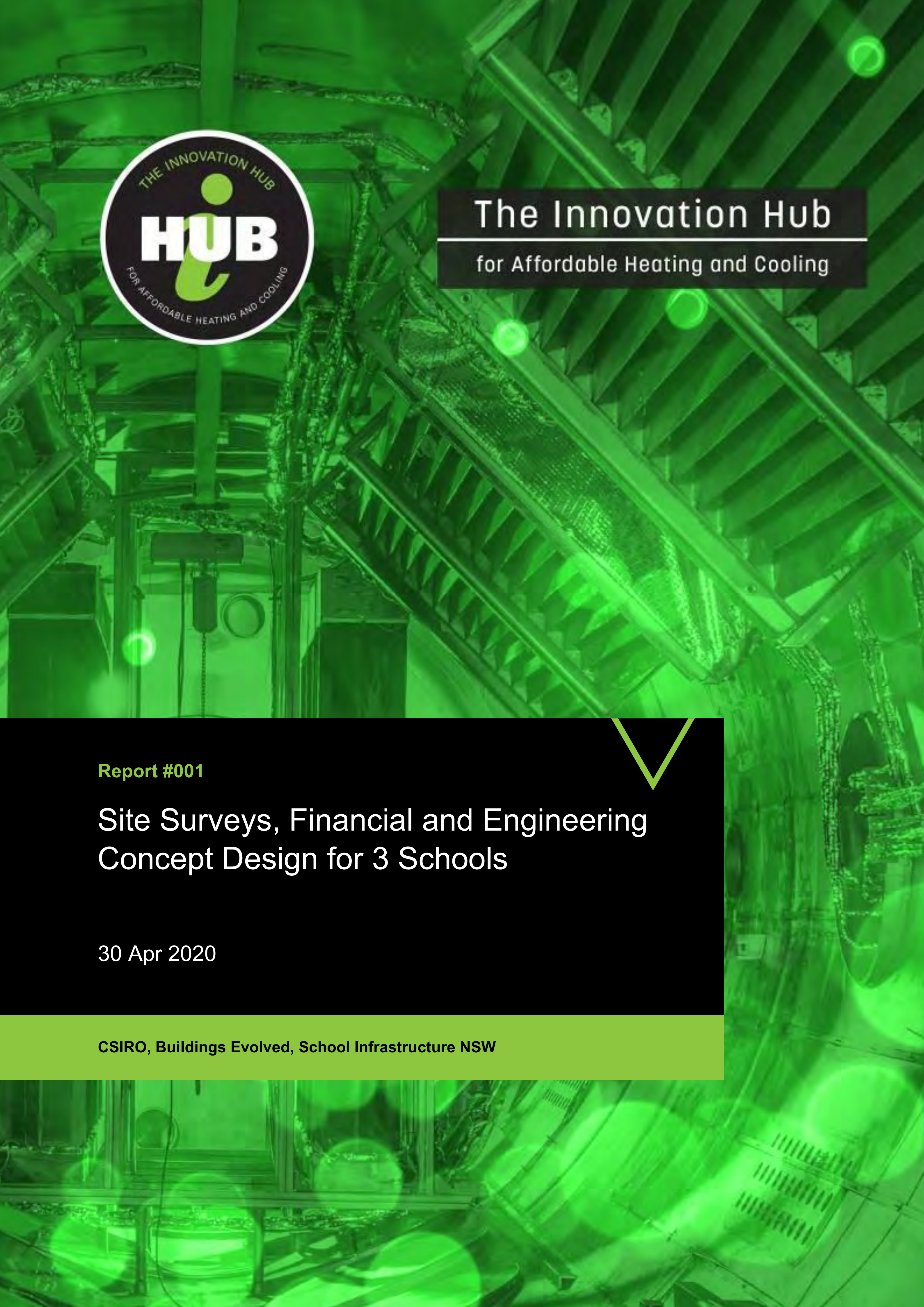

The Innovation Hub

for Affordable Heating and Cooling

Report #001

Site Surveys, Financial and Engineering Concept Design for 3 Schools

30 Apr 2020

CSIRO, Buildings Evolved, 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

[logo]

Data Clearing House (DCH) 6.1

The DCH6.1 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.

The potential exists for a future Stage 2 sub-project, for trial schools to be connected to the proposed iHub Data Clearing House (DCH). The DCH will 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 DCH6.1 forms part of the wider $18.3m ARENA funded Affordable Heating and Cooling Innovation Hub (i-Hub) project.

