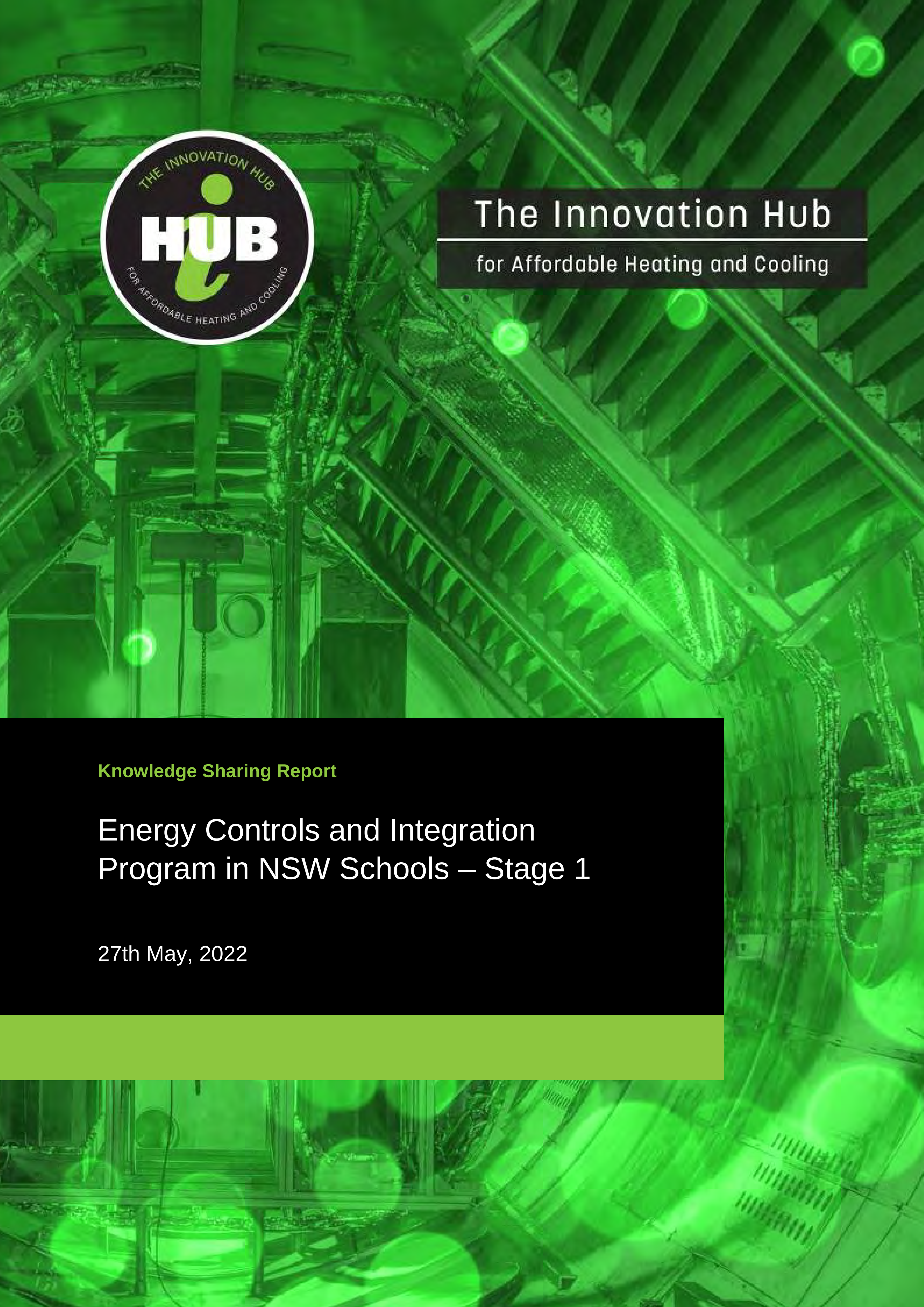

The Innovation Hub

for Affordable Heating and Cooling

**Knowledge Sharing 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.**
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**Primary Project Partner**

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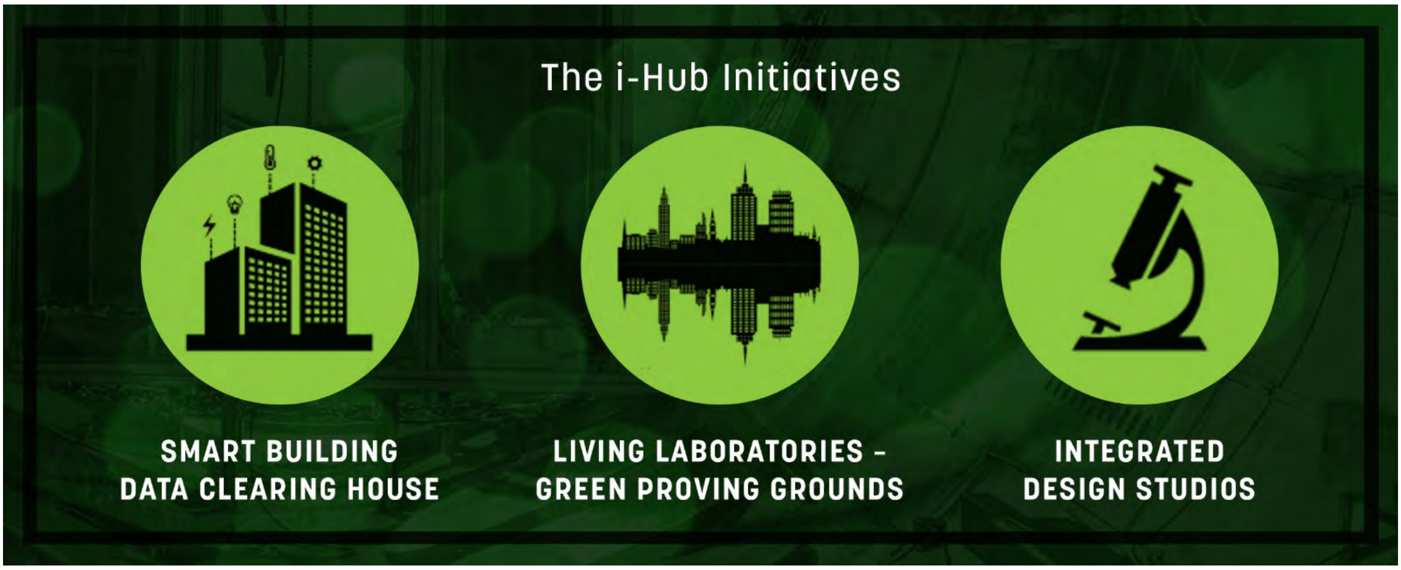

## Energy Controls and Integration Program in NSW Schools – Stage 1

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

### Project commencement date

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### Completion date

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# 1 SUB-PROJECT OVERVIEW, OBJECTIVES, AND IMPORTANCE TO INDUSTRY

## 1.1 Overview

As a part of the i-Hub Data Clearing House (DCH) initiative, CSIRO worked with NSW Department of Education, and Buildings Evolved on a project involving the integration of solar PV, battery storage and Heating, Ventilation and Air-Conditioning (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);

to reduce energy costs and provide a better understanding of the requirements and impacts of demand response initiatives. A secondary benefit was to improve occupant comfort and educational outcomes.

The 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 Objectives

The objectives of the project were 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 (CCP), and create a control application to integrate the installations at each site.

Due to impacts from Covid-19, procurement of batteries and expanded solar PV occurred during 2021, while the HVAC controls installation tender has been awarded but not yet completed at the time of writing in May 2022. As a result, a living lab was built to simulate a classroom in the BE offices, and detailed simulations of control were modelled in order to produce multiple "what-if" business cases for various combinations of equipment and tariff structures, based on available data.

Potential future stages of work for the schools includes connection to the i-Hub Data Clearing House which will acquire additional variables such as weather and NEM spot market prices and, taking in to account data acquired for the site, facilitate control algorithm sot further optimise the operations and maintenance of the equipment onsite.

## 1.3 Importance to market/industry

The NSW Government is investing record amounts into public school infrastructure for students and communities across NSW. This includes investing $500 million to provide sustainable air conditioning for NSW schools, under the Cooler Classrooms Program. Cooler Classrooms now covers 768 schools across the state. The NSW government also plans to install smart battery systems alongside rooftop solar, on government buildings, including schools.

