The Innovation Hub

for Affordable Heating and Cooling

Lesson Learnt Report

Energy Control and Integration Program in NSW Schools – Stage 1 M5 Report

Project DCH6.1

27th May 2022

School Infrastructure NSW

About i-Hub

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

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

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

Primary Project Partner

i-Hub Lessons Learnt Report

Guidance notes for completion of the Lessons Learnt Report:

- This report is intended to be made public.
- Please use plain English, minimise jargon or unnecessary technical terms.
- Please use your organisation's branding for the report.
- The report should meet your organisation's publishing standards.
- Please use one template per each major lesson learnt and include as many as are relevant for your sub-Project. If what you learnt is more technical, this is the section to include technical information.
- The content of these Lessons Learnt Reports can be compiled (and updated, where necessary) for inclusion in the (public) Project Knowledge Sharing Report, for submission at the completion of your sub-Project.

Lead organisation	School Infrastructure NSW		
Sub-Project number	6.1		
Sub-Project commencement date	30th March 2020	Completion date	27th May 2022
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Lessons learnt

Lesson learnt #1	The business case for battery storage is less favourable compared with HVAC controls for the purpose of Demand Response.					
Category	Technical, Commercial, Societal, Regulatory					
Choose from:	*Technical*	*Commercial*	*Social*	*Regulatory*	*Logistical*	*Other (specify)*

Describe what you learnt about this aspect of the Project.

Through extensive literature review and sophisticated modelling of the electricity wholesale spot price against an optimisation algorithm, it was found that the introduction of advanced controls for heating, ventilation and air-conditioning (HVAC) systems fared better than the use of batteries for the purpose of demand response (DR).

Studies of the expected versus actual operations of the University of Queensland (UQ) 1.1MW battery storage system found that "peak lopping", or discharging the battery to mitigate peak demand events, did not align with modelled predictions. The findings show 95% of income in the operation of a battery is derived from the Frequency Control and Ancillary Services (FCAS) and virtual capacity markets, with the remaining 5% from arbitrage (buying low and selling high). It is notable that arbitrage actually increases carbon emissions at UQ, as the battery is charged and discharged at all hours of the day, and the round-trip efficiency is less than 1.

Another major factor influencing the ability of a battery storage system to effectively "peak-lop" is the availability of the system. Most electricity distribution network service providers (DNSP) charge for capacity based on the maximum electrical demand for a 12-month rolling period. One unusually high peak demand event will be brought forward as the expected capacity requirements, and the end-user is charged accordingly. If the battery system is off-line for any period, a peak-demand event can easily occur, and any benefit is lost. UQ expected their battery to be online 98% of the time, but the reality was 94%.

The cost of discharging the battery is a consideration in regards to battery lifecycle replacement times. FCAS and virtual capacity markets infrequently call upon the services of a battery in comparison with the operation of peak-lopping or arbitrage, therefore the battery system will inherently have a better lifespan. UQ and Hornsdale Power Reserve do participate in arbitrage, but in the case of UQ for academic purposes, and in the case of Hornsdale, backed by a wind farm to provide much of the charge capacity. Time shifting load has a business case for Hornsdale as a consequence, but again the vast majority of income is derived from FCAS market participation.

Conversely, the modelled results for HVAC controls represent an excellent business case – ranging from a BCR of 2x to 2.5x – as the ability to load shift peak electrical demand through night ventilation purge and pre-heat/pre-cool is demonstrated, as well as energy efficiency opportunities. 50% demand reduction and 30% consumption savings are anticipated through simulations driven by a model predictive control algorithm. It should be noted that HVAC controls provide a wide range of co-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.

Extensive research and modelling by CSIRO and Buildings Evolved indicate that distributed batteries across NSW schools, in the schools studied, will not significantly assist in demand reduction. However, the use of distributed batteries could potentially assist with a broader technical or regulatory policy requirements of government to help support DNSP infrastructure. NSW Schools offer a unique opportunity to host batteries if this were the motivating factor due to their scale, distribution by population, and proximity to electrical demand.

Please describe what you would do differently next time and how this would help. What are the implications for future Projects?

The project was designed to test the hypothesis that outcomes for students could be improved through a mix of generation, storage and demand management. The hypothesis also extends to covering the operational and life-cycle replacement costs for solar PV, HVAC and other systems from the benefit created. Available data at the time of forming the hypothesis, particularly that from vendors, suggested that batteries were flexible enough to deal with peak lopping and load shifting. The reality, as proven by the actual operation of "big batteries" is that peak lopping never materialised, arbitrage can be detrimental both technically and commercially, and the vast amount of income was generated through FCAS and other capacity market payments, as indicated in reports from UQ and (to a lesser extent) Hornsdale Power Reserve.