Lead organisation

Department of Education, School Infrastructure NSW (SINSW), Buildings Evolved, CSIRO

Project commencement date

4 March 2020

Completion date

21 May 2021

Date published

30 April 2020

Contact name
Dr Stephen White

Email
Stephen.D.White@csiro.au

Project website
Ihub.org

Table of contents

List of tables and figures

1 Executive Summary

As a part of the i-Hub Data Clearing House (DCH) initiative, CSIRO is working with NSW Department of Education, and Buildings Evolved to install battery storage and control equipment in three schools, and evaluate the opportunities to reduce energy costs and participation in the Demand Response (DR) wholesale market. This document outlines the activities carried out during the M3 milestone period, namely, considering the benefits of energy related technologies, optimal sizing of components, considering comfort levels of HVAC and documenting the building typology for design and systems commissioning activities.

During this milestone period Buildings Evolved has conducted a preliminary business case desktop study that explores the benefits for 'smart' operation of behind-the-meter solar PV, batteries and air conditioning assets at the three identified pilot sites; Nimbin Central School (Nimbin CS), Jamison High School (Jamison HS), and Singleton High School (Singleton HS). This investigation looks at each school having the capability to operate in isolation or as a distributed energy resource (DER) to achieve benefits from managing and operating advanced energy technologies and applications.

Research has identified that the full gamut of technological capability is not fully supported by current regulation and business models. The potential benefits of smart controlled operation can be quantified however through modelling and analysis to better understand the future capabilities enabled by technologies, mechanisms, network, and market reforms. Whilst the lead time for reform is uncertain, it is posited that SINSW can benefit by pursuing a smart controls strategy that capitalises on innovative and emerging energy technologies. It is anticipated that the DCH pilot will inform the application of smart controlled solar PV and battery systems in other areas of the SINSW portfolio.

Separately, during this milestone period, CSIRO has carried out the following activities.

1) Data gathering, review: CSIRO team has reviewed the data available from the sites. This includes evaluation of solar PV and air conditioning equipment data at the site, review of available load data, electricity tariff data, controls and connectivity information available from reports. A summary of main observations are:

   - Jamison HS has a 36kW solar PV system, while Nimbin CS has a 3.96kW system, and Singleton HS has a 35kW system. None of the schools currently have battery storage systems.
   - Nimbin has 15-minute interval electricity load data for Nimbin CS for 5 months. Load data of other schools not available. Nimbin has electricity tariff information for nearly one-year period (10 months). Tariff information from other schools not available.
   - Details of HVAC system installed in these schools are available however, energy sub-metering and indoor conditions data are not available from these schools. Cooler Classrooms project control functionality manual stipulates 22.5 ±3^{o}C as the operating conditions for air conditioning units.
   - Details available regarding communication, control features of equipment available at the site(s) is insufficient. Further discussion with stakeholders or a site visit may be required to obtain this information.

Following review of existing data, the CSIRO team has obtained historical weather data from nearby weather stations for modelling and used this in the preliminary analysis carried out below. The team also obtained Typical Meteorological Year (TMY) solar radiation data for the sites.

2) Preliminary evaluation of solar PV & battery storage system sizing: The team carried out initial studies using interval electricity consumption data available for Nimbin CS. Detailed study of available load data

has been carried out to study school load data for different seasons, weekday and weekend usage profiles and identify peak day profiles for a given month. Load demand data for a whole year, with at least one-hour resolution, is required for modelling tools. Five months of 15-minute interval data for the period from 27th June 2018 to 8th December 2018 made available for Nimbin CS was extrapolated to create one year of load data for preliminary modelling conducted. System Advisor Model (SAM) and Distributed Energy Resources Customer Adoption Model (DER-CAM) were chosen to carry out this study. Results from this study show:

- The available weekday load data shows daily peak during winter happens between 9 to 10 am whereas the peak load during November shifts to afternoon periods. Weekend load profiles also exhibited similar peaks. Moreover, it was observed that peak load during winter and summer (only November data) were of similar magnitude.
- Two scenarios were modelled using SAM, one with a 100kW solar PV system and another with a 50kW solar PV system, and both with a 5kW, 10kWh battery storage system. The 100kW solar PV system results in an annual saving of $30,221 on the electricity usage and the corresponding saving for the 50kW solar PV system is $18,621. Future simulation work will focus on determining optimal configurations/combinations of solar PV system and battery storage system sizes for the school, which may be different depending on goals (e.g. peak reduction, solar self-consumption, carbon emissions reduction). Additional data is required for accurate modelling results.

Further results from these studies are available in related sections within this document.