The project outcomes are:

1. Integrate hardware components of solar, batteries and air conditioning into an energy system at a school. The challenge will be to use combinations of solar, batteries and air conditioning demand management to minimise costs (capital and operating).
2. With optimal management of solar PV, storage and load control, DoE could potentially participate in a virtual power plant program, earning revenue from providing energy services to the NEM.
3. In addition to energy cost savings and electrical infrastructure benefits, DoE would like to achieve visibility of operational data to facilitate maintenance and better communicate the benefits of the Cooler Classrooms initiative and energy systems to school communities and other stakeholders.

To date consolidating operational and performance data of solar PV installed across NSW schools, has proved difficult with proprietary vendor solutions. DoE is regularly approached by vendors with interesting data analytics solutions, including Fault Detection and Diagnostics (FDD), performance visualisation, etc. However, logistically it is difficult to support the diversity of offerings and systems available. In this context, the Data Clearing House is a potentially attractive solution for enabling both better integration of HVAC, PV and batteries, and opening up the potential to work with a wider variety of Australian service providers.

There are >2,300 public schools in the state of New South Wales, and alongside the other states, the independent and catholic schools, the impact of change could be enormous – allowing schools to act in a net positive way for integration of renewable energy sources onto the electricity network.

# 2 CHALLENGES FACED AND OVERCOME

## 2.1 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, the intent is for data to 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.

## 2.2 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 school's 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<br>Jamison & Singleton to 2022<br>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<br>Unreliable and of limited use |
| Alpha ESS | Battery Management System | 5 minute interval (KW instantaneous)<br>Provides data for:<br>• System SOC<br>• Grid consumption<br>• PV generation<br>• Battery charge/discharge | Jamison since Sep 20<br>Nimbin since Jan 21<br>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

## 2.3 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.

## 2.4 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.

# 3 LESSONS LEARNT

The DCH 6 sub-project sought to determine the optimum integration method of generation, storage and demand response via advanced HVAC controls. This proved to be a significant challenge due to the inherent complexity of electricity tariffs (network & retail time-of-use), and of the National Electricity Market (NEM) with its constantly changing spot price of electricity.

The key lesson that encompasses all aspects of the project, is that a variable price of electricity is a key motivator to act in the best interests of the electricity network – load shifting through night purge, pre-heat & pre-cool; load shedding during peak demand events (e.g. >$400/MWh); and obtaining payments from the electricity market for capacity and demand reduction. The business case for either wholesale pass-through NEM pricing via a retailer[1] or direct participation in the NEM via a Virtual Power Plant (VPP). Conversely, conventional retail tariffs do not provide the correct incentives based on events in the NEM. With the correct controls in place, the benefit of the NEM can be unlocked while mitigating risk of peak price events negatively impacting the bottom line.

Breaking down this key lesson, we find the following lessons learnt:

1. Modelling energy finance outcomes is extremely complicated.
2. Exposure to the wholesale electricity spot price provides significant benefit if demand response technologies are already in place
3. Battery storage is not (yet) an effective method of demand response compared with HVAC controls

## 3.1 Modelling energy finance outcomes is extremely complicated

Traditional approaches to producing financial outcomes associated with energy costs assumed that tariffs were time-of-use based, with the significance that producing those financial outcomes could be done using relatively simple methods and tools, such as spread sheets. Complexity was limited to a handful of ‘representative’ daily load profiles for each season, accommodating peak demand and consumption to allow the estimation of energy costs into the future.

The hypothesis of the project, that a mix of generation, storage and demand management could produce better commercial and societal outcomes, was predicated upon the use of the wholesale market (as a VPP) or through the use of wholesale pass-through retailers such as Power Shop or Amber Electric. The preliminary financial modelling could not handle the infinite complexity of a constantly changing price of electricity. An alternative was sought in software to create simulations of outcomes based on historic datasets that could model the wholesale spot price, network tariffs in conjunction with a range of other inputs.

All of the available energy finance modelling tools were created for overseas markets which do not have the level of complexity inherent in the Australian NEM, so therefore a tool had to be created in-house to solve for the hypothesis core to the sub-project.

A tariff engine was constructed to represent the various complexities of both network and retail tariffs including time-of-use, demand charges, environmental and other charges that appear on utility invoices. Meter data, sourced from the meter data agents, and the same data that is utilised by retailers, can then be parsed through the tariff engine to generate replica utility bills, for example. But more importantly, the tariff engine then allows for projection of costs into the future by applying projection curves (inflation, cost of electricity, etc).

FCAS and other markets have complexities that are difficult to model. Business cases for Hornsdale and UQ have varied from operational results, both financially and what was possible from an engineering perspective.

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[1] For example, Amber Electric or PowerShop

### 3.2 Exposure to the wholesale electricity spot price provides significant benefit if demand response technologies are already in place

Exposing a building or portfolio to the wholesale electricity price allows the systems within the building to respond to price signals, both forecast and real-time. Doing so allows the retailer hedge to be removed and makes the building responsive to electricity generation needs. It further allows access to the FCAS markets, unlocking revenues that make battery storage systems viable. Given that schools are too small to join the wholesale market (must be >1MW), aggregation of sites into a Virtual Power Plant could make this outcome possible. Retailers such as Amber Electric provide wholesale pass-through pricing allowing individual schools exposure to the wholesale price. FCAS payments would have to be negotiated via this arrangement.

The project was intended to produce real-world data as inputs to simulations for optimum control, and this work is yet to be done. However, the model predictive control algorithms used in the financial modelling have been developed ready for input from real-world sensor driven thermal models, and the development of the financial modelling tool has been invaluable in providing outputs associated with wholesale market participation. Simulation data based on real inputs would provide further assurance of the value of the approach studied in the project.

### 3.3 Battery storage is not (yet) an effective method of demand response compared with HVAC controls

It was found through extensive literature review and sophisticated modelling of the electricity wholesale spot price against an optimisation algorithm that batteries could not effectively help with demand response (DR) in a technical or commercial way compared with the introduction of advanced controls for heating, ventilation and air-conditioning (HVAC) systems.

Battery storage systems, when exposed to the NEM as a VPP, have the capability to generate income from virtual capacity markets and the Frequency Control and Ancillary Services (FCAS) market run by the Australian Energy Market Operator (AEMO). In this circumstance, the battery system has a payback of 9-12 years with a benefit/cost ratio of a little over 1.1x.

Conversely, HVAC controls were found to have an excellent business case – ranging from a BCR of 2x to 2.5x – as modelling showed the ability to load shift peak electrical demand through night ventilation purge and pre-heat/pre-cool, as well as energy efficiency opportunities. 50% demand reduction and 30% consumption savings were anticipated through simulations driven by a model predictive control algorithm.

### 3.4 Increased risk management is required in implementing projects where the technology is yet to reach maturity

Throughout the project it was evident that increased risk management is required in areas where there is technological immaturity, particularly in the process of interfacing these technologies in older buildings, in a retrofit context. While the installation and commissioning of the solar PV was relatively straightforward at the three schools, the battery energy storage systems and HVAC controls presented a number of difficulties.

In relation to the batteries, extended lead times, installation and fault detection issues, and commissioning of communications, was compounded by challenges presented by the Covid-19 pandemic. The tendering of the HVAC controls also posed challenges, particularly in establishing the contractors understanding of how the systems might interface with existing buildings and systems, with several rounds of tendering and contract negotiations required before a contractor could be engaged.

Although SINSW had a good understanding of the challenges around implementing less mature technologies, and several controls implemented to manage these risks, there has been a steep learning curve for suppliers and contractors which has resulted in additional time imposts, more intensive project management, and the requirement for increased dialogue between stakeholders including manufacturers, sub-contractors and the NSW Department of Education Information Technology Directorate.

# 4 EVALUATION OF PROJECT IMPACT AND TECHNOLOGY

This sub-project was of interest to the NSW Department of Education to assist in providing strategic direction to the energy system uplift of the building stock across the state, following the investment of $500m into the Cooler Classroom Project. The project was designed to make the HVAC systems financially sustainable, and to reduce their total cost of ownership through reduction in energy consumption and peak demand, as well as feed into better maintenance practises that increase equipment lifespan.

The sub-project has completed extensive engineering and financial modelling:

1. CSIRO System Advisor Model (SAM)
2. CSIRO internal system size modelling
3. Aeris Capital preliminary financial modelling (using business-as-usual tariffs)
4. CSIRO battery arbitrage simulation
5. Buildings Evolved HVAC optimisation simulation
6. Builidngs Evolved financial modelling tool using wholesale market pricing against the above

Each model confirmed completed found similar findings: HVAC controls and demand response provided significantly better financial returns than installation of batteries. HVAC controls also have the ability to improve occupant comfort directly, leading to improved educational outcomes.

