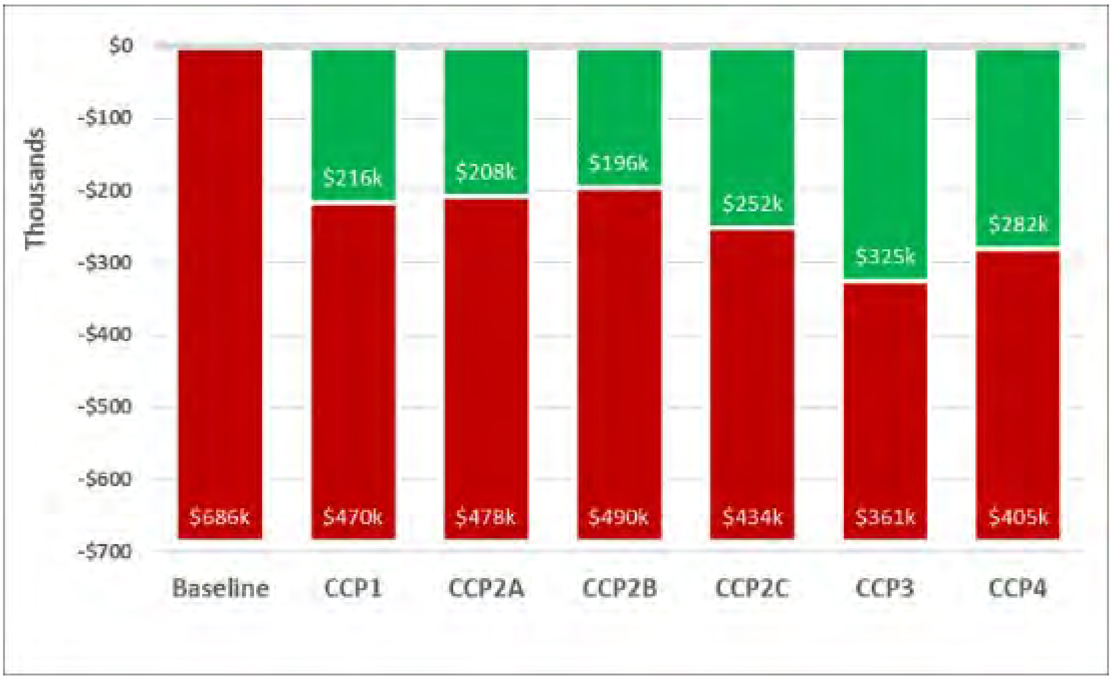


Figure 110: preliminary finance - Nimbin CS 50-year NPV results

Snapshot of network differences

Figure 111 shows the baseline composition of energy costs for each school. Jamison at left appears to have a well balance cost stack. Singleton in the middle is dramatically skewed by having 44.1% of its energy costs allocated to peak demand charges. This is a result of the distinction illustrates in Figure 111. Nimbin has a simple cost stack reflective of its small customer, bundled tariff structure.

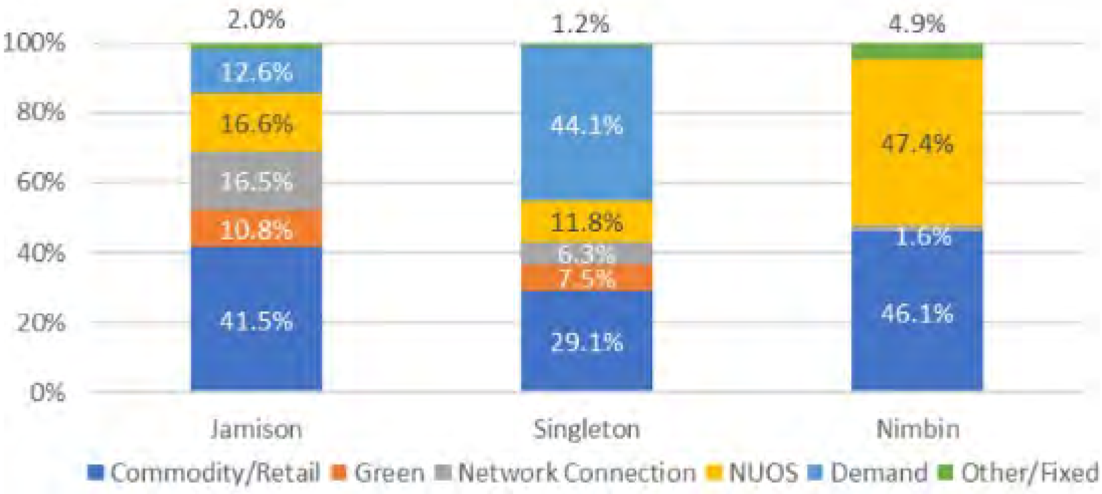


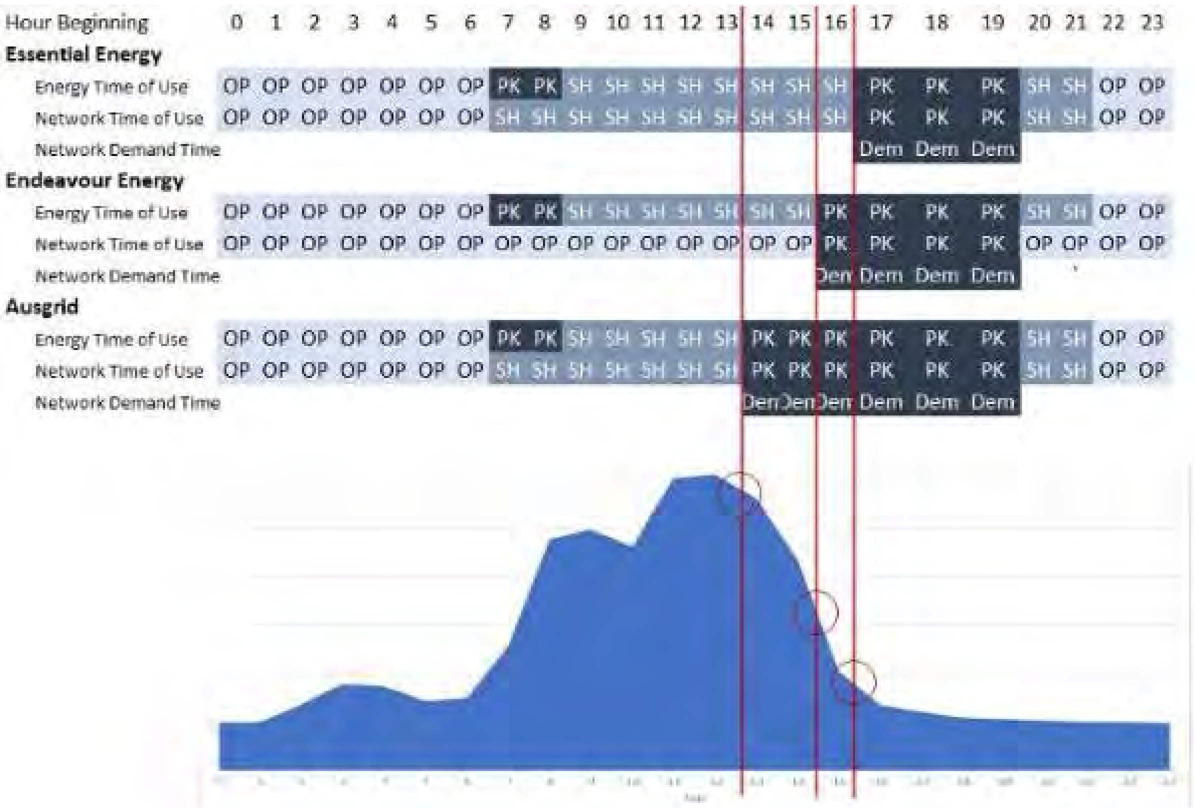
Figure 111: preliminary finance - composition of energy costs

Importantly each school is located in a different distribution network area and as a consequence is exposed to different network tariffs. The tables and chart shown in Figure 112 illustrate network Time-Of-Use bands and network demand periods for each of the three NSW electricity distributors.

The load profile shown, for illustrative purposes, is the average weekday for Singleton high school in February. The red vertical lines show where peak demand for the month or year would be struck had this school been located in each of the three distribution network areas.

What stands out is that in the Ausgrid network area, peak demand is measured from 2pm, which is still within the school day. As a result, Singleton high school incurs very high demand

Conversely Jamison and Nimbin (if it were on a demand tariff) incur (or would incur) very modest demand charges because the start of the demand period commences at the end or after the end of the school day. This can be seen by the middle and rightmost vertical red lines.



Hour Beginning	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Essential Energy																								
Energy Time of Use	OP	OP	OP	OP	OP	OP	OP	PK	PK	SH	SH	SH	SH	SH	SH	SH	SH	PK	PK	PK	SH	SH	OP	OP
Network Time of Use	OP	OP	OP	OP	OP	OP	OP	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	PK	PK	PK	SH	SH	OP	OP
Network Demand Time																		Dem	Dem	Dem				
Endeavour Energy																								
Energy Time of Use	OP	OP	OP	OP	OP	OP	OP	PK	PK	SH	SH	SH	SH	SH	SH	SH	PK	PK	PK	PK	SH	SH	OP	OP
Network Time of Use	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP	PK	PK	PK	PK	OP	OP	OP	OP
Network Demand Time																	Den	Dem	Dem	Dem				
Ausgrid																								
Energy Time of Use	OP	OP	OP	OP	OP	OP	OP	PK	PK	SH	SH	SH	SH	SH	PK	PK	PK	PK	PK	PK	SH	SH	OP	OP
Network Time of Use	OP	OP	OP	OP	OP	OP	OP	SH	SH	SH	SH	SH	SH	SH	PK	PK	PK	PK	PK	PK	SH	SH	OP	OP
Network Demand Time															Den	Den	Den	Dem	Dem	Dem				

Figure 112: preliminary finance - illustration of network demand tariff periods

What this chart explains is that to the extent that solar PV, batteries and controls can shift load out of the network peak demand period then the subject school's cost of energy can be significantly reduced. This in turn can produce very high returns on investment for SINSW.

7.2 Analytical method

NMI interval data

A mixture of NMI interval data and NMI NEM12 format data was provided. Using pivot tables this data was resolved back to a continuous 30-minute time series for analytical purposes.

The following meter data ranges (by school) was provided by SINSW:

School	From:	To:
Jamison	01-Jul-2015 00:00 hrs	07-Apr-2020 23:00 hrs
Nimbin	27-Jun-2018 10:00 hrs	31-Jul-2020 21:00 hrs
Singleton	01-Jul-2015 00:00 hrs	07-Apr-2020 23:30 hrs

Figure 113: preliminary finance - NEM12 data availability

Solar PV data

The NMI meter data, or electricity consumption data for each site is inclusive of the energy use in air-conditioning at each school. Air-conditioning use is primarily a function of:

- temperature conditions; and
- whether the school is operating or not

Solar PV output is a function of:

- time of year; and
- cloud cover (or absence of)

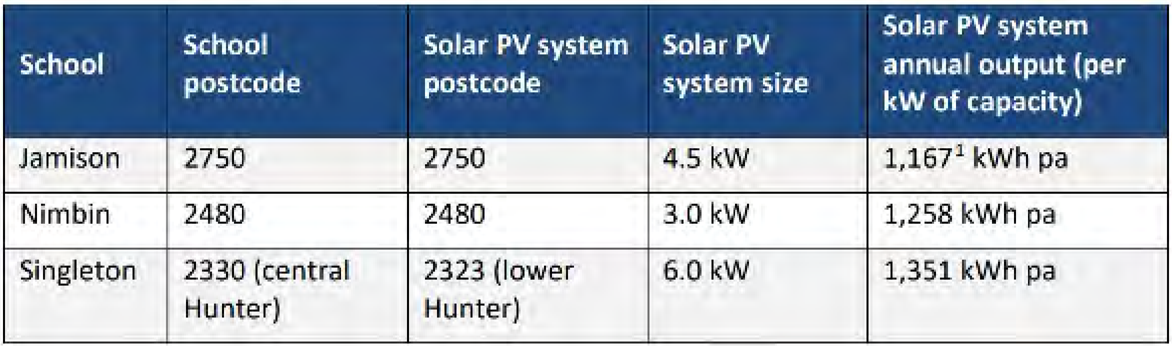
Aeris Capital was provided with a solar PV output profile by CSIRO based on an average solar year. Aeris Capital elected not to use this data as:

- there is no match between actual temperature and weather conditions, embodied within the NMI data for each school, and the design year solar PV data.
- the mismatches in actual versus average weather conditions produces a basis mismatch which will lead to over or under-stating the benefits of solar PV on the net electrical load of the school.

In lieu of using CSIRO’s average design year solar PV data, Aeris searched libraries of data it has which were scraped from the website pvoutput.org. This website hosts the data of thousands of solar PV systems from around the world, but in particular Australia. Many of the solar PV systems linked to pvoutput.org publish their data in 5, 15 or 30-minute intervals. Aeris Capital procured a sub-contractor to scrape meter data for 1,000 solar PV systems in Australia. Each data set was reconciled back to a date and 30-minute time intervals for analytical use. The data is catalogued by postcode, system size and in some cases tilt and orientation.

Aeris Capital search its library of data to try and find solar PV systems which are in the local area (postcode) of the relevant school. The aim being that cloud cover, which dramatically affects solar PV system output is localised. Therefore if solar PV data can be found in the same area as the school in the same time intervals as the relevant meter data then we can better estimate what impact solar PV would have actually had on the net electricity consumption of each school.

The three solar PV systems found had the following characteristics:



School	School postcode	Solar PV system postcode	Solar PV system size	Solar PV system annual output (per kW of capacity)
Jamison	2750	2750	4.5 kW	1,167[1] kWh pa
Nimbin	2480	2480	3.0 kW	1,258 kWh pa
Singleton	2330 (central Hunter)	2323 (lower Hunter)	6.0 kW	1,351 kWh pa

Figure 114: preliminary finance - potential solar PV output per school

This basis difference between CSIRO’s average, solar year data and Aeris Capital’s pvouput.org, data scrape is illustrated in Figure 115 and Figure 116 in respect to the solar PV data for Nimbin. Eight continuous days in the months of February and July are shown. Typically these are the critical months for determining peak demand at any of the three schools. The reader will note that the basis differences can be significant. This mismatch will result in a materially different projection of net grid consumption of electricity and therefore a different Net Present Value (‘NPV’) outcomes. In both charts the orange line is the projected PV output by CSIRO and the blue line is the actual solar PV output for a local solar PV system.

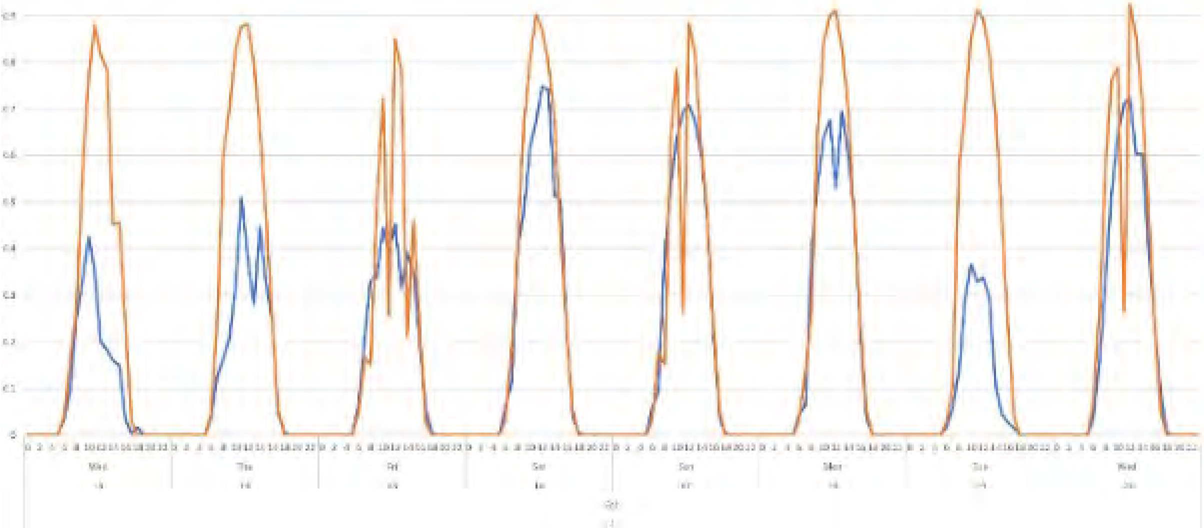


Figure 115: preliminary finance - comparison of solar PV data for February (Nimbin CS)

This was re-scaled to 1,400 kWh pa for analytical purposes. The data for this system showed that it was not a shade affected system. The tilt, orientation, quality age and derating of this system was unknown.

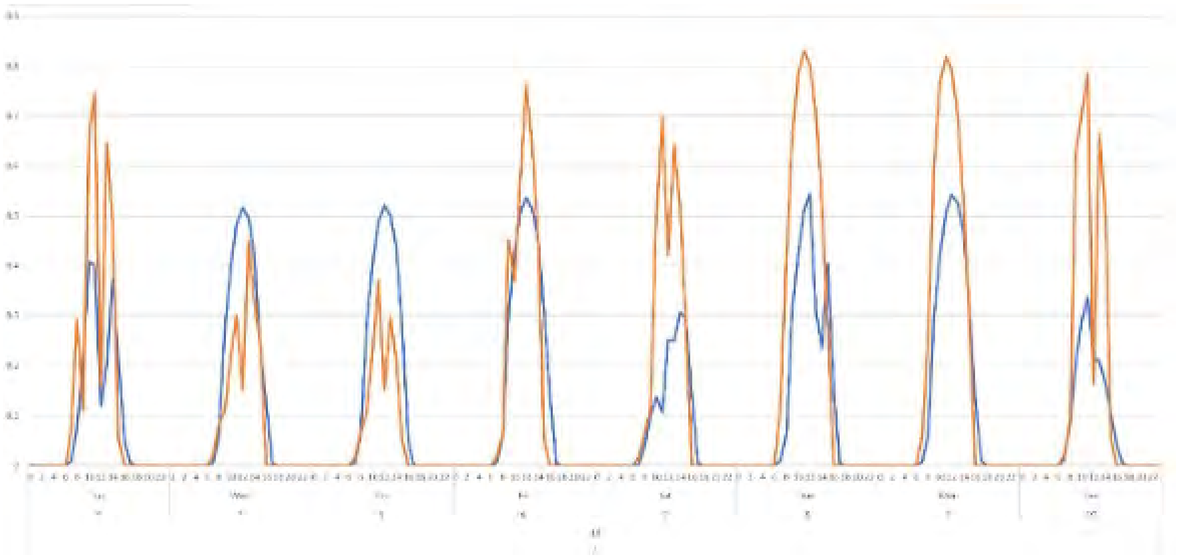
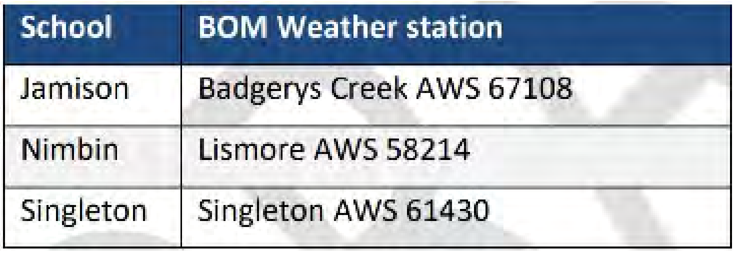


Figure 116: preliminary finance - comparison of solar PV data for July (Nimbin CS)

Temperature data

Temperature data was sourced from the Bureau of Meteorology. Daily minimum and maximum temperatures for each day was sourced. Hourly temperature data was not available freely.

The weather stations selected are shown in Figure 117:



School	BOM Weather station
Jamison	Badgerys Creek AWS 67108
Nimbin	Lismore AWS 58214
Singleton	Singleton AWS 61430

Figure 117: preliminary finance - selected BoM weather stations

Minimum temperatures were assumed to occur at 5am each day and maximum temperatures at 3pm. Hourly temperatures were estimated using a sinusoidal curve to interpolate between minimum and maximum temperatures.

Temperature data was used to assess the requirement of each school for heating and cooling.

Humidity was not considered.

Isolating the HVAC load

- Clearly each school has a different load profile however there are some stark similarities to the patterns influenced by school operating hours, weekends and public holidays.
- The original RCA was undertaken to assess the NPV impact of the installation of solar PV, batteries and AC controls on HVAC augmentations being undertaken by SINSW's as a part of its cooler classroom program ('CCP').
- In the original RCA, as with this assessment, Aeris sought to isolate the HVAC load profile out of the combined NMI interval data for each school. Isolating the HVAC load profile was done by:
- isolating data for:
  - those days of the year when school was in session; and
  - those days where the requirement for AC was either nil or negligible - days with the mildest recorded temperatures, then

- the electrical load profile for the 24 hours of each of these mild days was isolated and then averaged into a single 24-hour nil-HVAC day load profile. The nil-HVAC day load profile is estimated to be the base load profile of the school;
- the nil HVAC day load profile was then subtracted from the actual load profile for the whole calendar year;
- any negative results from the difference were reallocated a zero value; and
- the positive differences is estimated to be the resulting HVAC load profile.
- The data for the nil-HVAC days is isolated and shown for each school in Figure 118, Figure 119 and Figure 120.
- February is sampled and shown in Figure 121, Figure 122 and Figure 123 to illustrate the separation of the AC load profile from the base load profile.
- The assertion of this technique is that on the mildest days, behaviourally, schools (among others) are likely to use least (or nil) AC as it is simply not required to achieve thermal comfort.

Note the average of the blue line forms the base load. In any period, the base load is subtracted from the initial load and the difference is recoded as the AC load profile. Where the difference produces a negative result the difference is changed to zero. The revised base load is shown as the orange line.

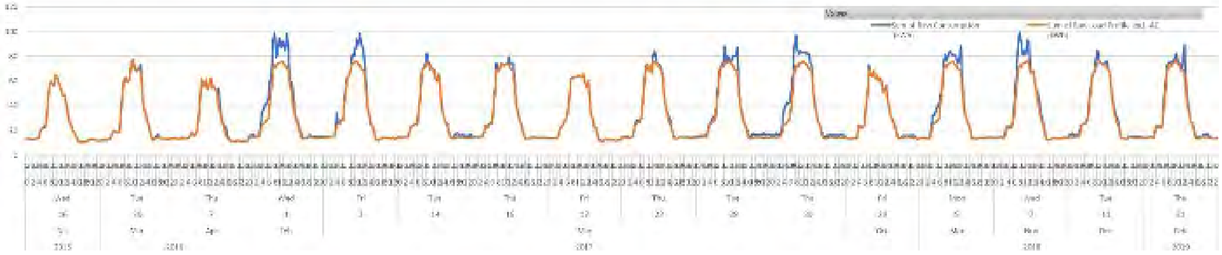


Figure 118: preliminary finance - Jamison HS days in NMI interval data set with min >18°C and max <25°C

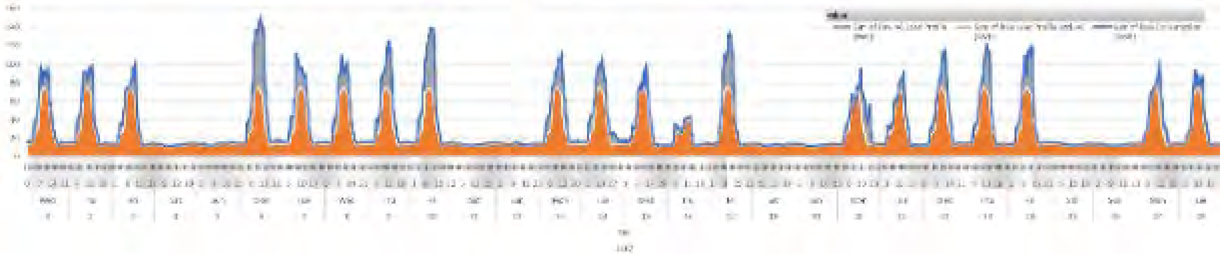


Figure 119: preliminary finance - Jamison HS Feb 2017 sampled to illustrate the base & AC loads

Figure 120: preliminary finance - Nimbin CS days in NMI interval data set with min >16°C and max <24°C

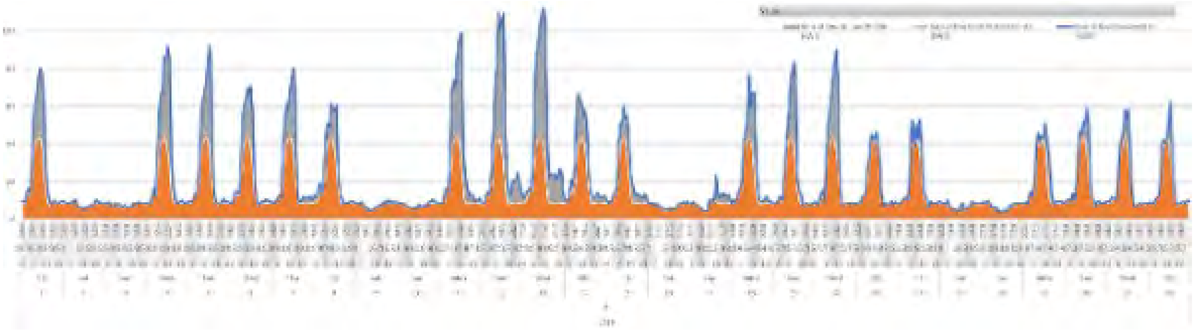


Figure 121: preliminary finance - Nimbin CS Feb 2019 sampled to illustrate the base & AC loads

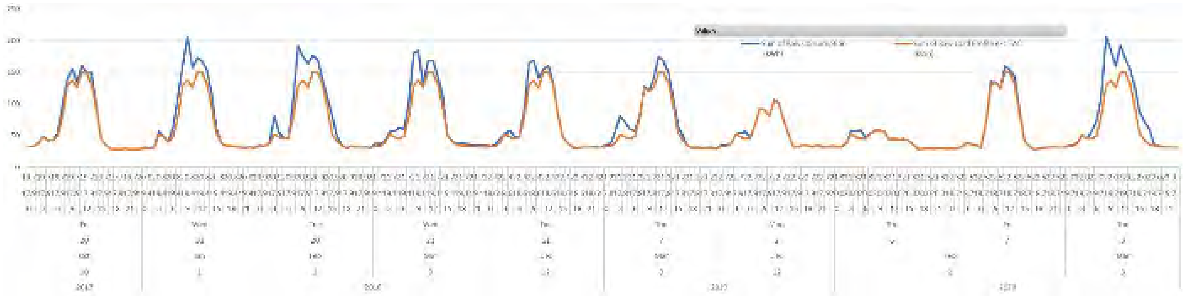


Figure 122: preliminary finance - Singleton HS days in NMI interval data set with min >17°C and max <23°C

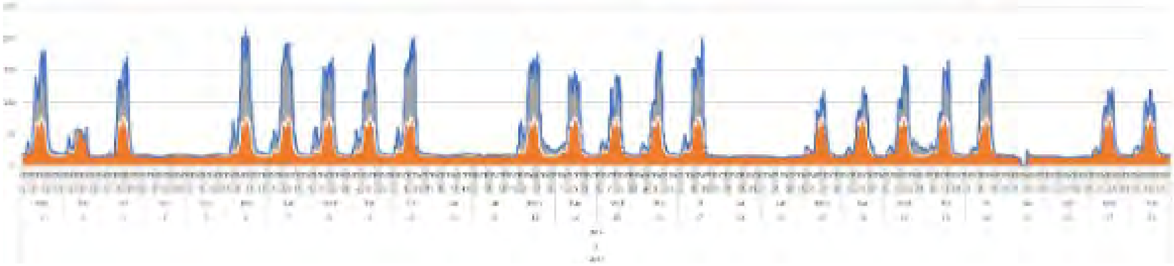


Figure 123: preliminary finance - Singleton HS Feb 2017 sampled to illustrate the base & AC loads

7.3 Site Specific Adjustments

Both Nimbin and Jamison had site specific conditions which needed to be considered before the meter data for these sites could be used.

Nimbin adjustments

Nimbin benefits from having a small [3.9] kW solar PV installation. After analysis the base load NMI data for Nimbin was not adjusted to compensate for the presence of the [3.9] kW solar PV system as it was determined that its impact on the data was minimal.

The minimal impact was determined through observing weekend electricity consumption in February of each year (the month of maximum solar output) and checking that at no time did the small solar PV installation push the school's load into net export. As weekends are periods of very low electricity consumption, if the PV output is so small as to not overcome the school's small load then the impact was deemed negligible. In the scheme of the uncertainties of the remainder of the analysis this was determined as an acceptable error.

Jamison adjustments

SINSW advised that an LED retrofit had been carried out at Jamison High School around 2 December 2019. The impact of the LED retrofit was substantial and it meant that the NMI interval data which pre-dated the LED retrofit was unfit to use without adjustment.

Aeris Capital sought to establish the difference in the post-LED (non-HVAC) baseload and the pre-LED (non-HVAC) baseload. Like the technique used in section 3.4 above, the base load was split into two time series, pre and post LED retrofit. The two were compared and it was found that on average the post LED retrofit baseload was 57% lower than the pre-LED retrofit baseload. The 30-minute time interval data for the pre-LED retrofit period was then adjusted down by the difference in the pre and post baseloads. The net effect was to adjust the NMI interval data sufficient to create a historical data set which was suitable for analytical use.

This is illustrated in Figure 124. Here we can see the blue line is the pre-LED retrofit electrical load for 2-10 February of each year in the sample data set. The Orange line is the adjusted pre-LED retrofit NMI interval data. For 2020 the orange line shows unadjusted, post-LED retrofit NMI interval meter data.

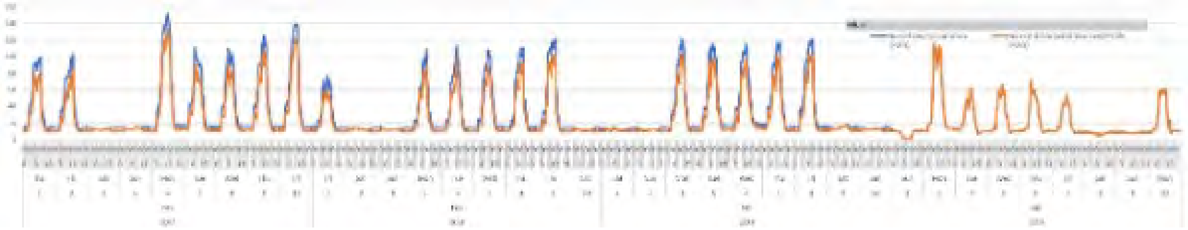


Figure 124: preliminary finance - Jamison Feb data for each calendar year showing pre and post LED retrofit adjusted NMI interval data

7.4 Description of Each Scenario Step

Overview

An analytical ‘Baseline’ was established, and a number of different scenarios were tested using the available data to determine the financial impact of each. The scenarios are:

- **baseline** – school as is
- **CCP1** – solar PV only
- **CCP2A**– solar PV + batteries controlled to maximise solar electricity usage
- **CCP2B**– solar PV + batteries controlled to minimise network peak demand charges
- **CCP2C**– solar PV + batteries controlled to maximise retail tariff arbitrage
- **CCP3** – solar PV + AC controls to reduce peak demand
- **CCP4**– solar PV + AC controls + batteries to reduce peak demand & retail charges

Each of these are explained in greater detail below.

Baseline

The baseline case involves:

- estimating the cost of electricity in the coming year for each school as it is
- inflating the year 1 costs for each subsequent year according to each cost sub component;
- the costs are allocated into a profit & loss, balance sheet and cashflow statement;
- the final cashflows for each year are discounted to create a net present value.

The present values are done in two parts:

- years 1-15 and
- years 16 to 50.

The baseline case like all other subsequent cases requires that the use of electricity in each hourly interval is allocated into its components of:

- peak;
- shoulder; and
- off-Peak.

which are then summed to create annual totals. This has to be done for both network times of use as well as retail contract times of use. Finally, the peak demand for each month or each year is determined. The relevant tariffs for:

- network tariffs and charges;
- energy tariffs;
- environmental charges;
- ancillary and market charges;
- other (metering and daily supply) charges;

are multiplied by the appropriate consumption or peak demand figure to give total cost. This is set out in the invoice calculation table in Figure 125.

Units	Loss Factor or Other	Tariff or Charge	Cost
Energy			
Peak Usage (kWh)	x MLF x DLF	x Peak energy tariff	Peak energy cost
Shoulder Usage (kWh)	x MLF x DLF	x Shoulder energy tariff	Shoulder energy cost
Off-Peak Usage (kWh)	x MLF x DLF	x Off-Peak energy tariff	Off-Peak energy cost
Energy Sub-Total			**Total energy cost**
Network			
Peak Usage (kWh)	X 1.00	x Peak network tariff	Peak network cost
Shoulder Usage (kWh)	X 1.00	x Shoulder network tariff	Shoulder network cost
Off-Peak Usage (kWh)	X 1.00	x Off-Peak network tariff	Off-Peak network cost
Peak Demand (kW)	x Days	x Peak Demand tariff	Network demand cost
Network Connection	Days	x Connection charge / day	Network connection cost
Network Sub-Total			**Total network cost**
Environmental			
Total Consumption (kWh)	x DLF	x LRET tariff	LRET cost
Total Consumption (kWh)	x DLF	x SRES tariff	SRES cost
Total Consumption (kWh)	x DLF	x ESS tariff	ESS cost
Environmental Sub-Total			**Total environmental cost**
AEMO (regulated)			
Total Consumption (kWh)	x DLF	x AEMO Participant tariff	AEMO participant cost
Total Consumption (kWh)	x DLF	x AEMO ancillary tariff	AEMO ancillary cost
Market Sub-Total			**Total AEMO costs**
Other			
Metering	Days	x metering daily charge	Metering fixed charge
Retail Charges	Days	x retail daily charge	Retail fixed charge
Other Sub-Total			**Total other costs**

Figure 125: preliminary finance - energy calculation methodology

The baseline financial results for each school is shown in the appendices.

CCP1 – Solar PV only

In this scenario solar PV is added to each school.

Solar PV output in each 30-minute time interval is subtracted from the electricity load of the school in the matching time period.

If the difference is negative this is treated as export.

If the difference is positive then the school remains a net consumer of electricity in that time period.

The net consumption of the school in each 30-minute time period is summed across a year, into each of the energy (retail) and network time periods. The peak demand is measured according to the criteria set down by the network supplying each school.

This is illustrated in Figure 126 which shows the week of 5-11 February 2017 for Jamison.

- **Orange** line is the solar PV output
- **Blue** line is the school's initial load (incl. HVAC) before solar PV; and
- **Grey** area is the school's net electrical load after the solar PV output.
- **Yellow** area (below the x-axis) is the school's export of electricity back to the grid.

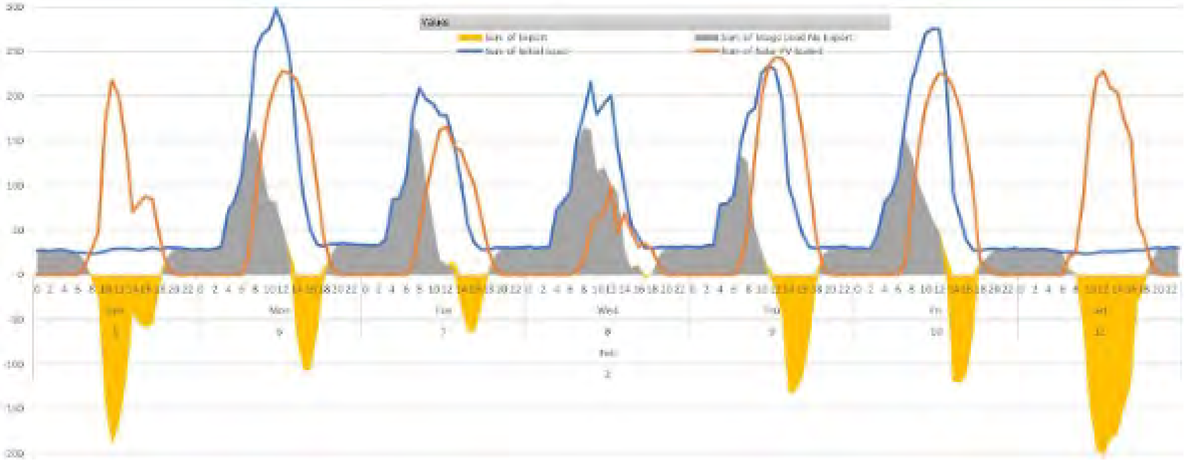


Figure 126: preliminary finance - Jamison HS from 5 to 11 Feb 2017 with 100kW of solar PV

CP2A – Solar PV + batteries controlled to maximise solar electricity usage

In this scenario the inclusion of the battery is done so on the basis that it is controlled to maximise the use of the generated solar PV electricity meeting the school's load. Here:

the battery is only charged by solar PV electricity that would otherwise have been exported. That is only if the solar PV system produces more electricity than the school requires in a 30-minute time period does the battery charge; and

the battery discharges at any time the school has a net positive demand on the grid. That is when there is either no solar or not enough solar PV electricity to meet the school's electrical load the battery will discharge up to its maximum or a lesser amount so as to bring the school's load back to zero.