Additionally, the CSIRO team has started a review of methods to size storage systems for VPP projects. These studies indicate the sizing of solar PV and battery storage system primarily focuses on the needs/goals of the site itself, e.g. peak reduction, solar self-consumption. Any additional capacity/energy available from the solar PV-battery system is fed in (and therefore traded) to the grid. Considering grid support from VPPs is only needed on a small number of days every year (typically about ten days or so), a decision on sizing the solar PV and battery system should take this into consideration in addition to other benefits such as revenue/incentives from VPP providers. The understanding is that the VPP providers ensure local load demand is satisfied by the solar PV-battery system and only excess available energy/generation is used to provide grid support when needed. A review of existing VPP projects, primarily in residential space indicates that in some cases, about 10 to 20% of storage capacity is reserved for homeowners while the remainder is used for participation in VPP. This study will be further expanded to include research literature and international projects of similar nature.

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

In order to identify the potential for set point-based HVAC control in pilot schools, the team has developed a comfort calculator based on the ASHRAE 55 Standard. This standard specifies methods to determine thermal environmental conditions in buildings and other spaces that a significant proportion of the occupants will find acceptable.

The ASHRAE 55 ‘Adaptive Comfort Model’, one of two models defined in the standard, was formulated based on analysis of 21,000 sets of data compiled from thermal comfort field studies conducted in 160 buildings located on four continents in varied climate zones. Detailed physical measurements, along with responses to questions about thermal sensation, acceptability, and preference were analysed to determine the relationship between optimum indoor temperature and outdoor temperature. It is becoming a widely adopted standard globally for designing and operating buildings where the occupant has some form of control over the temperature conditions and has led to energy savings worldwide.

The Adaptive Comfort Model calculates a dynamic comfortable operating temperature band that is more closely related to average ambient (outside) conditions and seasonal changes, as opposed to static design-time rules of thumb, such as 22.5 ±3^{o}C. By adjusting the temperature set point towards the upper and lower bounds of the comfort band (depending on season), energy efficiency and cost savings can be achieved, whilst maintaining thermal comfort conditions.

The team has analysed the Adaptive Comfort Model output and created a dashboard to visualise the dynamic operating comfort band based on either a 7-day or 30-day ambient temperature average data. Further details about this Adaptive Comfort Model implementation and visualisation dashboard are available in the relevant section within this document.

Buildings Evolved also conducted site visits and documentation culminating in a site visit report. The key findings and recommendations for both schools are as follows:

1. Change fan from on/off to variable speed – no additional equipment required
2. PLCs are wired to the Schools Network per the scope of works, and that BACnet control functionality is tested by the contractor at a central point on the school's network.
3. The Mitsubishi HVAC systems installed as part of Cooler Classrooms receive a control upgrade.

The details of works by key project partners; CSIRO and Buildings Evolved outlines carried out during the M3 milestone period is documented herein.

2 Introduction

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 (CCP), and create a control application to integrate the installations at each site.

The potential exists for a future Stage 2 sub-project, for the schools to be connected to the proposed iHub Data Clearing House (DCH). The DCH will acquire additional variables such as weather and NEM spot market prices and, taking into account data acquired from site, will facilitate control algorithms to further optimise the operations and maintenance of the equipment onsite.

This report is an interim report covering the DCH6.1 Milestone 3 (M3) deliverables from key project partners CSIRO and Buildings Evolved. Each deliverable artefact and its purpose are defined as:

CSIRO – Component sizing, concept design and comfort level determination. Deliverable artefact; '*i-Hub DCH6.1: "Energy Control and Integration Program in NSW Schools – Stage 1'.* The purpose of this report is to ensure that the technical equipment is appropriately sized and capable of delivering on project objectives; to reduce energy costs and participation in the Demand Response (DR) wholesale market. Whilst ensuring that optimal temperature comfort levels are achieved in the Cooler Classrooms Program.

Buildings Evolved – preliminary business case and site visit reports. Deliverable artefacts; 1) *'Schools Preliminary Business Case, Advanced maintenance, operations, demand response and virtual power plants'*, and 2) 'Site & Engineering Reports'. The purpose of these artefacts is to; 1) explores the benefits for 'smart' operation of behind-the-meter solar PV, batteries and air conditioning assets at the three trial sites to identify systems and mechanisms to deliver on project objectives - to reduce energy costs and participation in the Demand Response (DR) wholesale market, and 2) to identify, and record onsite technical infrastructure across the three sites to inform contractors, commissioning agents and the project team to plan for key project activities, solar PV system, battery and component sizing and communication/control strategies, design and commissioning.

The next section of the document outlines the work completed by CSIRO – Component sizing, concept design and comfort level determination required to model technical requirements of the project.