HVAC controls provide a wide range of benefits, improving the business case in non-technical or non-commercial ways:

- Societal, regulatory: 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 demountable building 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.
- Commercial, regulatory: offset other capex costs
  - value engineer by removing DRED controllers/DRED capable equipment from CCP specification document; and
  - avoided electrical infrastructure upgrade costs by managing maximum demand.
- Commercial, technical, regulatory: 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;
  - 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.

The sub-project outcomes provide a strategic vision for the NSW government on how best to improve the operation of government buildings while simultaneously reducing costs and assisting the broader electrical distribution network.

# 5 OUTCOMES & KPIs ACHIEVED

## 5.1 Project outcomes

**Outcome 1:** Evidence provided to support proof of concept to integrate solar PV, batteries and demand response enabled HVAC systems at schools, reducing operating costs against BAU.

Due to the delays to procurement and installation of batteries, wiring and programming of controls the planned outcomes were only partially met, or are still ongoing. A contractor has been engaged for the installation of the communications and controls equipment, with program of works established for the next 12-14 weeks (from May 2022). The installation will be completed subsequent to the completion of the DCH 6.1 agreement due to the aforementioned delays.

However, in recognition of this as a likely outcome, project partners engaged in sourcing more data to create an advanced financial modelling tool driven by battery and HVAC control simulations. Six different models and simulations built by three different parties (CSIRO, Aeris Capital and Buildings Evolved) provided complimentary results. Solar PV + HVAC controls, driven by optimisation algorithms hosted in the DCH, provide better commercial, technical and societal outcomes than any other mix of technologies.

The broader electrical network has the ability to benefit as 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.

**Outcome 2:** Staff and contractors are empowered to deliver better asset management services through better access to data.

See outcome 1.

## 5.2 Project key performance indicators (KPIs)

**KPI 1:** Batteries, solar PV and integrated air conditioning controls installed and operating in 3 schools.

Milestone 7 has seen two main issues; the impacts of which have been felt by all partners in a multitude of ways.

- Additional delays to procurement of batteries and control systems
- Initial pricing from the market to gauge the capital costs for installation within each school was out of the foretasted milestone budget.

The impact of these the issues has a meant additional time and effort has been spent by all partners to address these to find a way forward. Working collaboratively, the project partners are committed to completing the installation beyond the time frames of the agreement.

**KPI 2:** Actual cost and cost variance.

The installation of solar PV has already had an impact upon the cost of operations at the three schools, although the data is still likely impacted somewhat by changes in operations surrounding the Covid-19 pandemic. Given the commissioning date and operational modes of the batteries have been extremely limited, this can be excluded as a factor given the sample range of the data in the table below.

| School | Baseline 2019 | MWh/KVA 2019 | Baseline 2022^ | MWh/KVA 2022 | $ saving<br>% saving | MWh saving<br>KVA saving | Network impact |
|---|---|---|---|---|---|---|---|
| **Jamison HS** | $61,000 | 283MWh<br>295KVA | $46,500 | 210MWh<br>226KVA | -$14,500<br>-31% | -73MWh<br>-69KVA | -25% MWh<br>-23% KVA |
| **Singleton HS** | $120,000 | 408MWh<br>400KVA | $98,000 | 356MWh<br>324KVA | -$22,000<br>-18% | -52MWh<br>-76KVA | -13% MWh<br>-19% KVA |
| **Nimbin CS** | $35,000 | 145MWh* | $18,500 | 59MWh* | -$16,500<br>-47% | -86MWh | -59% MWh |

* Small market sites (<100MWh/p.a.) do not provide data for maximum demand
^ 55-60KW solar PV & 60KWh/30KW battery

The forecasts in modelling show that HVAC controls have the potential to reduce consumption by 30% and maximum demand by 50% (in addition to the above), reflecting results of advanced HVAC optimisation in trials of a similar nature across the world. 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.

**KPI 3:** Schedule variance and major milestone achievements.

Key accomplishments include:

- Site visits & report
- Implementation & project management plan, timeline
- Comfort levels determination
- Engineering reporting
- Preliminary business case
- Front-end component sizing – business-as-usual scenario evaluation using System Advisor Model (SAM)
- Control methodology for HVAC system in schools
- Import asset data from three schools into test asset management system 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 Buildings Evolved (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

Overall, the sub-project has seen two main issues; the impacts of which have been felt by all partners in a multitude of ways.

- Additional delays to procurement of batteries and control systems
- Initial pricing from the market to gauge the capital costs for installation within each school was out of the foretasted milestone budget.

The impact of these the issues has a meant additional time and effort has been spent by all partners to address these to find a way forward. Working collaboratively, the project partners are committed to completing the installation beyond the time frames of the agreement.

# 6 OUTCOMES

## 6.1 Summary of results

The modelling demonstrates HVAC controls *without battery* consistently returns the best benefit cost ratio (BCR) of all three sites in DCH 6.1, 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 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.

## 6.2 Impetus for advanced financial modelling

The methodology employed 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.

### 6.3 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[2] [3] [4] [5]and as shown in Figure 1 [6].

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[2] Sayadi, Saeed & Morosuk, Tatiana. (2016). Reducing the Energy Consumption of HVAC Systems in Buildings by Using Model Predictive Control.

[3] Dong, Olama, Kuruganti, Nutaro et al (2018). Model Predictive Control of Building On/Off HVAC Systems to Compensate Fluctuations in Solar Power Generation.

[4] Godina, Rodrigues, Pouresmaeil et al (2018). Model Predictive Control Home Energy Management and Optimization Strategy with Demand Response.

[5] Merema, Carton, Saelens et al (2021). Implementation of MPC for an all-air system in an educational building.

[6] Serale, Fiorentini, Capozzoli et al (2018). Model Predictive Control (MPC) for Enhancing Building and HVAC System Energy Efficiency: Problem Formulation, Applications and Opportunities.

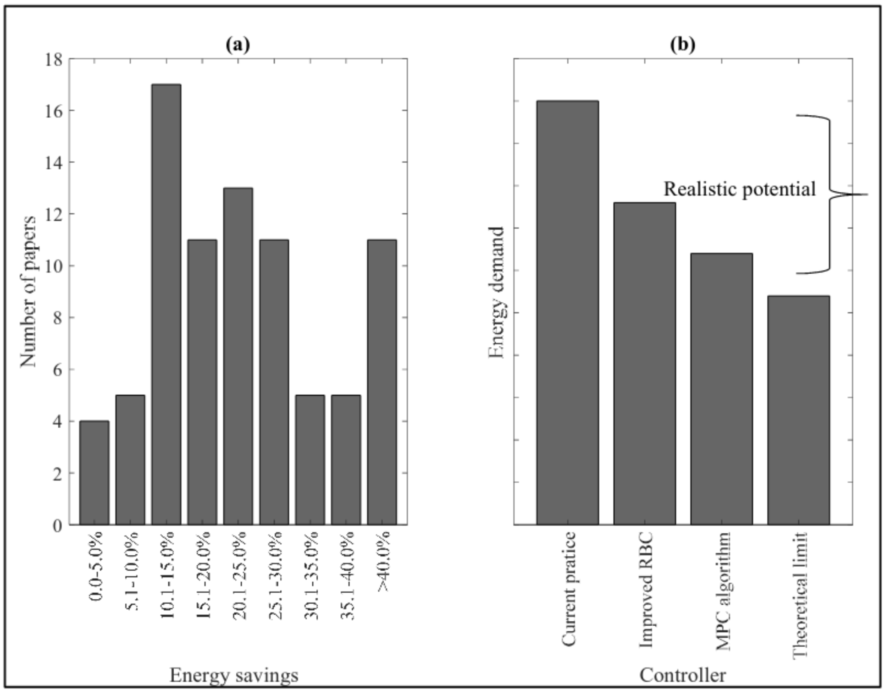

*Figure 1: Financial modelling - frequency distribution of the paper about the extent of energy saving consequent to the implementation of MPC algorithms; (b) estimation of energy saving potential exploitable employing the implementation of MPC algorithms for building energy management.*

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[7] 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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[7] https://sustainability.uq.edu.au/files/11868/EPBQtyRptq12020.pdf

## 6.4 Results for Jamison High School

Figure 2 shows the result of the 15 and 50 year benefit cost ratio (BCR) for Jamison High School. Figures 2 and 3 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 its own right.