This scenario is illustrated in Figure 127 which shows the week of 5-11 February 2017 for Jamison.

- **Orange** line is the solar PV output
- **Blue** line is the school's initial load (incl. HVAC) before solar PV;
- **Grey** area is the school's net electrical load after the solar PV output and the battery charge and discharge;
- **Green** area is the charging of the battery using the surplus solar PV electricity;
- **Bright green** area is the discharging of the battery; and
- **Yellow** area is the export of surplus solar PV electricity

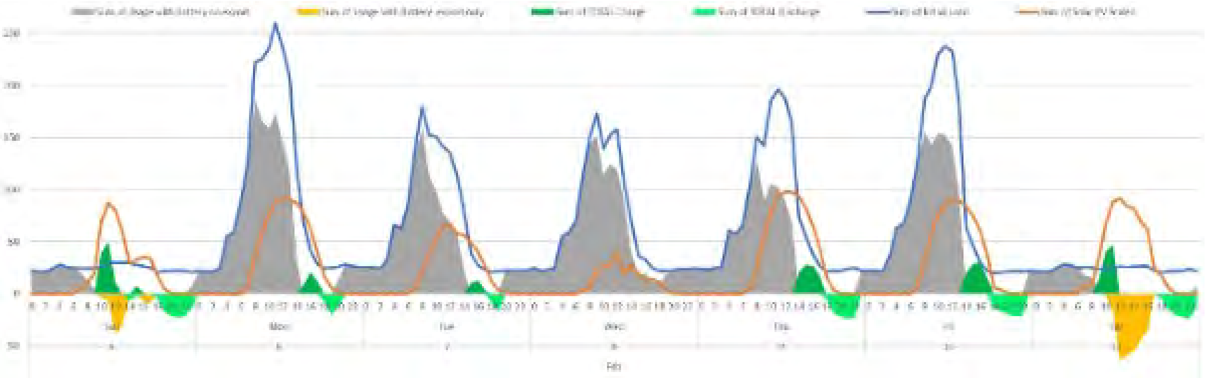


Figure 127: preliminary finance - CCP2A Jamison HS from 5 to 11 Feb 2017 w/ 100kW of solar PV + 100 kWh battery

CCP2B – Solar + batteries controlled to minimise network peak demand charges

In this scenario the inclusion of the battery is done so on the basis that it is controlled to minimise the peak demand charges the school is exposed to. That is minimise demand on the grid at peak times (network). Here:

- the battery is charged either in the early AM off-peak if it is below full capacity or from surplus solar PV electricity that would otherwise have been exported; and
- the battery discharges during times of network peak demand. The extent of discharge is limited to that amount which would produce the maximum reduction in peak demand for that month, in the case of Jamison and Nimbin, or the maximum reduction in annual peak demand for Singleton.

This scenario is illustrated in Figure 128 which shows the week of 19-25 February 2017 for Jamison. 20 Feb is the day of highest peak demand.

- **Orange** line is the solar PV output
- **Blue** line is the school's initial load (incl. HVAC) before solar PV;
- **Grey** area is the school's net electrical load after the solar PV output and battery charging and discharging;
- **Green** area is the charging of the battery;
- **Bright green** area is the discharging of the battery into a time of peak demand; and
- **Yellow** area is the export of surplus solar PV electricity.

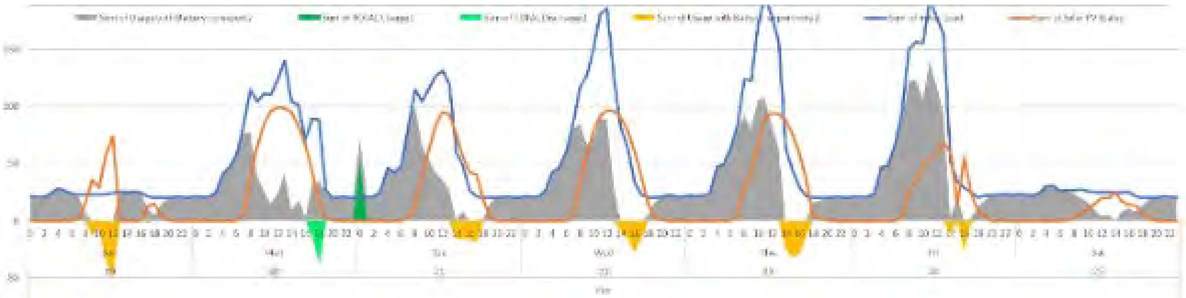


Figure 128: preliminary finance - CCP2B Jamison HS from 19 to 25 Feb 2017 w/ 100kW of solar PV + 100 kWh battery

CCP3 – Solar + HVAC controls to minimise network peak demand charges

In this scenario the inclusion of AC controls is done so on the basis that only the controls only operate in periods network peak demand. The modelling requires a percentage reduction in peak HVAC demand be selected, a starting iterative position. The model then measures, after applying the HVAC peak demand reduction, how many school hours are affected. It also measures what is the average percentage reduction in cooling during the HVAC reduced operating hours.

For Nimbin, where peak network demand starts at 5pm, the model is working to reduce AC use at a time which sits comfortably outside school hours. The percentage reduction in HVAC for Nimbin in the hours of 5pm to 8pm (network peak demand) could theoretically be 100% without affecting the teaching day. Having said that there will always be parent teacher conferences or staff meetings which will require HVAC at these times.

Somewhat arbitrarily the count of school hours affected by the HVAC control was targeted at approximately 10-15 hours (Nimbin excluded). A secondary impact being judged was the degree to which unconstrained HVAC use is being limited in the affected hours. Again, arbitrarily it was selected that in the hours when HVAC use was being curtailed, the average curtailment would not exceed 20%. The percentage reduction in HVAC peak demand was then iterated up and down to achieve a result that sat within the described bands. This scenario is shown in Figure 129. It shows select days in June and July for Jamison. The white space between the blue area and the orange line is the impact of the HVAC controls. Note that these impacted hours, for Jamison, are after 4pm, when network peak demand starts for the Endeavour network area.

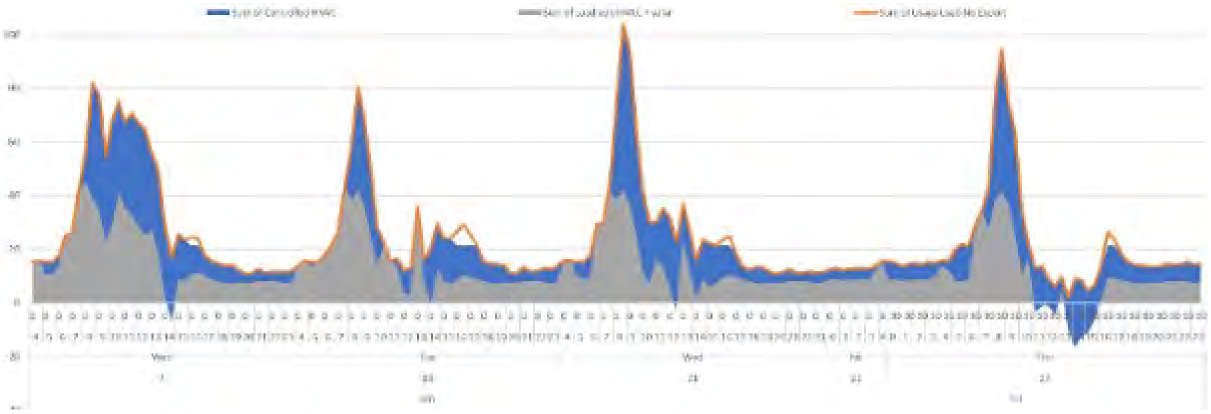


Figure 129: preliminary finance - CCP3 Jamison HS select days in June and July where HVAC controls is affecting load

CCP4 – Solar + HVAC controls + batteries to minimise both network peak demand charges and retail energy charges

In this scenario the HVAC is controlled as per CCP3 and the battery is controlled as per CCP2B (1st layer) and CCP2C (2nd layer). The intention being to minimise both peak demand charges as well as reduce energy costs.

This scenario is illustrated in Figure 130 which shows the week of 5-11 February 2017 for Jamison.

- **Orange** line is the solar PV output
- **Blue** line is the school's initial load (incl. HVAC) before solar PV;
- **Grey** area is the net of the school's net electrical after the solar PV output and battery charging and discharging;
- **Green** area is the charging of the battery;
- **Bright green** area is the discharging of the battery into a time of peak demand; and
- **Yellow** area is the export of surplus solar PV electricity.

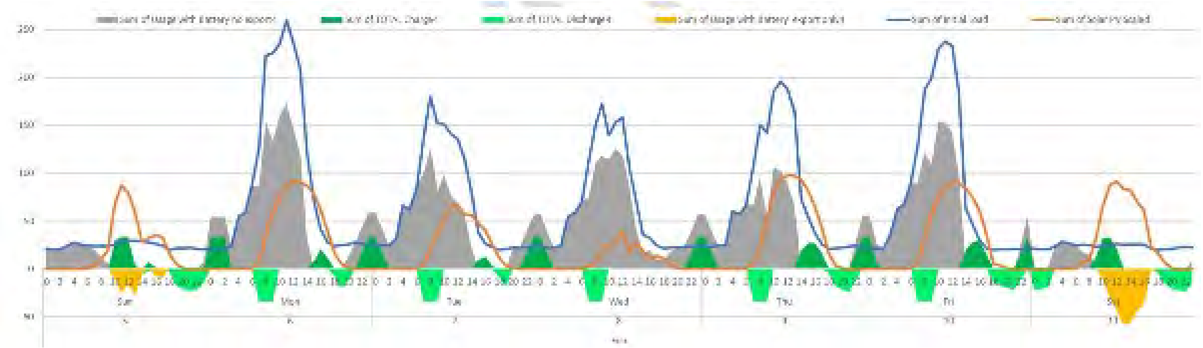


Figure 130: preliminary finance - CCP4 Jamison HS from 5 to 11 Feb 2017 w/ 100kW of solar PV + 100 kWh battery + HVAC controls

7.5 Description of Financial Analysis

Energy tariffs

As set out in section “baseline”:

- network tariffs and network charges;
- energy tariffs;
- environmental charges;
- ancillary and market charges; and
- other (metering and daily supply) charges;

are multiplied by the consumption or peak demand figure to give total annual cost.

Each school’s net consumption is costed through the invoice template as set out in Table 125, above. The total annual cost for the baseline is then added back as revenue whereas the total cost of the scenario is treated as a cost. That is, the Baseline is revenue (the avoided cost) whereas the scenario becomes the new, incurred cost. The difference between the two (Baseline minus Scenario) is the net benefit the scenario produces.

The net benefit, measured in the cashflow statement, includes the cost of installing and maintaining the solar PV system over the analysis period. The resulting net cashflow are discounted produce a set of present values. The sum of these gives the net present value or NPV of the scenario.

Network tariffs

Network tariffs for each school were taken from the Australian Energy Regulator’s website. Network tariffs for the relevant distribution network provider for current year were used as a baseline. Network tariffs were escalated in price each year using a CPI-X% methodology as used by the Australian Energy Regulator when it sets network tariffs. The X% figure was lifted from the Australian Energy Regulator’s most recent publications about network tariff 5-year forecasts. None of the schools appear to qualify for a change of network tariff as a result of this exercise.

Energy volumes

Energy volumes were taken from NMI interval and NMI NEM 12 format meter data. Generally, the 2017 year was selected as this aligned with Aeris Capital’s solar PV data sets used in this analysis.

Energy tariffs

Energy tariffs were taken from invoices provided by SINSW in the case of Nimbin and Singleton. As Jamison and Singleton high schools qualify as large retail customers the tariffs applicable at Singleton were applied without variation at Jamison.

Energy Tariffs beyond 2020 were modified using the recently settled prices for electricity futures on the Australian Stock Exchange. Beyond this a simple rate of inflation was applied.

The tariffs provided by SINSW were from energy invoices dated in H2 2019 and would have arguably continued to apply until 30 June 2020 - depending on the B777 and B776 contract terms. Aeris Capital made the assumption that as of 1 July 2020 the contract prices would reset and the energy tariffs would step down to reflect the change in wholesale electricity forward contract pricing since the on-set of the COVID induced recession.

Solar PV and battery system decay/deterioration

No allowances have been made for a deterioration in the output of the solar PV system or battery. This is a short coming of the model and one which can only be addressed through visual basic programming and a substantial increase in the model's size and operating speed. Based on other past modelling exercises Aeris Capital contends that the absence of these two decay features does not materially diminish the fidelity of the modelled outcomes. Rather, there is such great variation in either the discounts rates or the other assumptions around energy price inflation that the impact of a small percentage change in output each year is insignificant versus the errors ranges within the existing assumption sets.

Maintenance and replacement capital expenditure

Maintenance expenditure and replacement capital expenditure were assumed to occur as follows:

	Item	Replacement cycle	Price / inflation / deflation
Solar PV	Initial Installation	Year 0 only	$1.50 per Watt
	Maintenance (cleaning)	Annual	$10 per kW pa (SINSW figure from original RCA)
	Inverters	12.5 years	Deflating at 3.5% pa
	Panels	25-years	Deflating at 3.5% pa
	Racking and fixtures	None assumed	NA
Batteries	Initial Installation	Year 0 only	$500 per kWh
	Whole battery inverters and cells	20 years (equivalent to 10,000 cycles)	Deflating at 4.0% pa

Figure 131: preliminary finance - capex and opex assumed costs

Discount rates

The NSW Treasury's business case guidelines stipulate projects which are exposed to "market risk" should employ a discount rate (in the NPV calculations) which reflects a weighted average cost of capital "reflective of the risks inherent in the project". For this analysis energy market risks and asset performance risks are present and so a discount rate of 5.6% has been chosen being a weighted average cost of capital comprising:

- 50% debt;
- 50% equity;
- a pre-tax cost of debt of 5.3%;
- a post-tax cost of equity of 7.4%; and
- a tax rate of 30%.

Approach to net present value

Aeris Capital converts each schools energy costs into a:

- Profit and loss statement;
- Balance sheet statement; and
- Cashflow statement.

The cashflow statement reconciles the timing differences between the balance sheet and the profit & loss statements.

Aeris Capital discounts the net cashflow available to the NSW government from each scenario. Aeris Capital asserts that this is the best approach as it is the financial line most inclusive of all the benefits and all the costs of each scenario.

Consistency with NSW Treasury business case guidelines

Aeris Capital has not sought to complete this analysis and RCA report with complete adherence to the NSW Treasury's business case guidelines. The report format and analytical approach are however substantially consistent with the guidelines SINSW must meet in NSW Treasury's guidelines.

7.6 Summary of results (preliminary) – Jamison HS

Initial Load Profile

Jamison high school's load required adjustment as set out sections above.

Other than as noted, Aeris Capital did not observe anything about Jamison high school's meter data that was out of the ordinary or uncharacteristic.

Equipment specifications

- Solar PV size = 85 kW
- Battery Size = 80 kWh
- Battery Discharge rate = 40 kWh maximum

Note the rate of battery discharge (range between 2 to 3 hours) was optimised to achieve the greatest reduction in peak demand. Some schools get a better peak demand reduction from a slow discharge (where more school hours cross over with network peak demand) whereas others benefit from a fast discharge.

Network area considerations

- Jamison is in the Endeavour Energy network area.
- Jamison qualifies for Endeavour's N19 tariff. This is for large business customers consuming more than 160 MWh pa.
- The N19 tariff consists of:
  - Peak, Shoulder and Off-Peak NOUS tariffs;
  - A peak demand tariff; and
  - A network access daily fixed charge.
- Endeavour's peak demand period commences at 4pm and runs until 8pm each working weekday. Peak demand is the highest metered consumption during the peak demand time period in each calendar month.
- Endeavour has a high season and a low season for peak demand. A different tariff applies at each season.
- High season runs from 1 November through to 31 March
- Low season runs from 1 April through to 31 October
- There is an approximate difference of 2 ¢/kWh in between peak NOUS and off-peak NOUS tariffs.

The bulk of SINSW's capacity to reduce the cost of network tariffs and charges lies in reducing peak demand. As peak demand is measured from 4pm, after the conclusion of the school day, SINSW has a strong chance of achieving significant savings for large schools like Jamison located within the Endeavour Energy network area. This is best illustrated in scenario CCP3.

Results

Figure 132: preliminary finance - Jamison baseline & CCP3 cost stacks

Figure 133 and Figure 134 set out the results of the financial analysis for Jamison high school over 50-year and 15-year timeframes.

Figure 47 and Figure 48 are to be read as follows:

- The **red** bar at left labelled ‘Baseline’ is the net present cost of providing electricity to
- Jamison high school, as it is, over the 50-years and 15-years.
- Moving from left to right the **red** bars generally become smaller as the net present cost
- of providing electricity to Jamison high school shrinks with each scenario
- The **green** bars starting with CCP1 and moving left across to CCP4 show the net present value of each of the tested scenarios. Broadly these increase from left to right.

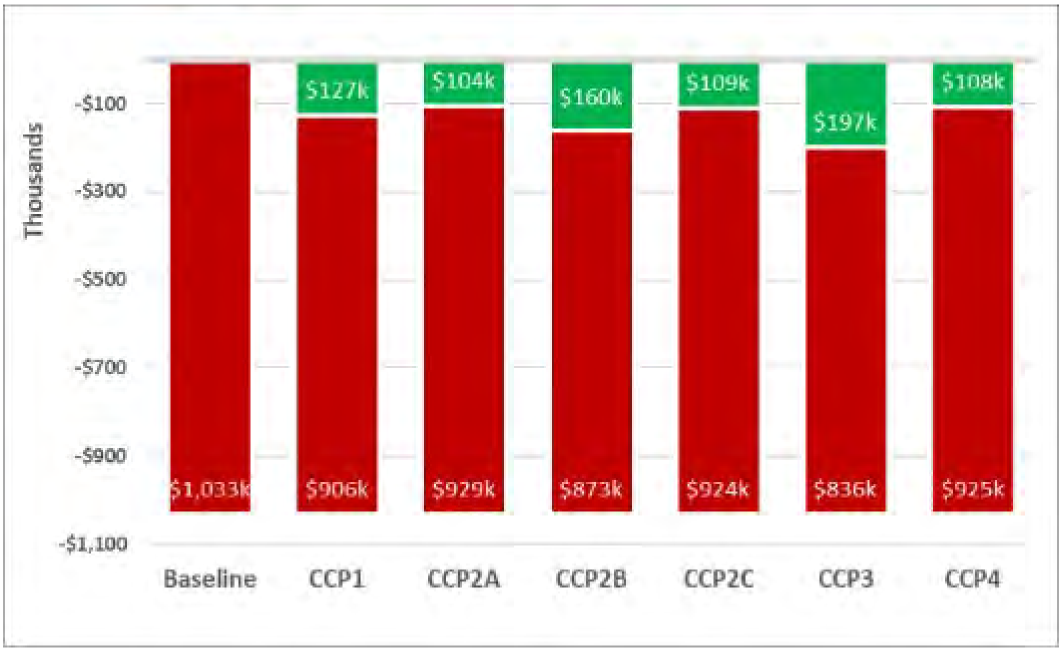


Figure 133: preliminary finance - Jamison HS 50-year NPV results

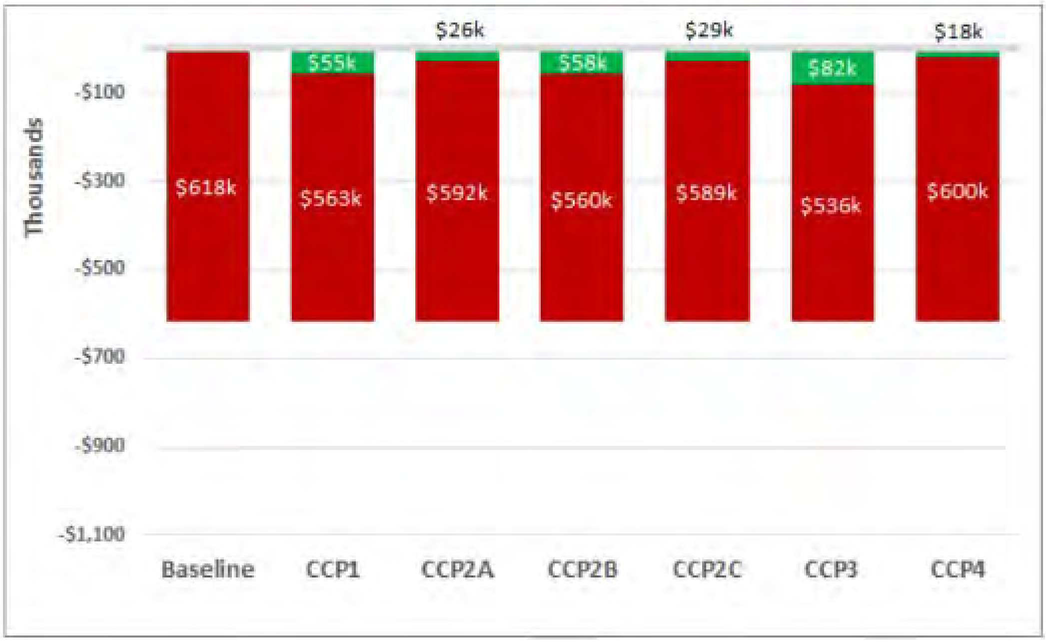


Figure 134: preliminary finance - Jamison HS 15-year NPV results

Conclusions

- Four scenarios are financially attractive for Jamison high school:
  - CCP1 –85kW solar PV only
  - CCP2B – 85kW solar PV + 80 kWh battery controlled for peak demand reduction
  - CCP3 – 85kW solar PV + HVAC controls to limit peak demand
  - CCP4 –85kW solar PV + 80 kWh battery + HVAC controls to limit peak demand
- CCP3 has the highest NPV at $197,000 and produces the greatest reduction in net present cost over 15-years and 50-years.
- CCP3 at $197,000 of benefit is close behind and could easily be enhanced through improved battery and HVAC control logic.

Outstanding Issues/Concerns

None

7.7 Summary of results (preliminary) – Singleton HS

Initial Load Profile

Aeris Capital did not observe anything about Singleton high school's meter data that was out of the ordinary or uncharacteristic.

Equipment specifications

- Solar PV size = 100 kW
- Battery size = 100 kWh
- Battery discharge rate = 50 kW maximum controlled to a maximum of 40 kW

Note the rate of battery discharge (range between 2 to 3 hours) was optimised to achieve the greatest reduction in peak demand. Some schools get a better peak demand reduction from a slow discharge (where more school hours cross over with network peak demand) whereas others benefit from a fast discharge.

Network considerations

- Singleton is in the Ausgrid network area.
- Singleton qualifies for Ausgrid’s EA305 tariff. This is for large business customers consuming >160 MWh and <750 MWh pa.
- The EA305 tariff consists of:
    - peak, shoulder and off-peak NOUS tariffs;
    - a peak demand tariff; and
    - a network access daily fixed charge.
- Ausgrid’s peak demand period commences at 2pm and runs until 8pm each working weekday. Peak demand is the highest metered consumption during network peak demand time for the preceding calendar year.
- There is an approximate difference of 4 ¢/kWh in between peak NOUS and off-peak NOUS tariffs.

The bulk of SINSW’s capacity to reduce the cost of network tariffs and charges lies in reducing peak demand. As peak demand is measured from 2pm, toward the end of the school day, SINSW will be operationally challenged achieving significant savings for large schools like Singleton located within the Ausgrid network area.

Results

Figure 135 shows the year 1 (2021) **estimated** cost stack for Singleton high school (based on 2019/20 data). On the left is Singleton’s baseline cost stack and on the right is the cost stack for case CCP3 which is solar PV + controls. This shows estimated savings of almost **$34,000 p.a.**

Figure 135: preliminary finance - singleton baseline & CCP3 cost stacks

Figure 136 and Figure 137 set out the results of the financial analysis for Singleton high school over 50-year and 15-year timeframes.

- The **red** bar at left labelled ‘Baseline’ is the net present cost of providing electricity to Singleton high school, as it is, over the 50-years and 15-years.
- Moving from left to right the **red** bars generally become smaller as the net present cost of providing electricity to Singleton high school shrinks with each scenario
- The **green** bars starting with CCP1 and moving left across to CCP4 show the net present value of each of the tested scenarios. Broadly these increase from left to right.

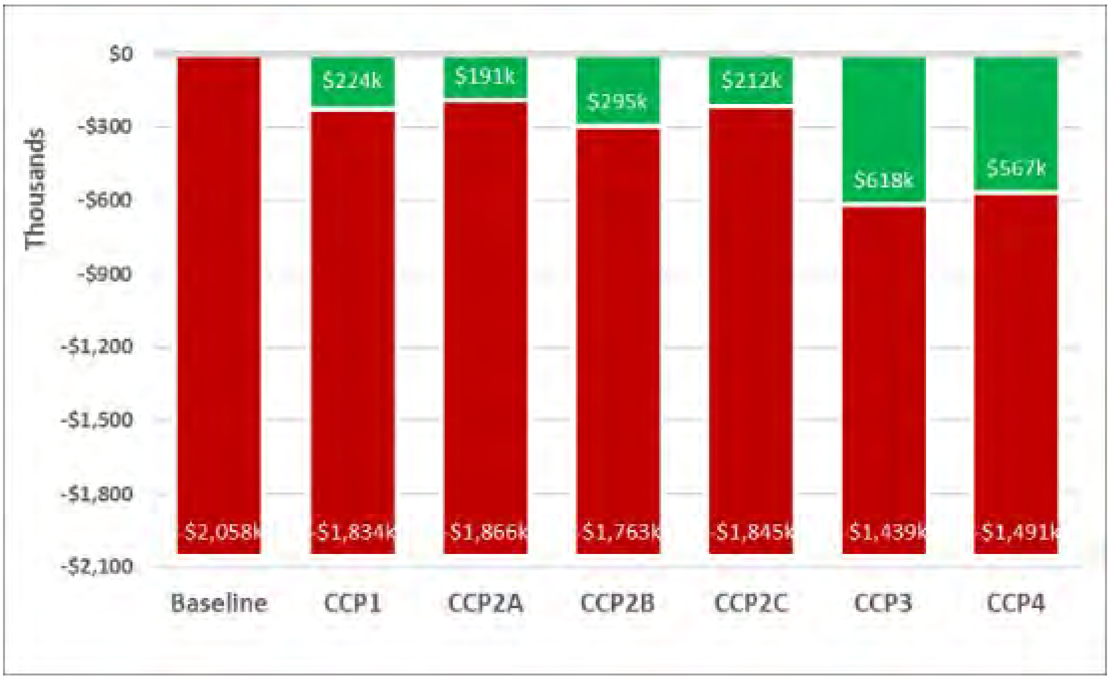


Figure 136: preliminary finance - Singleton HS 50-year NPV results

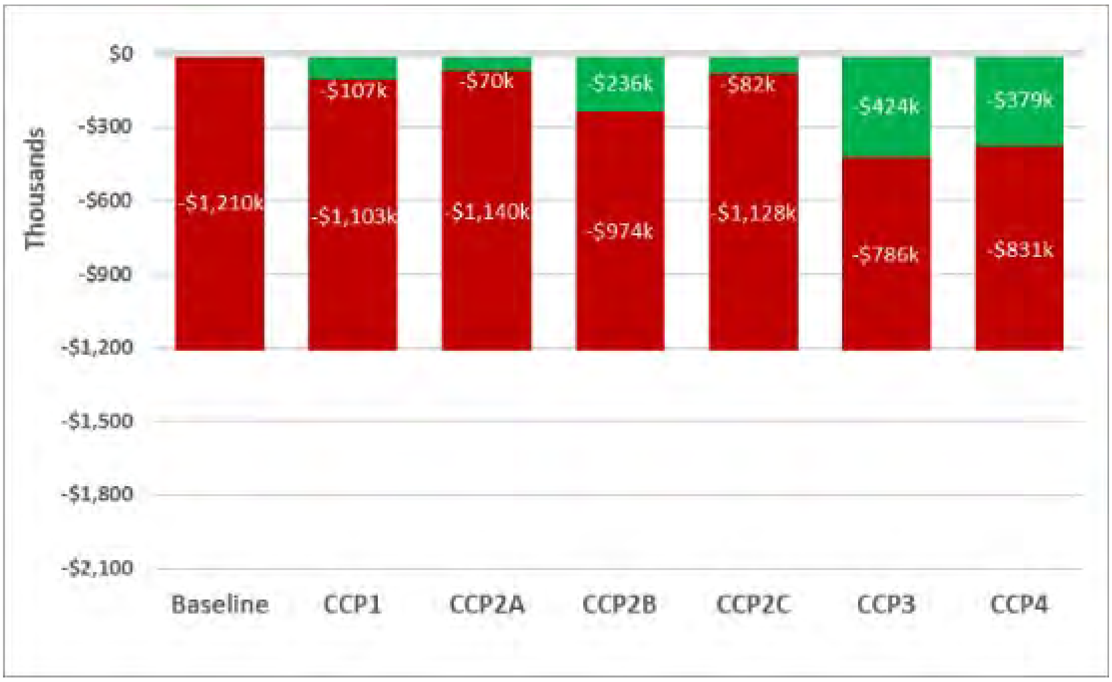


Figure 137: preliminary finance - Singleton HS 15-year NPV results

Conclusions

- Three scenarios are financially attractive for Singleton:
    - CCP3 – 100kW solar PV + HVAC controls to limit peak demand
    - CCP4 – 100kW solar PV + 100 kWh battery + HVAC controls to limit peak demand
- CCP3 at $618,000 has the highest NPV and produces the greatest reduction in net present cost over 15-years and 50-years.
- CCP4 at $567,000 of net benefit is close behind and could easily be enhanced through improved battery and HVAC control logic.

- Both of these scenarios provide SINSW with excellent financial returns for NSW for the given risks.

Outstanding issues/concerns

None

7.8 Summary of results (preliminary) – Nimbin CS

Initial load profile

Aeris Capital did not observe anything about Nimbin's meter data that was out of the ordinary or uncharacteristic.

Equipment specifications

- Solar PV size = 65 kW (ignoring the 3.9 kW unit presently installed)
- Battery Size = 60 kWh
- Battery Discharge rate = 30.0 kWh maximum

Note the rate of battery discharge (range between 2 to 3 hours) was optimised to achieve the greatest reduction in peak demand. Some schools get a better peak demand reduction from a slow discharge (where more school hours cross over with network peak demand) whereas others benefit from a fast discharge.

Network considerations

- Nimbin central school is located in the Essential Energy network area.
- It is likely that Nimbin is currently on Essential Energy's 'BLNT2AL', small business time of use network tariff (consumption of <160 MWh pa). This tariff consists of:
    - Quite high Peak, Shoulder and Off-Peak NOUS tariffs; and
    - A network access daily fixed charge.
- Essential Energy's peak NOUS period commences at 5pm and runs until 8pm each working weekday.
- There is an approximate difference of 3.5 ¢/kWh in between peak NOUS and off-peak NOUS tariffs.

As peak demand is measured from 5pm, after the conclusion of the school day, SINSW has a strong chance of achieving significant savings for small schools like Nimbin located within the Essential Energy network area. This is best illustrated in scenario CCP3.

Results

Figure 138 shows the year 1 (2021) estimated cost stack for Nimbin central school. On the left is Nimbin's baseline cost stack and on the right is the cost stack for case CCP3 which is solar PV + controls. This shows estimated savings of more than $18,000 pa

Figure 138: preliminary finance - Nimbin baseline & CCP3 cost stack

Figure 139 and Figure 140 set out the results of the financial analysis for Jamison high school over 50-year and 15-year timeframes.

Figure 139 and Figure 140 are to be read as follows:

- The **red** bar at left labelled 'Baseline' is the net present value cost of providing electricity to Nimbin central school, as it is, over the 50-years and 15-years.
- Moving from left to right the **red** bars generally become smaller as the net present cost of providing electricity to Nimbin central school shrinks with each scenario
- The **green** bars starting with CCP1 and moving left across to CCP4 show the net present value of each of the tested scenarios. Broadly these increase from left to right.

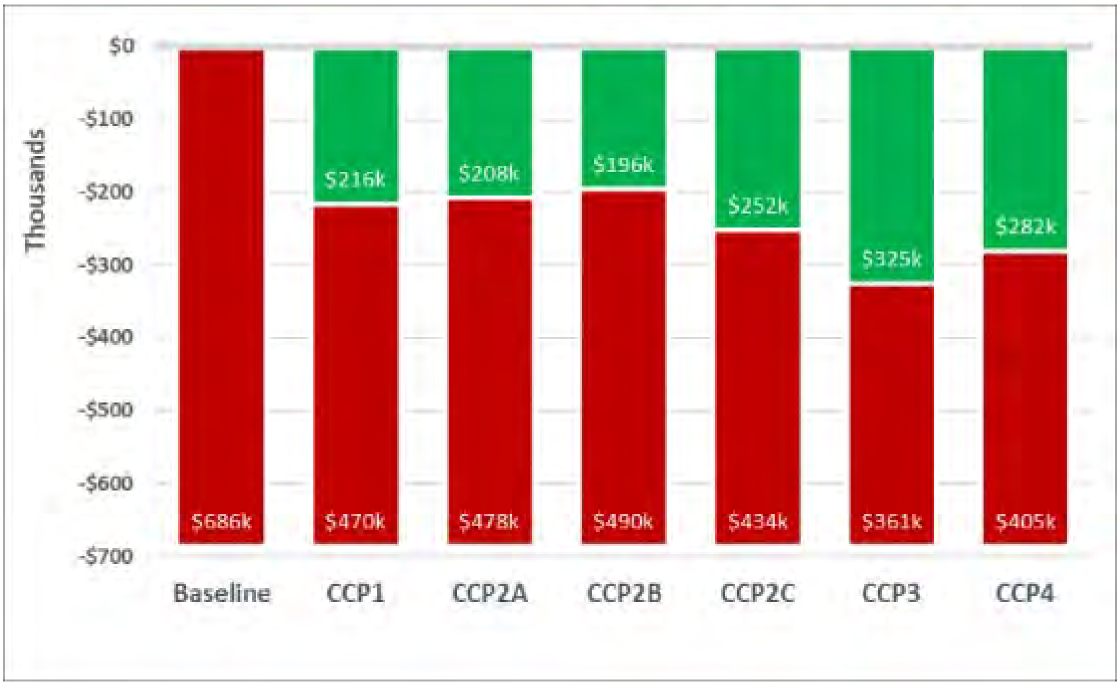


Figure 139: preliminary finance - Nimbin CS 50-year NPV results

Figure 140: preliminary finance - Nimbin CS 15-year NPV results

Conclusions

- Three scenarios are financially attractive for Nimbin:
  - CCP3 – 65kW solar PV + HVAC controls to limit peak demand
  - CCP4 – 65kW solar PV + 100 kWh battery + HVAC controls to limit peak demand
- CCP3 at $325,000 (inclusive of $175,000 or tariff change benefits) has the highest NPV or produces the greatest reduction in cost over 15-years and 50-years.
- CCP4 at $282,000 is close behind and could easily be enhanced through improved battery and HVAC control logic.
- Both of these scenarios provide SINSW with excellent financial returns for NSW for the given risks.

Outstanding issues/concerns

None.

8 FINANCIAL MODELLING

The following modelling has been completed by Buildings Evolved with input from SINSW and CSIRO.

The financial modelling is designed to test the hypothesis that orchestration of generation, storage and demand could significantly reduce operational costs of new heating, ventilation and air-conditioning (HVAC) systems installed in NSW Schools under the *Cooler Classrooms Program* (CCP) (program initiated in 2018). Key to testing the hypothesis is that wholesale or wholesale-pass-through pricing from retailers such as Amber Electric allows demand flexibility to be utilised for the benefit of the government portfolio as well as the broader electrical distribution network.

Several baselines are provided for context: 2019, before the installation of additional solar, battery or control systems; and 2022 which includes the increased solar PV systems (in the range 55-60KW) and 60KWh/30KW battery systems installed at the three proof of concept sites under this trial: Jamison High School (Penrith), Singleton High School and Nimbin Central School. HVAC controls, a central precept of the hypothesis, are not installed at the time of writing. Therefore, control simulations are built on historical data from the three sites, principally comprising utility & weather data coupled with the price of electricity to predict electrical load at each time interval. HVAC loads are disaggregated from the base-load electricity using a fuzzy logic algorithm to understand the amount of flexible load at any given point in time.

CSIRO have optimised their battery control algorithm against weather, distribution network service provider (DNSP) fees *and* wholesale spot price of electricity (WSP) in scenario CCP6, so therefore this document provides financial modelling conducted against the WSP rather than conventional retail step tariffs. Buildings Evolved developed a model predictive control (MPC) algorithm represented by scenario CCP7 that uses weather, WSP & utility interval data to solve for optimum daily load profiles by shifting load, using a price based demand response mechanism and altering HVAC modes according to external conditions; again the focus here is on the opportunity brought by accessing the WSP.

These algorithm generated load profiles are loaded through a tariff engine to generate financial summaries consistent with the requirements of NSW Treasury business case guidelines.