2.1 Preliminary evaluation of solar PV & battery storage system sizing using System Advisor Model (SAM)

The System Advisor Model (SAM) is a techno-economic software model that facilitates decision-making for people in the renewable energy industry. SAM has been developed and maintained by the National Renewable Energy Laboratory (NREL) of USA. The model is used to evaluate different system configurations to maximise earnings and savings from electricity sales and consumption. It can also be used to experiment with different incentive structures.

SAM was chosen as one of the modelling software to assist in the sizing of solar PV and battery storage systems for the “Energy Control and Integration Program in NSW Schools – Stage 1 (DCH6.1)” project. The input data required for modelling a site using SAM was reviewed and this was assessed against data made available from the three pilot schools. It was found that only limited data was available for all three pilot schools. A decision was made to model the Nimbin CS using SAM due to the availability of 5 months of 15-minute interval data and corresponding tariff information. No interval data was available for Jamison HS and Singleton HS.

15-minute interval data for the Nimbin CS was available for the period from 27th June 2018 to 8th December 2018, and is illustrated in Figure 1. SAM requires hourly data for at least a whole year as one of the inputs, so this required the extrapolation of the available data into a whole year (1st Jan – 31st Dec 2018) taking into consideration the school holiday and term periods.

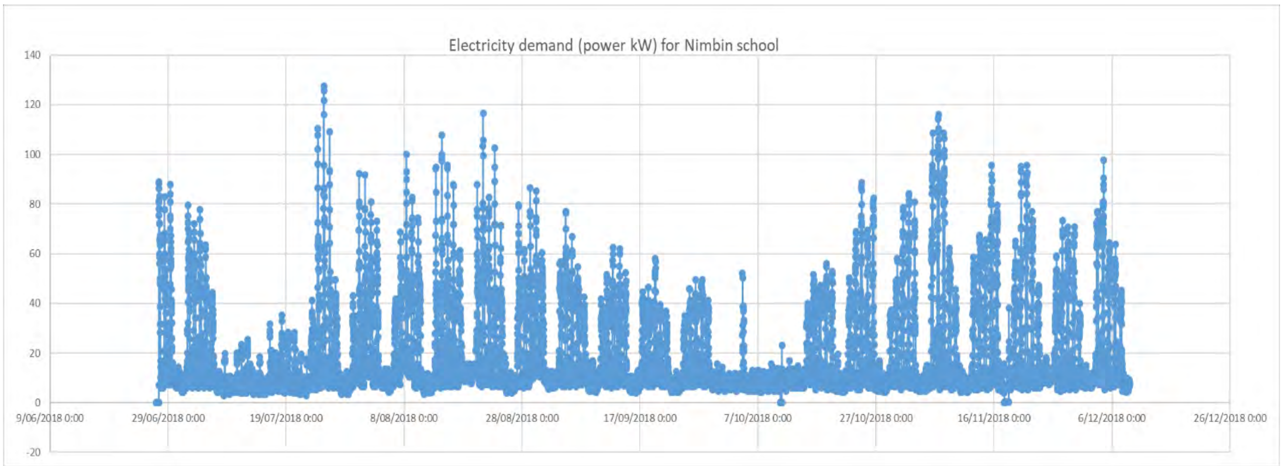

Figure 1 – Electricity demand of Nimbin CS for period 27th June 2018 to 8th December 2018 (15-minute resolution)

Solar resource data used was from typical meteorological year (TMY) data from the Lismore airport weather station (closest weather station to Nimbin) and this was used in SAM to estimate solar power output. The Global Horizontal

Irradiance (GHI) data is illustrated in Figure 2. As expected, higher solar irradiance levels is seen in the summer months and considerably lower levels in the winter months.

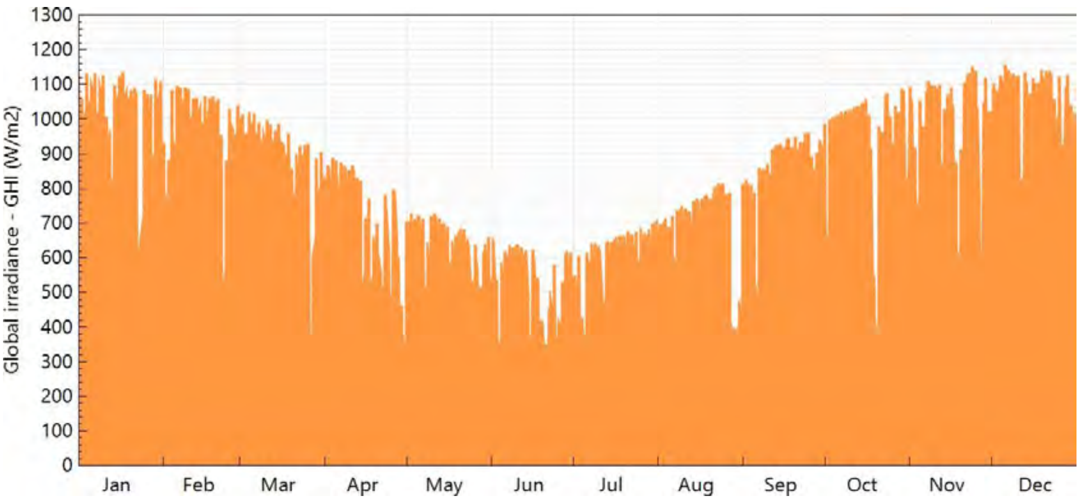

Figure 2 – TMY Global Horizontal Irradiance (GHI) data for Lismore airport weather station