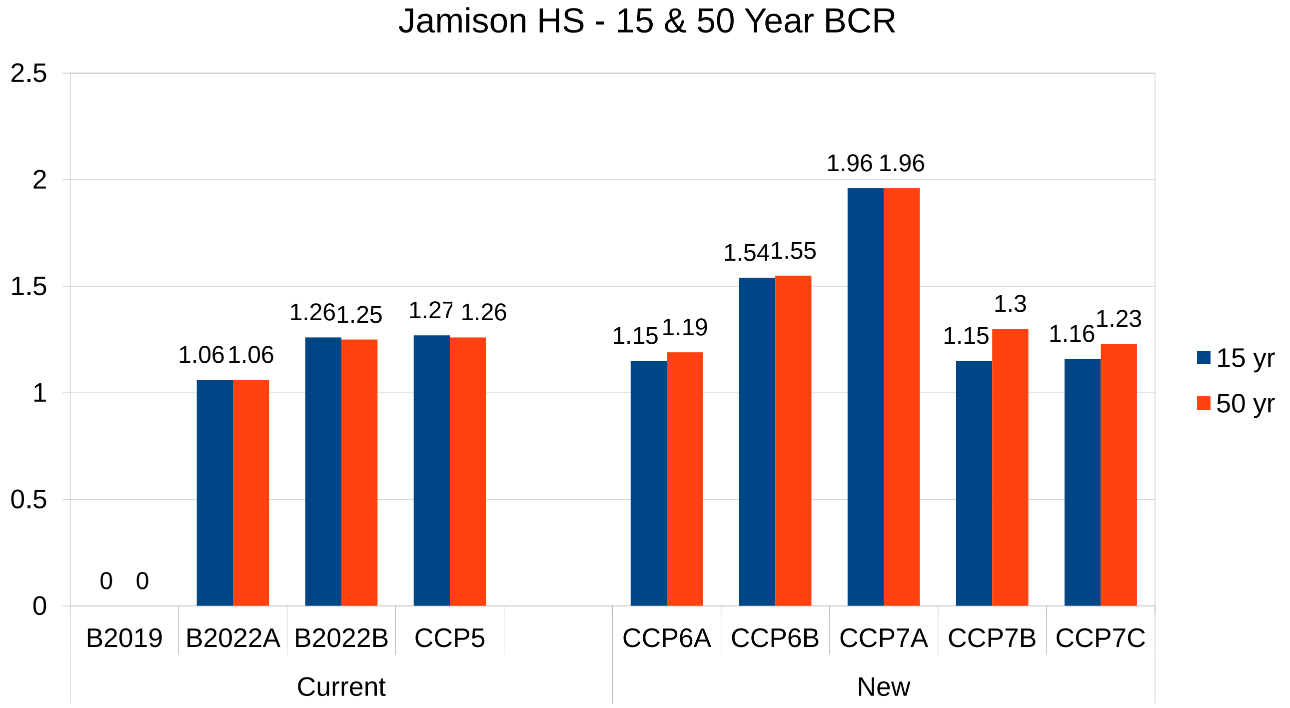

*Figure 2: Financial modelling - Jamison 15 & 50 year BCR results – DCR 5.6%*

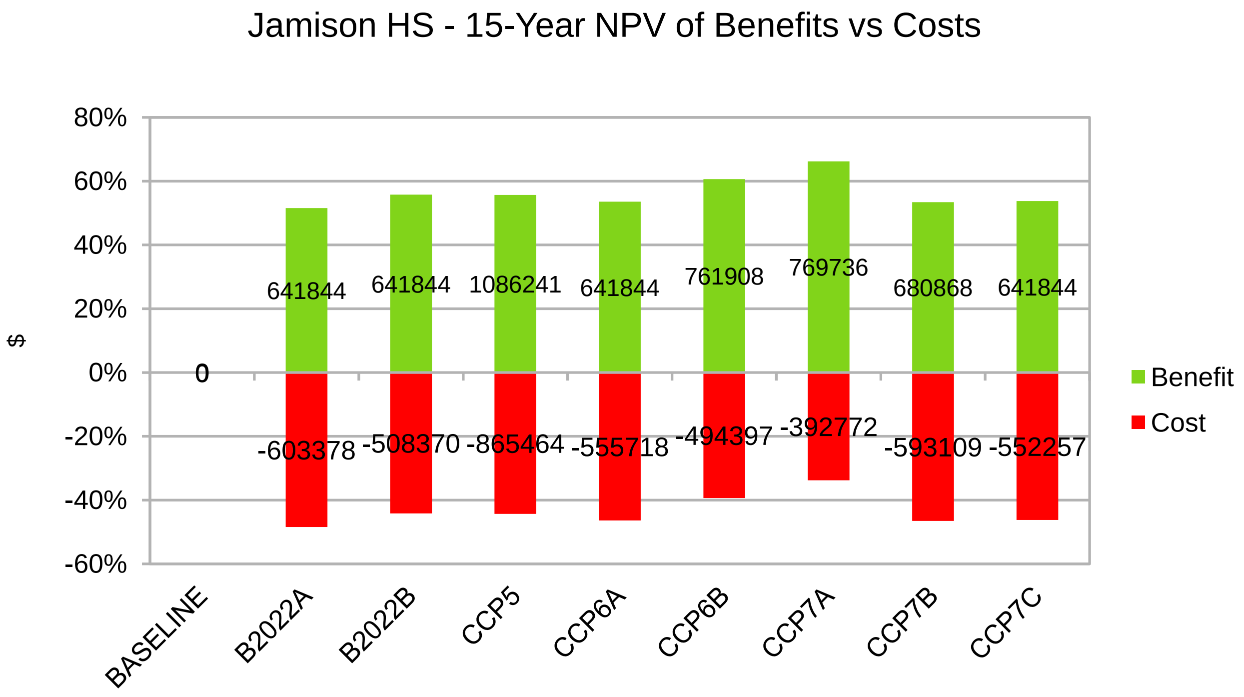

*Figure 3: Financial modelling - Jamison HS 15 year NPV benefits vs costs*

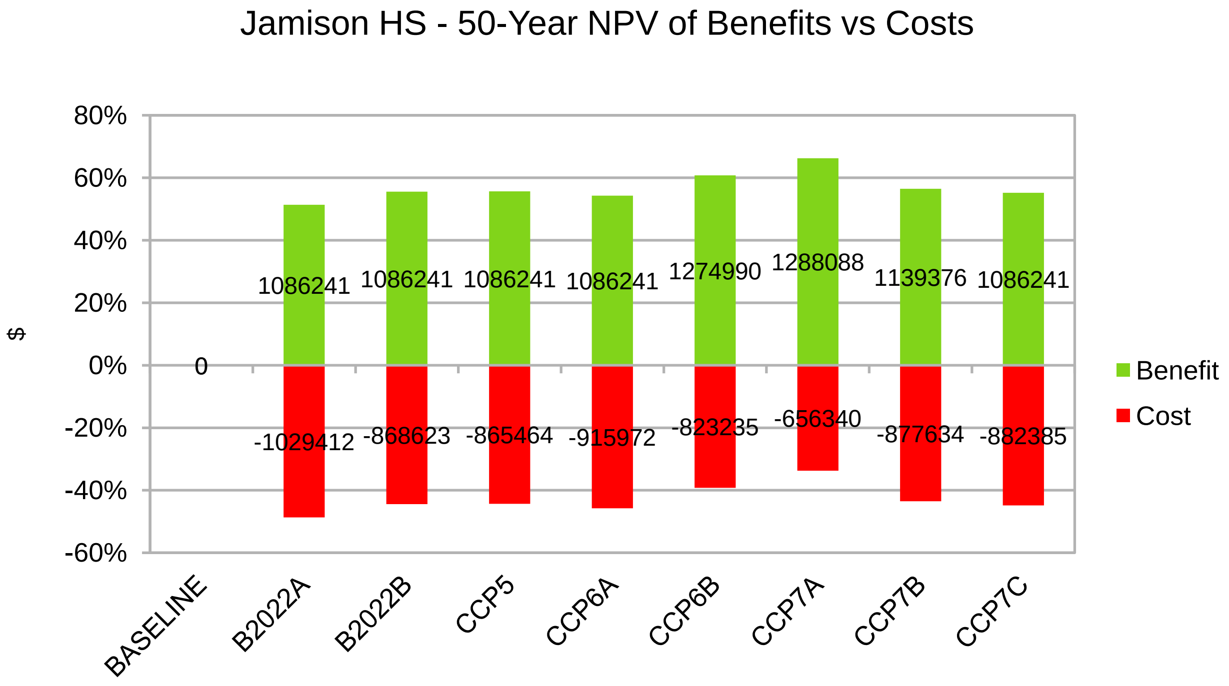

*Figure 4: Financial modelling - Jamison HS 50 year NPV benefits vs costs*

## 6.5 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 5 shows the result of the 15 and 50 year benefit cost ratio (BCR) for Singleton High School. Figures 6 and 7 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.