The hypothesis therefore was faulty insofar that it relied on faulty information from the market as to the capability of battery storage systems. However, the hypothesis was proven correct that optimisation of school HVAC could deliver positive technical, commercial and societal outcomes as opposed to purely commercial outcomes, particularly concerning the reliability of demand reduction compared with batteries.

Battery storage systems have a very particular mechanism to create a business case, as was explored the final report for DCH 6.1. The limited real-world business case has no impact upon student educational outcomes as a consequence.

The impact for other projects is to:

- Understand the real-world impact that battery storage systems have from a technical and commercial aspect, and to put aside preconceived notions of capability and outcomes based on industry marketing initiatives.
- Reconsider the value proposition of less well-known methods of reducing commercial and societal impact through technologies such as demand management.
- Consider technical solutions such as HVAC optimisation as solving for commercial and societal outcomes (improved educational outcomes) in balance.

If your Project learnings have identified any knowledge gaps that need to be filled, please state it below.

Modelling of some costs was not included in the assumptions as those costs were unknown or in other budgets. Additional knowledge could be obtained by including specific costs around HVAC, controls and battery maintenance into the financial models, to see if the improved operation of schools could pay for the operational and capital life-cycle replacement costs of all contributing components over 50 years.

Additional modelling of publicly available UQ battery data could inform a possible approach to aggregation of multiple batteries, should the business case be deemed sufficient.

Costs/overheads for a VPP operator, or the use of a wholesale pass-through retailer were not factored in, due to materiality in context of the outcomes of the project. Additional input costs could be added to the modelling tool with relative ease to produce more complete models.

Thermal models were missing from the model predictive control algorithm that was used to build individual daily load profiles. Having access to real-world sensor data would improve the accuracy of the algorithm.

Thermal comfort models for each room would similarly add efficiency through dynamic set-point control based on external conditions.

Please include any other information you feel is relevant or helpful in sharing the knowledge you learnt through this stage of the Project. This may be qualitative or quantitative and may include a graph, chart, infographic or table as appropriate.

The above topics are covered in greater detail in section 8 of the **final report for DCH 6.1**

Lesson learnt #2	Exposure to the wholesale electricity market provides significant benefit if demand response technologies are already in place

Category	Technical & Commercial

Choose from:	*Technical*	*Commercial*	*Social*	*Regulatory*	*Logistical*	*Other (specify)*

Describe what you learnt about this aspect of the Project.

Exposing a building 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.

While the benefit of making this change is present regardless of HVAC controls (due to the daily load profiles of schools), the BCR is magnified from 1.7x to 2.6x over 15 or 50 years in the Singleton HS modelled scenario, by removing the battery to reduce capex costs, and implementing advanced HVAC controls when exposed to the wholesale market. Further analysis shows that exposing a wholesale market-oriented optimisation algorithm has a negative impact upon the BCR, as controlling loads in concert with the needs of the network are not recompensed.

Retail supply contracts provide hedging for consumers in order that they do not pay for extreme price events which can reach a maximum of $14,000 / MWh in the wholesale market. Most of these events occur on extremely hot days when a generator goes offline – high HVAC demand and reduced supply equates to price spikes in the wholesale spot market. Therefore, not having controls to enable demand response could negate any savings made during other periods when the wholesale pass-through price is lower than the retail price.

To uncover the above, a sophisticated financial modelling tool was developed to handle the complexities inherent in the Australian electricity markets. The model allowed us to validate that retail supply contracts with typical step tariffs did not provide the proper incentive or reward structure to maximise value.

A simulation using a model predictive control algorithm for optimum HVAC control based on weather, wholesale spot price and network tariffs allowed the production of a full year of optimised daily load profiles to run through a tariff engine capable of recreating invoices through to full 50-year cash flow analysis with BCR and NPV outputs compared with a baseline.

Please describe what you would do differently next time and how this would help. What are the implications for future Projects?

Instead of pursuing modelling in spread sheets, the software development associated with the financial modelling tool should have been in the original project plan and brought forward to better inform decision making earlier in the project timeline. This, however is with the benefit of hindsight as prior to COVID, the installation of equipment and associated sensor data was intended to inform an engineering model and more accurate simulation of the impact of HVAC controls – for example taking into account a thermal model of the schools as an input to the model predictive control algorithm.

Had the project plan included the financial modelling software, system size and predicted financial outcomes could have been better defined, as well as the inherent challenges associated with exposure to the wholesale spot price, either through aggregation or via a wholesale pass-through price arrangement.

Given the final report outcomes, priority should have been given to the installation of HVAC controls ahead of the battery storage systems. However, this was again confounded by impacts of the COVID pandemic in relation to planning, procurement and availability of labour and parts.

If your Project learnings have identified any knowledge gaps that need to be filled, please state it below.

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.

Further analysis of retailers offering wholesale pass-through pricing is required to understand the difference between those market offers compared to aggregation and direct participation in the wholesale market.