Electricity tariff information was extracted from the various Origin Energy electricity bills that were made available for periods between 10th December 2018 and 25th October 2019. The school's electricity tariff structure changed from a flat to time-of-use (ToU) tariff on 1st March 2019. The electricity tariffs used for modelling purposes were obtained from the school's electricity bill issued on 5th November 2019, and these are as follows:

- Peak tariff (incl GST): 28.9432 c/kWh
- Off-peak tariff (incl GST): 16.918 c/kWh
- Shoulder tariff (incl GST): 27.3922 c/kWh
- Supply charge (incl GST): 640.585 c/day
- Solar feed-in (incl GST): 9 c/kWh

The ToU rates apply as follows: Peak: 7am-9am and 5pm-8pm weekdays | Shoulder: 9am-5pm and 8pm-10pm weekdays | Off-peak: all other times.

Initial modelling was performed using the abovementioned load demand data, solar PV capacity of 100kW and a battery storage of 10kWh (5kW). The load demand data across the year used for modelling is shown in Figure 3. The 100kW solar PV system size was arbitrarily chosen for preliminary modelling based on the load profile data seen in Figure 1 where power consumption of around 100kW appears to be quite common during the school term days, especially around late July and August which would presumably be due to heating requirements in the winter months.

Financial parameters used for preliminary modelling were all very rough estimates, most of which were left as default values stated in the modelling software. Most of the default cost values used in SAM represent costs for projects in the United States. These costs will need to be replaced with actual local costs to ensure accuracy of our own analysis. Values for system losses (e.g. inverter efficiency, PV system performance losses) were also left as default values and these could be looked at in more detail for future modelling work.

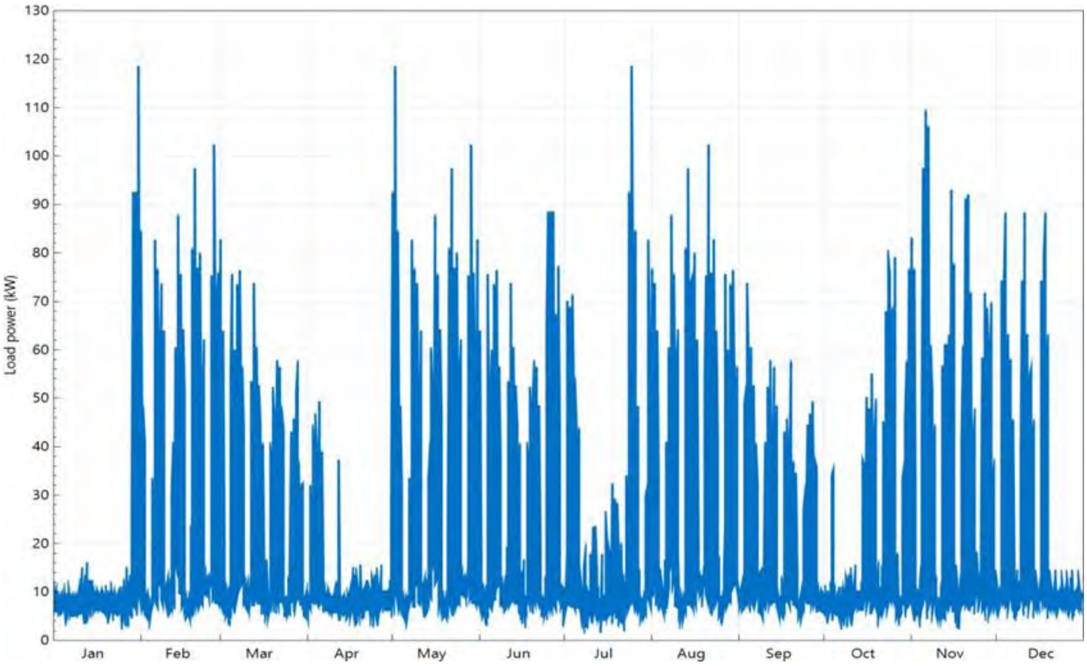

Figure 3 – Electricity load profile across a year (extrapolated data) for Nimbin CS used for SAM Modelling (hourly resolution)