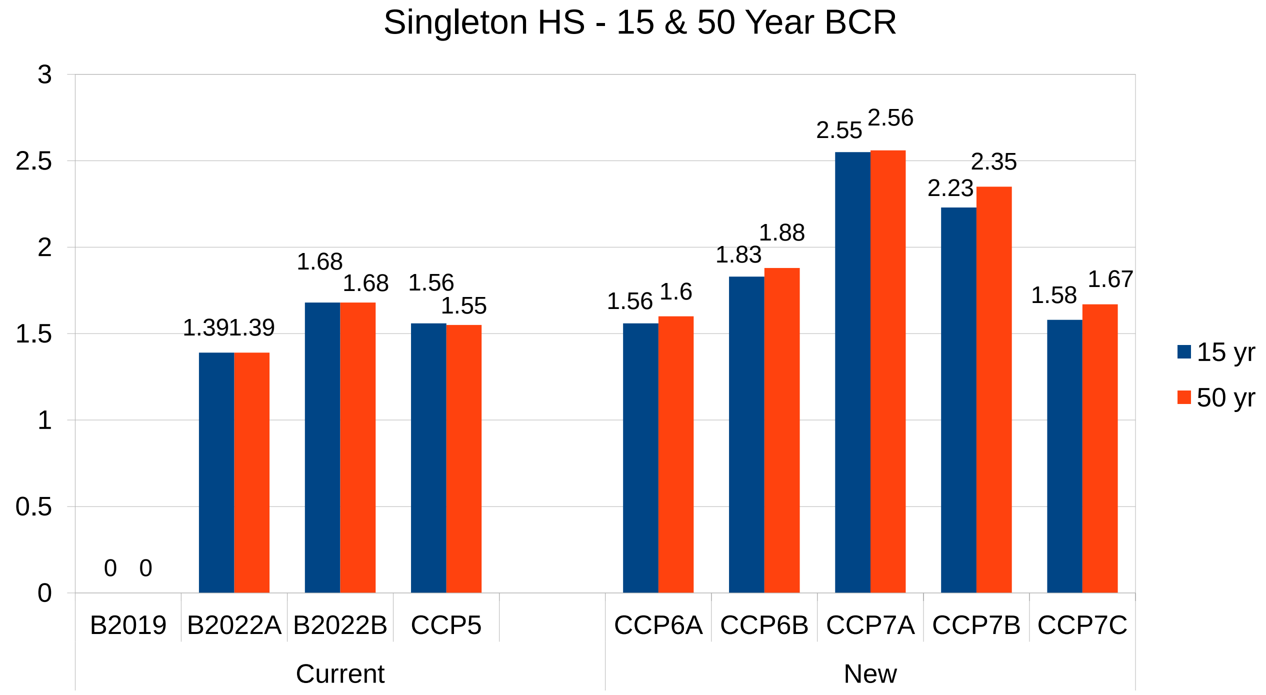

*Figure 5: Financial modelling - Singleton HS 15 & 50 year BCR results*

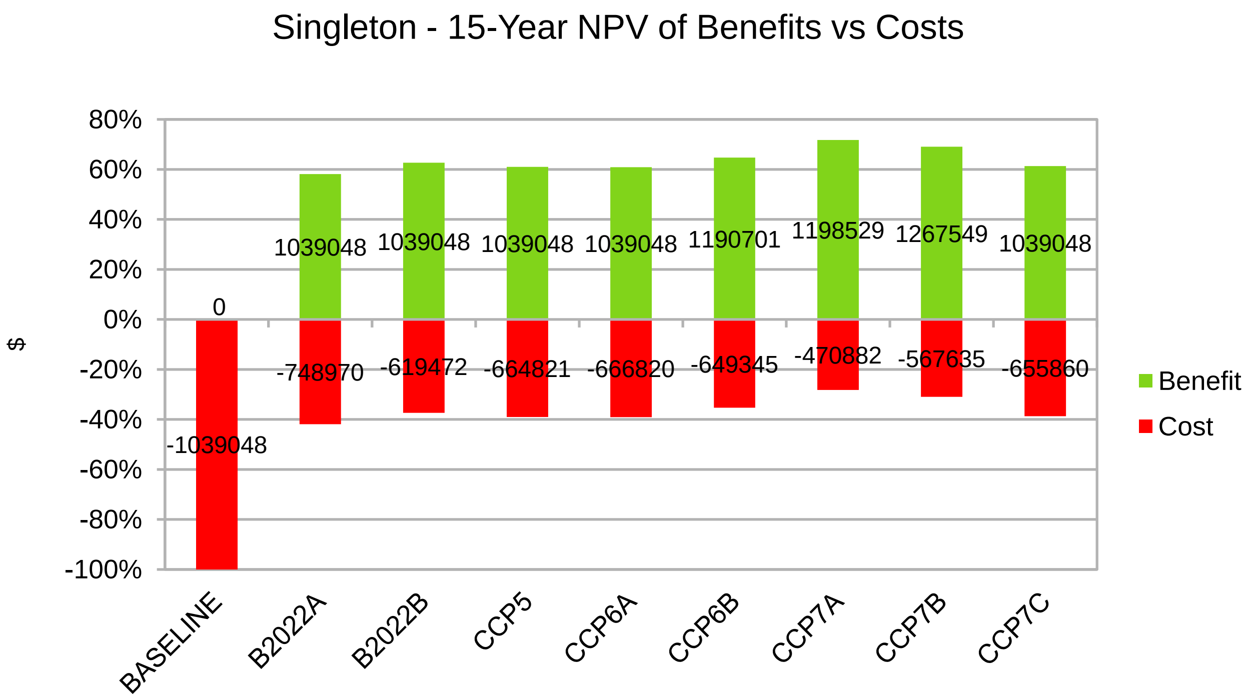

*Figure 6: Financial modelling - Singleton HS 15 year NPV benefits vs costs*

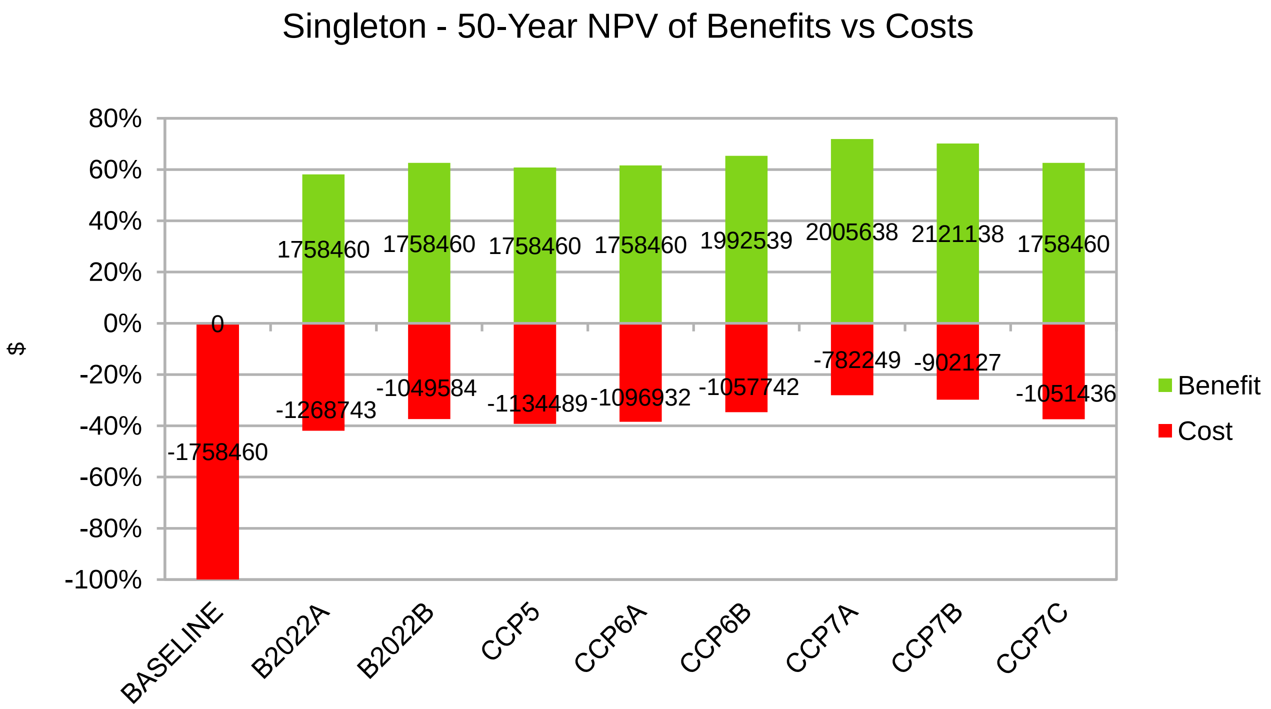

*Figure 7: Financial modelling - Singleton HS 50 year NPV benefits vs costs*

### 6.6 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 8 shows the result of the 15 and 50 year benefit cost ratio (BCR) for Nimbin Central School. Figures 9 and 10 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.