This work supersedes the preliminary financial modelling given the changes in as-installed system sizes and prior lack of analysis of WSP and MPC.

8.1 Summary

The methodology employed by Aeris Capital in the preliminary financial modelling had a key limitation – it was unable to calculate wholesale spot price on an interval-by-interval basis: core to testing the hypothesis. While the Aeris Capital method allowed annual aggregation of each tariff type, and easy conversion to a financial cost, it also limited the capability to answer the hypothesis: Optimisation of generation, storage and demand against the wholesale spot price & network tariffs would allow a significant improvement in NPV over that of conventional stepped retail tariffs as it did not allow for what-if scenarios to be generated at scale.

Buildings Evolved moved to fill the capability gap by researching available tools in the market, or other consultants with more advanced tooling. This was not available, as expected based on previous research, as Aeris Capital are one of the leading energy modelling consultancies in Australia. Generic modelling tools available on the internet, such as EnergyPlus, or System Advisor Model (SAM) are not designed with the Australian market in mind, and nor do such tools focus on tariff structures, discounted cash rates, cost of capital and other variables in the way a financial expert approaches it. Nor is the output of these ‘off-the-shelf’ solutions even close to the requirements that NSW Treasury has regarding business cases.

Buildings Evolved took the view that a more sophisticated modelling tool had to be developed in order that the hypothesis could be tested and answered. The tool had requirements to:

- ingest data via ETL;
- lay down data into a database;
- allow scripts to run across datasets to calculate required outputs;
- allow an array of scenarios and child assumptions to represent the different what-if scenarios for modelling;
- automatically calculate costs on an interval-by-interval basis; and
- produce report output.

The tool was required to ingest data from sources including:

- electricity meter data agent (NEM12);
- electricity retailer invoices (ERM & Origin);
- Bureau of Meteorology (BoM);
- Australian Energy Market Operator (AEMO);
- solar irradiance data (Solcast);
- GHG gas emissions factors;
- battery management system; and
- solar PV inverters.

Various open-source applications were used to develop the solution including:

- Python
- JavaScript
- PostgreSQL
- React.JS

Therefore, the reader should see this section as differences or uplift in methodology from the previous chapter outlining the preliminary financial modelling methodology and outputs.

8.2 Extending and updating the scenario modelling

Preliminary modelling was used by SINSW to determine how to size the solutions for installation at each school. Once this phase was complete, much of the preliminary modelling became redundant due to variations in the as-installed size to modelled size, as outlined in the section "Preliminary results & as-built system sizes". We lay out all the scenarios that were modelled, and in which report they feature.

Preliminary results are available in the section "preliminary financial modelling". This section will deal with the as-built systems, as well as several what-if scenarios.

Scenario	**Retail or Wholesale**	**Description**	**Prelim report**	**Final report**
2019	Retail	School prior to any additional works (Baseline 2019)	✓	✓
CCP1	Retail	~~Solar PV only~~	✓	
CCP2A	Retail	~~Solar PV + batteries controlled to maximise solar electricity usage~~	✓	
CCP2B	Retail	~~Solar PV + batteries controlled to minimise network peak demand charges~~	✓	
CCP2C	Retail	~~Solar PV + batteries controlled to maximise retail tariff arbitrage~~	✓	
CCP3	Retail	~~Solar PV + AC controls to reduce peak demand~~	✓	

CCP4	Retail	~~Solar PV + AC controls + Batteries to reduce peak demand & retail charge~~	✓	
CCP5	Retail	Baseline 2019 + 2022 as-installed solar (exclude battery)		✓
2022A	Retail	Baseline 2019 + 2022 as-installed solar + battery (system state May ‘22)		✓
2022B	Wholesale	Per 2022A		✓
CCP6A	Wholesale	2022B + CSIRO battery control logic (arbitrage)		✓
CCP6B	Wholesale	2022B + battery for FCAS		✓
CCP7A	Wholesale	CCP5 + model predictive HVAC controls (exclude battery)*		✓
CCP7B	Wholesale	2022B + model predictive HVAC controls* + as-installed battery for FCAS		✓
CCP7C	Retail	Per CCP7B		✓

* Based on academic papers that MPC + AFDD is capable of 50% reduction in demand & 30% reduction in consumption[33] [34] [35] [36]and as shown in Figure 141 [37].

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[33] Sayadi, Saeed & Morosuk, Tatiana. (2016). Reducing the Energy Consumption of HVAC Systems in Buildings by Using Model Predictive Control.

[34] Dong, Olama, Kuruganti, Nutaro et al (2018). Model Predictive Control of Building On/Off HVAC Systems to Compensate Fluctuations in Solar Power Generation.

[35] Godina, Rodrigues, Pouresmaeil et al (2018). Model Predictive Control Home Energy Management and Optimization Strategy with Demand Response.

[36] Merema, Carton, Saelens et al (2021). Implementation of MPC for an all-air system in an educational building.

[37] Serale, Fiorentini, Capozzoli et al (2018). Model Predictive Control (MPC) for Enhancing Building and HVAC System Energy Efficiency: Problem Formulation, Applications and Opportunities.

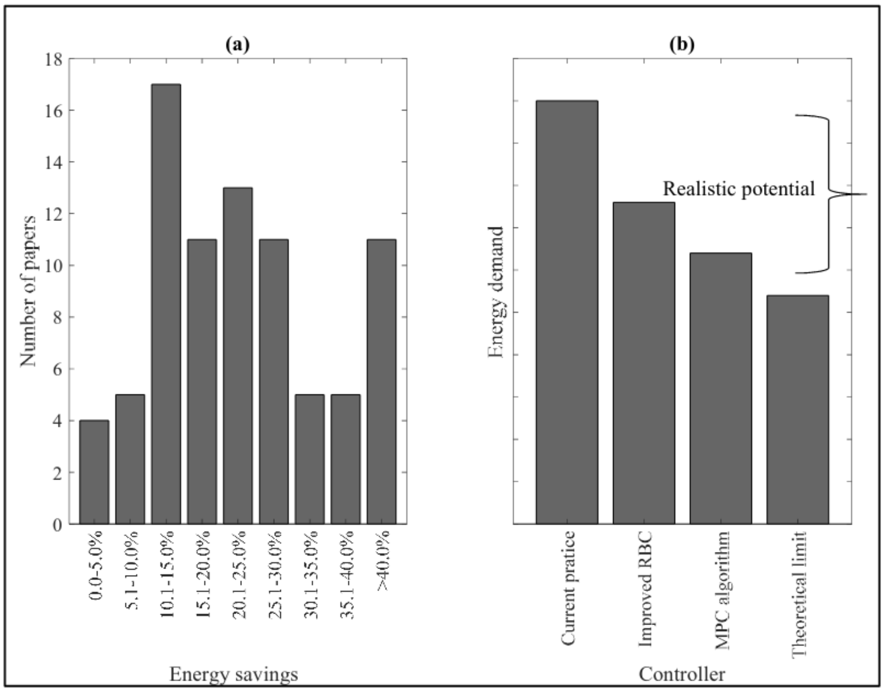

Figure 141: financial modelling - frequency distribution of the paper about the extent of energy saving consequent to the implementation of MPC algorithms; (b) estimation of energy saving potential exploitable employing the implementation of MPC algorithms for building energy management.

As can be seen from the above list of scenarios, the final report will not consider modelling retail step tariffs against optimisation strategies that rely on the presence of a WSP. For comparison basis, we have run retail and WSP across the non-controlled PV and battery that forms baseline 2022 (2022A & 2022B). Similarly, it was deemed that there was little point in modelling CCP1-4 given the system sizes used do not reflect the as-built.

Further, it was found that such narrow intent with respects battery controls in CCP2A-2C are a fallacy due to the physical constraints of the energy profiles at the three schools. In reality, only CCP2B seemed realistic in what could be achieved with a modest battery storage system as was proposed by both CSIRO and Aeris Capital. However CCP2B did not include FCAS payments, which has been shown in work done by University Queensland[38] to be an important source of revenue, making up >62% of income. Arbitrage only makes up 11.5% with the balance of 26% in a virtual market cap. These real-world results make the preliminary battery modelling largely irrelevant. Lessons learnt have been brought forward into this phase of modelling. Instead, battery modelling assumes a spread of revenue sources as outlined by UQ.

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[38] https://sustainability.uq.edu.au/files/11868/EPBQtyRptq12020.pdf

8.3 Results for Jamison High School

Figure 142 shows the result of the 15 and 50 year benefit cost ratio (BCR) for Jamison High School. Figures 142 and 143 show the financial analysis for each of the scenarios. The results show that CCP7A (solar + HVAC controls) delivers the highest financial returns, primarily due to the enormous savings in electrical consumption and peak demand that can be yielded from controlling flexible HVAC and other discretionary loads.

Batteries in B2022A, B2022B, CCP6A, CCP6B, CCP7B and CCP7C generally generate lower returns from the non-battery scenarios modelled in CCP5 and CCP7A. Arbitrage in CCP6A produces much lower returns than operating the battery in purely capacity markets such as FCAS, as shown in CCP6B.

Retail electricity accounts inhibit the ability for the control systems to produce a financial return. This is shown in the difference between B2022A and B2022B where WSP increases BCR noticeably. CCP5 – larger solar PV (no battery or controls) using retail electricity accounts shows an impressive BCR in it's own right.

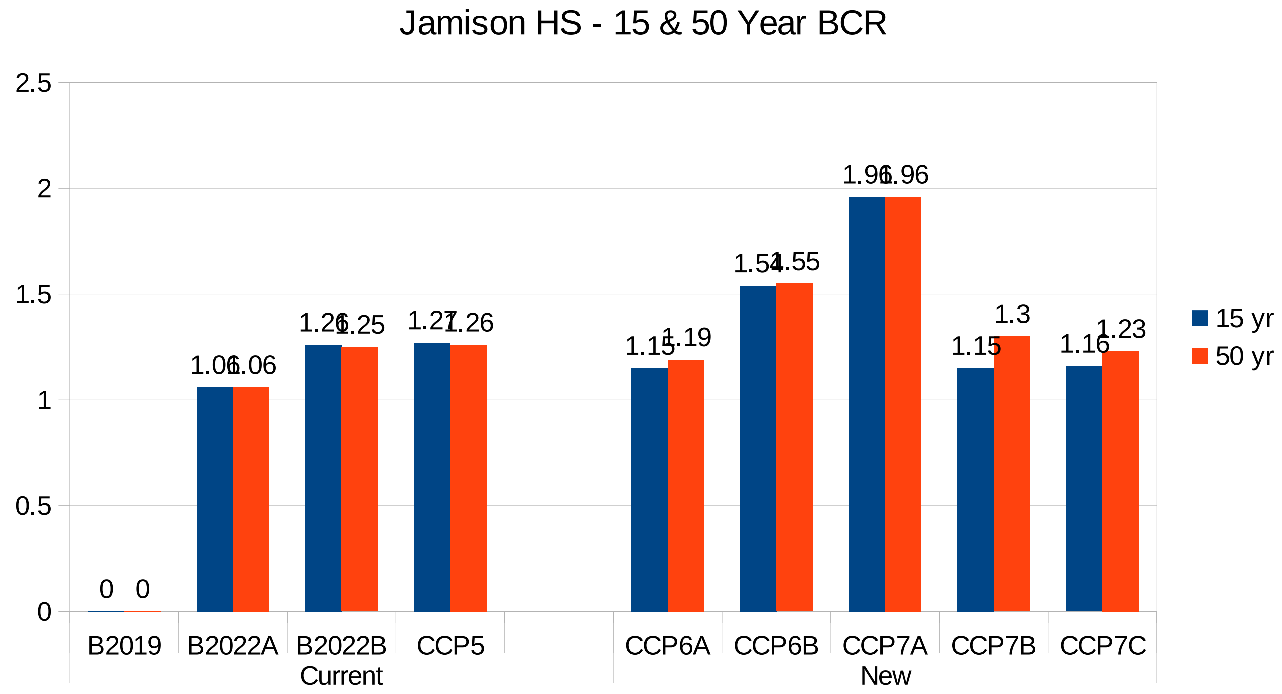


Figure 142: financial modelling - Jamison 15 & 50 year BCR results – DCR 5.6%

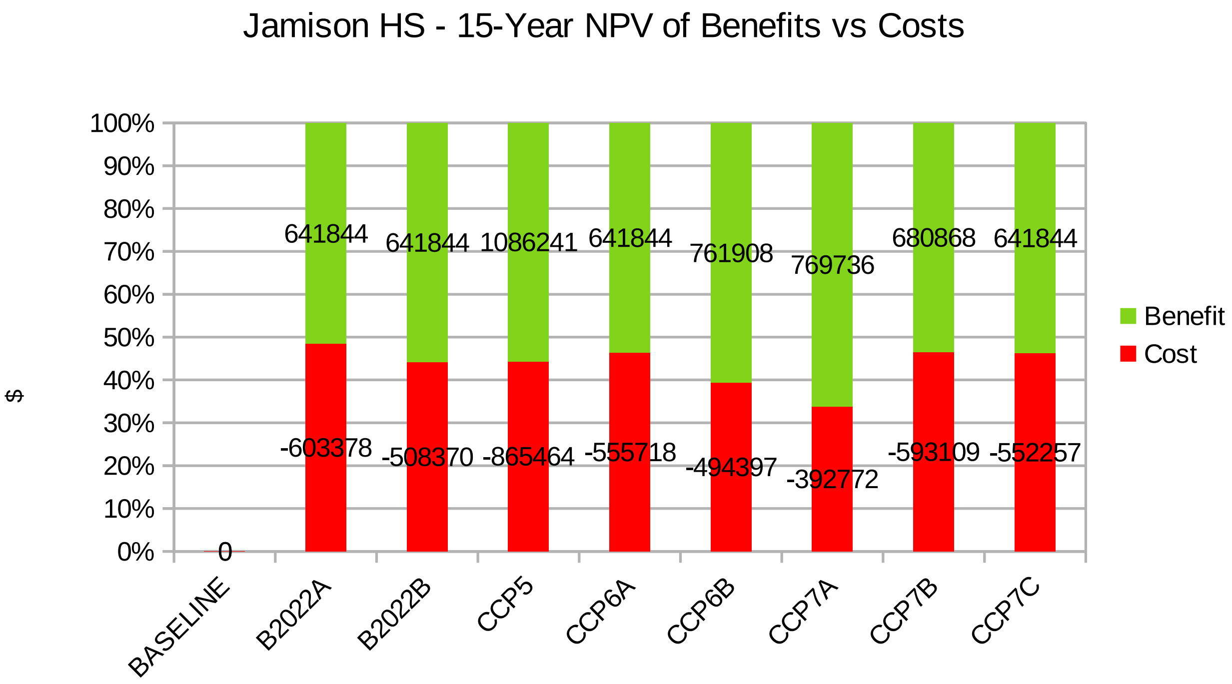


Figure 143: financial modelling - Jamison HS 15 year NPV benefits vs costs

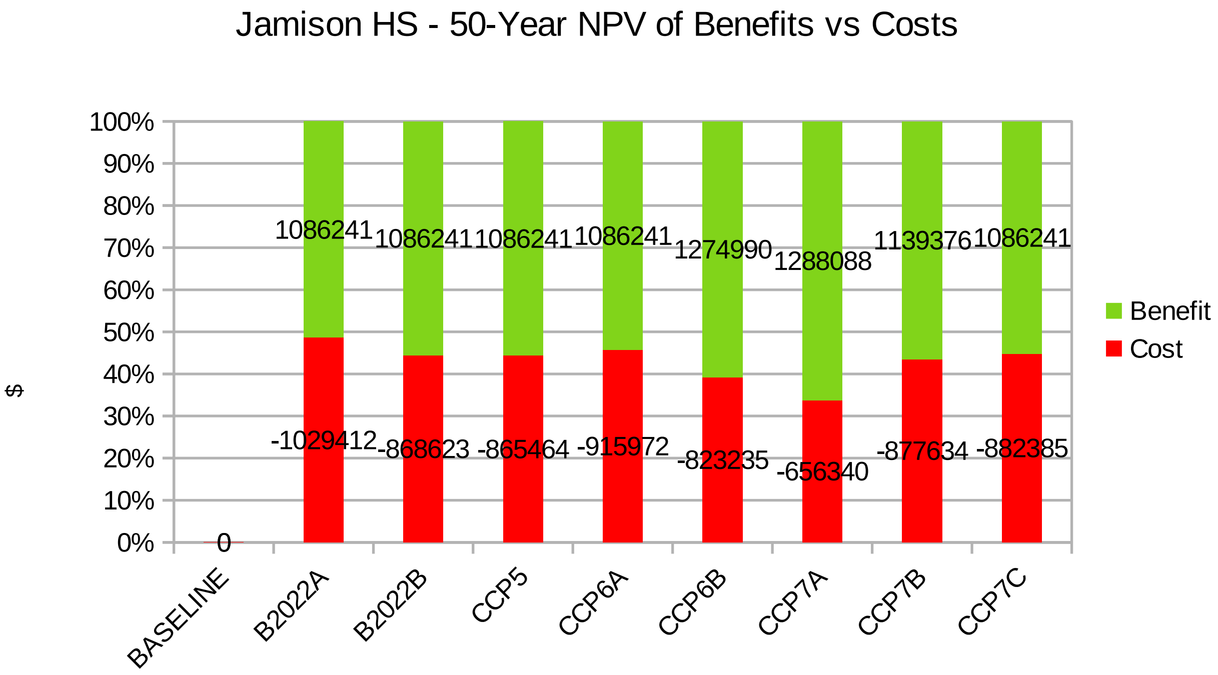


Figure 144: financial modelling - Jamison HS 50 year NPV benefits vs costs

8.4 Results for Singleton High School

Singleton HS is the largest energy consumer of the three schools covered in this report – as such opportunities for savings are larger than the other schools, yielding a better return on investment per dollar spent.

Figure 145 shows the result of the 15 and 50 year benefit cost ratio (BCR) for Singleton High School. Figures 146 and 147 show the financial analysis for each of the scenarios. Same as Jamison HS, the results show that CCP7A (solar + HVAC controls) delivers the highest financial returns, primarily due to the significant savings in electrical consumption and peak demand that can be yielded from controlling flexible HVAC and other discretionary loads.

Due to higher demand, batteries in B2022B provide a marginal improvement in the BCR compared with the non-battery scenario covered in CCP5. This result implies batteries are more likely to have a financial return in schools with larger electrical loads. Notable too is CCP7B, where the addition of a battery does not negatively impact the financial returns from HVAC controls as compared with the other two sites.

Batteries in CCP6A, CCP6B, CCP7B and CCP7C offer a lower financial return compared with the results from CCP7A (solar + controls) which demonstrated the best outcome with a BCR of over 2.5x.

The modelling also demonstrated that retail electricity accounts inhibit the ability for the control systems to produce a financial return. This is shown in the difference between B2022A and B2022B where WSP increases BCR noticeably. CCP5, the larger solar PV (no battery or controls) scenario using retail electricity accounts also shows an impressive BCR in its own right.

Further modelling would test the business case at 10% discounted cash rate rather than the default 5.6% used in the following results.

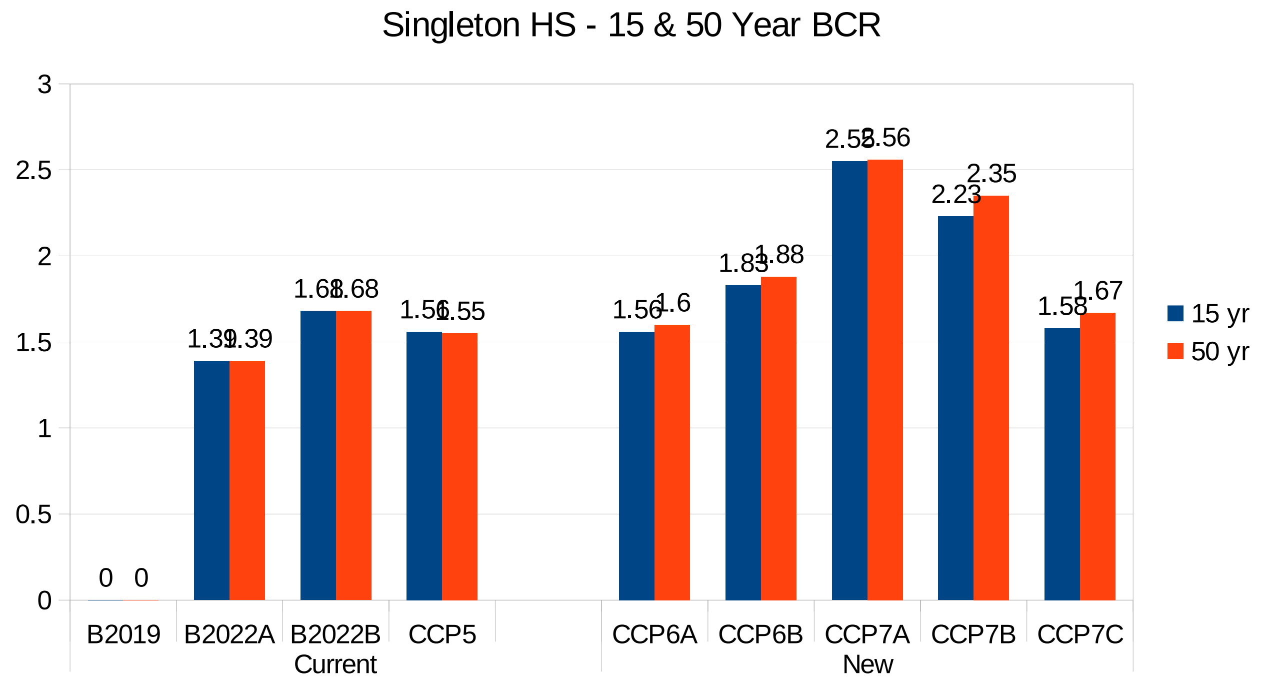


Figure 145: financial modelling - Singleton HS 15 & 50 year BCR results

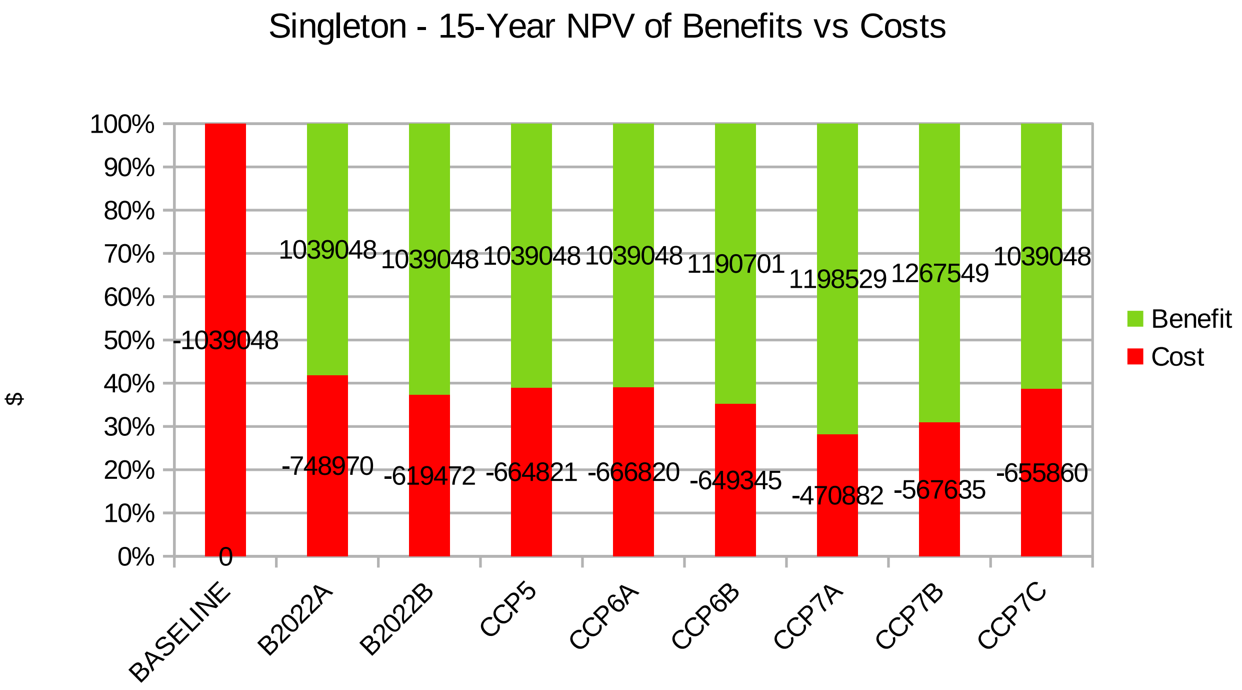


Figure 146: financial modelling - Singleton HS 15 year NPV benefits vs costs

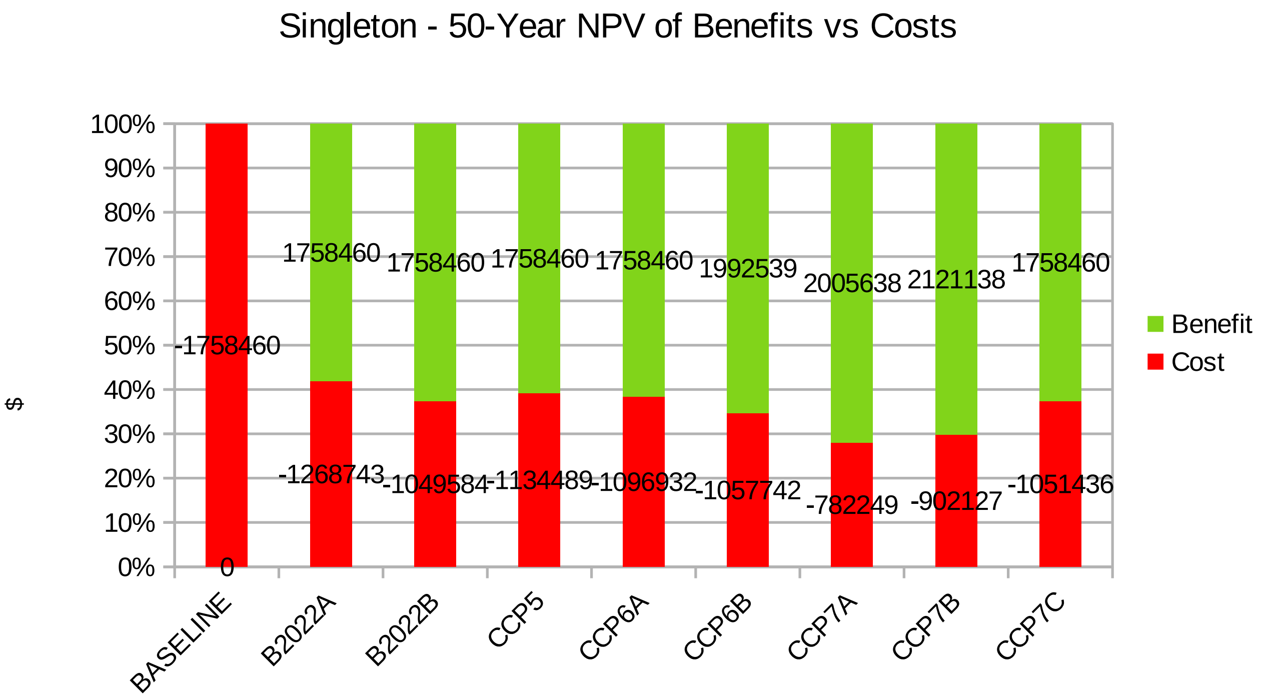


Figure 147: financial modelling - Singleton HS 50 year NPV benefits vs costs

8.5 Results for Nimbin Central School

Nimbin CS is the smallest energy consumer of the three schools covered in this report – As such opportunities for savings are smaller than the other schools, reducing the BCR, particularly on battery dependent models.

Figure 148 shows the result of the 15 and 50 year benefit cost ratio (BCR) for Nimbin Central School. Figures 149 and 150 show the financial analysis for each of the scenarios. Similar to the other schools, the results show that CCP7A (solar + HVAC controls) consistently delivers the highest financial returns.

The lower electrical demand reduces the opportunity to provide economic returns from battery storage systems compared with Singleton HS, for example. Where the battery does not reduce the BCR of non-battery scenarios too much, the effect is exaggerated in a smaller site such as Nimbin CS. Exposure to the WSP using only solar PV reduces the BCR over a retail contract, while WSP with controls has a significantly improved BCR.

The modelling of batteries in CCP6A, CCP6B, CCP7B and CCP7C demonstrate a lower financial return compared with scenario CCP7A (solar + controls) which has a BCR of over 2x.

Retail electricity accounts inhibit the ability for the control systems to produce a financial return. This is shown in the difference between CCP7B and CCP7C where WSP increases BCR noticeably. In this case only, CCP5 – larger solar PV (no battery or controls) using retail electricity accounts, shows a reduced BCR of below 1 over 50 years.

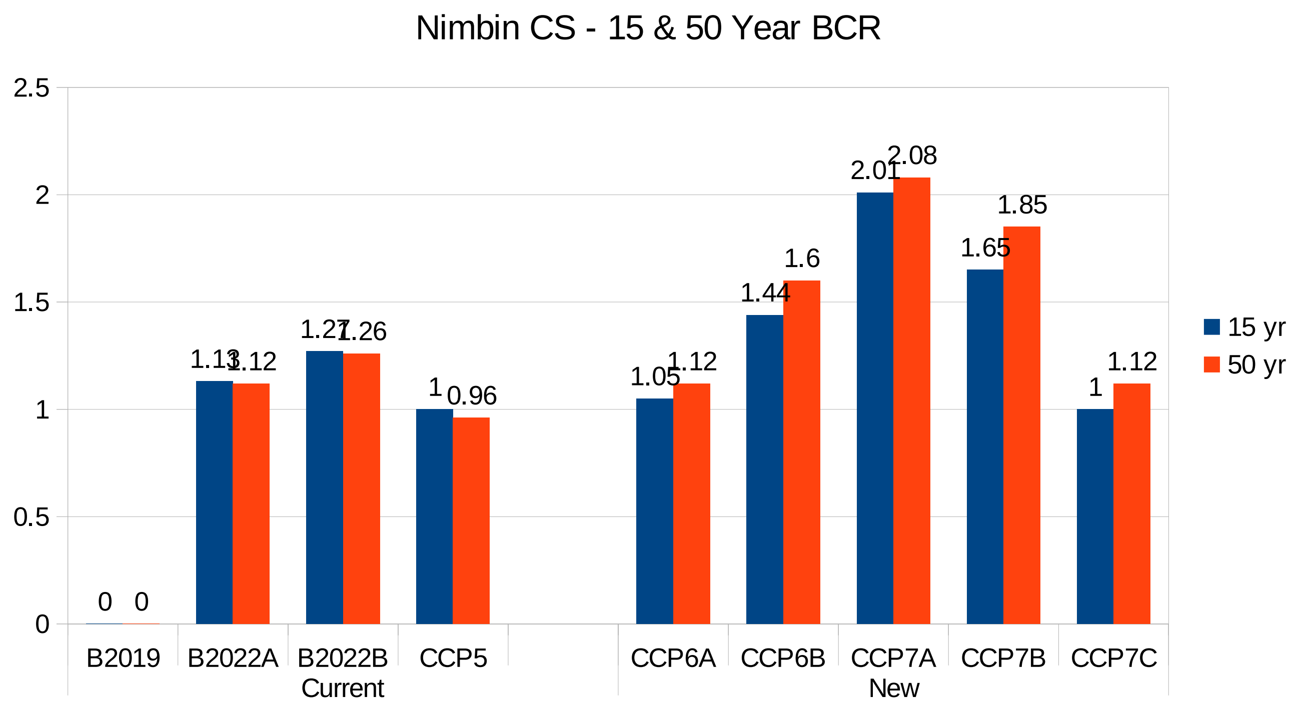


Figure 148: financial modelling - Nimbin CS 15 & 50 year BCR results

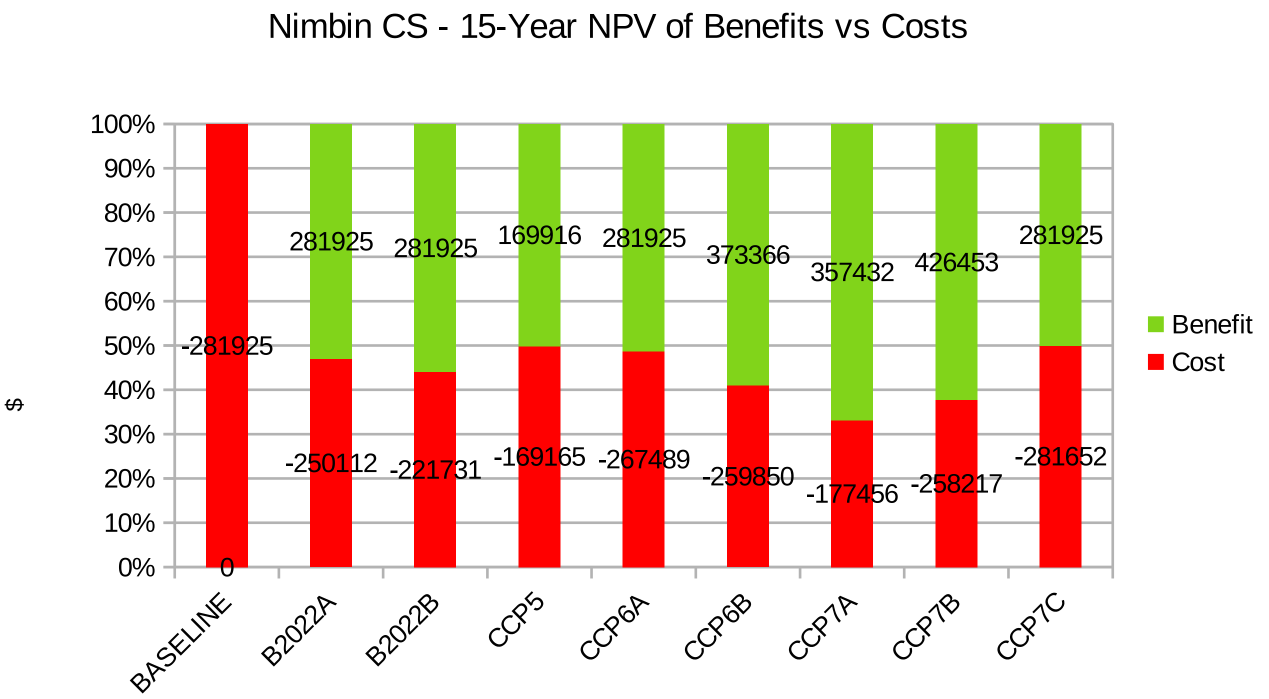


Figure 149: financial modelling - Nimbin CS 15 year NPV benefits vs costs

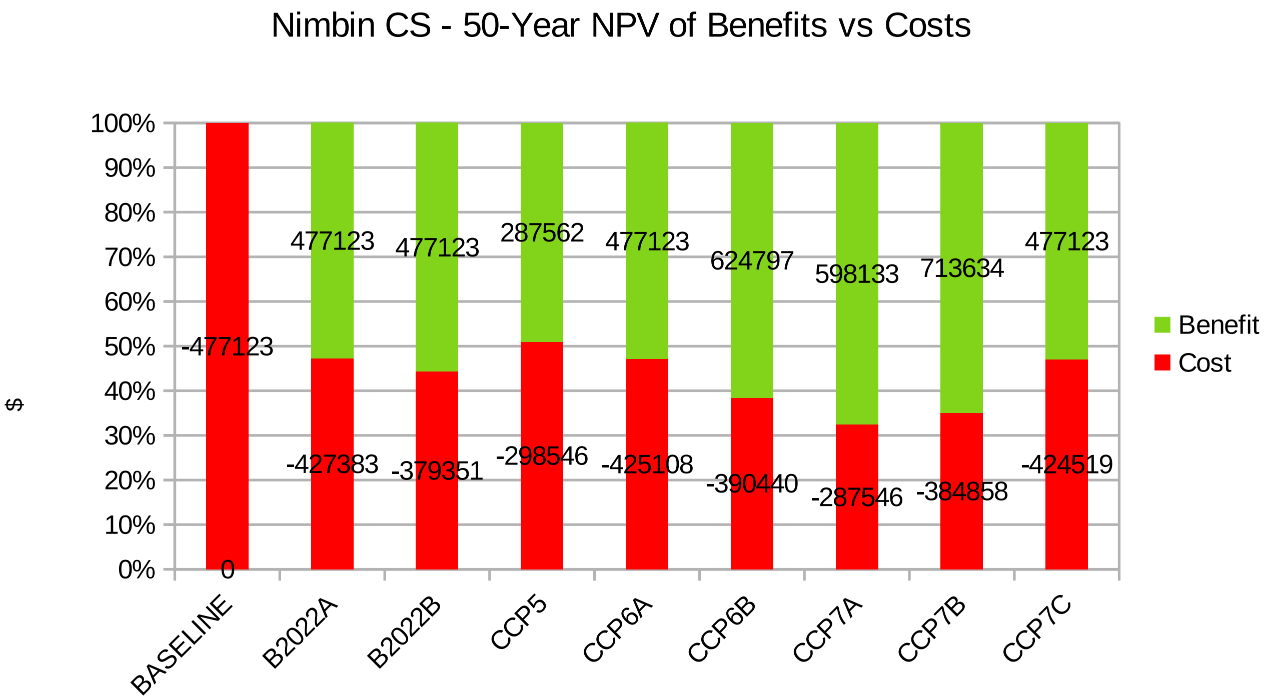


Figure 150: financial modelling - Nimbin CS 50 year NPV benefits vs costs

8.6 Scope of impact

The three schools in this pilot program are already demonstrating results simply by adding additional solar PV to the rooftops of the three schools. It is unclear what impact the battery has on the savings found between the two baselines of 2019 and 2022, however this will become clear throughout this chapter.