The first scenario modelled was for a configuration comprising a 100kW solar PV system and a 5kW, 10kWh battery storage system. Results showed that the 100kW solar PV system is estimated to generate about 152MWh of electricity across the year (estimated solar PV generation profile is shown in Figure 4) and this, in combination with the battery storage system, can reduce the school's annual electricity bill significantly from $36,424 to $6,203. This constitutes a saving of $30,221 for electricity usage in the first year. This is based on the electricity usage and fixed daily supply charges found on the school's Origin Energy bill. As demand charge data was not available in the bills, these were not included in the model. For further simulation work going forward, demand charges will need to be investigated and included in the model if they apply. The simulation results also include payback period for the system installed. This, however, is not mentioned in this report as it is based on default cost and incentive figures used by SAM, which are mostly based on projects in the United States. These data can be adjusted to reflect actual local figures for modelling to be performed for the next project milestone.

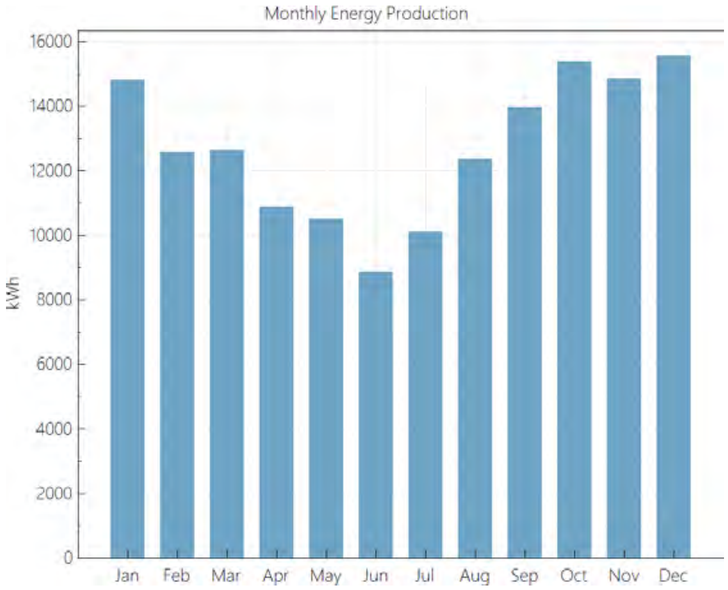

Figure 4 – Estimated monthly electricity generation from a 100kW solar PV system at Nimbin (based on solar irradiance at Lismore airport weather station)

Estimated solar PV generation against monthly electricity demand, along with corresponding excess local generation that is sold to the grid at the solar feed-in tariff is illustrated in Figure 5.

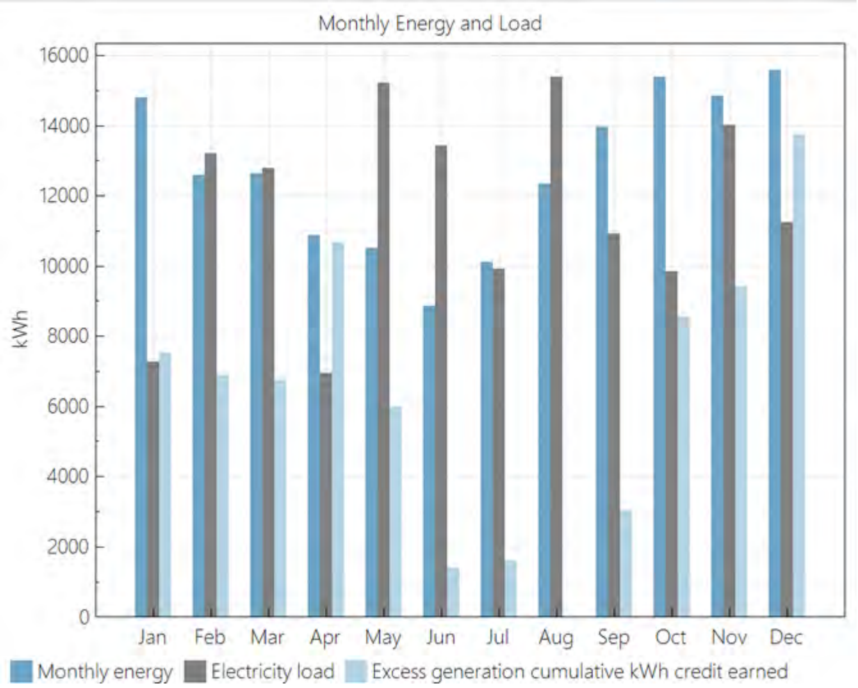

Figure 5 – Monthly electricity generated by 100kW solar PV and 5kW, 10kWh battery storage system (“Monthly energy”) against school’s load consumption. Also shown is excess local generation sold to grid

The amount of electricity (hourly) exported to and imported from the local grid with the 100kW solar PV and 5kW, 10kWh battery storage system installed at the school can be seen in the plot shown in Figure 6. Due to larger output from the solar PV system during the summer months compared to winter months, more electricity is seen to be exported to the grid in the summer months.