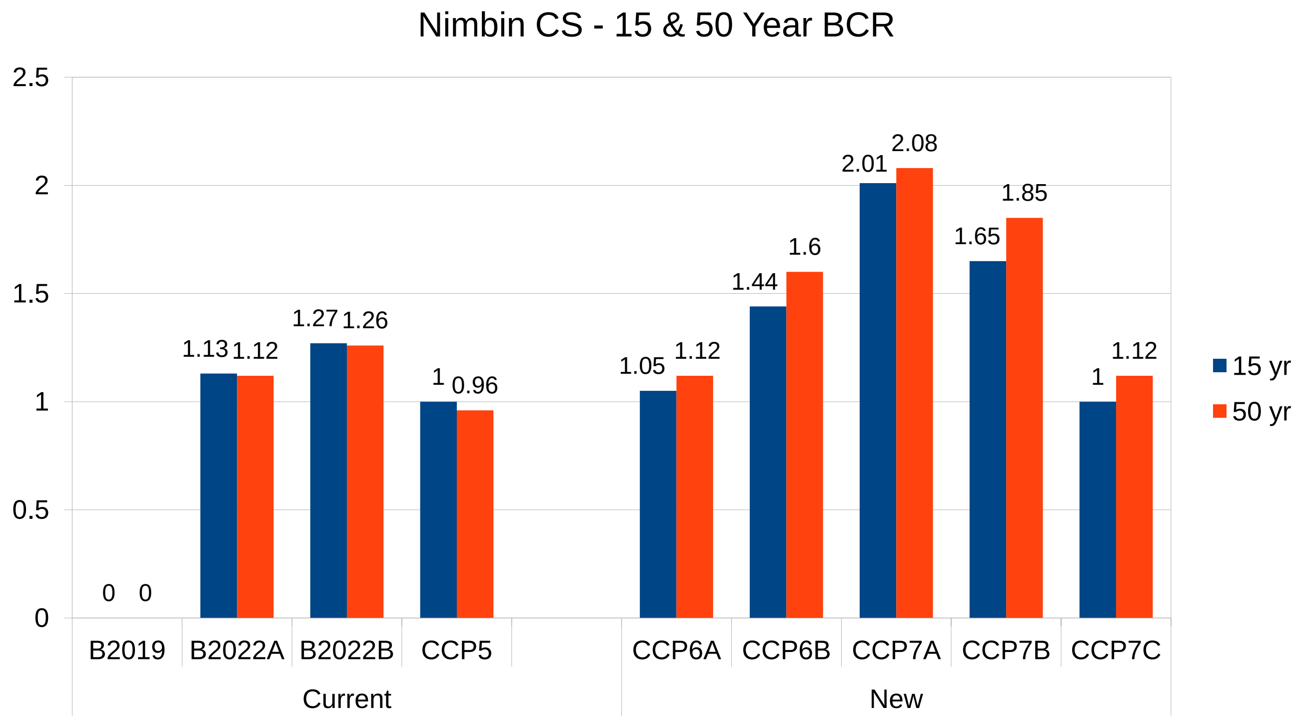

*Figure 8: Financial modelling - Nimbin CS 15 & 50 year BCR results*

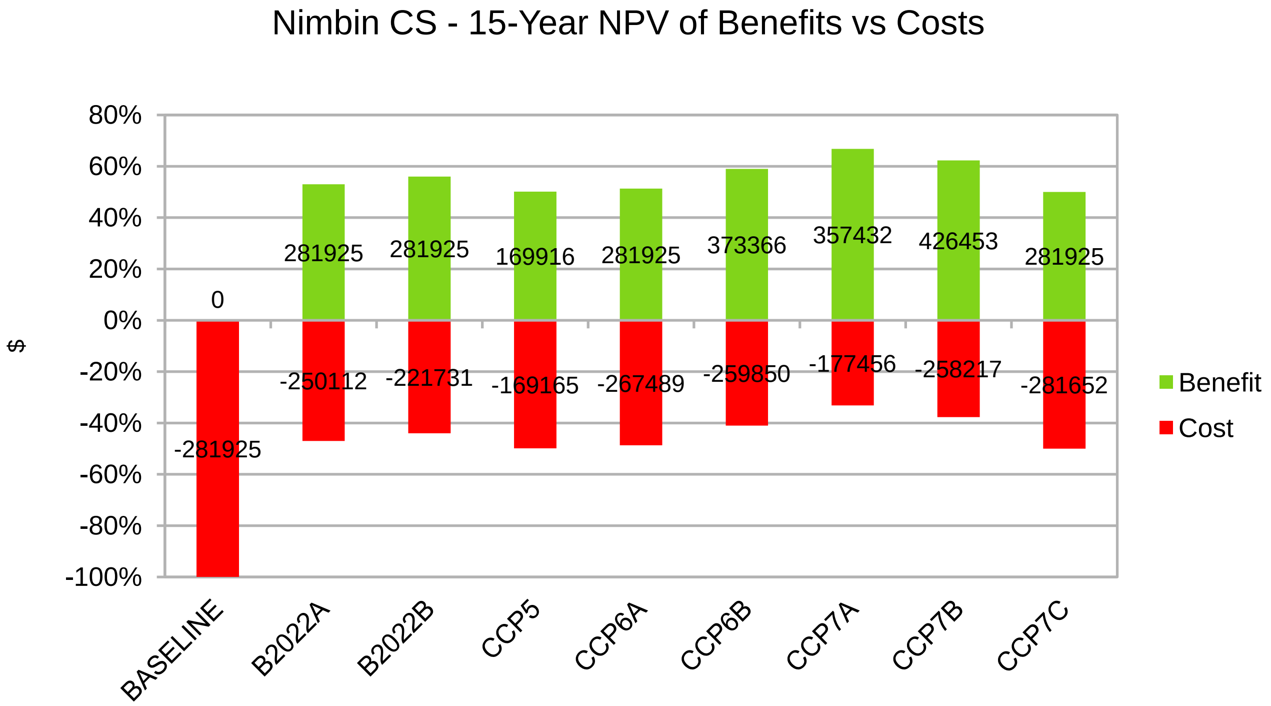

*Figure 9: Financial modelling - Nimbin CS 15 year NPV benefits vs costs*

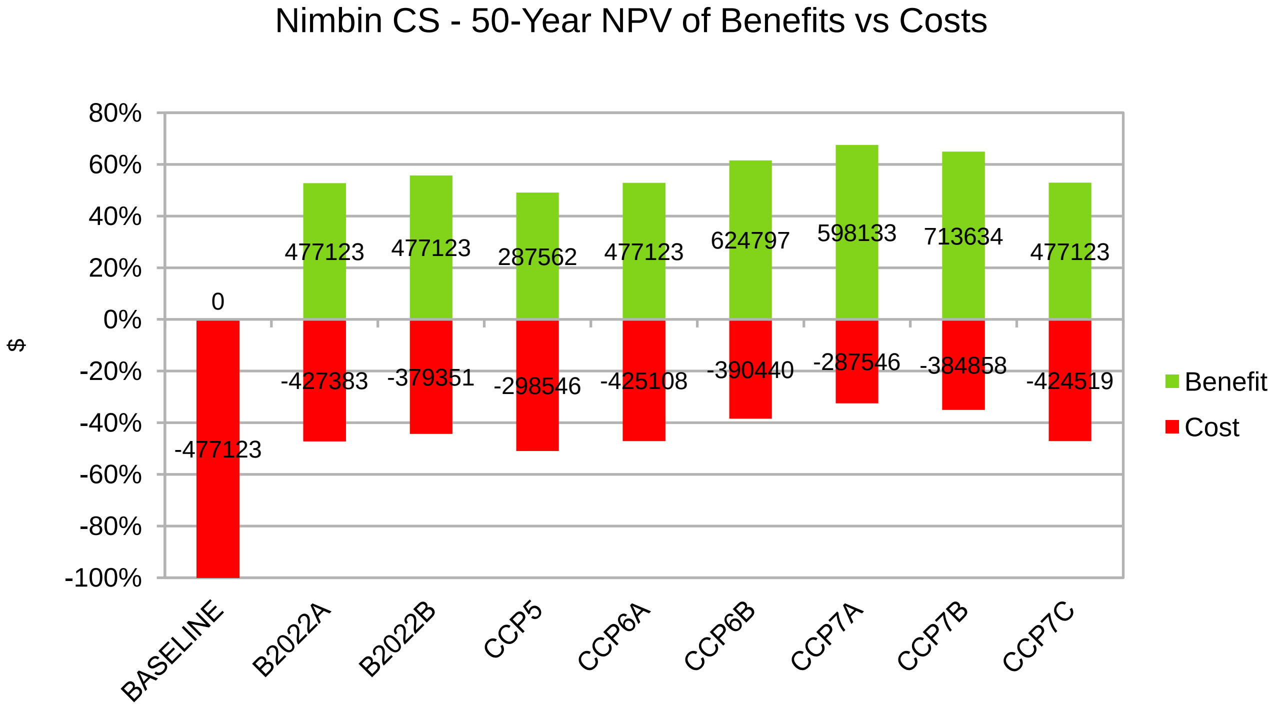

*Figure 10: Financial modelling - Nimbin CS 50 year NPV benefits vs costs*

### 6.7 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 11: 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 11. 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”[8].