School	Baseline 2019	MWh/KVA 2019	Baseline 2022^	MWh/KVA 2022	$ saving % saving	MWh saving KVA saving	Network impact
Jamison HS	$61,000	283MWh 295KVA	$46,500	210MWh 226KVA	-$14,500 -31%	-73MWh -69KVA	-25% MWh -23% KVA
Singleton HS	$120,000	408MWh 400KVA	$98,000	356MWh 324KVA	-$22,000 -18%	-52MWh -76KVA	-13% MWh -19% KVA
Nimbin CS	$35,000	145MWh*	$18,500	59MWh*	-$16,500 -47%	-86MWh	-59% MWh

* Small market sites (<100MWh/p.a.) do not provide data for maximum demand
^ 55-60KW solar PV & 60KWh/30KW battery

Operational times

Schools are occupied 45% of the year based on the following method:

- schools are unoccupied 25% the year due to school holidays; and
- schools are unoccupied on weekends, another 20%;
- for a total of 45%.

Investment in HVAC equipment can only have a maximum utilisation of 45% of the year with the result that the BCR and NPV of HVAC scenarios listed is skewed downwards compared with the opportunity that a battery storage system has, year-round. This is evident in the FCAS opportunity associated with flexible HVAC load compared with that of a battery. Therefore, any positive BCR and NPV calculation associated with HVAC controls is at an automatic disadvantage to that of battery storage systems.

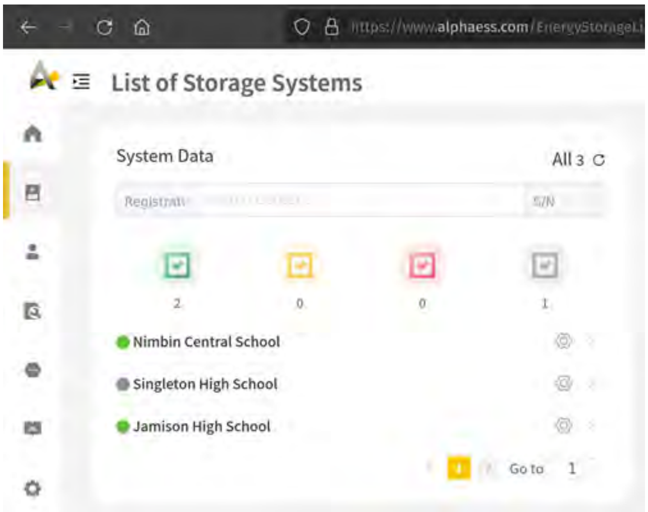
Tariff change impact

Raw costs are not the sole measure of improvement. Tariff change, particularly that for Nimbin CS, will alter financial outcomes dramatically. Therefore the % change in consumption and demand is a more reliable method to gauge the impact of change to the energy mix.

Benefits derived from shifting energy to minimise peak load will not apply for small market sites such as Nimbin CS under present tariffs. Options include switching to a wholesale price pass-through electricity retailer such as Amber Electric, or aggregating loads into a virtual power plant and exposing the schools to the wholesale spot market. Both measures should only be considered once a school has smart controls in place to shift loads in a reliable and predictable manner. The hedge that electricity retailers provide still has utility; there is no appetite to expose schools to high price events with no method to curtail electrical demand.

Battery installation impact

The battery for Singleton HS has not yet been seen online via the Alpha/ESS web portal at the time of report writing as is shown in Figure 151.



https://www.alphaess.com/EnergyStorageLi

List of Storage Systems

System Data

All 3

Registrati

S/N

2	0	0	1

● Nimbin Central School

● Singleton High School

● Jamison High School

Go to 1

Figure 151: financial modelling - Alpha/ESS website showing Singleton HS battery offline (image 27th May 2022)

<u>Nimbin CS:</u>

It is worth noting is the considerable impact that 60KW of solar PV has had on Nimbin CS, given the relative over-sizing based on consumption compared with Singleton HS in particular.

The battery at Nimbin CS was commissioned 8th March 2022. We note that the battery appears to not be operating at Nimbin CS since 23rd April 2022, therefore we can disregard the impact of the battery on the reduction in the above electrical load and consumption figures as it was operating for only 46 days, and only for 8 days in the 90 day billing period that the above baseline covers (through to end of Q1 2022). In addition, no NEM12 data is available for Nimbin since June 2021, due to the tariff change.

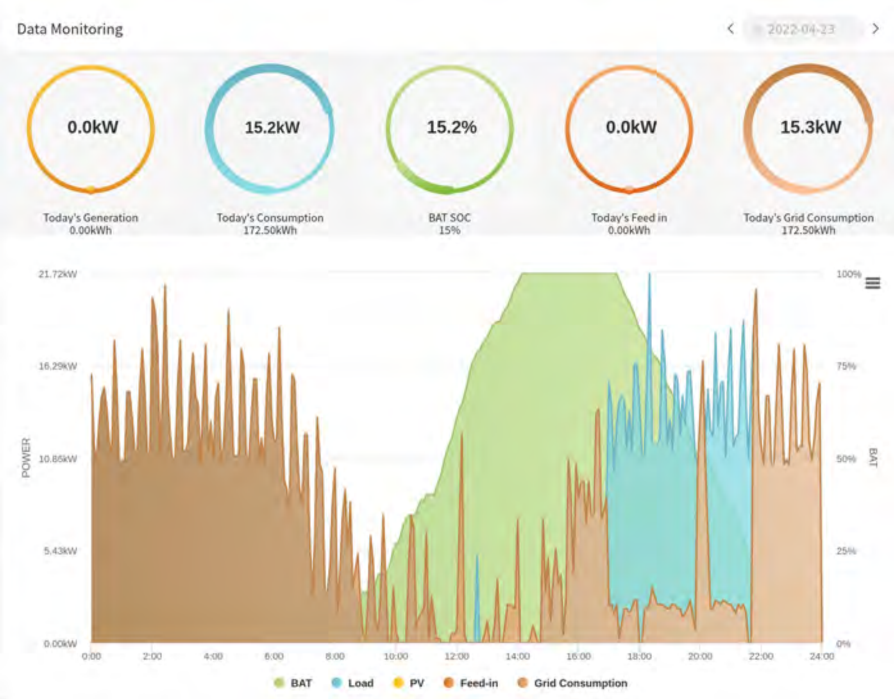
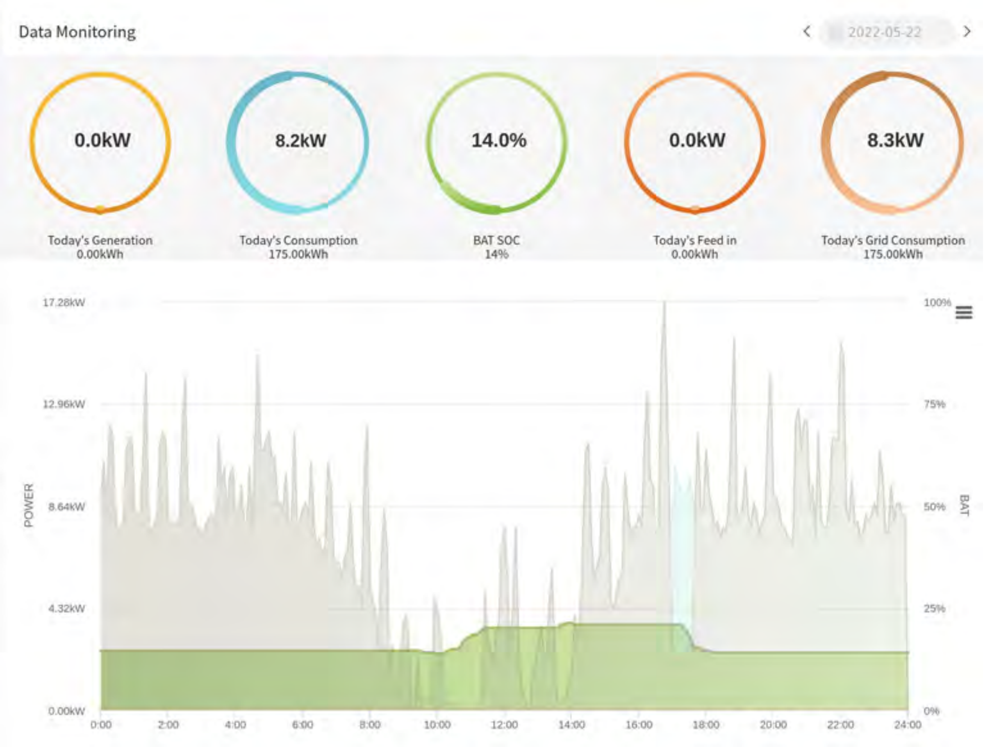


Figure 152: financial modelling - Nimbin CS battery in operation

During the operational period of the battery, as indicated in Figure 152, the battery was configured to charge during the day (solar charge strategy), and it appears that the solar PV has also been configured to not export electricity. The battery is configured to export the grid during the evening peak (indicated by the blue lines). The battery is not used to support energy consumption during the school day, as the discharge cycles begin at 5pm ending at some time after 22:00. It is worth noting that the battery state of charge (SoC) is being run down to 10%, where prior modelling had inferred a minimum SoC 50% to increase battery lifespan. It is possible that the usage pattern over a short duration has impacted on battery lifespan, causing the outage in battery operation, or conversely it could be that the loss of solar PV generation data has caused the battery management system to halt operations. This is unclear at the time of writing but warrants further investigation by SINSW.


Data Monitoring

2022-05-22

0.0kW	8.2kW	14.0%	0.0kW	8.3kW
Today's Generation 0.00kWh	Today's Consumption 175.00kWh	BAT SOC 14%	Today's Feed in 0.00kWh	Today's Grid Consumption 175.00kWh

Figure 153: financial modelling - Nimbin CS battery offline since 23rd April 2022

Regardless of the reason for battery outage, it reinforces the approach to the modelling: do not rely on batteries to be online or charged to participate peak lopping or load shifting. The vastly decreased charge/discharge cycles when using the battery for FCAS capacity reserve makes this a more likely way to ensure the battery is online for such contingencies that the market determines is necessary for intervention by the battery storage system. This is discussed in further detail below.

The impact of the battery when operating as-installed is largely negated by the results contained in the financial modelling which proves that arbitrage is financially unsound in the present market, a result largely constrained by the capability of batteries, particularly in limited charge/discharge cycles and battery degradation over time. It is likely, though not the topic of this report, that a step-change in battery technology and/or dramatic reduction in costs will be required to make such a proposition viable from both an engineering and financial standpoint.

Jamison HS:

Jamison HS battery has been operating online since the 30th September 2021. It appears from the data obtained from the Alpha/ESS daily load profile that the battery is configured to discharge between 22:00 and 00:00, and charge between 00:00 and 02:00 yielding:

- negative impact on the grid;
- no benefit to students or the operation of the school;
- increased carbon emissions due to round trip loss in the battery (particularly at midnight - 2am)[39];
- decreased operational lifespan with no value added (opportunity cost); and
- negative returns on investment.

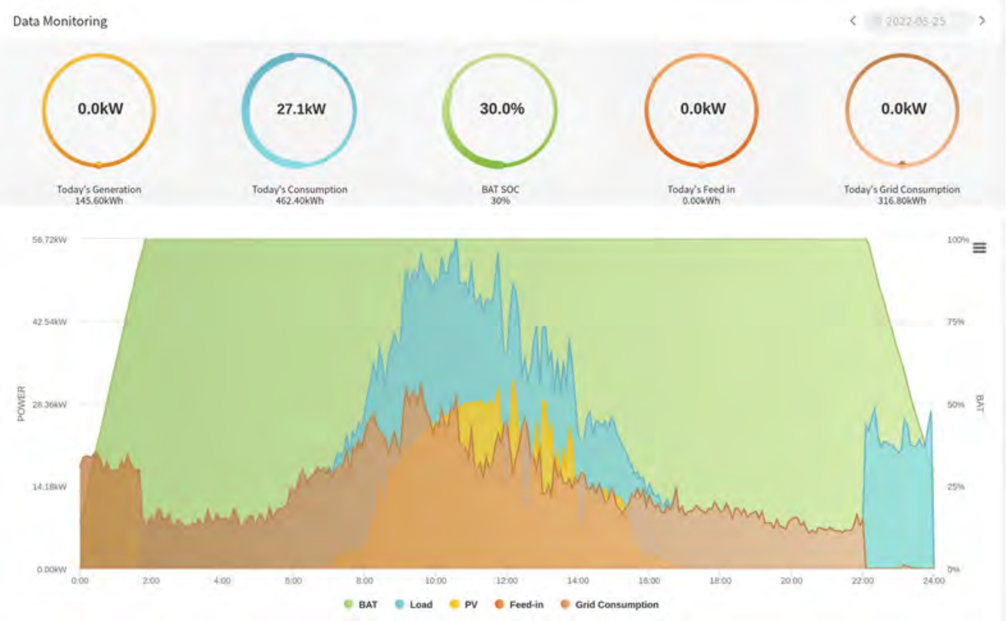


Figure 154: financial modelling - Jamison HS battery daily load profile indicating poor operational management

It is visually apparent how much more energy is required to charge the battery than is discharged – not only is the duration of discharge shorter than the charge, the quantity of electricity dispatched is approximately 20% less than taken from the grid, or an 80% round-trip-efficiency. Round-trip-efficiency will decrease over time. The rate of the decrease is largely contingent on the use case for the battery, and in particular the charge/discharge cycles and depth of discharge (50% SOC was assumed for modelling).

Consequently, the modelling removes the battery charge/discharge cycles to produce the CCP5 scenario which then forms the basis for many of the other modelling scenarios. This was replicated on both Jamison HS and Nimbin CS through adjusting the energy consumption based on the 2019 with the 2022 as-installed solar PV increase system size, as discussed below in the calculation methodology.

Jamison HS has a reduced electricity cost from 2019 to 2022, which, given the above, can likely be attributed solely to the impact of the increased size of the solar PV system.

8.7 Preliminary results vs as-built system sizes

The preliminary financial modelling results were supplied to SINSW to inform their decision making process as to what system size would likely be optimal using the existing C777 and C776 stepped retail tariffs for the whole of NSW Government. This decision making therefore didn't take into account the wholesale price, as the financial modelling tool set was not capable of producing these results.

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[39] Both due to lower temperatures at the time of charge/discharge, and the more carbon intensive electricity at night-time which is not factored into net carbon emissions factor calculations.

Site	**Prelim modelled PV Size**	**Prelim Battery Size**	**As-built PV Size**	**As-built Battery Size**
Jamison HS	85KW	80KWh/40KW	55KW	60KWH/30KW
Singleton HS	100KW	100KWh/50KW	56KW	60KWH/30KW
Nimbin CS	65KW	60KWH/30KW	60KW	60KWH/30KW

As can be seen from the above table, SINSW applied the remodelled battery size for Nimbin CS to all three schools. PV system sizes were close to the preliminary modelling on Nimbin, but much smaller on Jamison and Singleton high schools. Applying the same system size to the three schools despite their disparate size and electrical network impact provides an opportunity for analysis of which system size respective to consumption and peak demand provides the best return on investment which is extremely valuable in this stage of financial modelling.

8.8 Summary of results

The major components are addressed, namely the mix of

- battery storage systems;
- solar system sizes; and
- HVAC controls

in relationship with each-other. Each of the scenarios modelled produce different optimised system sizes and different financial outcomes dependent on the technology mix.

Battery storage systems and PV systems were installed through the duration of the project, while HVAC controls and monitoring did not get installed in time for project reporting. The HVAC controls tender is awarded and due to be signed prior to the completion of the contract on May 27th 2022.

It was found that the optimum mix of technologies comprised a modest solar PV system coupled with HVAC controls. Battery storage systems for the purpose of arbitrage were found to provide less benefit from an engineering or financial standpoint compared with a larger PV system alone, and/or with the addition of HVAC controls. The use of batteries for participation in the FCAS market demonstrated a better return, attracting ~$7,000 in payments p.a. per school based on the as-installed system sizes. The co-benefits of HVAC controls are also noted, not only delivering load flexibility and peak demand management, but also presenting opportunities for better educational outcomes through the improvement of indoor environment quality.

Based on research during this project, battery storage systems have physical constraints resulting in charge and discharge cycle costs, both economically in terms of equipment lifespan and carbon emissions. Due to constraints in way batteries can charge and discharge, strategies known as “solar soaking” or “peak lopping” are not feasible from an engineering perspective, nor would the business case stack up. Arbitrage, or buying low and selling high, can make a return, but in doing so increases the emissions intensity of electricity when sourced from the grid as the battery round trip efficiency is less than 1. An arbitrage strategy incurs a large amount of charge/discharge cycles for minimal financial gain, and with an impact in terms of emissions. The study found that providing capacity to the reserve FCAS market returns the vast majority of income for a battery storage system without the requirement for constant charge and discharge cycles, increasing equipment lifespan and providing both a positive impact for the grid and minimising the impact of carbon emissions.

Figure 155: financial modelling - CCP HVAC control panel

Modelling found that, on average, 10% of total school energy consumption is wasted in operating the CCP HVAC systems during times when outdoor conditions should not mandate use (green LED), as pictured in the Figure 155. This means that users are turning on the HVAC systems while the green LED is illuminated indicating “Outdoor conditions favourable. Open windows instead of AC”. It is also likely that doors/windows are inadvertently being left open while HVAC systems are on, or that ventilation systems as installed likely evacuate more conditioned air to the outside atmosphere than is absolutely necessary. Education campaigns to change behaviour may work to a point. HVAC controls would categorically solve this problem by forcing the use of fan and dry modes, as well as ramping set point temperature up and down based on external conditions. By itself, these savings would pay for HVAC controls on a typical school within 4-5 years if done as retrofit, less if done during the CCP construction phase.

Tuning of optimisation strategies using various technology mixes can be achieved to favour occupant comfort over financial benefit or vice-versa dependent on the requirements of the client. In this case, NSW Education has the objective of providing improved learning environments to deliver better educational outcomes. NSW Energy have the objective of transforming the energy grid to deliver renewable energy integration to the grid, while NSW Treasury has the objective of investing appropriately to improve services and reduce operational costs of government. All three objectives can be delivered, in balance, to each party listed above dependent on policy objectives of the government.

Battery storage systems

According to Ausnet services, an electrical distribution network, “the main quantifiable benefit of [battery] storage to the network is in peak demand management”[40].

As installed costs

The price of battery storage sits at >$1000 per installed KWh in the market, while the schools faced costs of $1,450 per installed KWh. In every case excluding FCAS, in engineering modelling from CSIRO, or from the financial modelling tool the BCR of battery storage (retail or wholesale spot price) is marginal, just over 1 in some scenarios. When the question was asked of the model “solve for the optimum battery size”, the CSIRO model produced results pointing to the smallest available size (10KWh/10KW) – but without answering the question “would you be better of without”? The CSIRO algorithm did not consider HVAC controls, yet still solved for the smallest size battery storage system.

Aeris Capital concluded in the preliminary modelling that larger battery sizes could provide a marginal return on investment – the advice for Nimbin CS was used in specification and procurement of the batteries for the three locations by SINSW.

As part of the revised financial modelling methodology, Buildings Evolved separately developed an optimisation algorithm *that was mindful of HVAC controls*, which ultimately produced exactly the same results as CSIRO: a smaller

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[40] https://www.ausnetservices.com.au/-/media/Files/AusNet/Business-Electricity/Demand-Management/Residential-Battery-Storage-Trial-Case-study.ashx?la=en p12

battery system is better than large. The algorithm was also tasked with solving the “better off without” question *if HVAC controls existed*. The answer was categorical: small scale solar PV (<100KW due to STCs) coupled with HVAC controls delivered better financial outcomes than if the battery was in the energy mix. FCAS, however, may provide an opportunity to redeem the business case by providing standby services to the grid through an FCAS aggregator. The results of these scenarios are found within CCP6A (arbitrage) and CCP6B (FCAS + virtual cap).

As-installed state

Jamison HS battery system is charging itself between 22:00 and 00:00, and then discharging between 00:00 and 02:00 while Nimbin CS is trickle charging during the day and discharging between 17:00 and 22:00. There is no data available for Singleton HS at the time of writing this report, but we assume it is the same as Nimbin CS. This scenario is modelled in “Baseline 2022”.

Battery operational modes

In March of 2016, Ausnet services identified several battery operational modes related to demand management[41]:

Mode	Charge	Discharge	Advantages	Disadvantages
Peak lopping with fixed setpoint	Grid only, off-peak time	Lower customer load to given setpoint (e.g. 30KW)	Certainty of customer load on network energy price arbitrage between the charge and discharge	Often results in under or over-utilised battery and sub-optimal demand reduction
Peak lopping with dynamic setpoint	Fully charge from grid during off-peak times	Lower demand to custom setpoint during rest time of day. The setpoint is minimised based on historic customer data. Setpoint minimised within constraint of battery capacity.	Allows the system to follow changing patterns of customer demand throughout the year	Rolling average does not include a predictive element
Solar charging (Nimbin CS)	Only charge by excess solar power during day	Lower customer net demand to custom setpoint at all times	Reduced solar exports, 100% renewable energy used to charge battery	Battery often not full due to lack of PV, leading to lack of peak demand reduction
Tariff optimisation	Cheapest power to achieve a full charge. Pre-charges using off-peak power based on expected PV production next day	Supports all load (lop as much as possible between 2pm and 11pm	Maximises value of energy price arbitrage. Allows support of all load, not just that above a setpoint.	Complex to program (this is the output provided by CSIRO into CCP6A)
Scheduled operation **(Jamison HS)**	Fully charge from the grid during off-peak time	Discharge at high power across the three hour evening peak. Match local distribution substation peak,	Provides maximum support to local network to reduce network loads	Can create costs to the consumer due to low price paid for exports to the grid, assuming a typical retail tariff

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[41] https://www.ausnetservices.com.au/-/media/Files/AusNet/Business-Electricity/Demand-Management/Residential-Battery-Storage-Trial-Case-study.ashx?la=en

		or feeder peak		scenario as SINSW has presently

Modelling work for this paper, and evidence from the operation of the battery at UQ & Hornsdale Power Reserve would dictate additional operational modes, respectively:

Mode	**Charge**	**Discharge**	**Advantages**	**Disadvantages**
FCAS standby + virtual cap	Maintain charge at max levels using cheapest available power (solar PV in preference)	Only when called upon by the FCAS market and virtual capacity market	Reduces the charge/discharge cycles, drastically improving battery life. Generates best income for each charge/discharge cycle. Payments are made regardless of use. Provides support to the network when required.	The battery is under-utilised. No demand reduction is made available from the battery system, and instead relies on demand management of HVAC or other discretionary loads
FCAS + arbitrage + virtual cap **(UQ battery, Hornsdale Power Reserve et al)**	Cheapest power to achieve a full charge. Pre-charges using off-peak power based on expected PV production next day	Lower customer load to given setpoint (e.g. 30KW), maintain sufficient SOC to be able to respond to FCAS and virtual capacity markets	Certainty of customer load on network energy price arbitrage between the charge and discharge	Often results in under or over-utilised battery and sub-optimal demand reduction

This list is indicative and does not delve into the complexities of the FCAS markets.

The final option, as used by UQ and most grid-scale batteries such as Hornsdale, is to segment the battery into different functions. In the case of Hornsdale, 10MWh/70MW of the available 100MW is reserved for system security services, contracted to the SA government[42]. The remaining 119MWh/30MW is available for the operator, Neoen, for market participation. It would be possible to achieve the above using orchestration from an operator of a virtual power plant across a distributed network of batteries. The modelling does not cover scaling a distributed energy storage solution or VPP per se; however results from each school in the study can be interpreted in that context.

It is noteworthy that the CSIRO battery algorithm developed for this project runs the SOC to 50%, allowing FCAS and other services to be offered with the remaining capacity. The modelling found similar results to UQ: arbitrage was marginal and peak lopping undesirable: the vast majority of income was derived from simply having capacity on call to the market. The batteries as installed at Jamison HS and Nimbin CS evidenced minimum SOC of 10% - unadvisable if lifespan is a consideration.

Notable too: if peak lopping is the desired outcome, then off-peak power will inevitably have to make up for lack of excess PV generation during cloudy periods. This invokes several issues with the approach that will be discussed below, principally that the demand reduction comes at a cost of increased emissions that would otherwise not be present with a demand management regime that covers HVAC and other discretionary loads.

Peak demand “lopping”

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[42] https://hornsdalepowerreserve.com.au/wp-content/uploads/2020/07/Aurecon-Hornsdale-Power-Reserve-Impact-Study-year-2.pdf

HVAC controls address the problem of controlling demand, rather than using a battery in discharge mode to supply the increased electrical demand at any given point in time. The market is motivated to shift loads through the cheapest available method, and batteries are not the cheapest method as is shown in results below. In addition, round trip loss in batteries makes discharge to deliver peak reduction an expensive way of mitigating peak demand charges – again, this was found to be nonviable from a financial perspective at the time of writing. It is likely that the economic viability of batteries will improve over time as the cost of battery technology reduces, and/or new functionality becomes available.

The other inherent difficulty with relying on a battery to regulate peak demand is that the battery has to both be online 100% of the time, and be charged to a sufficient state of charge to respond to peak demand events, noting the current nonoperational state of Nimbin CS battery. It is also worth noting that UQ states that the battery availability was forecast at 98%, but ran at 94.3% in the first quarter of operations[43].

If these two conditions cannot be satisfied, the benefit of increasing supply to match increasing demand could easily be lost. It only takes one peak demand event annually to increase costs for capacity charges for a full 12 months, based on the way capacity pricing is typically calculated in the NEM. Peak lopping, as proven through the UQ battery trials, was anticipated to produce savings, but in reality, these never materialised[44] at the time of writing. There is no evidence that peak lopping has been activated in the operation of the UQ battery – rather the team there is focusing on arbitrage optimisation, but realise that the vast majority of financial benefit flows from FCAS and a virtual cap.

The findings in this report that peak-lopping is unachievable and non-financial contradicts the NSW Government final business case summary for *Cooler Classrooms Program – Tranche 1* which states[45]:

> *"Environmental sustainability is a key driver of the Program*
>
> *Sustainability is a key focus of the Program to control energy usage and offset additional energy requirements through the installation of solar photovoltaic (PV) systems. Demand management initiatives and, where feasible, energy storage in the form of batteries will be installed to reduce the extent and cost of electrical infrastructure upgrades and demand on the electricity network."*

It is noteworthy that the policy objective of reducing electrical demand as stated is not tackled by actually reducing electrical demand, rather, it is tackled by supplying more electricity (with higher effective carbon emissions) to cater to the variable/increased demand. It is suggested by the results of this report that policy as articulated in the above quotation be altered in favour of using HVAC controls over batteries. It should also be acknowledged that solar PV cannot be relied on to reduce electrical demand on cloudy days. Further, it is logical to state that there is no demand management strategy until control exists over flexible electrical demand.

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[43] https://sustainability.uq.edu.au/files/11868/EPBQtyRptq12020.pdf pp17

[44] https://sustainability.uq.edu.au/files/11868/EPBQtyRptq12020.pdf pp11

[45] https://www.infrastructure.nsw.gov.au/media/2630/insw-business-case-evaluation-summary_cooler-classrooms-program.pdf

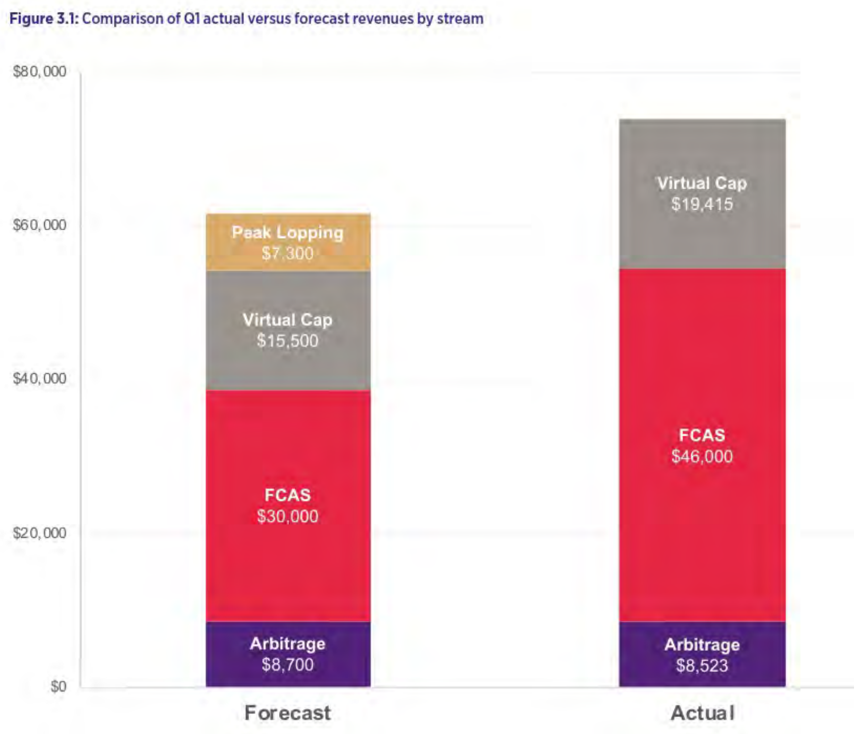

Figure 156: financial modelling - UQ battery income Q1 2020, projected vs actuals. SINSW batteries are 1/39 of the size and income of the 1.1MW UQ battery.

Reinterpreting the chart in Figure 156, we can study the percentage totals of forecast vs actual income of the UQ battery to identify which income streams have a value proposition in the real world.

Income stream	Forecast %	Actual %	Change %
Peak lopping	11.8%	0%	-100%
Virtual cap	25.2%	26.3%	+4%
FCAS	48.8%	62.2%	+21.59%
Arbitrage	14.1%	11.5%	-22.7%

Arbitrage

Charging the battery from excess solar PV generation was found to not be a reliable method of having charge available at evening peak due to variability in cloud cover and electrical demand. It is noted through the UQ study that invariably the battery is used to buy electricity from the WSP when prices are low, and sells when prices are high. Publicly available data shows the battery cycling between charge and discharge on a frequent basis per day, including night time.

Dr Mark Goldsworthy from CSIRO Energy team notes through his analysis that *"with full emissions credit for exported power, and given the emissions intensity of the grid doesn't vary largely for NSW, the **battery actually leads** to an **increase in overall net emissions** (because round trip efficiency is less than 1 so net power from the grid increases).*" Therefore one should not choose to use a battery storage system to improve carbon emissions unless the solar PV system is extremely oversized comparative to electrical demand, thereby allowing the percentage of green power to increase over that of carbon-intensive grid electricity. Other reasons must exist to generate a business case, such as FCAS, grid support, or potentially seeking to provide resilience during power outages, or for use in an off-grid location, as this reports there is no merit to use batteries on a financial or engineering basis in a grid connected methodology for arbitrage.

Because of the above factors, the business case for battery storage systems with arbitrage is still extremely thin, varying from a BCR of 0.7 to 0.8 over 50 years.

UQ state that the peak lopping functionality was promised, but was yet to be delivered at the time of report writing. It is unclear if this functionality is now available, or what impact it might have on UQ operational costs[46].

Therefore it was determined that battery arbitrage:

1. is likely to have a negative impact on carbon emissions due to round trip losses;
2. creates large amount of charge/discharge cycles increasing the expected battery life-cycle replacement costs;
3. provides a tiny fraction of income that can be derived from the FCAS market, which does not mandate intensive use of the battery; and
4. as a consequence has best case BCR of 1.6x, and worse case 1x over 15 years.

Therefore a battery coupled with arbitrage does not necessarily provide sound financial, engineering or environmental outcomes and should be avoided as a default strategy.

FCAS opportunity (wholesale market)

FCAS support services allow the AEMO to issue commands to wholesale market participants on the broader distribution and transmission network to allow synthetic frequency control across the NEM. Participants get paid for available load shedding or export capacity that can be brought online within 6 seconds. Payments occur whether the FCAS system is utilised or not, allowing investment in storage and demand response technologies over the long term that the operator sees as important for grid stability. FCAS markets are only available to loads >1MW, requiring 34x more schools with the same battery capacity forming an aggregation pool (or VPP), or an external FCAS aggregator providing services to the existing batteries as-installed. The FCAS participant is required to respond in <6 seconds to signals from AEMO, although these are infrequent at 1-3 events per quarter.

FCAS payments tend to be highest during the 7-9pm time period each day, which provides a potential business case for the presence of batteries in the project from a financial and engineering standpoint. FCAS payments tends to be the lowest during daytime hours. This means the schools have a capacity to attract a relatively small percentage of the available FCAS payments using HVAC controls alone. However with a battery storage system, additional FCAS payments can be made available due the ability for the battery storage system being made available 24/7.

The modelling shows that the return from attracting FCAS payments is far more attractive than arbitrage as shown in the CSIRO battery control modelling work. This is to the point that you would be better off having the battery in standby ready for FCAS events rather than having one or many charge/discharge cycles per day.

School	**Battery storage**	**FCAS + virtual market cap (UQ methodology -arbitrage)**
Jamison HS	30KW (2hrs)	$6,922 (cost $73,800) = 10.6 year payback
Singleton HS	30KW (2hrs)	$6,922 (cost $73,800) = 10.6 year payback
Nimbin CS	30KW (2hrs)	$6,922 (cost $73,800) = 10.6 year payback

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[46] https://sustainability.uq.edu.au/files/11868/EPBQtyRptq12020.pdf pp4

Operating the battery in an FCAS availability mode requires significantly fewer charge/discharge cycles as it is called on demand from AEMO relatively infrequently. This means the battery will have a significantly longer lifespan than if used in peak lopping or arbitrage mode. Reduced use means the battery is more likely to be online and available for FCAS, and over a longer duration, increasing equipment life-cycle. In our assumptions, we increased life-cycle replacement from 15 to 25 years.

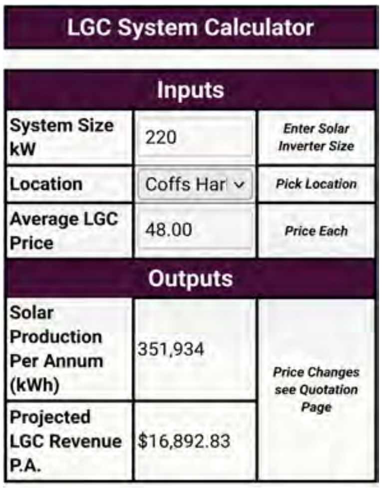
FCAS markets along with fast frequency response (FFR) services are a continually evolving suite of market instruments developed by the AEMC and AEMO to address engineering challenges associated with the rapid integration of renewable energy sources in a grid transitioning away from coal fired generation sources. As generation becomes less consistent with the influx of small-scale generators, it is predicted that the FCAS market will continue to develop in scope and scale as the transition away from coal continues, despite the impact of large participants such as the Hornsdale Power Reserve (HPR) battery in SA, and others on reducing extreme FCAS prices (therefore income earning potential).

See HVAC controls for more on the FCAS opportunity.

Solar system sizes

STC vs LGCs

The STC market yields are significantly better than those for LGCs, and the STC price is stable compared to that of the LGC which has increased marginally over time to above that of STCs[47]. The much reduced return with LGCs (as shown in Figures 157 and 158) makes the business case for any solar system install in excess of 100KW marginal, and financially incentivises the market to not install systems >100KW. This is a perverse outcome influenced by government policy that is interfering in the market. In an ideal situation, there would not be such a stark divide between the outcomes achieved from STCs vs that from LGCs. It should be noted that LGC and STCs are legislated to expire at the end of 2030, negating this market distortion. Equipment replacement uses the same system size, adjusted for the end of STCs, inflation and improvements in technology efficiency.