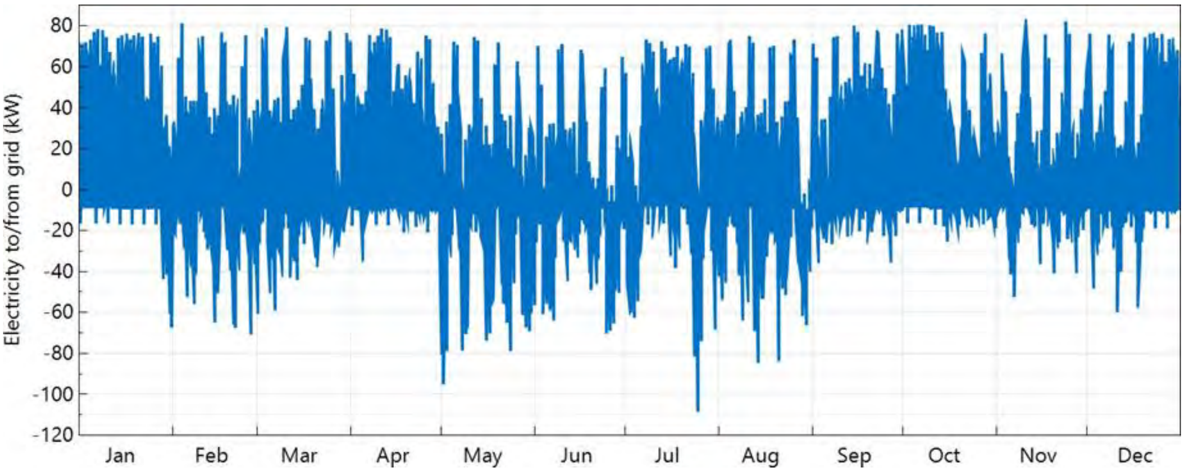

Figure 6 – Electricity exported to (positive) and imported from (negative) the local grid with a 100kW solar PV and 5kW, 10kWh battery storage system

A second scenario was also modelled, and this was for a 50kW solar PV system with a 5kW, 10kWh battery storage system. Results showed that the 50kW solar PV system is estimated to generate about 76MWh of electricity across the year (estimated solar PV generation profile is shown in Figure 7) and this, in combination with the battery storage system, can reduce the school's annual electricity bill from $36,424 to $17,803. This constitutes a saving of $18,621 in electricity usage for the first year. Further results, such as payback period, can be reported in future reports once actual local cost and incentive data are obtained and input into the model.

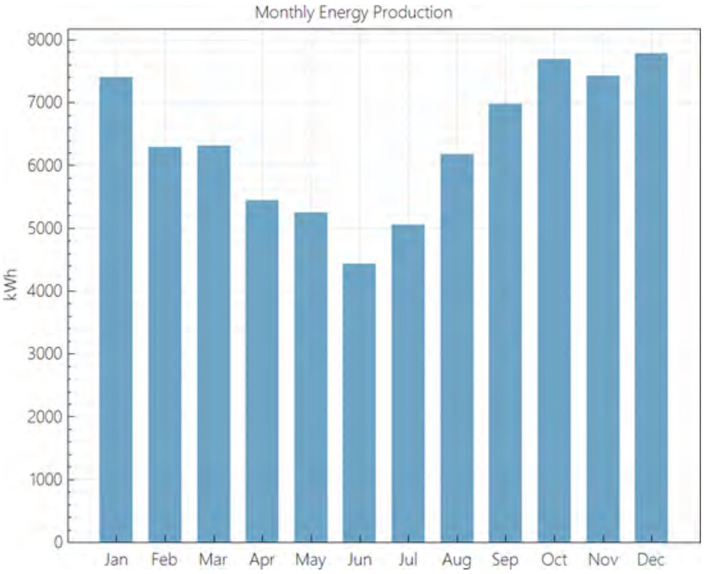

Figure 7 – Estimated monthly electricity generation from a 50kW solar PV system at Nimbin (based on solar irradiance at Lismore airport weather station)

The estimated electricity generation from the 50kW solar PV and 5kW, 10kWh battery storage system against monthly electricity demand is illustrated in Figure 8. Note that there is not much excess generation with the 50kW solar PV system, only a small amount of which is seen in January.