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 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[9]:

| Mode | Charge | Discharge | Advantages | Disadvantages |
|---|---|---|---|---|
| **Peak** | Grid only, off-peak | Lower customer load to | Certainty of customer | Often results in under or |

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[8] https://www.ausnetservices.com.au/-/media/Files/AusNet/Business-Electricity/Demand-Management/Residential-Battery-Storage-Trial-Case-study.ashx?la=en p12

[9] https://www.ausnetservices.com.au/-/media/Files/AusNet/Business-Electricity/Demand-Management/Residential-Battery-Storage-Trial-Case-study.ashx?la=en

| | | | | |
|---|---|---|---|---|
| **lopping with fixed setpoint** | time | given setpoint (e.g. 30KW) | load on network energy price arbitrage between the charge and discharge | 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**<br>**(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, or feeder 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 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 +** | Cheapest power | Lower customer load to | Certainty of customer | Often results in under or |

| | | | | |
|---|---|---|---|---|
| **arbitrage + virtual cap**<br>**(UQ battery, Hornsdale Power Reserve et al)** | to achieve a full charge. Pre-charges using off-peak power based on expected PV production next day | given setpoint (e.g. 30KW), maintain sufficient SOC to be able to respond to FCAS and virtual capacity markets | load on network energy price arbitrage between the charge and discharge | 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[10]. 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”

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.

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[11].

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[12] 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.

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

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[10] https://hornsdalepowerreserve.com.au/wp-content/uploads/2020/07/Aurecon-Hornsdale-Power-Reserve-Impact-Study-year-2.pdf

[11] https://sustainability.uq.edu.au/files/11868/EPBQtyRptq12020.pdf pp17

[12] https://sustainability.uq.edu.au/files/11868/EPBQtyRptq12020.pdf pp11

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.

*Figure 12: 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 12, 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 or reduce impact on the grid, 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[13].

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 by Dr Mark Goldsworthy. 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.

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[13] https://sustainability.uq.edu.au/files/11868/EPBQtyRptq12020.pdf pp4

| 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 |

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[14]. The much reduced return with LGCs (as shown in Figures 13 and 14) 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.

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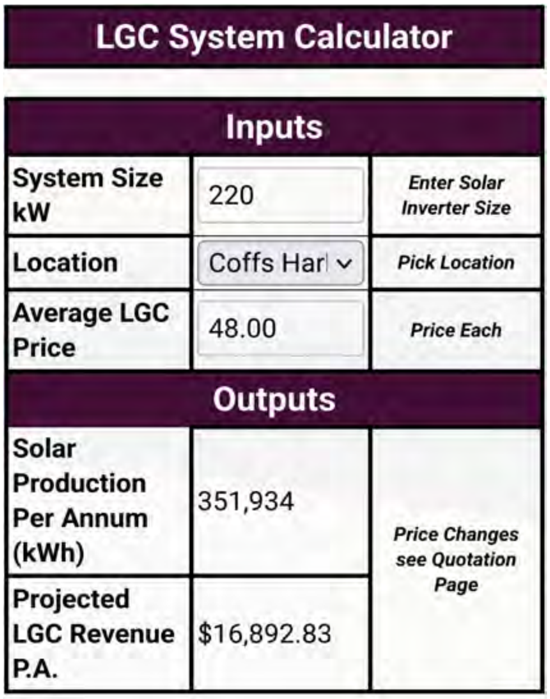
[14] http://www.cleanenergyregulator.gov.au/RET/Scheme-participants-and-industry/Renewable-Energy-Target-liable-entities/Calculating-certificate-liability



LGC System Calculator

| Inputs | | |
|---|---|---|
| System Size kW | 220 | Enter Solar Inverter Size |
| Location | Coffs Harl | 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 13: Financial modelling - LGC calculator from smartconsult.com.au

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 14: 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 15: 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 15, 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[15]. 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

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[15] http://www.cleanenergyregulator.gov.au/RET/Scheme-participants-and-industry/Renewable-Energy-Target-liable-entities/Calculating-certificate-liability

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:
    - 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[16];
  - 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** |
|---|---|---|
| 201 | 61 | 81 |
| 292 | 39 | 44 |
| 127 | 39 | 74 |

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[16] 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.

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 Error: Reference source not found) 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.

Further education campaigns would likely help reduce HVAC consumption further, particularly tackling open doors and windows while HVAC systems are turned on[17]. Another far more costly approach 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:

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[17] 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.

- leverages existing equipment installed under the *Cooler Classrooms Program* thereby not requiring any additional sensors HVAC systems or PLCs to be installed[18];
- 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.[19]), 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 |

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.

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[18] 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).

[19] 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

# 7 CONTRIBUTION TO I-HUB OUTCOMES

## 7.1 i-Hub outcomes

**1. Improve the control of HVAC&R compared to business as usual by demonstrating the capability within a selection of building types to reduce onsite energy use by at least 25%.**

Installation of larger Solar PV systems has reduced onsite consumption by:

- Jamison HS: 25%;
- Singleton HS: 13%;
- Nimbin HS: 59%; and
- with a reduction across three schools of 25.23%

| School | Baseline 2019 | MWh/KVA 2019 | Baseline 2022^ | MWh/KVA 2022 | $ saving<br>% saving | MWh saving<br>KVA saving | Network impact |
|---|---|---|---|---|---|---|---|
| **Jamison HS** | $61,000 | 283MWh<br>295KVA | $46,500 | 210MWh<br>226KVA | -$14,500<br>-31% | -73MWh<br>-69KVA | -25% MWh<br>-23% KVA |
| **Singleton HS** | $120,000 | 408MWh<br>400KVA | $98,000 | 356MWh<br>324KVA | -$22,000<br>-18% | -52MWh<br>-76KVA | -13% MWh<br>-19% KVA |
| **Nimbin CS** | $35,000 | 145MWh* | $18,500 | 59MWh* | -$16,500<br>-47% | -86MWh | -59% MWh |

HVAC controls have not yet been installed, however it has been demonstrated through simulations of flexible HVAC load that reductions in energy use of 30% are achievable beyond that of the solar PV. Due to delays in installation of HVAC controls, the capacity for savings has not yet been verified in the real-world, but is intended to be completed in due course by the NSW Department of Education.

**2. Reduce peak demand and demand charges as well as increase the hosting capacity of solar through load control combined with onsite renewable energy.**

Larger Solar PV system have reduced demand by:

- Jamison HS: 23%;
- Singleton HS: 19%;
- Nimbin: (unknown); and
- with a reduction across the two schools of 20%

HVAC controls, as simulated in this project, have the ability to reduce maximum demand by 50% beyond that delivered through the additional Solar PV systems.

**3. Increase the value of open data platforms and deliver innovation in the built environment to deliver energy savings.**

Data from the three schools is not available in the DCH at the time of writing, however it is scheduled to be online in the DCH before August 2022. The Buildings Evolved living lab, an analogue of a single classroom, has been connected to the DCH since August of 2020. An additional solar-passive residential house was added to the platform in September of 2020.

DCH 6 has assisted by providing input to the DCH 1 sub-project – development of the data clearing house – by providing requirements to help shape its development, and will continue to do so in future as the three schools are brought online into the DCH.

**4. Improve developer and building owner decision making capabilities by demonstrating the value of non-monetary benefits of energy productivity measures.**

The project has helped identify a wide range of non-monetary benefits aimed at improving the educational outcomes of students within NSW Schools centred on indoor environment quality associated with the introduction of HVAC controls.