LGC System Calculator

Inputs		
System Size kW	220	Enter Solar Inverter Size
Location	Coffs Har	Pick Location
Average LGC Price	48.00	Price Each
Outputs		
Solar Production Per Annum (kWh)	351,934	Price Changes see Quotation Page
Projected LGC Revenue P.A.	$16,892.83	

Figure 157: financial modelling - LGC calculator from smartconsult.com.au

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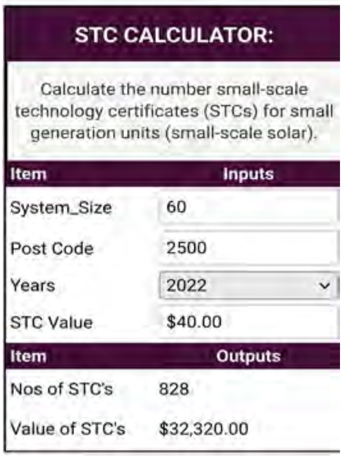
[47] http://www.cleanenergyregulator.gov.au/RET/Scheme-participants-and-industry/Renewable-Energy-Target-liable-entities/Calculating-certificate-liability

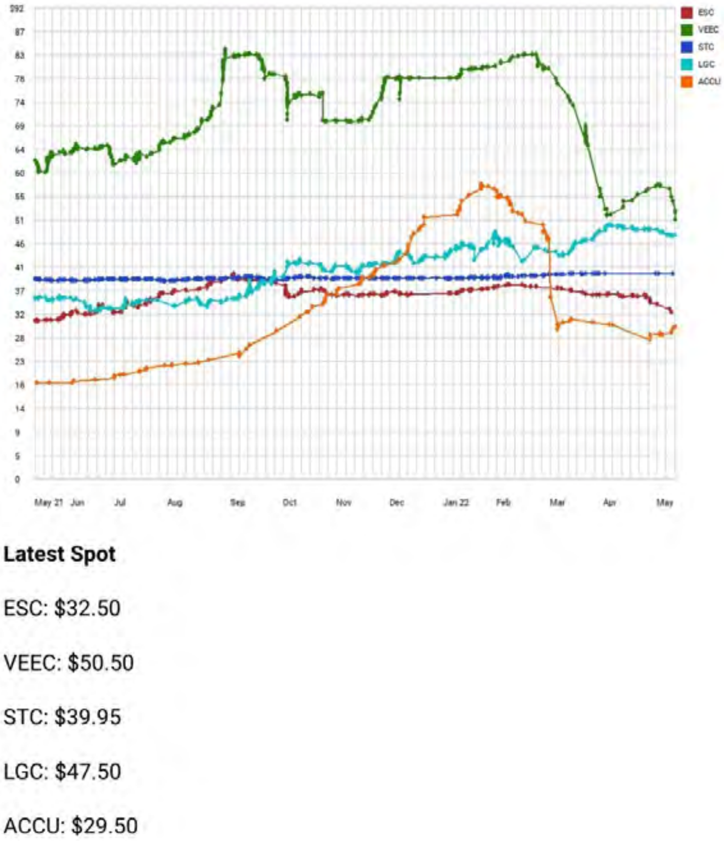


STC CALCULATOR:

Calculate the number small-scale technology certificates (STCs) for small generation units (small-scale solar).

Item	Inputs
System_Size	60
Post Code	2500
Years	2022
STC Value	$40.00
Item	**Outputs**
Nos of STC's	828
Value of STC's	$32,320.00

Figure 158: financial modelling - STC calculator from smartconsult.com.au



Latest Spot

ESC: $32.50

VEEC: $50.50

STC: $39.95

LGC: $47.50

ACCU: $29.50

Figure 159: financial modelling - certificate market price trends from demandmanager.com.au – retrieved 17th May 2022

As can be seen from the above market price trend graph in Figure 159, LGCs are increasing in yield price marginally over time, however STCs have a consistent price of ~$40/certificate. STCs are calculated differently to LGCs, the method of calculation is covered by the Clean Energy Regulator[48]. The net effect of the difference is clear in the yield payments provided the above calculation scenarios from smartconsult.com.au. A 60KW system will yield ~$32,000 in STC payments, while a 220KW system will yield ~$15,500 in LGCs dependent on generation capacity based on region and using current LGC and STC prices (17th May 2022).

Therefore the difference in yield of STC vs LGC is as follows:

PV system size	STC Yield	LGC yield
60KW	$32,000 @ $40/certificate	N/A
220KW	If STC yields applied: $132,000	$15,500 @ $48/certificate

Optimum system size

Using the above constraints, the optimisation algorithm was employed to solve for the best solar PV size with and without a battery. In all circumstances, it was proven that the maximum system size available under the STC (100KW) produced the best financial result, but not the best engineering result. System over-sizing is beneficial in that cloudy days still allow for sufficient generation to cover much of the electrical demand during the day. It was found that for Jamison HS, the optimum system size (without battery or controls) on purely engineering terms is 220KW (where the as-built is 60KW), hence the above analysis using those figures. However, solving with the financial constraints created by the STC/LGC yield difference shows that 100KW is optimum for business cases. Given STC and LGC are set to expire in 2030, the market distortion will be removed, however this will also increase the costs of small-scale solar over time. However, for ease of reporting results, we opted to maintain a consistent solar PV and battery size.

HVAC controls plus a modest PV system (<100KWh) maintains or improves occupant comfort, and produces the best financial outcomes. Therefore, complimenting solar PV systems with batteries should not be the reflex action of policy makers. PV coupled with HVAC controls allows the effective PV system size to be reduced while simultaneously reducing actual maximum demand for the site. HVAC controls also have the advantage of being cheaper to implement than battery storage, provides improvement to occupant comfort and allows for load shifting along with a host of other advantages as listed below.

See report from CSIRO “iHub DCH6 Battery Schedule Report” for preliminary system size modelling prior to battery procurement.

HVAC controls

Adding HVAC controls provide the inherent ability to:

- improve occupant comfort:
    - set and achieve thermal comfort specifications (e.g. ASHRAE 55 as set by CCP requirements);
    - use night purge to provide fresh air to students at start of day;
    - provide thermal comfort models to adjust set points based on external conditions;
    - understand the thermal properties of each building and optimise against it (e.g. thermal mass of demountables vs a triple brick building);
    - improve ventilation to maintain a good indoor environment quality and reduce risk of infection;
    - alter modes automatically based on external conditions & forecast, and favour fan and dry modes where possible; and
    - reduce HVAC system downtime through better maintenance methods.
- offset other capex costs:

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[48] http://www.cleanenergyregulator.gov.au/RET/Scheme-participants-and-industry/Renewable-Energy-Target-liable-entities/Calculating-certificate-liability

  - value engineer by removing DRED controllers/DRED capable equipment from CCP specification document; and
  - avoided electrical infrastructure upgrade costs by managing maximum demand.
- decrease operational costs:
  - reduce maximum demand & improve efficiency (night purge, pre heat/cool);
  - be responsive enough to participate in FCAS markets (<6 second response);
  - respond to extreme WSP events (i.e. >$400/MWh) as demand response;
  - provide predictive maintenance for HVAC systems;
  - alter modes automatically based on external conditions & forecast, and favour fan and dry modes where possible
  - induce demand in periods of negative wholesale spot prices, and forecast controls to maximise this opportunity;
  - ability to participate in the wholesale demand response mechanism (WDRM) or Reliability & Emergency Reserve Trader (RERT) in future[49];
  - load shift to reduce maximum demand charges (above measures assist with this); and
  - use model predictive controls to provide forecast optimised control schedules against various inputs as outlined above.

Peak demand

HVAC controls mitigate the requirement for a battery storage system to mitigate peak demand events. Instead of attempting to supply electricity with a round-trip loss cost from a battery, the strategy is to orchestrate and plan for HVAC demand to match electrical supply (driven by the WSP). It shifts the paradigm, correctly, from *supply matching demand* through to *demand matching supply*. This is a much more cost-effective approach as will be illustrated in the financial modelling results below.

PV system over-size

HVAC controls mitigate the requirement for PV system over-sizing in order to reduce maximum demand on cloudy days. A model predictive control strategy is aware of weather as well as prices in order to determine the likelihood of a sunny vs cloudy day, and therefore if pre-heat/pre-cool/night purge is an effective strategy to reduce maximum demand while maintaining occupant comfort. HVAC controls therefore allow differential control strategies based on forecast conditions to optimise against both price and weather, with a primary focus on reducing maximum demand.

Energy efficiency opportunities

Through the analysis conducted for the financial modelling, it was noted that energy savings of 50% could be made with HVAC controls in place due to significant HVAC use and resultant energy consumption when external conditions should not mandate HVAC use.

Analysing data from Singleton HS using a kmeans clustering allows a breakdown of use based on weather conditions. Obtaining peak KVA in a cluster based on two sets of conditions. Our query to obtain the data from the modelling database reads thus:

- select count(1), mean from kmeans where mean <> 39 and (air_temp <= 24 or air_temp >= 18) group by mean;
- select count(1), mean from kmeans where mean <> 39 and (air_temp > 24 or air_temp < 18) group by mean;

Data from 2019 shows the following results:

KVA peak band	**Appropriate use (conditions 9am – 3pm > 24 or < 18): count of days**	**Inappropriate use (conditions 9am – 3pm <= 24 or >= 18): count of days**

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[49] WDRM and RERT rely on agreements with retailers and aggregators to calculate price. They are considered marginal income streams at this point in time based on preliminary modelling and published results from UOW LLHC2. Therefore both WDRM and RERT are excluded from the financial modelling.

201	61	81
292	39	44
127	39	74

Analysis of the results shows a high degree

The solution design allows automatic mode control on HVAC zones within the school. The notion would be to use the *Cooler Classrooms Program* definition of “favourable outdoor conditions” (indicated by a green LED indicator on the HVAC control panel near the entrance of each classroom – see Figure 9) to set the HVAC system to “Fan” mode. Conversely, when temperature is within the 18˚C-24˚C range, but above 70% humidity, the HVAC mode would be altered to “Dry”. This is identified as a major potential energy saving that HVAC controls could immediately deliver to the schools (as presently mode is manually set twice a year to either cool or heat, depending on seasonality).

The following table shows examples of the logic of dynamic mode selection in relation to energy saving. Lines in green show scenarios where manual mode selection matches automatic mode selection.

Season	**Example conditions temp/humidity**	***Cooler Classroom Program* as-installed mode selection**	***Cooler Classrooms program* + DCH potential auto mode selection**
Summer	25˚C / 80% RH	Cool	Cool
Summer	22˚C / 80% RH	Cool	Dry
Summer	22˚C / 65% RH	Cool	Fan
Summer	17˚C / 65% RH	Cool	Fan*
Winter	25˚C / 80% RH	Heat	Dry
Winter	22˚C / 80% RH	Heat	Dry
Winter	22˚C / 65% RH	Heat	Fan*
Winter	17˚C / 65% RH	Heat	Heat

* logically, the system would disallow cool mode in winter, and heat mode in summer. This functionality to be determined by SINSW if it were to be implemented.

Additional energy efficiency can be found through ventilation of buildings at night (“night purge”) using the external ventilation fan system, rather than mechanically removing or adding heat via the HVAC systems during the day. Flow on benefits from night purge is to create improved indoor environment quality at the beginning of each day. The benefits from night purge are not modelled, and instead are offset from increased duration of cooling or heating associated with pre-cool and pre-heat. No sensor data was available to generate a thermal model of the buildings that would have enabled the modelling to solve for this input in the MPC algorithm scope of works.

An education campaign (in addition to efforts shown in Figure 76) would help reduce HVAC consumption further, particularly tackling open doors and windows while HVAC systems are turned on[50]. Another far more costly approach

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[50] Note that current Department of Education Covid-19 management policy is to keep windows and doors open, with HVAC and fans running to maximise ventilation.

would be to add sensors and controls to automate for this scenario, but further analysis would be required to determine if this had a business case (in the author's view, unlikely). It is a concern exacerbated by a lack of data – one possible meaningful course of action would be conduct targeted education campaigns and measure the impact compared to other schools.

Operations

HVAC controls provide a significant uplift in terms of automation of operation as it:

- leverages existing equipment installed under the *Cooler Classrooms Program* thereby not requiring any additional sensors HVAC systems or PLCs to be installed[51];
- improves occupant comfort and energy efficiency by continually adjusting modes, set-points and fan speeds based on sensor inputs both inside and outside the building in addition to weather forecasts;
- improves efficiency in the operation of equipment by scheduling maintenance based on need, and in a predictive manner (e.g. considering run-time in scheduling of service, or responding to errors in a timely manner); and
- reduces the downtime for HVAC systems due to errors and faults being detected and acted upon in a timely manner.

FCAS opportunity

The University of Wollongong in the LLHC2 project showed that pure HVAC controls (no battery) could yield income from FCAS (where 104KW flexible load = $108,000 p.a.[52]), or $1,038/KW/p.a. However, LLHC2 is a 24/7 operation, changing the availability of flexible load for the FCAS market, compared with that of a school that has relatively sparse occupation.

Our methodology for estimating FCAS payments is for HVAC demand response capability in schools is summarised thus:

- schools are unoccupied 25% the year due to school holidays
- schools are unoccupied on weekends, another 20% for a total of 45%.
- schools are occupied between 8am and 4pm, covering 15% of available FCAS peak price events.
- therefore, the available DR based FCAS is approximately 6.75% of the total available FCAS from the example in LLHC2.

Further modelling work would be required to produce a more accurate estimate of income from FCAS, however it was determined that obtaining 5-10% more accuracy was largely irrelevant given the variable nature of FCAS payments and FCAS events, particularly year-on-year variations.

Extending these calculations for the three schools produces the following results:

School	**Max. HVAC electrical load**	**Battery storage**	**Using FCAS calc from UoW for HVAC load (adjusted)**	**Using FCAS calc from UoW for battery storage**	**Total FCAS (estimate) per annum**
Jamison HS	110KW	30KW (2hrs)	$7,707	$6,922	$14,629
Singleton HS	100KW	30KW (2hrs)	$7,006	$6,922	$13,928
Nimbin CS	76KW	30KW (2hrs)	$5,324	$6,922	$12,246

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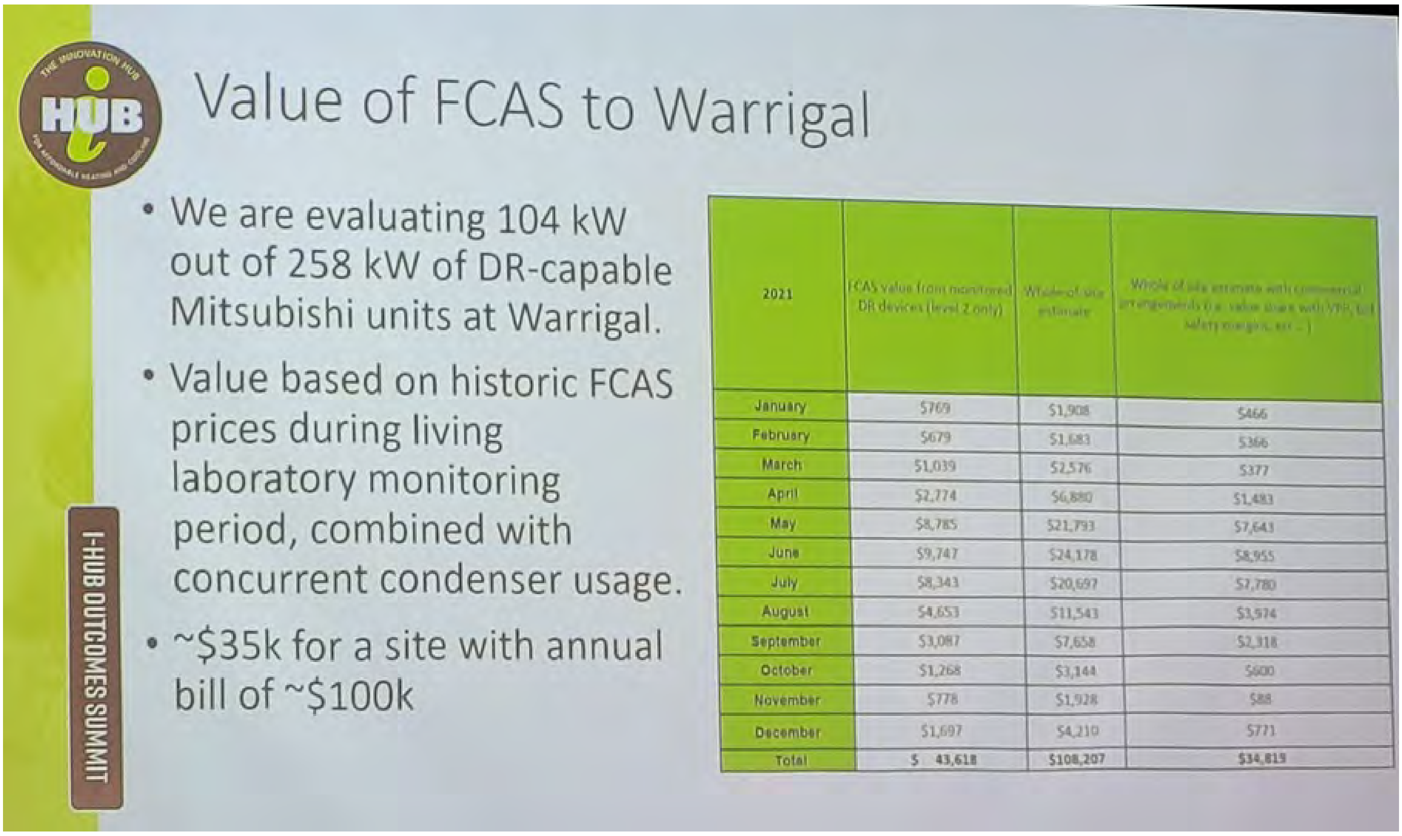
[51] Excepting some equipment such as a HVAC protocol gateway such as that used in the DCH 6.1 living lab, and compute to send data to and from the DCH (either self-hosted or supplied as a separate piece of hardware).

[52] https://www.airah.org.au/Content_Files/iHub/LLHC2_Baseline_V3.0_submitted.pdf; $ figure in slides presented at the iHub conference by University of Wollongong, 17th May 2022

Further analysis to improve the accuracy of these estimates will be conducted in the near future to replicate the results in the LLHC2 final report.



Value of FCAS to Warrigal

- We are evaluating 104 kW out of 258 kW of DR-capable Mitsubishi units at Warrigal.
- Value based on historic FCAS prices during living laboratory monitoring period, combined with concurrent condenser usage.
- ~$35k for a site with annual bill of ~$100k

2021	FCAS value from monitored DR devices (level 2 only)	Whole of site estimate	Whole of site estimate with commercial arrangements (i.e. value share with VPP, bid safety margins, etc ...)
January	$769	$1,908	$466
February	$679	$1,683	$366
March	$1,039	$2,576	$377
April	$2,774	$6,880	$1,483
May	$8,785	$21,793	$7,643
June	$9,747	$24,178	$8,955
July	$8,343	$20,697	$7,780
August	$4,653	$11,543	$3,574
September	$3,087	$7,658	$2,318
October	$1,268	$3,144	$600
November	$778	$1,928	$88
December	$1,697	$4,210	$771
Total	$ 43,618	$108,207	$34,819

Figure 160: financial modelling - value of FCAS for iHub LLHC2 (Warrigal aged care) living lab using HVAC controls only

8.9 Analytical method

Software architecture

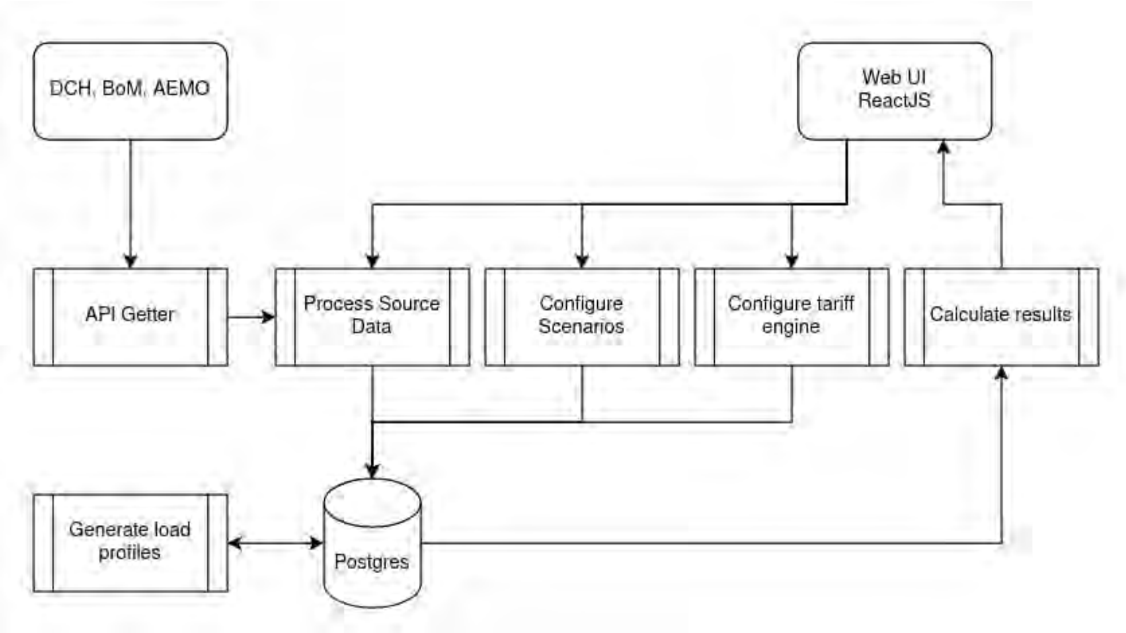


Figure 161: financial modelling - software architecture

Data sources

In the lead-up to writing the final report, the available datasets for the schools include:

Source	Role	Data	Range
PlusES	Meter Data Agent	NEM12 interval data	Last 7 years Jamison & Singleton to 2022 Nimbin to 2019*
Shell ERM	Energy Retailer	Monthly EDI invoice data	Last 7 years
Origin Energy	Energy Retailer	Quarterly EDI invoice data	Last 7 years
AER	Australian Energy Regulator	Network tariffs	Last 7 years
SMA Sunny Web Portal	Solar Inverter	30 minute interval (KWh volume)	Limited, some on Fronius Unreliable and of limited use
Alpha ESS	Battery Management System	5 minute interval (KW instantaneous) Provides data for: • System SOC • Grid consumption • PV generation • Battery charge/discharge	Jamison since Sep 20 Nimbin since Jan 21 Singleton – not available

CSIRO	Battery Control	Simulation data	Updated to consider new solar PV system size. Battery operation removed for simulation purposes**
Bureau of Metereology	Weather data provider	Hourly interval data	2019 to present date
AEMO	Wholesale spot price	Half-hourly average price per state in the NEM	2019 to present date
BE	Tariff engine	Use annual tariffs from bills or database to calc network & retail costs	2016 to present date
BE	Wet bulb temperature	Use BoM approved method to calc wet bulb from humidity + dry bulb	2019 to present date
BE	HVAC load isolation	Using NEM12 & weather data, calculate flexible load	2019 to present date
BE	Avoided infrastructure upgrade costs	Using the average cost per school to conduct electrical upgrades to support increased demand of HVAC systems	Snapshot May 2022

* Nimbin CS moved from large to small market account in 2019, terminating access to NEM12 data

COVID implications & re-base-lining

2019 had to be used as the baseline regardless of available data due to the impact of COVID on the typical school consumption/generation load profiles used for modelling. As of 2022, battery data was made available at Jamison and Nimbin (Singleton awaiting network connection) in addition to NEM12, and was one again reflective of typical operations. Therefore, the methodology to generate load profiles for each of the modelling scenarios outlined above had to inherently avoid data from the 2020 and 2021 calendar years in order to represent generation and demand accurately. During the 2020 and 2021 years, the schools were largely unoccupied, but also had solar PV and battery system upgrades as part of DCH 6.1. Therefore, we had to resample the 2019 data against the trend found in the 2022 data to date, from data obtained from both from NEM12 and the battery control system[53] in the 5 months of 2022 remaining on this project in order to have a full year of data for both:

- baseline 2019 + 2022 as installed solar PV (CCP5); and
- baseline 2019 + 2022 as installed solar PV + battery (Baseline 2022).

The former was required in order to provide data to the CSIRO battery control algorithm and other scenarios excluding batteries. The algorithm anticipates that there is no existing battery control affecting the daily load profile of grid consumption. To have existing data would force the algorithm to optimise on top of that existing control strategy, creating control conflict, and producing highly undesirable results.

The latter provides a full year snapshot of the “as-built” that we find in the three schools as at May 2022 regardless of the impacts of COVID in 2021. It also is faithful to the existing control logic found in the battery control system. Therefore any improvement modelled is then using this scenario (2022) as the new as-built 2022 engineering baseline. The 2019 financial baseline is maintained for ease of comparison.

Solar system upgrades

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[53] Except in the case of Singleton, which only had NEM12 data to rely on. Interpretation of the battery control data from the other sites informed what the likely case was for Singleton in terms of PV generation vs demand.

During the course of the project, SINSW installed larger solar PV systems either before or around the installation of the battery systems.

Preliminary financial model was completed using 2019 baseline data, prior to the battery & PV system install/upgrades. It was decided to remodel using assumptions of as-installed system sizes as well as solving for what the optimum system size would be for a combination of controls with solar PV and battery storage.

Solar system upgrade dates are listed in the table below.

Site	**Prelim modelling PV Size**	**2019 as-built PV size**	**Solar PV upgrade date**	**PV upgrade size**	**2022 total as-built PV size**
Jamison HS	*85KW*	35KW	19th August 2021	20KW	**55KW**
Singleton HS	*100KW*	25KW	30th November 2021	31KW	**56KW**
Nimbin CS	*65KW*	5KW	28th April 2020	60KW	**60KW***

* Given the age of the existing systems at Nimbin CS, it was decided to not include due to immateriality.

Note that as soon as the Nimbin CS solar system was installed, the site changed tariffs, causing a cessation in NEM12 data for that site.

Battery installation

The batteries were initially modelled against estimated sizes for maximum financial return. It was decided, however that it was simpler to procure one battery configuration for each of the schools, and that would provide an R&D advantage in that Nimbin CS is receiving a size as modelled, while the larger consumers will in effect have a smaller battery as a proportion of overall consumption, taking us in the direction of CSIRO preliminary modelling. It is worth noting, however, that preliminary modelling from both Aeris Capital and CSIRO could not model the impact of wholesale prices, so was not considered prior to the publication of this report in May 2022.

Site	**Prelim modelling battery size (2020)**	**Battery install date**	**As-built battery size (2022)**
Jamison HS	*80KWh/40KW*	30th September 2021	**60KWh/30KW**
Singleton HS	*100KWh/50KW*	Installed, but not yet online (no data)	**60KWh/30KW**
Nimbin CS	*60KWh/30KW*	19th January 2022	**60KWh/30KW**

Subsequent to the installation of the batteries, we have the opportunity to run far more sophisticated modelling scenarios through the financial modelling software developed during the R&D phase of the project, in particular modelling the effects of a wholesale/pass-through retail price structure on the long term viability of various configurations.

Our modelling captured the “as-built” state of the battery systems. Based on prior modelling from CSIRO and more recent modelling from BE, it was found that modelling larger battery storage systems produces negligible improvements in business case when solely using batteries for arbitrage or peak lopping. FCAS market participation shows a better outcome as outlined in the results.

8.10 Data sources

NEM12 interval data

Nimbin CS moved from a large market contract to a small market contract July 2020, causing a cessation in the availability of NEM12 data for that site from that date.

Jamison HS and Singleton HS have NEM12 data available to yesterday's date (rolling).

The team requested NEM12 interval data from PlusES for all three schools on three occasions, as the project completion date was moved back due to impacts of COVID. The ranges of NEM12 data available to the project is indicated in the table below:

School	From	To
Jamison HS	1st July 2015	10th March 2022
Singleton HS	27th June 2018	10th March 2022
Nimbin CS	1st July 2015	22nd July 2020

The NMI meter data, or electricity consumption data for each site is inclusive of the energy use in air-conditioning at each school. Air-conditioning use is primarily a function of:

- temperature conditions; and
- whether the school is operating or not

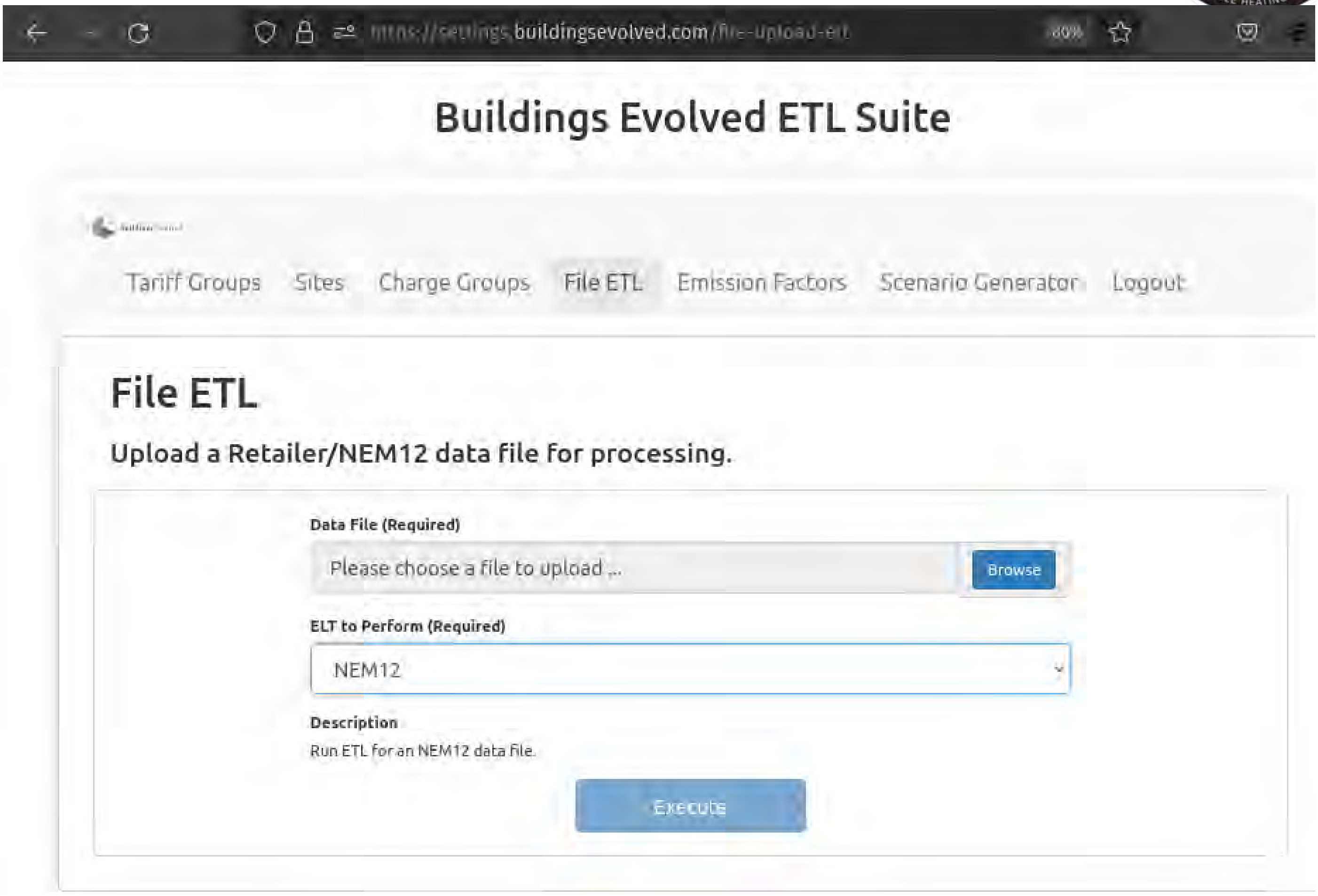
Solar PV output is a function of:

- time of year; and
- cloud cover (or absence of)

Solar PV output was not available in any meaningful way for existing or new solar PV systems on the schools. Data was in multiple vendor systems, and typically was records of instantaneous values, rather than a metered amount.

Notes:

- Averaged amounts do not work for this application as weather events directly impact upon electricity consumption. For purposes of this modelling, it is extremely important to understand what the weather conditions were on any given day so expectations of overall system performance can be remodelled against average number of sunny days, for example.
- Data is provided for both KWh and KVARh in 15 minute intervals until 1st October 2021, when it changed to 5 minute intervals in line with directions from AEMO and AEMC.
- NEM12 data is provided by the nominated Meter Data Agent (MDA), PlusES, as one or many zipped CSV files. Buildings Evolved wrote an ETL script in Python to parse the NEM12 file, reading the NMI, meter serial number and the serialised data into a table in the database.
- A web user interface was written in React.JS allowing users to upload data into the system themselves which is shown in the Figure 162.



Buildings Evolved ETL Suite

File ETL

Upload a Retailer/NEM12 data file for processing.

Data File (Required)

Please choose a file to upload ...

ELT to Perform (Required)

NEM12

Description

Run ETL for an NEM12 data file.

Figure 162: financial modelling - uploading NEM12 files via webpage to database

Retailer invoice data

Electronic Data Interface (EDI) files containing detailed billing information were collected from the two retailers pertaining to the three schools as part of the proof-of-concept trials. These were as follows:

- Shell/ERM Power (large market) for Jamison HS and Singleton HS; and
- Origin Energy (small market) for Nimbin CS.

The definition of large market in the context of NSW Schools is >100MWh p.a. There are some schools that vary their consumption due to, for example, solar PV upgrades or changes in demographics that effect school population. Accordingly, some schools in the band 90-110MWh p.a. cannot easily be defined as large or small market. Nimbin CS changed from large to small market on 22nd July 2020, thereby causing a cessation of NEM12 data from the MDA. Only large market sites have daily NEM12 data collected, small market is either daily direct interval data to the retailer (acting as MDA), or via monthly/quarterly manual reads. If small market, only 30 or 10 minute interval data *can* be available from the retailer. In our case, interval data was not available for Nimbin, making modelling a little more challenging. Our method for dealing with this variance in relation to Nimbin is outlined below in the battery system section of this document.

Uploading retailer supplied EDI files is similarly done via the settings webpage. Shown in Figures 163 and 164 are the options to upload Origin and ErmLarge on the financial modelling settings webpage. Also in the library are ErmSmall, denoting large or small market sites respectively.


Please choose a file to upload ...

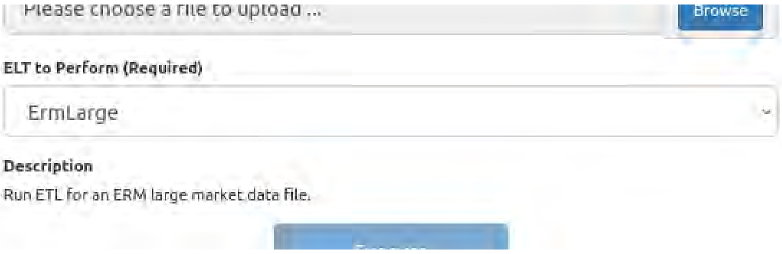
ELT to Perform (Required)

Origin

Description

Run ETL for an Origin data file.

Figure 163: financial modelling - uploading Origin Energy EDI file via webpage


Please choose a file to upload ...

ELT to Perform (Required)

ErmLarge

Description

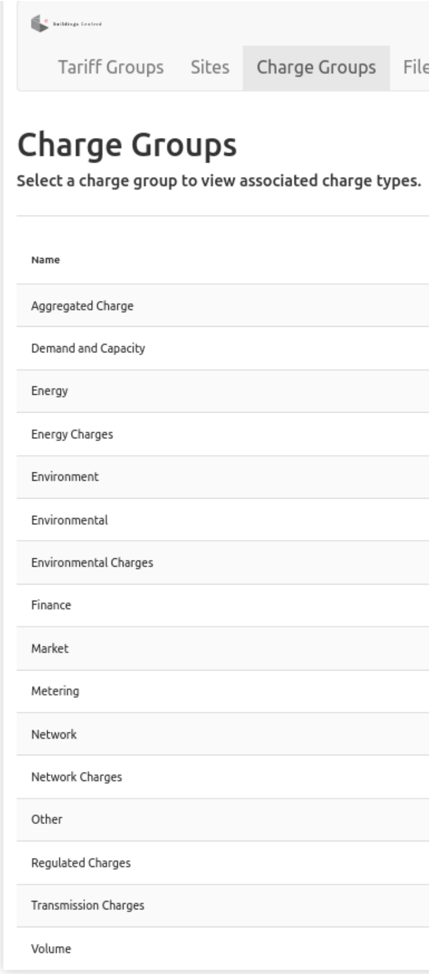
Run ETL for an ERM large market data file.

Figure 164: financial modelling - uploading ERM large market EDI file via webpage

A sophisticated method of normalising the myriad of tariff names from various retailers to a consistent name and type was employed. An example of this for “retail – peak” (quantity) would be:

- Shell/ERM Power: “RETAIL_ENERGY_PK_QTY”
- Origin: “Peak Usage”

These fields are normalised to “Retail” type for a “Peak” tariff. In this example, the rate and any total would also be extracted and placed into the retailer invoice table in the database. The same process applies to match up mismatching names to a common schema. The settings webpage for the financial modelling tool provides a function to view all stored tariffs via their charge type and charge groups. This allows the user to return a list of all tariffs that contain a particular charge type (from a charge group). This is shown in the Figures 165 and 166.