Please include any other information you feel is relevant or helpful in sharing the knowledge you learnt through this stage of the Project. This may be qualitative or quantitative and may include a graph, chart, infographic or table as appropriate.

These aspects of benefits associated with wholesale market participation are outlined in detail in section 8 of the **Final Report for DCH 6.1**.

Lesson learnt #3	Modelling energy finance outcomes is extremely complicated
Category	Technical

Choose from: *Technical* *Commercial* *Social* *Regulatory* *Logistical* *Other (specify)*

Describe what you learnt about this aspect of the Project.

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. The algorithm was set to solve for optimum battery arbitrage outputs, and, separately, optimum HVAC control outputs. Daily load profiles could then be produced as the output of the optimisation parameters in the algorithm, including knowledge of estimated HVAC load at each time interval. Demand response was added simply by triggering load shedding of the flexible demand for 30 minutes following a wholesale spot price of >$400/MWh.

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).

The daily load profiles, generated by optimisation algorithms, were then run through the tariff engine, with a network tariff and either a retail tariff or wholesale spot price configured as inputs. A full year of unique daily load profiles through the tariff engine then allowed report outputs to be generated that could finally answer the question posed in the hypothesis.

Please describe what you would do differently next time and how this would help. What are the implications for future Projects?

Acknowledge the limitations of methodologies and approaches when testing a new, more complex, hypothesis upfront and consider the research and development required to support the project outcomes in a more holistic way at project inception.

Buildings Evolved have developed the financial modelling tool in a web-based technology, that, with further development could be used by other consultants or market participants to model similar outcomes on a wide range of building typologies.

The clear business case of HVAC controls over that of battery storage was a problem that could not easily be answered with existing modelling tools in the private sector or academia (Energy Plus, SAM, Modelica et al) as these were largely developed for the US market.

The Australian electricity market is one of the most complex in the world, therefore modelling outcomes becomes extremely complicated.

If your Project learnings have identified any knowledge gaps that need to be filled, please state it below.

With future algorithmic controls optimising outcomes, a definition of how to balance competing objectives (e.g. occupant comfort vs energy savings) needs further work to avoid 'black box' solutions creating distrust in the market.

More historical data on FCAS in relation to VPPs (and more broadly) is required to inform the financial models. Broad estimates based on market data, published papers and public operational datasets were used and deemed to be acceptable due to the highly variable nature of the FCAS markets.

Further analysis of retailers offering wholesale pass-through pricing is required to understand the difference between those market offers compared to aggregation and direct participation in the wholesale market.

Please include any other information you feel is relevant or helpful in sharing the knowledge you learnt through this stage of the Project. This may be qualitative or quantitative and may include a graph, chart, infographic or table as appropriate.

Section 8 of the final DCH 6.1 report covers the research and development of the financial modelling tool in greater detail.

Lesson learnt #4	Increased risk management in implementing projects where there is immaturity of technology
Category	Regulatory, Logistical, Commercial
Choose from:	*Technical* *Commercial* *Social* *Regulatory* *Logistical* *Other (specify)*

Describe what you learnt about this aspect of the Project.

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 difficulties.

In relation to the batteries, extended lead times, installation and fault detection issues, and commissioning of communications, have been 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.

Please describe what you would do differently next time and how this would help. What are the implications for future Projects?

Given the immaturity of the industry, an increased focus on installation risk management from the project outset would be advised for future projects. This would provide for greater attention in the delineation between the responsibilities of the different installers of the solar PV, batteries, and HVAC controls.

Over the course of DCH6.1 additional consultants were engaged by SINSW during the battery installation process to ensure verification of contractor's work. Ideally these consultants would have been engaged earlier, to enable initial dialogue with the contractors to solidify delivery expectations. This auditing process was seen to be a necessary step in ensuring delivery standards and reducing issues further down the pipeline as subsequent contractors added their components to the electrical and communication systems. Future battery and HVAC projects within SINSW will benefit from the refinement of this auditing process. While this has meant a longer timeframe with less opportunities to overlap the installation of components, the importance of this became clear as defects were identified.

Future projects will also benefit from more refined task estimates and project scheduling. This will enable for more appropriate contingencies in terms of time for fault detection where there are atypical aspects of projects to be implemented (e.g. increased distances for the battery-meter communications as in the case of Singleton HS).

If your Project learnings have identified any knowledge gaps that need to be filled, please state it below.

As the technology increases in maturity it is anticipated that knowledge gaps relating to implementation, particularly in a retrofit context, will automatically be filled. This will result in more streamlined fault detection processes and reduced troubleshooting and defects, which will provide greater expediency in project delivery. The availability of more experienced contractors will also make tendering easier with a greater pool of contractors available in the market, improved competition and pricing, and greater capability in pricing specifications.

Please include any other information you feel is relevant or helpful in sharing the knowledge you learnt through this stage of the Project. This may be qualitative or quantitative and may include a graph, chart, infographic or table as appropriate.

N/A