It was found that optimisation is multi-faceted, and outcomes can be refined to suit the particular application or requirements of the building typology, in this case schools. At one extreme, the HVAC systems could be ineffective but deliver enormous energy savings, but at the other extreme, focuses entirely on occupant comfort neglecting the impact of cost. The policy setting as to exactly what is desirable in terms of savings vs performance are not the remit of this paper, and would be decided by government. However, it is known that ASHRAE 55 standards are desirable. Further modelling work would have to be undertaken to assess the cost impact of strict ASHRAE 55 compliance versus less strict compliance through a sensitivity analysis.

**5. Identify new technologies that can contribute to the decarbonisation of commercial buildings over the next decade.**

The sub-project identified and modelled various scenarios to discern which mix of technologies can contribute to the decarbonisation of commercial (or educational, in this case) buildings over the next decade. All permutations and combinations within the realm of sensibility were tested, focusing first on optimum system sizing and moving through to simulation of control and impact on the electrical daily load profile of the schools.

The combination of HVAC controls coupled with Solar PV showed the best financial returns. Given that financial impacts of energy consumption are directly tied to the environmental.

**Change the industry paradigm to make co-design a mainstream approach to deliver lower cost and higher performance buildings.**

Buildings Evolved have been working with the NSW Department of Education since 2014, acting as an independent consultant on renewable energy integration into schools across the state. BE has used a co-design approach with the department before and during the iHub DCH 6 project by working closely with key stakeholders within the department such as sustainability, cooler classrooms, smart energy schools as well as other departments such as NSW Department of Planning, Industry and Environment (DPIE).

## 7.2 I-Hub KPIs

**1. The capability to reduce onsite energy use by at least 25% (compared to BAU), by improving the control of HVAC&R and renewable energy, is demonstrated within a selection of three building types.**

The DCH 6 sub-project has assisted the i-Hub meet this KPI by providing evidence from real-world experience that energy savings of 25% have been made with expanded solar PV generation, and that modelling simulations show an additional 30% saving is possible using advanced HVAC controls in a school building typology.

**2. The capability of integrating HVAC load control with onsite renewable energy to significantly reduce peak demand (and demand charges) as well as increasing the hosting capacity of solar PV within the building or precinct is demonstrated within a selection of three building types.**

The DCH 6 sub-project has assisted the i-Hub meet this KPI by providing evidence from real-world experience that a reduction in peak demand reduction of 20% has been made with expanded solar PV generation, and that modelling simulations show an additional 50% reduction in peak demand is possible using advanced HVAC controls in a school building typology.

**3. Four Living Labs are created and operational.**

Although not part of the original project plan, due to the emergence of the Covid-19 pandemic, Buildings Evolved opted to build a living lab in a shared office space as an analogue to a classroom. Equipment was fitted out per the specification for the NSW Government Cooler Classrooms Program and then integrated to the DCH. Control algorithms were tested in the DCH to modify the set-points, mode and fan-speeds of the HVAC system in the living lab, testing a series of algorithms from adaptive thermal comfort, predicted mean vote, through to testing model predictive controls.

I-Hub could consider this an additional living lab created out of necessity through changed circumstances.

**4. i-Hub living labs contribute to the performance validation of 8 new technologies that can contribute to the decarbonisation of buildings over the next decade.**

As outlined in response to KPI 3, the Buildings Evolved living lab was used to test several algorithms including predicted mean vote, adaptive thermal comfort models and model predictive controls hosted in either the DCH or using software developed and hosted on the DCH edge server during the course of the sub-project. In addition, the sub-project utilised a battery hosted at CSIRO Energy Newcastle to inform simulations of arbitrage for the battery storage. The outcomes of financial modelling developed during the course of the DCH 6 sub-project provided an effective performance evaluation of different mixes of technologies and methods of engaging with the electricity market. During the course of the sub-project, 14 different mixes of technologies, system sizes, control strategies and market engagement were tested for each school, for a total of 42 what-if scenarios.

**5. One B2G DCH is created and operational (DCH 2.0).**

The i-Hub DCH 6.1 project did not have B2G as project deliverables or outcomes (this was foreshadowed originally for a potential DCH 6.2 stage 2), however future work by the NSW Department of Education could potentially incorporate a B2G strategy within it.

The MPC algorithm and simulation developed by Buildings Evolved solved for a range of inputs, including the wholesale spot price of electricity (forecast & actual), electricity network tariffs and weather (forecast & actual), and so should be considered a B2G application. It was created and used for modelling simulations, but was not deployed operationally during the sub-project. A possible path forward for NSW DoE is to use the MPC developed for simulations and operationalise it in the trial sites.

**6. The value of the DCH 2.0 open data platform to deliver increased innovation in the built environment and deliver further energy savings and other benefits to building owners and users is demonstrated using 6 B2G DCH Applications.**

The DCH 6.1 living lab was used by CSIRO and Buildings Evolved to test a range of control strategies and algorithms as part of the R&D phase of the sub-project. Predicted Mean Vote (PMV) and an adaptive thermal comfort model were tested directly on the living lab by DCH applications under development. Additional applications were developed and hosted on-premise including CSIRO with the battery control arbitrage optimisation and with Buildings Evolved, a range of rule-based control optimisations and a model predictive control algorithm for simulation and output of daily load profiles into the financial modelling tool.

We can therefore conclude that the living lab found in DCH 6.1 was used to test 2x applications hosted directly in the DCH (controlling real-world HVAC temperature set-points), 1x battery simulation using data from the DCH, and 2x control optimisations built and tested on-premise using DCH compatible code and technologies with a view to migrating these for commercial distribution in the future.

When the schools HVAC controls are brought online at Jamison HS and Nimbin CS after July 2022, sensor data will be loaded into the DCH in real-time from these two schools, allowing the development of thermal models and simulations of controls. The three schools will have a compliment of data from batteries, PV and the utility meter in the DCH.

Additional future stages (beyond simulations) will implement controls into the schools per the method used by the Buildings Evolved living lab to enable the deployment of optimisation algorithms into the DCH, for example the MPC application developed for the financial model.

**7. A pathway to 100MW of available demand response potential (proven and demonstrated through iHub sub-projects) is identified within the broader iHub portfolio (including the broader portfolio of partners).**

The sub-project demonstrated the peak demand reduction capability of 20% from larger solar PV systems using real-world data – comparing a 2019 baseline to a baseline from 2021-2022.

Modelling of HVAC controls showed a demand response capacity of 50% through use of 'night purge', pre-heat, pre-cool, smart mode selection, fan speed control, set-point control and control of ventilation fans.

Battery storage systems showed, through research, that the UQ battery is online 94.3% of the time. This alone invalidates the capacity of battery storage systems to adequately deal with peak demand events. While 'peak-lopping' was promised by vendors of battery systems, the reality has been very different. UQ report that 'peak-lopping' has not and is likely to never be implemented in their operation, instead focusing on improving their arbitrage algorithm and using mass thermal energy storage to reduce peak demand – acknowledgement that HVAC controls have inherent ability to shift loads in a more meaningful manner.

Providing the modelled results prove true in the testing stage, extrapolation to other sites would potentially present a pathway to 100MW of available demand response.

**8. X number of industry professionals, Y number of building owners and Z number of university students have been encouraged and provided the tools to make integrated co-design a mainstream approach to deliver lower cost and higher performance buildings.**

The sub-project was not intended to address this KPI.

**9. The benefits of early stage integrated design have been communicated to industry across 14 building projects.**

The sub-project was not intended to address this KPI.

**10. The Integrated design process is developed, documented, tested, released, and refined for different building topologies.**

The sub-project was not intended to address this KPI.

# 8 LIST OF PROJECT REPORTS

**Found in the final report by CSIRO Energy:**

1. Engineering modelling – System Advisor Model system sizing

**Found in the final report by Buildings Evolved:**

2. Buildings Evolved living lab
3. School site visit & recommendations
4. Asset management system integration and simulation
5. Preliminary business case & market analysis
6. Financial modelling using mix of retail, wholesale and network tariffs
7. 50 year forecast as cross-tab output from financial modelling
8. Knowledge sharing video script

**Found in the final report by Aeris Capital:**

9. Preliminary financial modelling using business-as-usual tariffs

**Other reports**

10. Battery sizing analysis for NSW schools: Nimbin, Jamison and Singleton High (CSIRO)
11. DCH 6.1 Technical Report: Site survey and concept design (Buildings Evolved)
12. DCH 6.1 Lessons learnt report v1.0 (October 2020)
13. DCH 6.1 Lessons learnt report v2.0 (May 2022)
14. DCH 6.1 Knowledge sharing report (this document)

# 9 NEXT STEPS

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 was 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 was to provide meaningful results that could be used to bring the project to the next stage should this be approved to proceed.

Once the additional HVAC controls are 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.