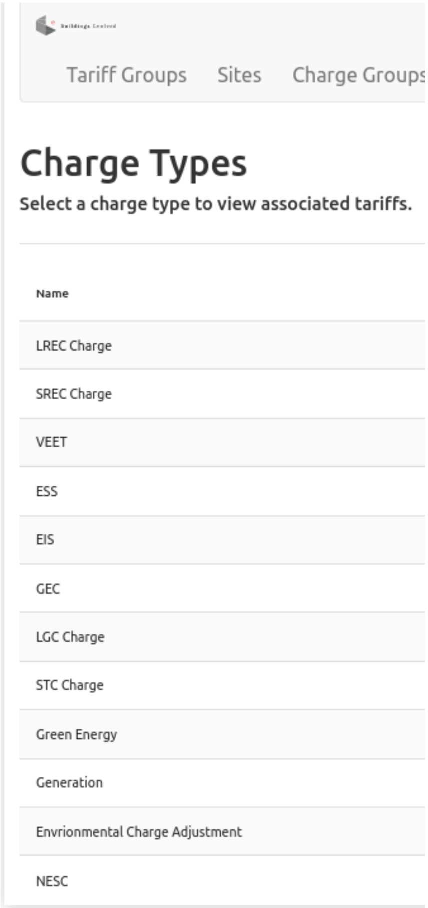


Charge Groups

Select a charge group to view associated charge types.

Name
Aggregated Charge
Demand and Capacity
Energy
Energy Charges
Environment
Environmental
Environmental Charges
Finance
Market
Metering
Network
Network Charges
Other
Regulated Charges
Transmission Charges
Volume

Figure 165: financial modelling - viewing a list of charge groups



Charge Types

Select a charge type to view associated tariffs.

Name
LREC Charge
SREC Charge
VEET
ESS
EIS
GEC
LGC Charge
STC Charge
Green Energy
Generation
Envrionmental Charge Adjustment
NESC

Figure 166: financial modelling - drilling into the environmental charge group

Shell/ERM Power provided files with 155 different fields while Origin Energy provided files with 30 different fields. These are both documented in the appendix of this report.

Network charges (TUOS/DUOS)

Network charges (transmission/distribution use of service – TUOS/DUOS) are levied separately for large market customers, and those exposed to the WSP. For small market sites (<100MWh/annum), network charges are incorporated into the retail charge for electricity. Network tariffs were sourced from the AER[54] and DNSP websites[55] and verified against supplied electricity bills for Ausgrid (Singleton CS), Endeavour (Jamision HS) and Essential Energy (Nimbin CS). Like retail charges, network charges have their own ToU that does not align with any given retailer, meaning that quite often peak network ToU could coincide with retailer shoulder ToU. An example of the ToU for Ausgrid is displayed in Figure 167[56].

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[54] https://www.aer.gov.au/networks-pipelines/determinations-access-arrangements/pricing-proposals-tariffs/ausgrid-annual-pricing-2019-20

[55] https://www.ausgrid.com.au/Industry/Regulation/Network-prices

[56] https://cdn.ausgrid.com.au/-/media/Documents/Technical-Documentation/ES/ES7-Network-Price-Guide.pdf?rev=eb27b065cd5949fdb3ea7fefdcc00ff2&hash=3AB1C52BEEFFA27E8368550B02FB4C1F

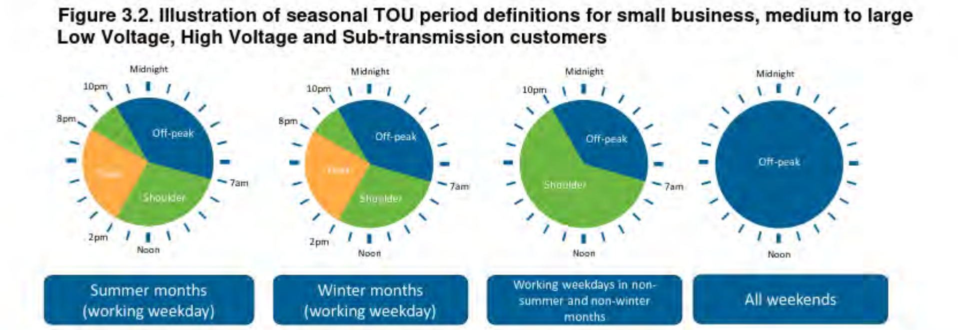
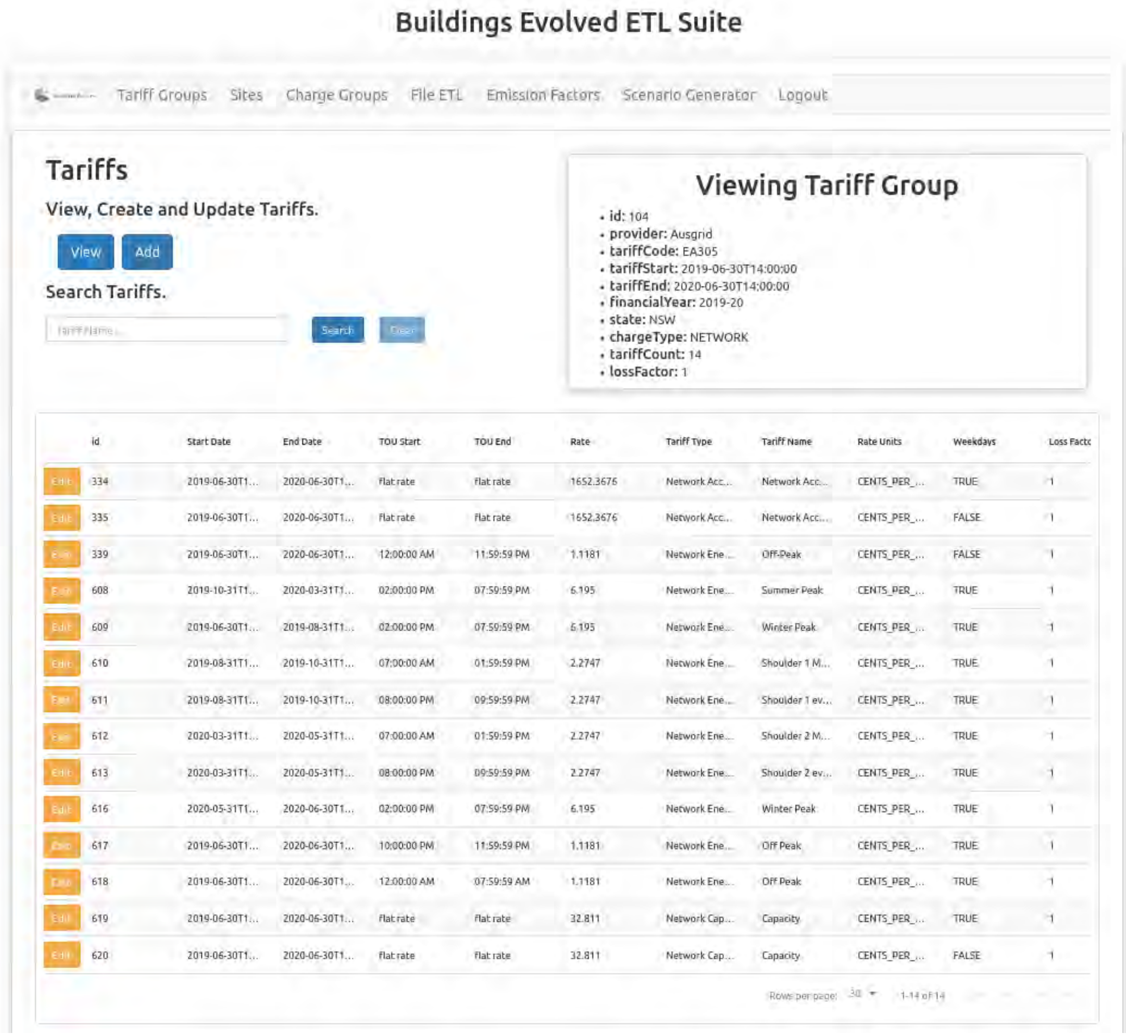


Figure 3.2. Illustration of seasonal TOU period definitions for small business, medium to large Low Voltage, High Voltage and Sub-transmission customers

Figure 167: financial modelling - Ausgrid ES7 network price guide displaying ToU on network charges

As an example, Ausgrid EA305 tariff[57] is represented in the tariff engine in Figure 168.



Tariffs

View, Create and Update Tariffs.

Search Tariffs.

Viewing Tariff Group

- **id:** 104
- **provider:** Ausgrid
- **tariffCode:** EA305
- **tariffStart:** 2019-06-30T14:00:00
- **tariffEnd:** 2020-06-30T14:00:00
- **financialYear:** 2019-20
- **state:** NSW
- **chargeType:** NETWORK
- **tariffCount:** 14
- **lossFactor:** 1

	id	Start Date	End Date	TOU Start	TOU End	Rate	Tariff Type	Tariff Name	Rate Units	Weekdays	Loss Factc
Edit	334	2019-06-30T1...	2020-06-30T1...	flat rate	flat rate	1652.3676	Network Acc...	Network Acc...	CENTS_PER_...	TRUE	1
Edit	335	2019-06-30T1...	2020-06-30T1...	flat rate	flat rate	1652.3676	Network Acc...	Network Acc...	CENTS_PER_...	FALSE	1
Edit	339	2019-06-30T1...	2020-06-30T1...	12:00:00 AM	11:59:59 PM	1.1181	Network Ene...	Off-Peak	CENTS_PER_...	FALSE	1
Edit	608	2019-10-31T1...	2020-03-31T1...	02:00:00 PM	07:59:59 PM	6.195	Network Ene...	Summer Peak	CENTS_PER_...	TRUE	1
Edit	609	2019-06-30T1...	2019-08-31T1...	02:00:00 PM	07:59:59 PM	6.195	Network Ene...	Winter Peak	CENTS_PER_...	TRUE	1
Edit	610	2019-08-31T1...	2019-10-31T1...	07:00:00 AM	01:59:59 PM	2.2747	Network Ene...	Shoulder 1 M...	CENTS_PER_...	TRUE	1
Edit	611	2019-08-31T1...	2019-10-31T1...	08:00:00 PM	09:59:59 PM	2.2747	Network Ene...	Shoulder 1 ev...	CENTS_PER_...	TRUE	1
Edit	612	2020-03-31T1...	2020-05-31T1...	07:00:00 AM	01:59:59 PM	2.2747	Network Ene...	Shoulder 2 M...	CENTS_PER_...	TRUE	1
Edit	613	2020-03-31T1...	2020-05-31T1...	08:00:00 PM	09:59:59 PM	2.2747	Network Ene...	Shoulder 2 ev...	CENTS_PER_...	TRUE	1
Edit	616	2020-05-31T1...	2020-06-30T1...	02:00:00 PM	07:59:59 PM	6.195	Network Ene...	Winter Peak	CENTS_PER_...	TRUE	1
Edit	617	2019-06-30T1...	2020-06-30T1...	10:00:00 PM	11:59:59 PM	1.1181	Network Ene...	Off Peak	CENTS_PER_...	TRUE	1
Edit	618	2019-06-30T1...	2020-06-30T1...	12:00:00 AM	07:59:59 AM	1.1181	Network Ene...	Off Peak	CENTS_PER_...	TRUE	1
Edit	619	2019-06-30T1...	2020-06-30T1...	flat rate	flat rate	32.811	Network Cap...	Capacity	CENTS_PER_...	TRUE	1
Edit	620	2019-06-30T1...	2020-06-30T1...	flat rate	flat rate	32.811	Network Cap...	Capacity	CENTS_PER_...	FALSE	1

Figure 168: financial modelling - Ausgrid EA305 tariff in the tariff engine

Note that Nimbin changed to a small market tariff in 22nd July 2020 as a result of solar PV pushing net electricity consumption below 100MWh/p.a.

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[57] https://shellenergy.com.au/wp-content/uploads/2021/01/AUSGRID-2020-21-Network-Price-List.pdf

Alpha/ESS battery storage system

The battery storage systems are identical across the three sites, and feed data to the vendor's web-based portal. The system records instantaneous KW readings every 5 minutes, providing disaggregated load information for:

- grid consumption;
- feed-in;
- PV;
- load; and
- battery state of charge.

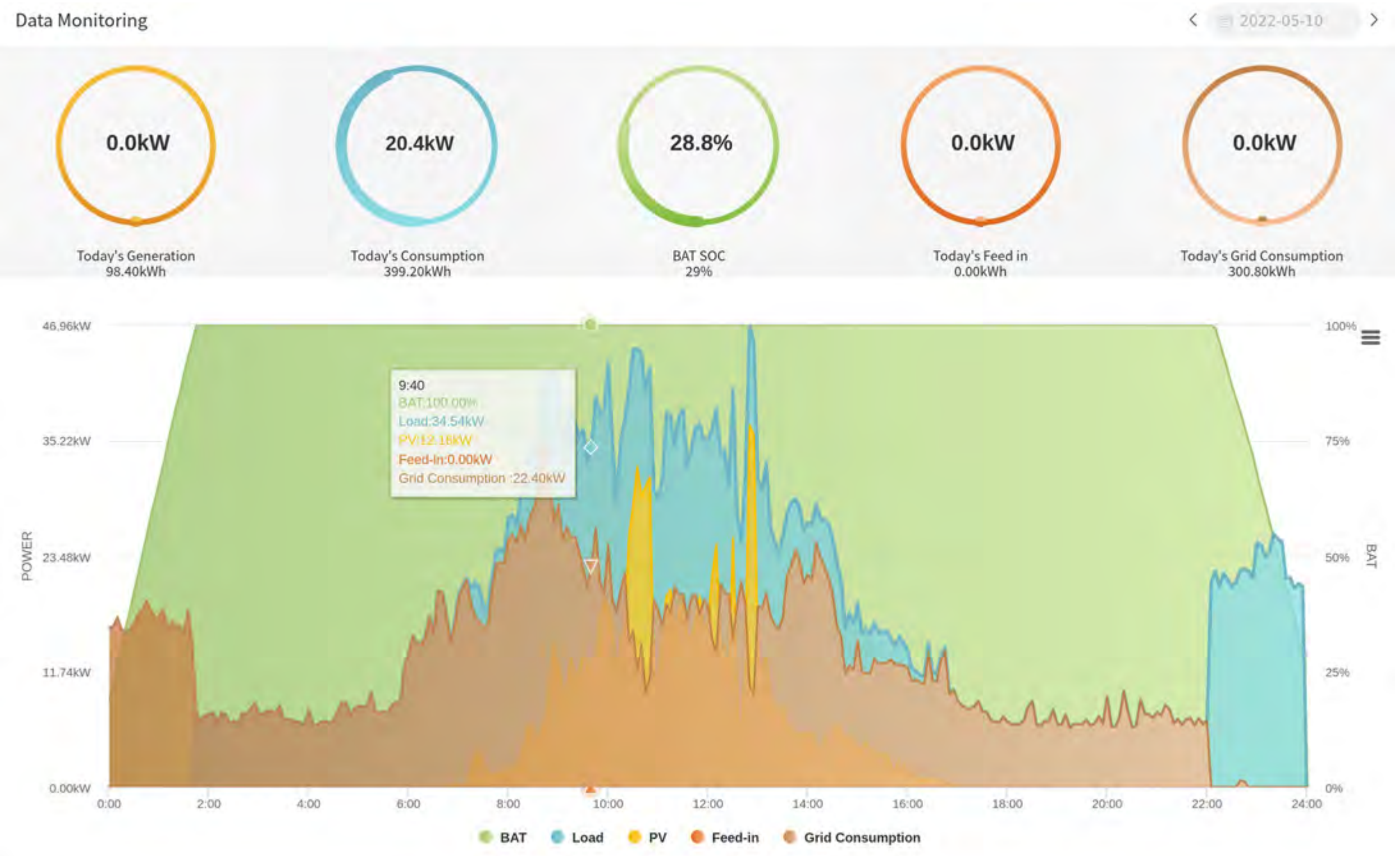


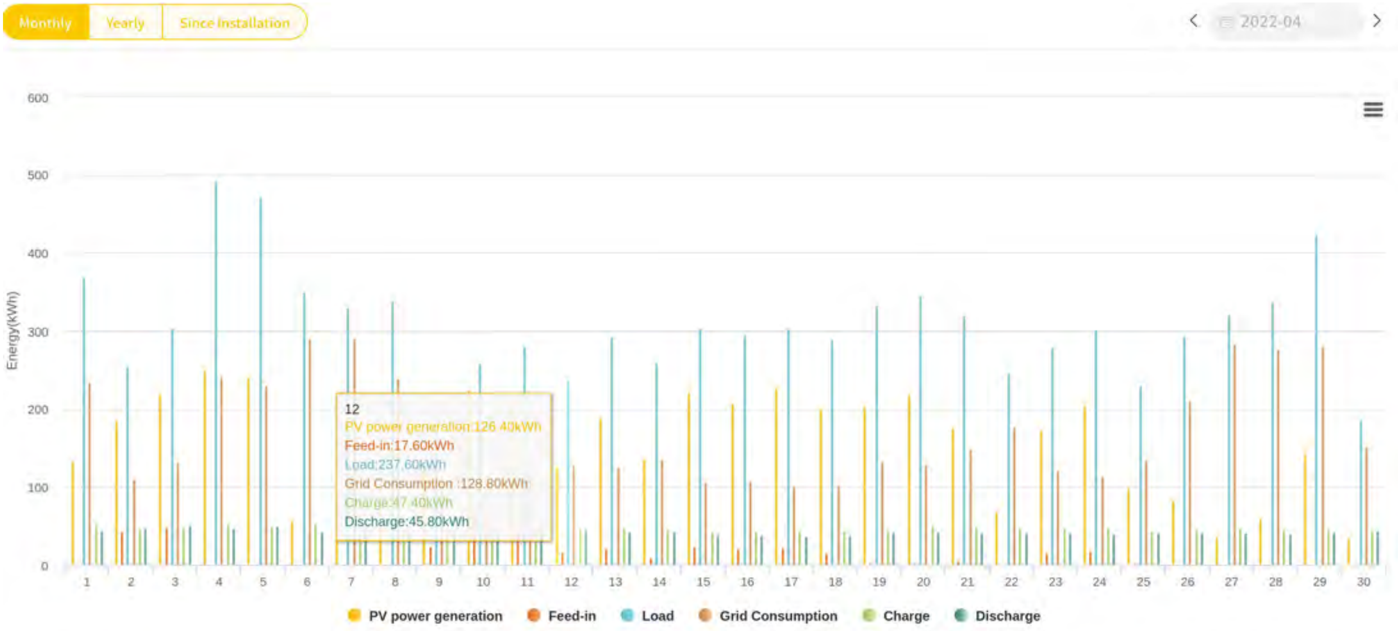
Figure 169: financial modelling - Alpha ESS battery system daily load profiles

Daily load profile data can be downloaded in CSV format, with each interval set at 5 minutes. The data is extremely useful in supplying the 'as-built' status of the system, including in this case, an inefficient use of the charge and discharge schedule before and after midnight. Downloaded data was sampled and adjusted using the following method:

- **accuracy** – Alpha ESS data is KW instantaneous samples rather than metered KWh. Therefore the system is incapable of capturing events that occur in the 4 minutes 59 seconds between each sample. Calculating the difference between the instantaneous values to metered data from NEM12 showed a range of variances per 15-minute interval, with each 5-minute interval from Alpha ESS averaged to create a 15-minute interval for comparison. The mean of the variance per 15-minute interval, compared with NEM12 interval data, was calculated to produce an offset for the instantaneous data. Across available sampled data, a mean variance of -25% was found with Alpha ESS vs NEM12. Therefore, AlphaESS data is uniformly adjusted by -25% to account for inaccuracy in the Alpha ESS system.
- **time of year** – seasonal adjustments applied to solar generation and HVAC use. Summer typically increases generation capacity, while winter reduces generation capacity while maintaining HVAC load for heating.

- **wet vs dry year** – solar generation is dramatically affected by cloud cover. Sample year data is classified as either sunny or cloudy and adjusted to the BOM historical average of cloudy days within a year. See below for more detail.
- **comparison with historical data** – time of year and wet/dry variances were assisted by the use of historical NEM12 data

Using the above adjustments, a full year of disaggregated Alpha ESS data was generated for use in financial modelling.



12
PV power generation:126.40kWh
Feed-in:17.60kWh
Load:237.60kWh
Grid Consumption :128.80kWh
Charge:47.40kWh
Discharge:45.80kWh

Figure 170: financial modelling - Alpha ESS battery system daily summaries

While the Alpha ESS monitoring system appears to provide KWh daily summary data, it does not correlate with the NEM12 data that provided by the utility. Each day varies by different amounts to the NEM12, indicating that it is not in fact metered KWh as implied, but rather an indicative calculation from the source instantaneous sample data. This is a an unexpected outcome – the expectation within the team was that it would be metered amounts.

In any case, daily summary data was not used for financial modelling purposes as it had no inherent advantage over extracting the source interval data.

Bureau of Meteorology

Since mid-2020, Buildings Evolved have setup a program to poll the BoM for hourly weather data observations for 426 automatic weather stations, which covers the three school locations. Map locations as latitude and longitude are parsed to the BoM observations map[58] to retrieve hourly weather observations. The BoM webpage stores three days of hourly observations, and the application is configured to run every day.

The three stations are:

School	Nearest AWS	Site number	Distance	From year
Jamison HS	Penrith Lakes AWS	067113	3.5km	1990

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[58] e.g. http://www.bom.gov.au/nsw/observations/map.shtml

~~Singleton HS~~	~~Elderslie AWS*~~	~~061092~~	~~15.4km~~	~~1990~~
Singleton HS	Singleton Defence AWS	061430	14.2km	2017
Nimbin CS	Nimbin Post Office	058044	0.8km	1990

* Only used for observations prior to 2017

The raw data from the BoM is transformed using a method outlined by Roland Stull to create wet-bulb temperature from relative humidity and air temperature[59] before being loaded into the database.

The data stored includes:

- BoM weather station id;
- reading date/time;
- air temp;
- relative humidity;
- pressure;
- wet bulb temperature; and
- dew point.

Australian Energy Market Operator

Historical AEMO data is downloaded and loaded into the database without transformation using the string https://aemo.com.au/aemo/data/nem/priceanddemand/PRICE_AND_DEMAND_${y}${m}_${REGION}.csv

Where Region = NSW, QLD and VIC

And y (year) and m (month) are variables set parameters when downloading the data. The CSV is simply loaded as-is into a database table for query by other applications. The data is used to project WSP based scenarios, as well as generate optimum load profiles based on the MPC algorithm.

Resultant data appears thus:

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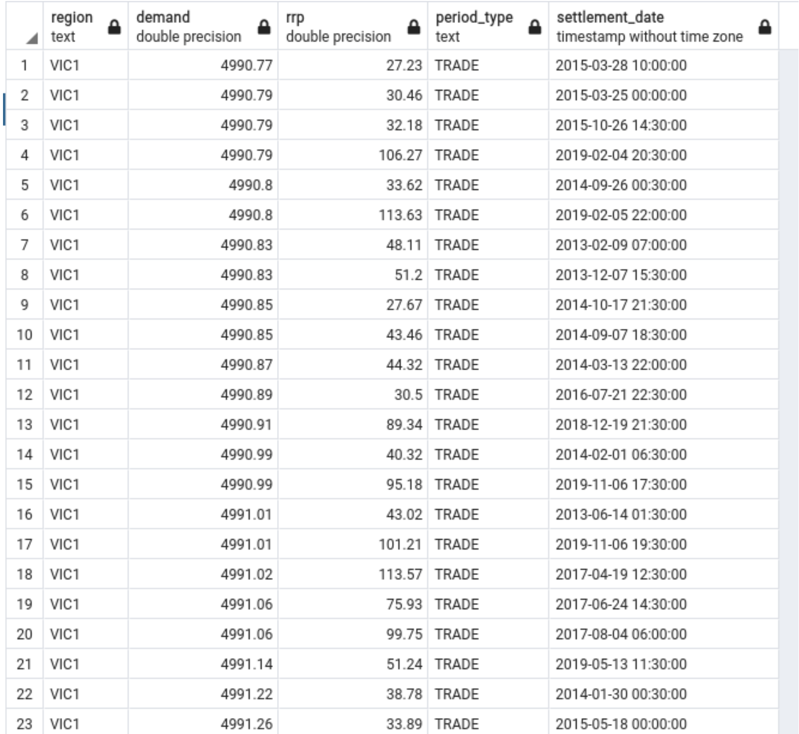
[59] https://journals.ametsoc.org/view/journals/apme/50/11/jamc-d-11-0143.1.xml



	region text	demand double precision	rrp double precision	period_type text	settlement_date timestamp without time zone
1	VIC1	4990.77	27.23	TRADE	2015-03-28 10:00:00
2	VIC1	4990.79	30.46	TRADE	2015-03-25 00:00:00
3	VIC1	4990.79	32.18	TRADE	2015-10-26 14:30:00
4	VIC1	4990.79	106.27	TRADE	2019-02-04 20:30:00
5	VIC1	4990.8	33.62	TRADE	2014-09-26 00:30:00
6	VIC1	4990.8	113.63	TRADE	2019-02-05 22:00:00
7	VIC1	4990.83	48.11	TRADE	2013-02-09 07:00:00
8	VIC1	4990.83	51.2	TRADE	2013-12-07 15:30:00
9	VIC1	4990.85	27.67	TRADE	2014-10-17 21:30:00
10	VIC1	4990.85	43.46	TRADE	2014-09-07 18:30:00
11	VIC1	4990.87	44.32	TRADE	2014-03-13 22:00:00
12	VIC1	4990.89	30.5	TRADE	2016-07-21 22:30:00
13	VIC1	4990.91	89.34	TRADE	2018-12-19 21:30:00
14	VIC1	4990.99	40.32	TRADE	2014-02-01 06:30:00
15	VIC1	4990.99	95.18	TRADE	2019-11-06 17:30:00
16	VIC1	4991.01	43.02	TRADE	2013-06-14 01:30:00
17	VIC1	4991.01	101.21	TRADE	2019-11-06 19:30:00
18	VIC1	4991.02	113.57	TRADE	2017-04-19 12:30:00
19	VIC1	4991.06	75.93	TRADE	2017-06-24 14:30:00
20	VIC1	4991.06	99.75	TRADE	2017-08-04 06:00:00
21	VIC1	4991.14	51.24	TRADE	2019-05-13 11:30:00
22	VIC1	4991.22	38.78	TRADE	2014-01-30 00:30:00
23	VIC1	4991.26	33.89	TRADE	2015-05-18 00:00:00

Figure 171: financial modelling - stored AEMO spot price data

Avoided infrastructure upgrade costs

The Infrastructure NSW report “SINSW Business Case Evaluation Summary: Cooler Classrooms Program” identifies electrical infrastructure upgrade costs as part the program alongside HVAC and solar PV upgrades. The document identifies sustainability as a key focus of the program, and that constitutes controlling energy usage and offsetting additional energy requirements from new/larger HVAC systems.

NSW Schools were not designed with HVAC loads in mind. All electrical equipment was built to support school activities without HVAC, plus an overhead of 30%. Therefore, some schools, dependent on population or increase in size, require electrical upgrades, while others do not.

Public Works Advisory and SINSW advise that of 746 schools completed under the CCP, 207 of these required electrical infrastructure upgrades. The range of costs was $30,000 to $340,000 and an average of $140,000. Therefore 28% of schools required an electrical upgrade. 28% of $140,000 therefore provides us with an amortised avoided infrastructure upgrade cost to apply to the HVAC controls financial models.

Given that the report shows that batteries cannot feasibly be used to control peak demand during school operations, we have not applied an avoided infrastructure upgrade cost to scenarios that only use batteries (Baseline 2022 & CCP6). Therefore $40,000 is the assumed value for amortised avoided infrastructure upgrade costs when employing HVAC controls for demand management (CCP7).

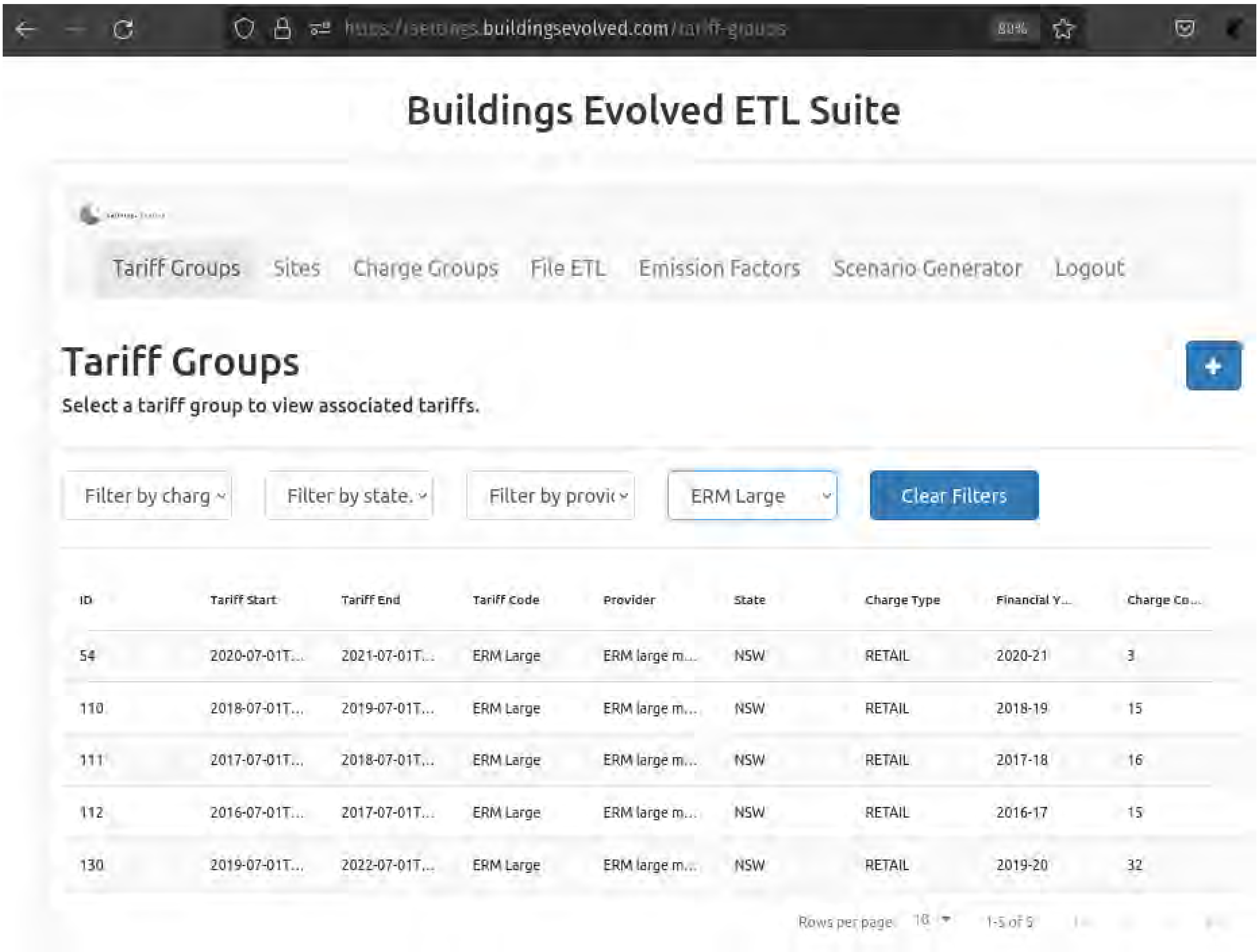
8.11 Calculations

Tariff engine

Buildings Evolved developed the ability to ingest raw NEM12 consumption data from the meter data agents, parsing the interval data through a tariff engine in order to generate invoices that are accurate in comparison with issued invoices from the retailer. The aim is broader than invoice recreation that has been done by the market for decades.

The purpose was to use historical data to create projections of cost for the full 50 years in the financial modelling. The data was also used in significant ways to generate baselines and scenario load profiles for modelling purposes.

The tariff engine functionality is outlined in Figure 172:



Tariff Groups

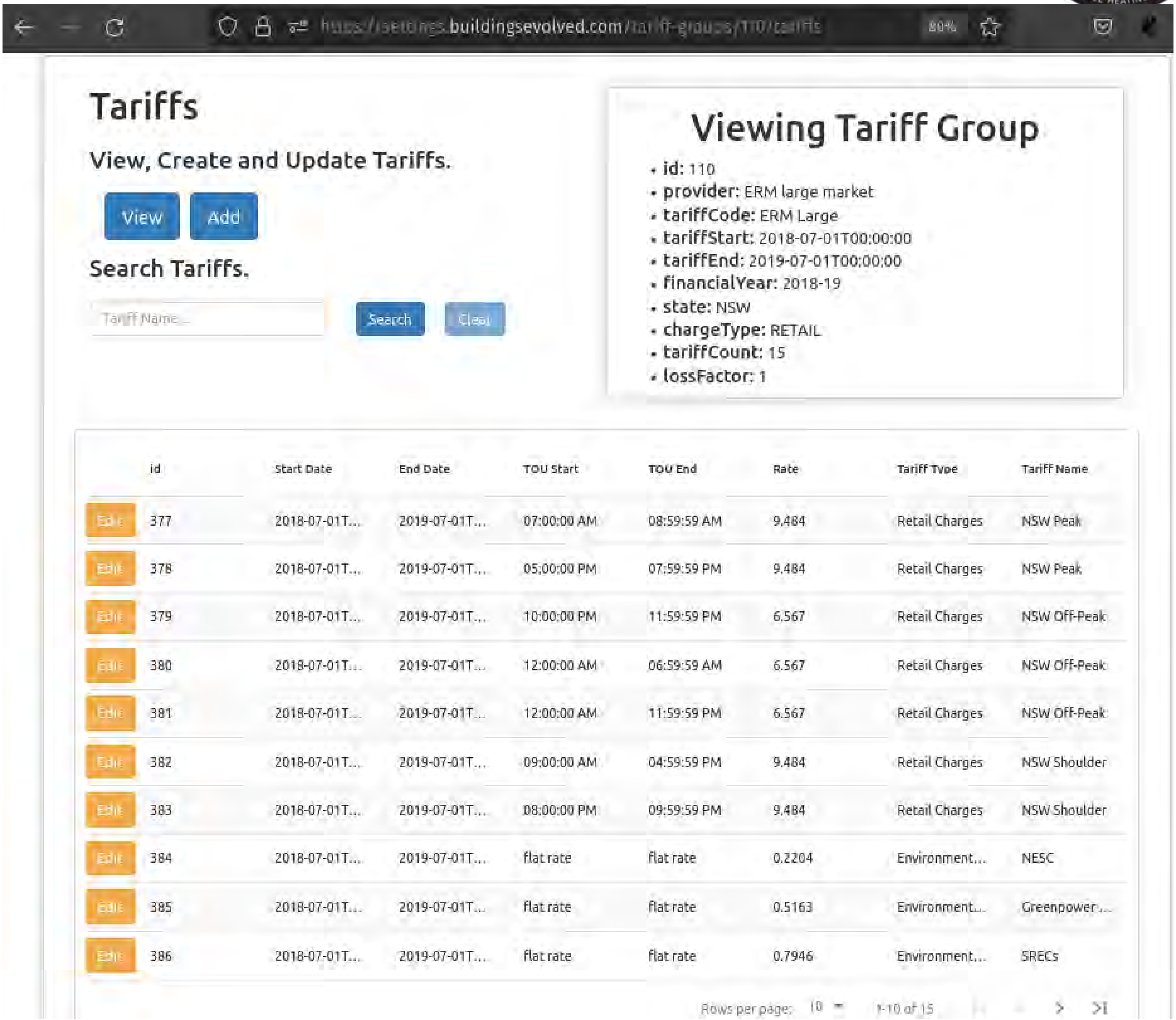
Select a tariff group to view associated tariffs.

ERM Large

ID	Tariff Start	Tariff End	Tariff Code	Provider	State	Charge Type	Financial Y...	Charge Co...
54	2020-07-01T...	2021-07-01T...	ERM Large	ERM large m...	NSW	RETAIL	2020-21	3
110	2018-07-01T...	2019-07-01T...	ERM Large	ERM large m...	NSW	RETAIL	2018-19	15
111	2017-07-01T...	2018-07-01T...	ERM Large	ERM large m...	NSW	RETAIL	2017-18	16
112	2016-07-01T...	2017-07-01T...	ERM Large	ERM large m...	NSW	RETAIL	2016-17	15
130	2019-07-01T...	2022-07-01T...	ERM Large	ERM large m...	NSW	RETAIL	2019-20	32

Figure 172: financial modelling - tariff groups on settings webpage

The tariff engine is represented within the financial modelling settings webpage. It extracts data from EDI files, where possible, by import to the database, or by manual data entry via the webpage. The following page represents ERM large market tariff for NSW Schools for various financial years from 2016-2021. Each tariff group contains individual tariff entries. These represent different rates for time periods within the day or weekend as shown in Figure 173.



Tariffs

View, Create and Update Tariffs.

Search Tariffs.

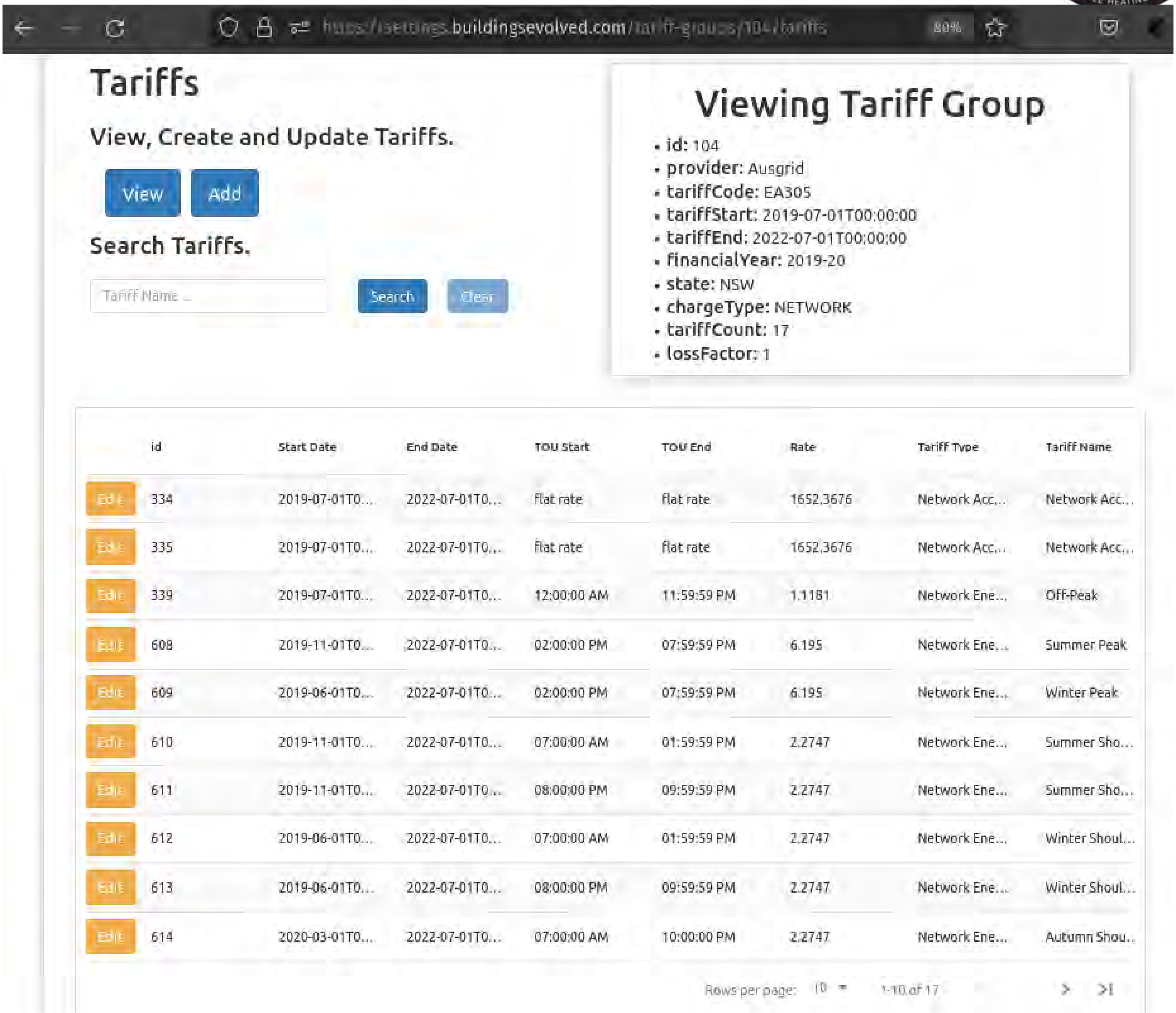
Viewing Tariff Group

- **id:** 110
- **provider:** ERM large market
- **tariffCode:** ERM Large
- **tariffStart:** 2018-07-01T00:00:00
- **tariffEnd:** 2019-07-01T00:00:00
- **financialYear:** 2018-19
- **state:** NSW
- **chargeType:** RETAIL
- **tariffCount:** 15
- **lossFactor:** 1

	id	Start Date	End Date	TOU Start	TOU End	Rate	Tariff Type	Tariff Name
Edit	377	2018-07-01T...	2019-07-01T...	07:00:00 AM	08:59:59 AM	9.484	Retail Charges	NSW Peak
Edit	378	2018-07-01T...	2019-07-01T...	05:00:00 PM	07:59:59 PM	9.484	Retail Charges	NSW Peak
Edit	379	2018-07-01T...	2019-07-01T...	10:00:00 PM	11:59:59 PM	6.567	Retail Charges	NSW Off-Peak
Edit	380	2018-07-01T...	2019-07-01T...	12:00:00 AM	06:59:59 AM	6.567	Retail Charges	NSW Off-Peak
Edit	381	2018-07-01T...	2019-07-01T...	12:00:00 AM	11:59:59 PM	6.567	Retail Charges	NSW Off-Peak
Edit	382	2018-07-01T...	2019-07-01T...	09:00:00 AM	04:59:59 PM	9.484	Retail Charges	NSW Shoulder
Edit	383	2018-07-01T...	2019-07-01T...	08:00:00 PM	09:59:59 PM	9.484	Retail Charges	NSW Shoulder
Edit	384	2018-07-01T...	2019-07-01T...	flat rate	flat rate	0.2204	Environment...	NESC
Edit	385	2018-07-01T...	2019-07-01T...	flat rate	flat rate	0.5163	Environment...	Greenpower ...
Edit	386	2018-07-01T...	2019-07-01T...	flat rate	flat rate	0.7946	Environment...	SRECs

Figure 173: financial modelling - a list of tariffs contained within a tariff group for ERM Power 2018-2019

Network tariffs are represented as different tariff groups. Therefore, each site requires two tariffs to be bound: network and retail.



Tariffs

View, Create and Update Tariffs.

Search Tariffs.

Viewing Tariff Group

- **id:** 104
- **provider:** Ausgrid
- **tariffCode:** EA305
- **tariffStart:** 2019-07-01T00:00:00
- **tariffEnd:** 2022-07-01T00:00:00
- **financialYear:** 2019-20
- **state:** NSW
- **chargeType:** NETWORK
- **tariffCount:** 17
- **lossFactor:** 1

	id	Start Date	End Date	TOU Start	TOU End	Rate	Tariff Type	Tariff Name
Edit	334	2019-07-01T0...	2022-07-01T0...	flat rate	flat rate	1652.3676	Network Acc...	Network Acc...
Edit	335	2019-07-01T0...	2022-07-01T0...	flat rate	flat rate	1652.3676	Network Acc...	Network Acc...
Edit	339	2019-07-01T0...	2022-07-01T0...	12:00:00 AM	11:59:59 PM	1.1181	Network Ene...	Off-Peak
Edit	608	2019-11-01T0...	2022-07-01T0...	02:00:00 PM	07:59:59 PM	6.195	Network Ene...	Summer Peak
Edit	609	2019-06-01T0...	2022-07-01T0...	02:00:00 PM	07:59:59 PM	6.195	Network Ene...	Winter Peak
Edit	610	2019-11-01T0...	2022-07-01T0...	07:00:00 AM	01:59:59 PM	2.2747	Network Ene...	Summer Sho...
Edit	611	2019-11-01T0...	2022-07-01T0...	08:00:00 PM	09:59:59 PM	2.2747	Network Ene...	Summer Sho...
Edit	612	2019-06-01T0...	2022-07-01T0...	07:00:00 AM	01:59:59 PM	2.2747	Network Ene...	Winter Shoul...
Edit	613	2019-06-01T0...	2022-07-01T0...	08:00:00 PM	09:59:59 PM	2.2747	Network Ene...	Winter Shoul...
Edit	614	2020-03-01T0...	2022-07-01T0...	07:00:00 AM	10:00:00 PM	2.2747	Network Ene...	Autumn Shou...

Figure 174: financial modelling - Endeavour network tariffs

Historical consumption data plus the tariff engine as outlined above allows the recreation of invoices, but more importantly, allows projections to be built from historical reality. The historical data plus tariff engine were used to create a baseline as well as programmatically generate estimated and projected load profiles for modelling.

Separating the network and retail cost components into clearly defined types allowed the team to model the WSP while factoring in network charges that would be faced in that scenario. It furthermore allowed the ability to model tariff changes, particularly those that might apply when a school becomes more energy independent and has the ability to control both demand and consumption to the point that it could move from large to small market tariff structures.

As-installed cost of solar PV and batteries

To obtain a representative cost of solar PV and batteries in schools, we were provided with as an-installed cost of solar PV and batteries in schools. Costs provided for solar were averaged across the provisioning of the *Cooler Classrooms Program* rather than the costs for the three schools in DCH 6.1. Conversely, the battery install costs were representative of the DCH 6.1 project. Analysis of the results showed the following:

System	Market $/KW installed	SINSW $/KW installed	Mark up %
Battery storage	$1,010	$1,450	30%
Solar PV <100KW	$810	$1,500	46%*

Noting that the direct cost of battery installation was 30% above the benchmark set by Solar Choice and small scale solar PV was 46% above the benchmark, we interpret the 16% difference as overheads or additional costs faced by the increased engineering, project management and procurement costs that were not within the scope of this project.

For the purposes of normalising costs and mark-ups compared with market rates, and factoring that the cost provided for small-scale solar PV is across a large project roll-out, we have adjusted the price to the same % mark up over the market price. The adjusted table also allows us to extrapolate the as-installed price of large-scale solar PV (>100KWh) for which SINSW do not have a price, as there are no large-scale PV systems in the SINSW portfolio.

System	Market $/KW installed	SINSW $/KW installed	Mark up %	Average = efficiency dividend
Battery storage	$1,010 (60KWh typ)	$1,450	30%	**$2,187**
Solar PV <100KW	$810 (30 KW typ)	$1,158*	30%	**$1,056**
Solar PV >100KW	$1,800 (200 KW typ)	$2,574*	30%	**$1,230**

* calculated figures

Adjusting the figures based on the additional cost for the battery installation allows us to project a more reasonable set of figures that accommodates:

- commercial grade installation requirements (racking, panels);
- a limited selection of PV inverters (Fronius, SMA) per SINSW requirements;
- the remote location of Nimbin CS;
- the regional location of Singleton HS;
- networking the inverters to the SINSW network & cloud platforms;
- a cabling panel per school limiting those able to cable a school; and
- additional safety, induction, working with children requirements.

The above costs for SINSW were then averaged against the market price to produce the assumed as-installed cost of battery storage and solar PV for the purposes of modelling.

The adjusted as-installed price represents an efficiency dividend that could be the basis of a target cost for procurement teams going forward.

Dry vs wet years

2021-2022 was an unusually wet year with all the cloud cover that comes along with it. We found that 2019 was unusually dry, as was evidenced by the extreme bushfires that year. Consequently, the project team sought to create an ‘average’ year from the mix of recent wet and dry years, supplementing the available NEM12 interval data.

The BoM previously collected observations of cloudy or clear days using a method retired in 2010 in favour of calculating solar exposure. For the purposes of financial modelling, historical means of cloudy vs clear days (and the intermediate) are adequate for variability of weather based on the geolocation.

From the BoM[60]:

> ***Mean number of clear days***
>
> *Average number of clear days in a calendar month or year, calculated over the period of record. This statistic is derived from cloud cover observations, which are measured in oktas (eighths). The sky is visually inspected to produce an estimate of the number of eighths of the dome of the sky covered by cloud. A completely clear sky is recorded as zero okta, while a totally overcast sky is 8 oktas. The presence of any trace of cloud in an otherwise blue sky is recorded as 1 okta, and similarly any trace of blue on an otherwise cloudy sky is recorded as 7 oktas. A clear day is recorded when the mean of the 9 am and 3 pm cloud observations is less than or equal to 2 oktas. This definition has changed slightly over time. Prior to this, a clear day was defined as having less than or equal to 2.5 oktas averaged over the 9 am and 3 pm observations.*
>
> ***Mean number of cloudy days***
>
> *Average number of cloudy days in a calendar month or year, calculated over the period of record. This statistic is derived from cloud cover observations, which are measured in oktas (eighths). The sky is visually inspected to produce an estimate of the number of eighths of the dome of the sky covered by cloud. A completely clear sky is recorded as zero okta, while a totally overcast sky is 8 oktas. The presence of any trace of cloud in an otherwise blue sky is recorded as 1 okta, and similarly any trace of blue on an otherwise cloudy sky is recorded as 7 oktas. A cloudy day is recorded when the mean of the 9 am and 3 pm cloud observations is greater than or equal to 6 oktas. This definition has changed slightly over time. Prior to this, a cloudy day was defined as having greater than or equal to 5.5 oktas averaged over the 9 am and 3 pm observations.*

The resultant data was inconsistent, with the last two sentences in the definition from the BoM may provide a reason as to why. There is also the obvious factor that the data is more than 19 years old. Many of the locations that do have sunny/cloudy day observations are now closed and replaced over time with automatic weather stations (AWS).

School	BoM site (site number)	Site number	Years monitored	Data
Jamison HS	Orchard Hills STP	067084	1971 - 1989	Clear: 102.6 Cloudy: 118.9
Singleton HS	Scone SCS	061089	1975 - 2002	Clear: 105.3 Cloudy: 57.1
Singleton HS	Singleton Army	061275	1969 - 1990	Clear: 70.7 Cloudy: 104.8
Nimbin CS	Lismore	058037	1957 - 2003	Clear 109.6 Cloudy: 126.3

An alternate or assistive method was sought. The BoM provides solar irradiance data on a daily basis from 1990 at the following nearby AWS sites:

School	Nearest AWS	Site number	Distance	From year
Jamison HS	Penrith Lakes AWS	067113	3.5km	1990

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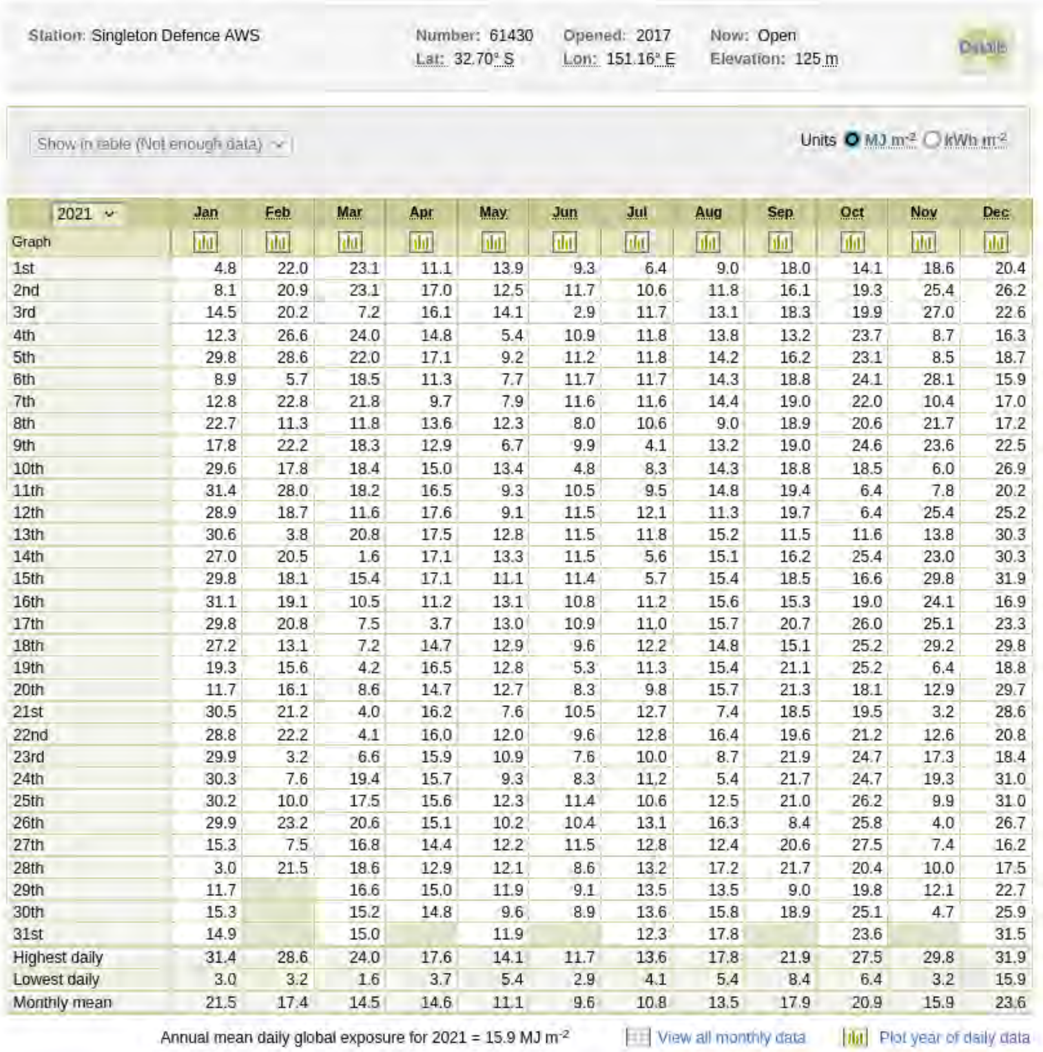
[60] http://www.bom.gov.au/climate/cdo/about/definitionsother.shtml#cleardays

~~Singleton HS~~	~~Elderslie AWS~~	~~061092~~	~~15.4km~~	~~1990~~
Singleton HS	Singleton Defence AWS	061430	14.2km	2017
Nimbin CS	Nimbin Post Office	058044	0.8km	1990

Source data from the BoM is represented thus:



Station: Singleton Defence AWS
Number: 61430
Lat: 32.70° S
Opened: 2017
Lon: 151.16° E
Now: Open
Elevation: 125 m

2021	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Graph												
1st	4.8	22.0	23.1	11.1	13.9	9.3	6.4	9.0	18.0	14.1	18.6	20.4
2nd	8.1	20.9	23.1	17.0	12.5	11.7	10.6	11.8	16.1	19.3	25.4	26.2
3rd	14.5	20.2	7.2	16.1	14.1	2.9	11.7	13.1	18.3	19.9	27.0	22.6
4th	12.3	26.6	24.0	14.8	5.4	10.9	11.8	13.8	13.2	23.7	8.7	16.3
5th	29.8	28.6	22.0	17.1	9.2	11.2	11.8	14.2	16.2	23.1	8.5	18.7
6th	8.9	5.7	18.5	11.3	7.7	11.7	11.7	14.3	18.8	24.1	28.1	15.9
7th	12.8	22.8	21.8	9.7	7.9	11.6	11.6	14.4	19.0	22.0	10.4	17.0
8th	22.7	11.3	11.8	13.6	12.3	8.0	10.6	9.0	18.9	20.6	21.7	17.2
9th	17.8	22.2	18.3	12.9	6.7	9.9	4.1	13.2	19.0	24.6	23.6	22.5
10th	29.6	17.8	18.4	15.0	13.4	4.8	8.3	14.3	18.8	18.5	6.0	26.9
11th	31.4	28.0	18.2	16.5	9.3	10.5	9.5	14.8	19.4	6.4	7.8	20.2
12th	28.9	18.7	11.6	17.6	9.1	11.5	12.1	11.3	19.7	6.4	25.4	25.2
13th	30.6	3.8	20.8	17.5	12.8	11.5	11.8	15.2	11.5	11.6	13.8	30.3
14th	27.0	20.5	1.6	17.1	13.3	11.5	5.6	15.1	16.2	25.4	23.0	30.3
15th	29.8	18.1	15.4	17.1	11.1	11.4	5.7	15.4	18.5	16.6	29.8	31.9
16th	31.1	19.1	10.5	11.2	13.1	10.8	11.2	15.6	15.3	19.0	24.1	16.9
17th	29.8	20.8	7.5	3.7	13.0	10.9	11.0	15.7	20.7	26.0	25.1	23.3
18th	27.2	13.1	7.2	14.7	12.9	9.6	12.2	14.8	15.1	25.2	29.2	29.8
19th	19.3	15.6	4.2	16.5	12.8	5.3	11.3	15.4	21.1	25.2	6.4	18.8
20th	11.7	16.1	8.6	14.7	12.7	8.3	9.8	15.7	21.3	18.1	12.9	29.7
21st	30.5	21.2	4.0	16.2	7.6	10.5	12.7	7.4	18.5	19.5	3.2	28.6
22nd	28.8	22.2	4.1	16.0	12.0	9.6	12.8	16.4	19.6	21.2	12.6	20.8
23rd	29.9	3.2	6.6	15.9	10.9	7.6	10.0	8.7	21.9	24.7	17.3	18.4
24th	30.3	7.6	19.4	15.7	9.3	8.3	11.2	5.4	21.7	24.7	19.3	31.0
25th	30.2	10.0	17.5	15.6	12.3	11.4	10.6	12.5	21.0	26.2	9.9	31.0
26th	29.9	23.2	20.6	15.1	10.2	10.4	13.1	16.3	8.4	25.8	4.0	26.7
27th	15.3	7.5	16.8	14.4	12.2	11.5	12.8	12.4	20.6	27.5	7.4	16.2
28th	3.0	21.5	18.6	12.9	12.1	8.6	13.2	17.2	21.7	20.4	10.0	17.5
29th	11.7		16.6	15.0	11.9	9.1	13.5	13.5	9.0	19.8	12.1	22.7
30th	15.3		15.2	14.8	9.6	8.9	13.6	15.8	18.9	25.1	4.7	25.9
31st	14.9		15.0		11.9		12.3	17.8		23.6		31.5
Highest daily	31.4	28.6	24.0	17.6	14.1	11.7	13.6	17.8	21.9	27.5	29.8	31.9
Lowest daily	3.0	3.2	1.6	3.7	5.4	2.9	4.1	5.4	8.4	6.4	3.2	15.9
Monthly mean	21.5	17.4	14.5	14.6	11.1	9.6	10.8	13.5	17.9	20.9	15.9	23.6

Annual mean daily global exposure for 2021 = 15.9 MJ m^{-2}

Figure 175: financial modelling - BoM daily solar irradiance data for Singleton AWS

The daily solar irradiance data was then used as an input to the model predictive control algorithm, and in addition to the historical cache of electricity meter data, daily solar irradiance data helped to normalise the weighting of the 2019 baseline solar generation data and baseline consumption data against the longer-term historical mean for scenario load profiles. This ensures the results are not affected unduly by modelling a particularly sunny or hot year against the historical mean.

Solar PV maintenance

SINSW benchmark price for solar PV system maintenance is $28/KW/year, or approximately $9/panel/year. Market research shows that for commercial installations, prices range from $3-$10/panel/year[61] [62] [63]. Simple calculations were applied to the various modelling scenarios to generate an operational expense on the cash flow projections. Given the bulk of PV was funded through the DCH 6.1 program, it was decided to include the 35KW of existing solar PV at Jamison HS and 25KW at Singleton HS into the budget for solar maintenance despite the capital expense being funded through the *Cooler Classrooms Program*. The purpose is to show the ability for the proof of concept generate enough income to mitigate the operational and life-cycle replacement costs of systems.

Site	**As installed system size**	**Cooler classroom funded PV**	**PV funded through DCH6.1**	**Annual solar maintenance cost @$28/KW**
Jamison HS	55KW	35KW	20KW	$1,540
Singleton HS	56KW	25KW	31KW	$868
Nimbin CS	60KW	*	60KW	$1,680

* Nimbin CS has two old PV systems of 1.5KW (>15 years old) and 4KW (<10 years old). Given their age and decay inherent in solar PV panels, it was decided to not include this generation as is not material to the load profiles, and it is likely that it is uneconomic to maintain.

8.12 Modelling scenarios

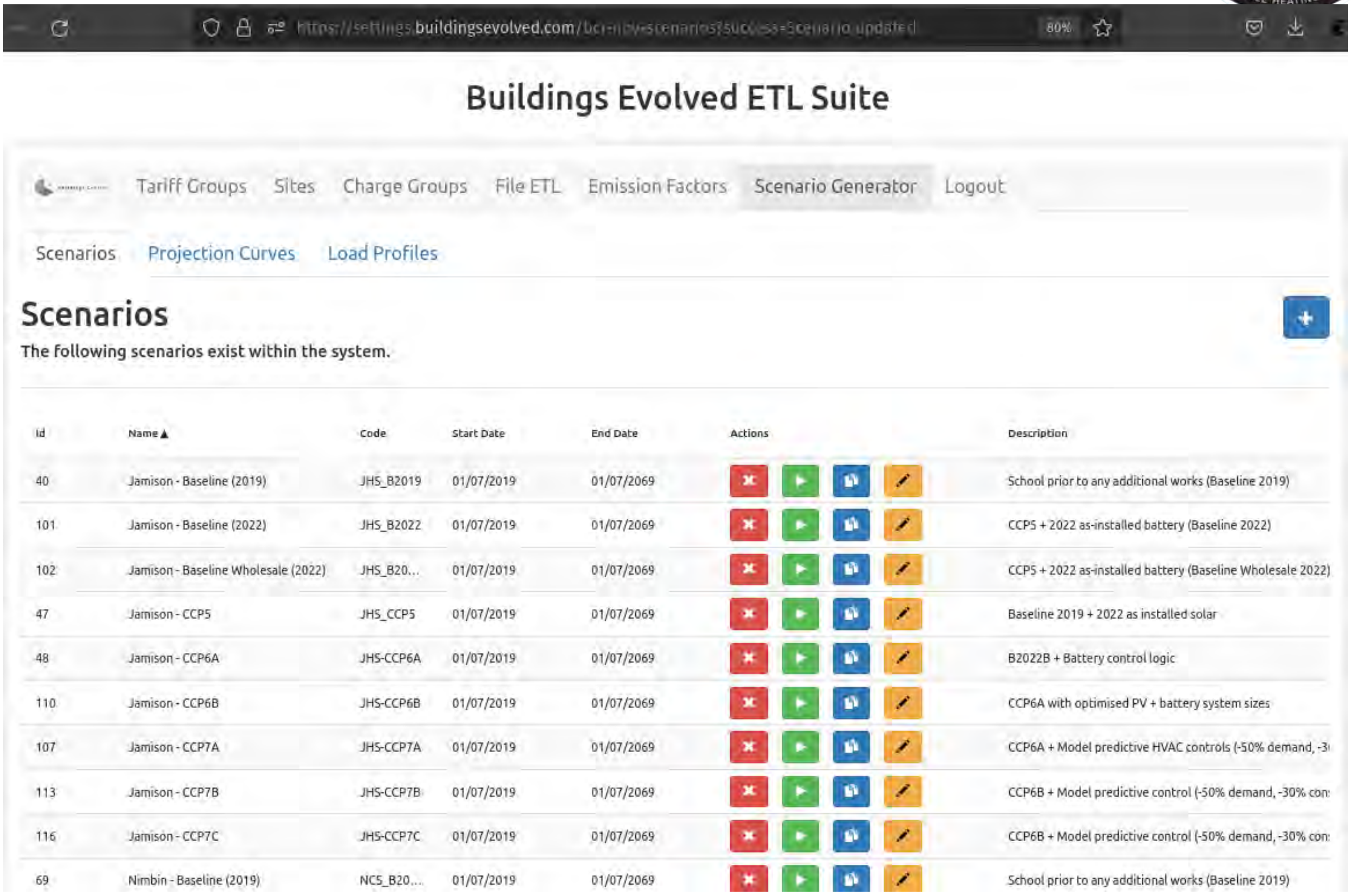
Each of the what-if modelling scenarios per school have a representation in the settings webpage as represented in Figure 176.

---

[61] https://gosolarquotes.com.au/cost/solar-panel-maintenance-cost/

[62] https://homeguide.com/costs/solar-panel-cost#more

[63] https://www.greenlancer.com/post/solar-panel-operation-and-maintenance



Scenarios

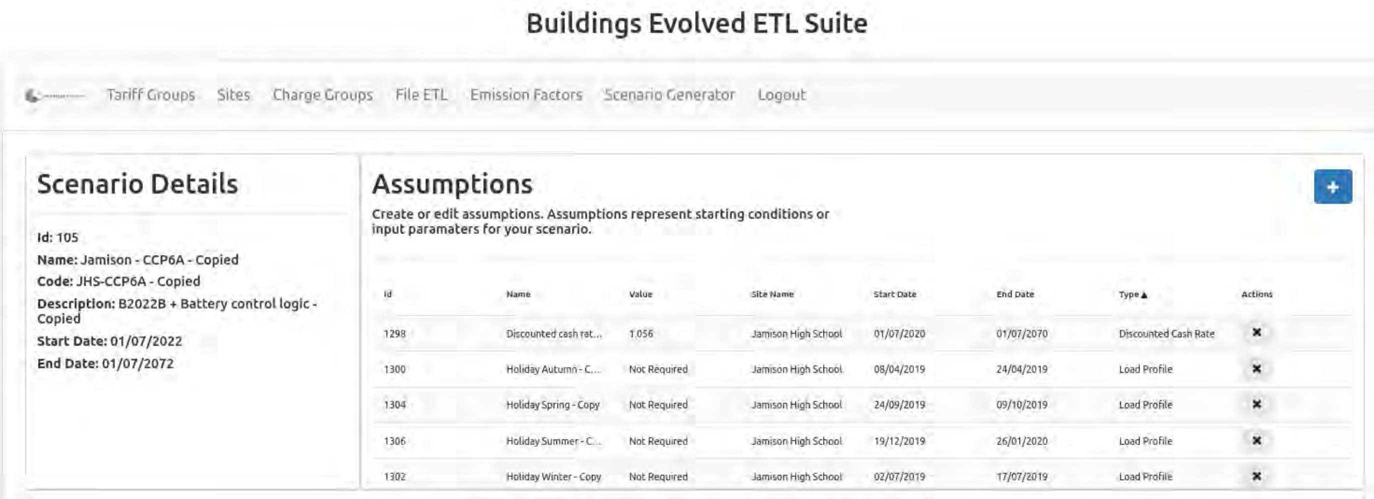
The following scenarios exist within the system.

Id	Name ▲	Code	Start Date	End Date	Actions	Description
40	Jamison - Baseline (2019)	JHS_B2019	01/07/2019	01/07/2069	✖ ▶ ⧉ ✎	School prior to any additional works (Baseline 2019)
101	Jamison - Baseline (2022)	JHS_B2022	01/07/2019	01/07/2069	✖ ▶ ⧉ ✎	CCP5 + 2022 as-installed battery (Baseline 2022)
102	Jamison - Baseline Wholesale (2022)	JHS_B20...	01/07/2019	01/07/2069	✖ ▶ ⧉ ✎	CCP5 + 2022 as-installed battery (Baseline Wholesale 2022)
47	Jamison - CCP5	JHS_CCP5	01/07/2019	01/07/2069	✖ ▶ ⧉ ✎	Baseline 2019 + 2022 as installed solar
48	Jamison - CCP6A	JHS-CCP6A	01/07/2019	01/07/2069	✖ ▶ ⧉ ✎	B2022B + Battery control logic
110	Jamison - CCP6B	JHS-CCP6B	01/07/2019	01/07/2069	✖ ▶ ⧉ ✎	CCP6A with optimised PV + battery system sizes
107	Jamison - CCP7A	JHS-CCP7A	01/07/2019	01/07/2069	✖ ▶ ⧉ ✎	CCP6A + Model predictive HVAC controls (-50% demand, -3
113	Jamison - CCP7B	JHS-CCP7B	01/07/2019	01/07/2069	✖ ▶ ⧉ ✎	CCP6B + Model predictive control (-50% demand, -30% con
116	Jamison - CCP7C	JHS-CCP7C	01/07/2019	01/07/2069	✖ ▶ ⧉ ✎	CCP6B + Model predictive control (-50% demand, -30% con
69	Nimbin - Baseline (2019)	NCS_B20...	01/07/2019	01/07/2069	✖ ▶ ⧉ ✎	School prior to any additional works (Baseline 2019)

Figure 176: financial modelling - modelling database scenarios

Each scenario is provided with a name, code, start/end date and a description. Alongside each line entry exists action buttons: delete, run, copy and edit (L-R). A plus icon allows the user to add blank scenarios as required, else the copy function serves to rapidly create scenarios based on others.

Contained within each scenario is a group of assumptions belonging to that scenario as shown in Figure 177.



Scenario Details

Id: 105
Name: Jamison - CCP6A - Copied
Code: JHS-CCP6A - Copied
Description: B2022B + Battery control logic - Copied
Start Date: 01/07/2022
End Date: 01/07/2072

Assumptions

Create or edit assumptions. Assumptions represent starting conditions or input paramaters for your scenario.

Id	Name	Value	Site Name	Start Date	End Date	Type ▲	Actions
1298	Discounted cash rat...	1.056	Jamison High School	01/07/2020	01/07/2070	Discounted Cash Rate	✖
1300	Holiday Autumn - C...	Not Required	Jamison High School	08/04/2019	24/04/2019	Load Profile	✖
1304	Holiday Spring - Copy	Not Required	Jamison High School	24/09/2019	09/10/2019	Load Profile	✖
1306	Holiday Summer - C...	Not Required	Jamison High School	19/12/2019	26/01/2020	Load Profile	✖
1302	Holiday Winter - Copy	Not Required	Jamison High School	02/07/2019	17/07/2019	Load Profile	✖

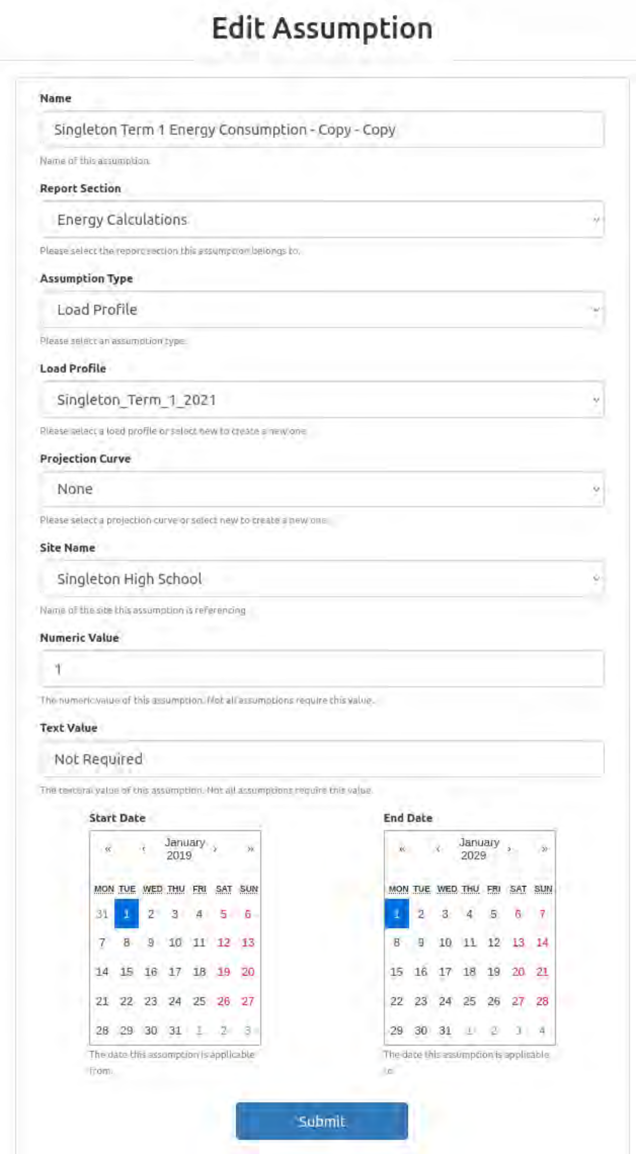
Figure 177: financial modelling - list of assumptions for modelling

Notes for Figure 177:

Contained within a typical scenario is a list of assumptions. Assumptions can run for specific time periods, or have types such as:

- Percentage change
- Static
- Load Profile
- Baseline scenario
- Revenue
- Power factor
- Discounted cash rate
- Tariff – retail
- Tariff – Network
- Tariff – Wholesale

Each of the assumption types returns a form pertinent to the type within the settings webpage. A typical load profile assumption appears in Figure 178.



Edit Assumption

Name
Singleton Term 1 Energy Consumption - Copy - Copy
Name of this assumption.

Report Section
Energy Calculations
Please select the report section this assumption belongs to.

Assumption Type
Load Profile
Please select an assumption type.

Load Profile
Singleton_Term_1_2021
Please select a load profile or select new to create a new one.

Projection Curve
None
Please select a projection curve or select new to create a new one.

Site Name
Singleton High School
Name of the site this assumption is referencing.

Numeric Value
1
The numeric value of this assumption. Not all assumptions require this value.

Text Value
Not Required
The textual value of this assumption. Not all assumptions require this value.

Start Date

« ‹ January 2019 › »

MON	TUE	WED	THU	FRI	SAT	SUN
31	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31	1	2	3

The date this assumption is applicable from.

End Date

« ‹ January 2029 › »

MON	TUE	WED	THU	FRI	SAT	SUN
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31	1	2	3	4

The date this assumption is applicable to.

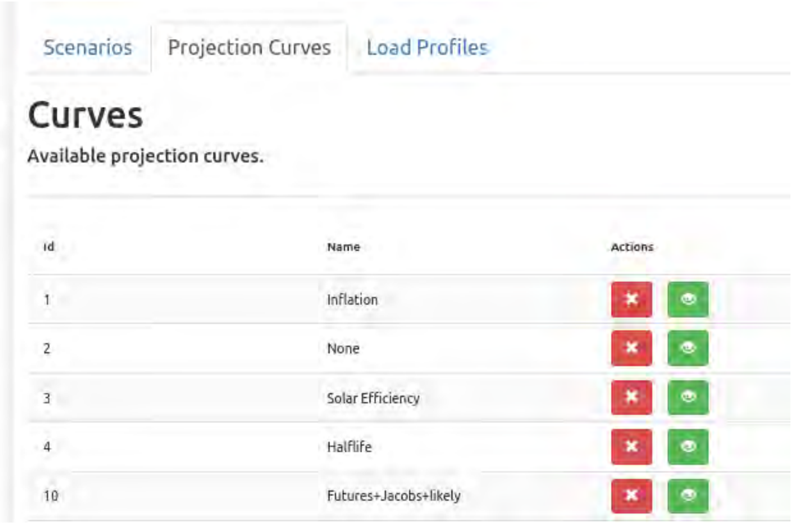
Figure 178: financial modelling - assumption input form

Notes for Figure 178:

- **Report section** defines if the assumption pertains to energy calculations, capital expenditure, operational expenditure or cashflow.
- **Assumption type** – as listed above
- **Load profile** (for type of same name) – returns a list of available load profiles
- **Projection curve** – returns a list of available projection curves to apply to the assumption
- **Site Name** – name of the site the assumption is referencing
- **Numeric value** – starting figure, or static figure depending on type
- **Date start/end** – selectors for what time period the assumption applies. e.g. this load profile could run for the first 20 years, with another in the second 20 years.

8.13 Projection curves

Projection curves are modifiers to assumptions that can be applied across time, for example the inflationary effect upon the cost of goods. The settings webpage as shown in Figure 179 offers the following view of configured projection curves brought forward from the preliminary financial modelling.



Curves

Available projection curves.

Id	Name	Actions
1	Inflation	✖ 👁
2	None	✖ 👁
3	Solar Efficiency	✖ 👁
4	Halflife	✖ 👁
10	Futures+Jacobs+likely	✖ 👁

Figure 179: financial modelling - projection curve selection

Notes for Figure 179:

Projection curves used in this model include:

- inflation;
- solar efficiency;
- installation costs;
- half-life; and
- futures+Jacobs+likely (electricity cost forecast) – detail shown in Figure 180.

This could also include engineering factors such as battery round trip cost, but such curves were rendered unnecessary through the use of load profiles representing engineering variables in the modelling.

Each projection curve can be rendered in the settings webpage, with the following Figure 180 rendering the futures+Jacobs+likely electricity cost forecast to 2054 (remainder of the graph is at 0% change).

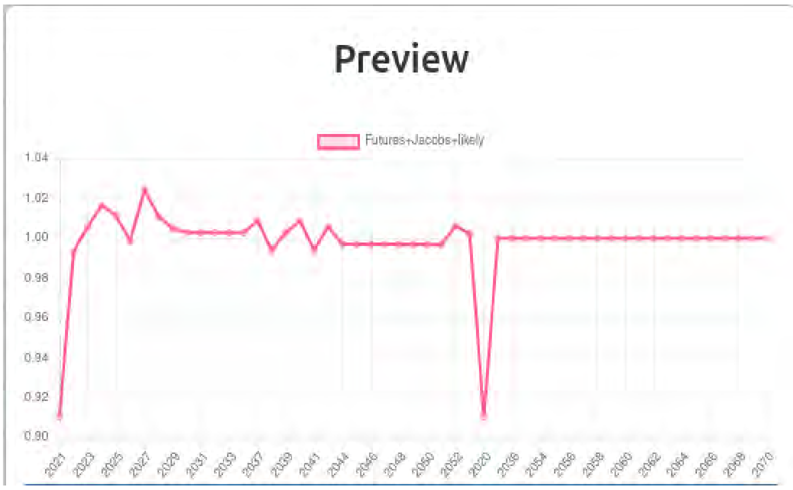


Figure 180: financial modelling - futures+Jacobs+likely electricity cost projection curve as % change year-on-year

8.14 Load profiles

The above data sources and calculations were used to generate load profiles for the modelling engine to process. A load profile represents the average consumption and maximum demand across the course of a single day, matching the output of the CSIRO battery control algorithm.

An infinite number of load profiles can be loaded into the modelling settings database. To keep this manageable, at first, a methodology from the preliminary financial modelling was brought forward: seasonality of analysis. A minor modification was added, increasing the sophistication of the model. Rather than considering summer, winter, summer/autumn and unoccupied, instead we shifted the model to:

- Term 1 – 4 (occupied)
- Summer, autumn, winter, spring holidays, weekends (unoccupied)

For a total of 8 load profiles per scenario per school. This allows for seasonal modelling of occupied versus unoccupied schools.

However, it was found that running the 2019 baseline for Singleton HS produced an energy cost of $72,300, far from the $130,000 in invoiced amounts during that same period. Using an algorithm that was developed for CCP7A where 365 unique load profiles are generated and applied on the 2019 baseline modelling scenario produced a result of $120,000 – within the margin of error – although it is acknowledged that with more time this figure would have become more accurate.

This method was then brought forward to all the modelling scenarios as clearly means and max based on seasons/unoccupied were not sufficient to capture the complexity of the energy market, evident on both retail and WSP modelling scenarios. The 365 unique daily load profiles generated represent a full year in order to capture the benefits of load shifting and demand response based on retail or WSP, per scenario, for a total of 10,220 individual daily load profiles across the three schools. The daily load profile method across a full year was ultimately the solution settled upon to produce accurate outputs.

A typical load profile appears in the modelling settings webpage thus:

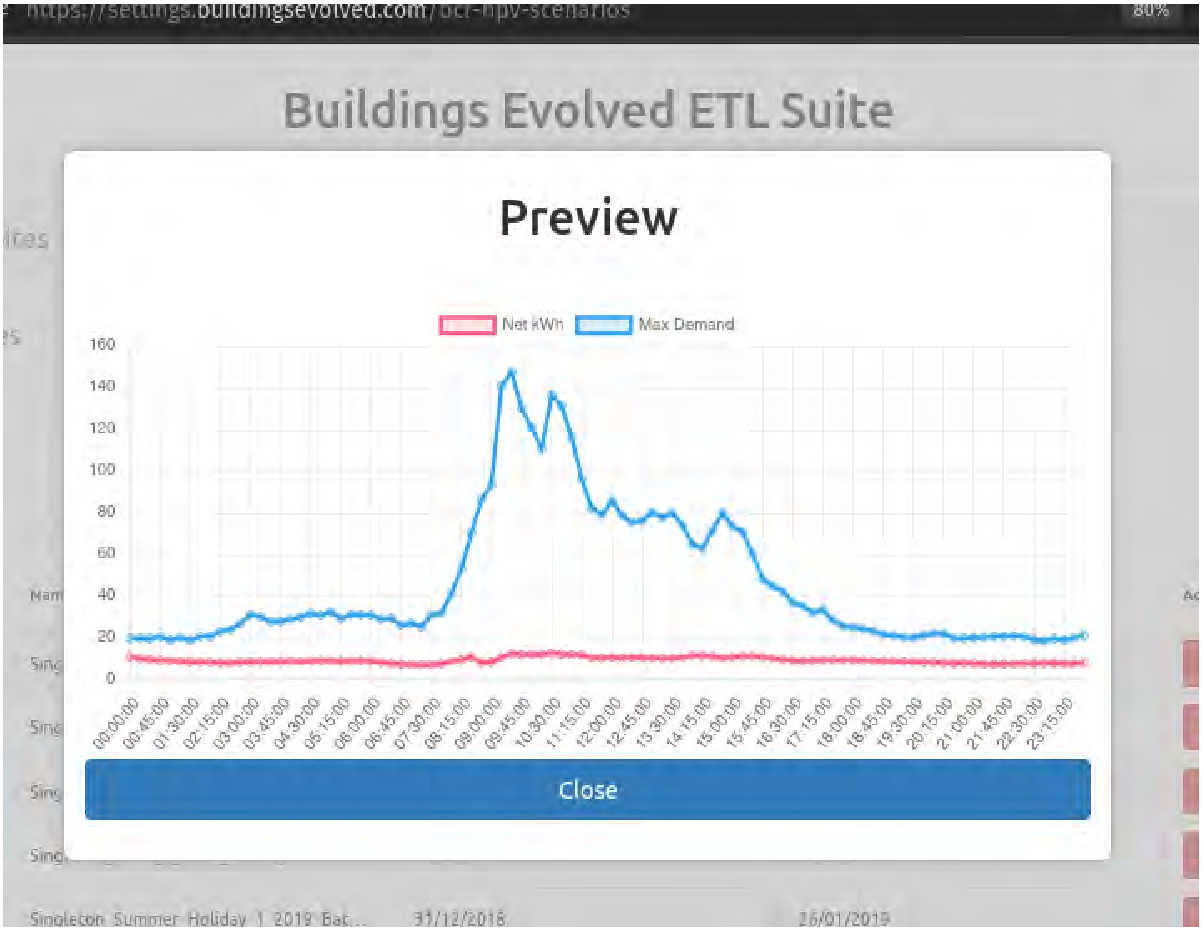
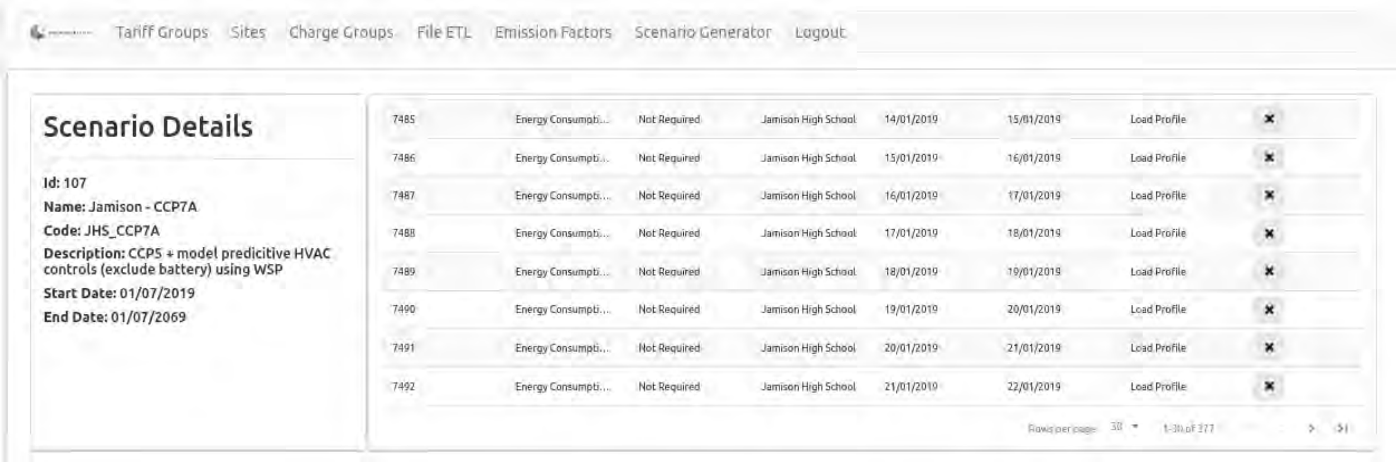


Figure 181: financial modelling - load profile example

The X axis is the time while the Y axis is KWh (**red** line) or KW (**blue** line). The KW line represents the max of all input data the model, in this case a day in October for Singleton (2019 modified data as baseline).

In excess of 10,200 load profiles have been generated through execution of various algorithms to process historical data as outlined above. A list of these load profiles are made available through the financial modelling settings page, as shown in Figure 182 and Figure 183, and can then be added to respective scenario/assumptions to generate the financial models.



Scenario Details

Id: 107
Name: Jamison - CCP7A
Code: JHS_CCP7A
Description: CCP5 + model predicitive HVAC controls (exclude battery) using WSP
Start Date: 01/07/2019
End Date: 01/07/2069

7485	Energy Consumpti...	Not Required	Jamison High School	14/01/2019	15/01/2019	Load Profile	✖
7486	Energy Consumpti...	Not Required	Jamison High School	15/01/2019	16/01/2019	Load Profile	✖
7487	Energy Consumpti...	Not Required	Jamison High School	16/01/2019	17/01/2019	Load Profile	✖
7488	Energy Consumpti...	Not Required	Jamison High School	17/01/2019	18/01/2019	Load Profile	✖
7489	Energy Consumpti...	Not Required	Jamison High School	18/01/2019	19/01/2019	Load Profile	✖
7490	Energy Consumpti...	Not Required	Jamison High School	19/01/2019	20/01/2019	Load Profile	✖
7491	Energy Consumpti...	Not Required	Jamison High School	20/01/2019	21/01/2019	Load Profile	✖
7492	Energy Consumpti...	Not Required	Jamison High School	21/01/2019	22/01/2019	Load Profile	✖

Figure 182: financial modelling - load profiles list in the settings webpage

Energy Consumption 2019-01-14 to 2019-01-15
Energy Consumption 2019-01-15 to 2019-01-16
Energy Consumption 2019-01-16 to 2019-01-17
Energy Consumption 2019-01-17 to 2019-01-18
Energy Consumption 2019-01-18 to 2019-01-19
Energy Consumption 2019-01-19 to 2019-01-20
Energy Consumption 2019-01-20 to 2019-01-21
Energy Consumption 2019-01-21 to 2019-01-22

Figure 183: financial modelling - load profile description detail

8.15 Algorithm generated what-if load profiles

Load profiles are the “what-if” engineering input to the financial model. The model allows for infinite daily load profiles to be created, either manually or programmatically. For our project we chose the latter path due to the sheer numbers of scenarios modelled and the complexity of model predictive controls. In order to project costs in a financial report, one must first develop a functional control algorithm that simulates an output, which is then captured into a report.

CCP6 (CSIRO battery control MPC) and CCP7 (Buildings Evolved HVAC MPC) are examples of fully functional MPC algorithms that use historical data to solve for what should the operation of that equipment be at any given point in time based on weather, WSP & network tariffs. CCP6 solves for optimum battery controls, and CCP7 solves for optimum HVAC controls, both in the form of daily load profiles.

Daily load profiles are then processed by the tariff engine on an interval-by-interval basis with a combination of either *network + retail tariff* or *network + WSP* to produce the financial summary tables. As each year is calculated, a projection curve can be applied to adjust the load profile proportionally up or down to track improvements in efficiency, or conversely accommodate an increasing population.

Baseline 2019

This is unaltered original data from 2019 representing the last full year of operations, but not including as-installed battery or solar PV as part of this project.

Baseline 2019 + 2022 as installed solar (CCP5)

Due to COVID impacting on electricity consumption and demand during 2020 and 2021, the last full year of representative use data is from 2019. Given battery and solar systems were installed at approximately the same time and the schools were unoccupied, there is no easy way to baseline the as-installed system sizes.

CCP5 is simple in effect – take the 2019 baseline, disaggregated generation based on weather patterns, and adjust the amount of generation by a factor to uplift to the as-installed solar system size. This work was aided by having access to disaggregated load information from the battery storage system.

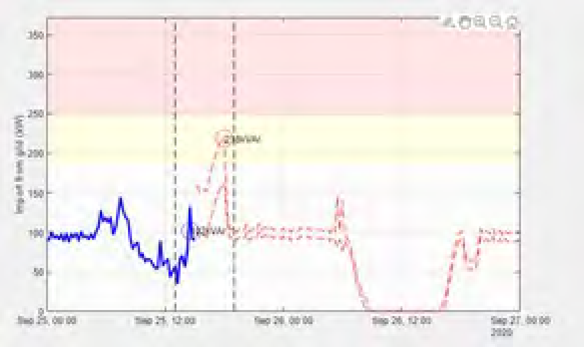
The impacts of battery operation is actively excluded from this scenario in order that we can appreciate the value of larger scale solar without the cost and complexity associated with battery storage systems. The outcome of this work was to produce a new 2022 baseline, minus battery storage that would then feed CCP6 and CCP7 scenario development. Battery data is important to remove from load profiles for further modelling, else you would be applying battery control logic on top of existing battery control logic.

Battery control algorithm (CCP6)

Significant progress has been made on the development of a battery control program for managing schools onsite energy demand. The objective of this program is to operate autonomously and provide charge/discharge control signals to the onsite battery based on a model predictive control algorithm (to be implemented in DCH6.2) that minimises electricity costs. Multiple battery control strategies are being developed ranging from simplistic charging to maximise self-consumption of PV generation, through to full 7 day ahead optimisation accounting for forecasting uncertainties and risk tolerance. An override feature enabling site managers to manually control battery charging/discharging is also planned to be included.

Key elements of the program include; i) forecasting algorithms for an individual schools electricity consumption and PV generation, ii) forecasts of weather at the site based on a blending of Bureau of Meteorology forecasts with site based measurements, iii) forecasts of wholesale regional reference electricity prices (for the case where electricity tariffs reflect wholesale costs), iv) a battery charge/discharge model, iv) the ability to input conventional tariff structures including fixed time of use, demand, capacity and feed in charges, and v) user configurable settings for example to adjust battery and model parameters.

Some results from the models developed for the battery control program are provided here.



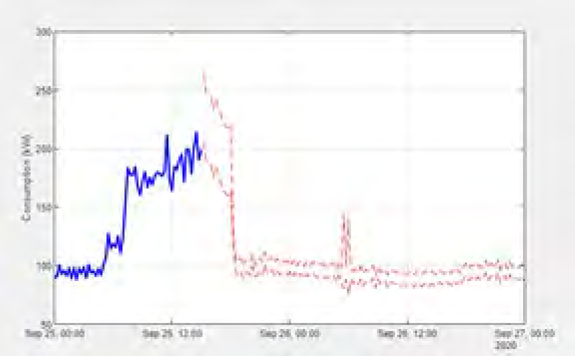


Figure 184: battery algorithm - energy use

Figure 185: battery algorithm - site consumption

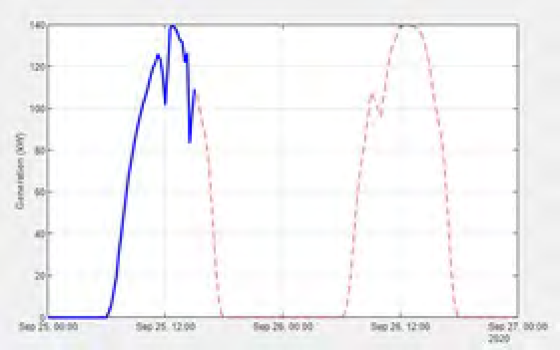


Figure 186: battery algorithm - site generation

Line	**Legend**
red-dashed	forecast
grey-dashed	historical forecast
solid blue	actual

The program interfaces with the DCH using Senaps API to send and receive data effectively in real time (every 5 minutes). Dashboards displaying real-time actual and forecast information on site consumption, generation, storage state of charge, planned charge/discharging profile, summary costs, and site grid import in comparison to current demand or capacity charge levels will be developed to facilitate user interaction.

However, through modelling it was found that arbitrage of the battery, even with a smart control algorithm from CSIRO, did not make the business case worthwhile with a BCR of 0.88 over 15 years and 1.5 over 50 years.

HVAC Model predictive controls (CCP7)

The expectation of MPC performance as an optimisation strategy is derived from literature which state MPC plus AFDD can reduce electrical maximum demand by up to 50% and electricity consumption by 30% as previously cited.

An MPC algorithm was developed by BE to create an estimated daily load profile for optimised control of HVAC by:

- importing historical NEM12 data;
- sampling the baseline consumption figures;
- understanding the nameplate electrical HVAC load;
- obtaining interval temperature and humidity data from the BoM; and
- being aware of wholesale spot price of electricity.

The steps in the algorithm are:

1. classing days as being occupied vs unoccupied;
2. classing days as being either sunny or cloudy;
3. use the above inputs to produce a multivariate regression analysis of the demand flexibility inherent in the HVAC systems;
4. negate any consumption during favourable outside conditions (by setting fan mode on HVAC systems);
5. identify high humidity but moderate temperature conditions (setting dry mode) and adjust consumption accordingly;
6. when the WSP goes above $400/MWh, initiate a demand response event (removing any HVAC flexible load) for a duration of 30 minutes; and
7. load shift forecast HVAC peak demand for extreme temperature days using various strategies including:
   a. pre-cool and pre-heat;
   b. night purge; and
   c. altering set points based on a thermal comfort model.

Work was done using genetic algorithms, fuzzy logic as well as MPC.

The MPC estimate method found in CCP7 is a likely case outcome if the schools deployed advanced algorithmic control of energy under a future second stage of this project.

MPC algorithms are using as inputs from constantly changing variables such as WSP, consumption, demand and weather, as well as static network tariffs in order to solve other unknown variables such as optimum system size and optimum daily load profile vs WSP. Given that the WSP changes on an interval-by-interval basis, no two days are the same. On this basis, it was decided to produce 365x daily load profiles for CCP7, rather than adopt the seasonality approach used in other modelling scenarios.

It is worth noting that pre-cool and pre-heat are likely to increase the amount of energy consumption, but dramatically reduce the peak load and associated energy costs. In our assumptions, we have offset this marginal increase in energy consumption with the increased efficiency delivered with a night purge strategy, both of which are a level of complexity not in the scope of this project. Real sensor data (not available at time of writing), however, would be able to provide this level of granular information and confirm results. Variability in thermal mass, aspect, age, insulation and other building fabric variables are not considered in this model, however this is again a level of complexity that was not in scope, and will become evident from real-world data when it becomes available.

8.16 Summary of assumptions

Common assumptions

Assumption	Value	Type
Discounted cash rate	1.056 (5.6%)	Per annum, adjusted by inflation
Solar PV capex	(New PV installed since 2019) x $1,056	Equipment replacement at 20 years
Solar PV opex	(2022 as-installed system size) x $28	Per annum, adjusted by inflation
Battery capex	$73,800	Arbitrage mode: replacement 15 years FCAS mode: replacement 25 years
Battery opex	Not provided	Per annum, adjusted by inflation
Controls capex	$25,000 for non HVAC control systems;	Equipment replacement at 25 years

	$50,000 for battery + PV control; $100,000 for HVAC controls; and $125,000 for HVAC + battery controls.	
Controls opex	Not provided	
FCAS	Battery: $6,922 per school. Controls: Jamison $9,424; Singleton $8,567; Nimbin $6,511	Per annum, adjusted by inflation
Avoided infrastructure upgrade cost	-$40,000	Once off

Energy calculations are the same as the preliminary financial modelling – see Figure 125.

Price projections

Inflation:

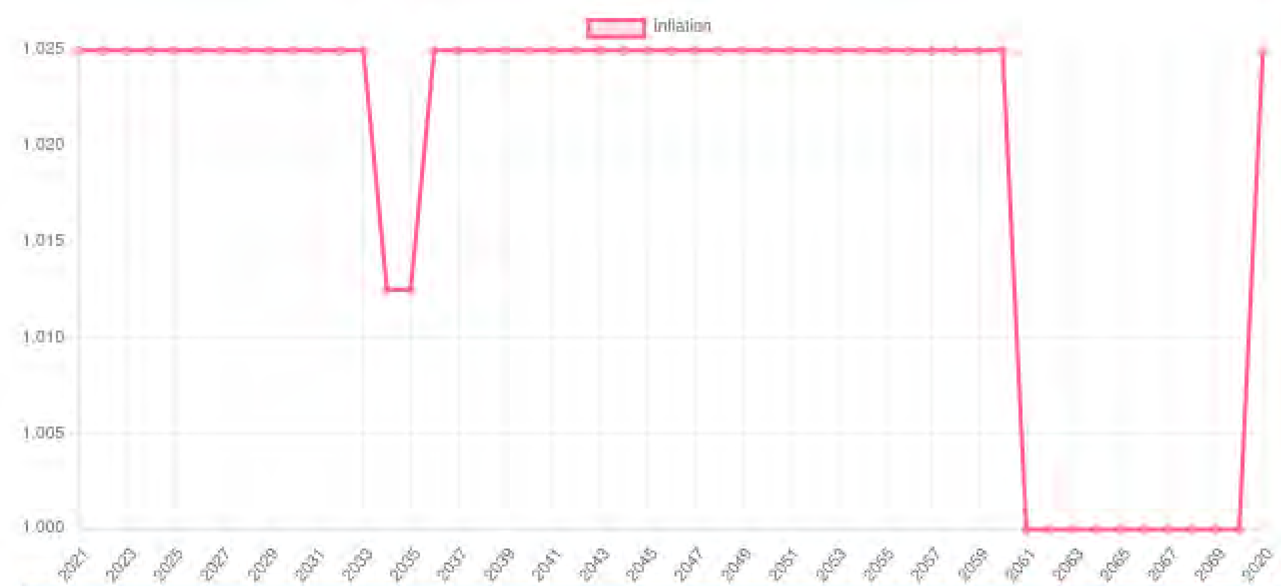


Figure 187: financial modelling - inflation assumption expressed as % change year-on-year

Futures+Jacobs+likely electricity price projection

Figure 188: financial modelling - Futures+Jacobs+likely electricity price forecast

9 APPENDICES

9.1 Knowledge Sharing: Video Script

This script was developed an shot by Buildings Evolved with input from SINSW and CSIRO. It is yet to be approved for release by media teams in SINSW and CSIRO.

What's the goal of this video? Why are we making the video in the first place?

- To share knowledge with stakeholders and the general public
- To raise awareness of a typical classroom control system used by SINSW
- To highlight the business case that the integration to the DCH brings
- To raise awareness of BE and drive traffic to the website

Who is the audience of this video?

- Project stakeholders
- Potential clients, organisations and industry personnel

What's our video topic?

- Building-to-grid data for real-time operational management and control
- Operational management and control of behind-the-meter assets
- Living laboratories – HVAC, energy data in response to internal and external conditions

What are the key takeaways of the video? What should viewers learn from watching it?

- How to wire, connect and commission a control system to the iHub DCH
- How buildings can respond dynamically to internal and external operating conditions to suit the needs of occupants and the broader energy network
- Increased efficiency with reduced operating costs and emissions
- Use of an adaptive thermal comfort model to improve occupancy comfort

What's our call-to-action? What do we want viewers to do after they've finished watching the video?

CTA: find out how buildings and technology can transform our energy network and market

View:

- BE website and blog
- BE white-paper
- I-Hub website

What's the wider marketing plan?

Website
External landing pages
Email campaign
Blog posts
Sales pitches

Audio	Visual Direction
In this video series: how to connect this [hold up PLC] to make it this [shot of MCC] connecting to these [shot of	hold up PLC

control panel, others in fast succession] in this [shot of office (Drone?)] to a cloud-based building-to-grid data clearing house capable of running machine-learning algorithms, model-predictive controls or other applications [screen capture of senaps] for Schools in NSW.	shot of MCC shot of school control panel
Welcome to the Buildings Evolved Living Laboratory in the Mid-north coast of NSW. This is the first in a series of videos walking you through our building-to-grid optimisation project for School Infrastructure NSW. Our other project partners are CSIRO and Data 61. Funding is from the Affordable Heating and Cooling Innovation Hub (iHub) ARENA project, which is administered by the Australian Institute of Refrigeration, Air Conditioning and Heating. Through this video we will demonstrate an IT centric approach to demand flexibility, energy efficiency, and thermal comfort in buildings. The neat thing about schools is that they are generally pretty evenly distributed by population. They have large rooftops for solar generation and plenty of area for battery storage. Schools also export electricity to the grid. Schools are located close to residential and commercial electrical demand, so the loss factors that make large-scale, and remote, generation projects inefficient are therefore reduced. Schools are also unoccupied for one third of the year, critically during the summer when electricity consumption is at it's highest, but also after 3pm every weekday. In future, the control system will be able to determine the operational energy mode of a school: should it be generating, charging, discharging or demand shifting? The aim of the project is to help schools consume less electricity, maximise return on investment, promote energy security, reduce electricity prices, and our carbon footprint. Through this series, we will show you how to wire, connect and commission the operational technology components like the air conditioning, batteries and solar inverters to the cloud for use by machine-learning optimisation algorithms.	Title slide Animated text displaying the opening line: DCH6.1 living lab Cut to drone footage of Bellingen Cut to Ariel/Arne Cut to HVAC and then Solar images
OK, so let's run through the components that we are integrating for our living laboratory.	
The first component in our setup is our private EDMI MK7	

electricity utility meter. This is “private” because we want to control the programming of it for R&D purposes, so it is downstream of our actual authority meter. In the schools, this is a 1:1 with what is supplied by the utility.	
The next component is a Fronius solar inverter. We can get data from inverters like the electricity meter, via Modbus, but with a richer set of data, and the ability for programmatic control.	cut to inverter
Inside we have a complete package air conditioning unit similar to what is found in a typical classroom. In our case, we chose a Daikin VRV ducted air conditioning system. We will refer to this as the HVAC system throughout our video. The original Daikin controller is behind this curtain, and is still fully functional. On the wall near the entry door we have a control panel that is IDENTICAL to those installed in the schools, enabling us to replicate the functionality of a typical classroom for R&D purposes. On the panel: • The black button is on/off • A blue light indicates that the HVAC is on • A green light indicates outside conditions are favourable for opening windows and doors. This is determined by the schools to be between 18 and 24 Celsius and less than 70% relative humidity • A yellow light indicates the maximum C02 level of 1500ppm has been reached or exceeded. At this point, a ventilation fan would turn on in a school. We have just replicated it with a relay for testing purposes.	
The custom wall control panel for schools connects to the mechanical control centre or MCC - the heart of the system. Later we’ll get onto the brain! At the core of any MCC is a programmable logic controller, or PLC for short. This one is from EasyIO, but we have found Distech, OzTech, and Omni Pro in the schools we have visited. Any of these brands and more are suitable for integration. The PLC connects sensors, the control panel, HVAC on/off and the ventilation fan together. A PLC has a simple layout: Ins here, Outs there, and a communication port or 3: here, here and here. These requirements are set by School Infrastructure NSW and are designed to maximise the indoor	cut to controller cut to server cut to CSIRO cloud/scientist

environment quality for students while ensuring energy efficiency is achieved.	
	- Cut to server - Cut to energy chart PLC screen capture
Inside the programming tool for the PLC, we see raw voltage and current values converted to actual values with an analogue filter applied. This gives us real-time indoor temperature and CO2, and outdoor temperature and humidity. The logic mentioned earlier is applied through this programming tool with the outputs being switched on or off for the control panel lights, fan on/off or HVAC on/off.	PLC screen capture
Moving from the “heart” to the “brain” of the system. Or the on-prem part of the brain, at least. The DCH Edge Server – here, a SuperMicro 1RU micro server running Debian and Docker. All the information we require from our various components onsite: our solar and battery inverter, utility meter and HVAC system are polled and transformed by the open source Node Red – a flow based programming tool that makes it easy for the controls industry to gain some powerful integrations. From the cloud, control algorithms, models, simulations, and applications can be run, with control signals transmitted back to the local environment in <1second. This architecture provides capability for control of onsite plant and equipment in standalone mode or as part of an integrated fleet of assets regardless of their geographic location. From a single site to an entire location, area or portfolio. An internet centric approach to operational management has the potential to balance the needs of occupants with the objectives of schools, the government, and the energy network. Click the link below to follow the project and its specific applications and algorithm development in operation.	- Cut to Arne - Cut to Node Red - Cut to info-graphic/video of cloud architecture - Cut to drone footage of solar - Cut to sunny city landscape
Hoped you like the video. Next in our series; we’ll be tearing down our living lab so we can rebuild it bit-by-bit. Like and subscribe, and tune in for our next video.	

9.2 Appendix – Origin Energy EDI data format

- C Contract Account Id
- Contract Account Name
- Address
- Division Txt
- Ca State
- Point Of Delivery Id
- Cont Movein Date
- Meter Read Date
- Peak Usage
- Off Peak Usage
- Control Load Usage
- Shoulder Usage
- Demand Usage
- Green Usage
- Solar Usage
- Unmetered Usage
- Other Usage
- Peak Cost
- Off Peak Cost
- Control Load Cost
- Shoulder Cost
- Demand Cost
- Green Cost
- Solar Cost
- Unmetered Cost
- Other Income
- Fixed Cost
- Discount Cost
- Concessions
- Num Of Days Billed

9.3 Appendix – Shell/ERM Power EDI data format

- ACCOUNT_NAME
- ACCOUNT_NUMBER
- INVOICE_NUMBER
- NMI
- VERSION
- ADDRESS_LINE_1
- ADDRESS_LINE_2
- SUBURB
- STATE
- POSTCODE
- FROM_DATE
- TO_DATE
- ISSUE_DATE
- DUE_DATE

- PREVIOUS_BALANCE
- PAYMENTS_RECEIVED
- OPENING_BALANCE
- INV_EX_$
- INV_GST_$
- INV_TOTAL_$
- NMI_EX_$
- NMI_GST_$
- NMI_TOTAL_$
- PASS_THROUGH_TYPE
- PERMIT_PRICE
- EMISSIONS_INTENSITY
- CARBON_QTY
- CARBON_RATE
- CARBON_LOSSES
- CARBON_$
- RETAIL_PK_QTY
- RETAIL_PK_RATE
- RETAIL_PK_LOSSES
- RETAIL_PK_$
- RETAIL_OP_QTY
- RETAIL_OP_RATE
- RETAIL_OP_LOSSES
- RETAIL_OP_$
- RETAIL_SH_QTY
- RETAIL_SH_RATE
- RETAIL_SH_LOSSES
- RETAIL_SH_$
- POOL_QTY
- POOL_RATE
- POOL_LOSSES
- POOL_$
- GECS_QTY
- GECS_RATE
- GECS_LOSSES
- GECS_$
- LRECS_QTY
- LRECS_RATE
- LRECS_LOSSES
- LRECS_$
- SRECS_QTY
- SRECS_RATE
- SRECS_LOSSES
- SRECS_$
- ESCS_QTY
- ESCS_RATE
- ESCS_LOSSES
- ESCS_$
- NGACS_QTY
- NGACS_RATE
- NGACS_LOSSES
- NGACS_$

- AGACS_QTY
- AGACS_RATE
- AGACS_LOSSES
- AGACS_$
- NESC_QTY
- NESC_RATE
- NESC_LOSSES
- NESC_$
- VRET_QTY
- VRET_RATE
- VRET_LOSSES
- VRET_$
- GREEN_QTY
- GREEN_RATE
- GREEN_LOSSES
- GREEN_$
- TARIFF_CODE
- MAX_DEMAND_KW
- MAX_DEMAND_KVA
- POWER_FACTOR
- DLF
- TLF
- NET_ENERGY_PK_QTY
- NET_ENERGY_PK_RATE
- NET_ENERGY_PK_LOSSES
- NET_ENERGY_PK_$
- NET_ENERGY_OP_QTY
- NET_ENERGY_OP_RATE
- NET_ENERGY_OP_LOSSES
- NET_ENERGY_OP_$
- NET_ENERGY_SH_QTY
- NET_ENERGY_SH_RATE
- NET_ENERGY_SH_LOSSES
- NET_ENERGY_SH_$
- TUOS_ENERGY_PK_QTY
- TUOS_ENERGY_PK_RATE
- TUOS_ENERGY_PK_LOSSES
- TUOS_ENERGY_PK_$
- TUOS_ENERGY_OP_QTY
- TUOS_ENERGY_OP_RATE
- TUOS_ENERGY_OP_LOSSES
- TUOS_ENERGY_OP_$
- TUOS_ENERGY_SH_QTY
- TUOS_ENERGY_SH_RATE
- TUOS_ENERGY_SH_LOSSES
- TUOS_ENERGY_SH_$
- NET_CAPACITY_QTY
- NET_CAPACITY_RATE
- NET_CAPACITY_LOSSES
- NET_CAPACITY_$
- NET_DEMAND_PK_QTY
- NET_DEMAND_PK_RATE

- NET_DEMAND_PK_LOSSES
- NET_DEMAND_PK_$
- NET_DEMAND_OP_QTY
- NET_DEMAND_OP_RATE
- NET_DEMAND_OP_LOSSES
- NET_DEMAND_OP_$
- NET_DEMAND_SH_QTY
- NET_DEMAND_SH_RATE
- NET_DEMAND_SH_LOSSES
- NET_DEMAND_SH_$
- NET_DEMAND_SUM_QTY
- NET_DEMAND_SUM_RATE
- NET_DEMAND_SUM_LOSSES
- NET_DEMAND_SUM_$
- NET_EXCESS_QTY
- NET_EXCESS_RATE
- NET_EXCESS_$
- NET_SERVICE_RATE
- NET_SERVICE_$
- NET_STANDING_RATE
- NET_STANDING_$
- CAC_$
- ASC_QTY
- ASC_RATE
- ASC_LOSSES
- ASC_$
- MARKET_FEE_QTY
- MARKET_FEE_RATE
- MARKET_FEE_LOSSES
- MARKET_FEE_$
- METERING_RATE
- METERING_$
- NMI_ADJUSTMENT_$
- NMI_ADJUSTMENT_GST_$
- ACCOUNT_ADJUSTMENT_$
- ACCOUNT_ADJUSTMENT_GST_$
- OTHER_$