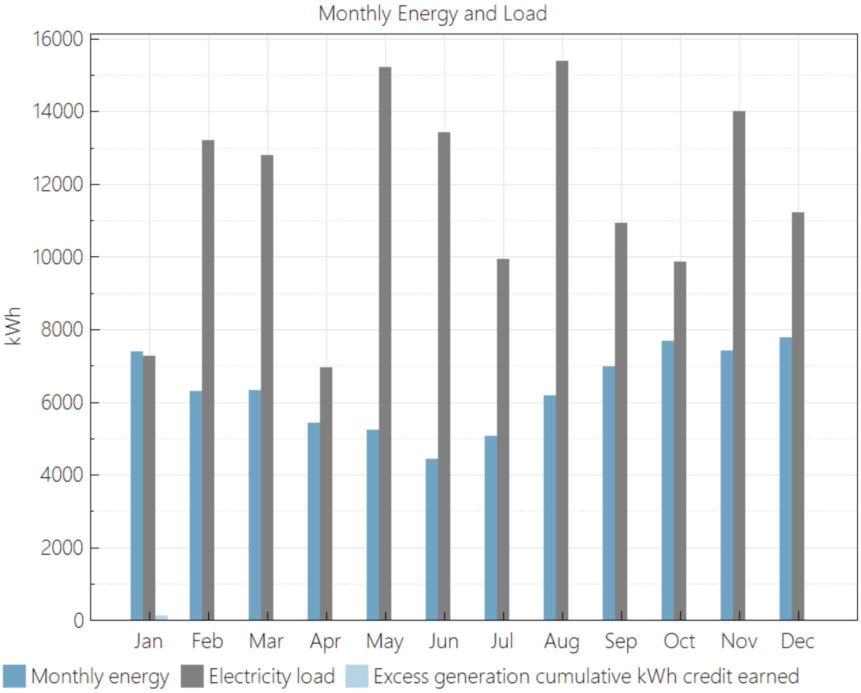

Figure 8 – Monthly electricity generated by 50kW solar PV and 5kW, 10kWh battery storage system ("Monthly energy") against school's load consumption. Also shown is excess local generation sold to grid, only a tiny amount of which is seen to happen in January

The amount of electricity (hourly) exported to and imported from the local grid with the 50kW solar PV and 5kW, 10kWh battery storage system installed at the school can be seen in the plot shown in Figure 9.

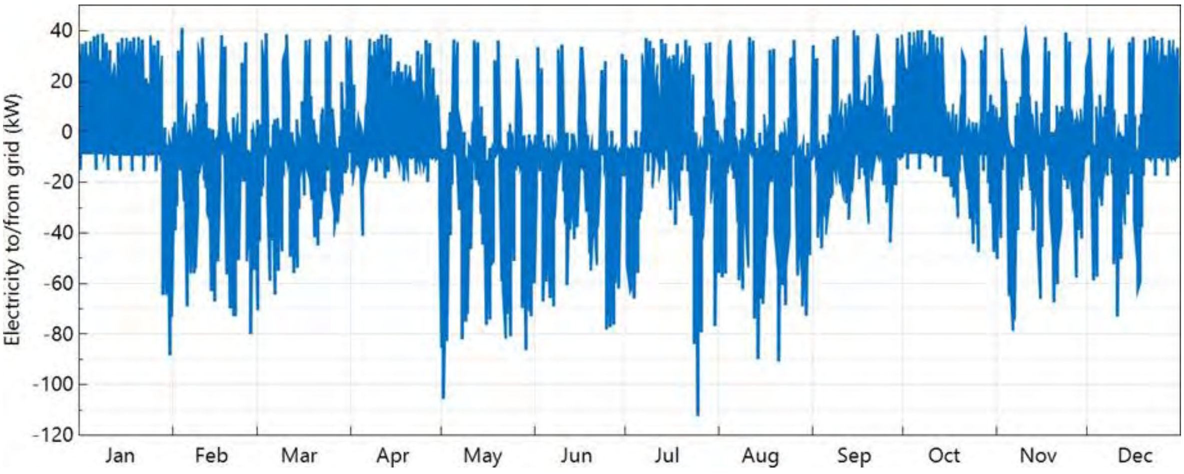

Figure 9 – Electricity exported to (positive) and imported from (negative) the local grid with a 50kW solar PV and 5kW, 10kWh battery storage system

Summary and next steps:

- Two scenarios were modelled in SAM using load profile data for a whole year extrapolated from five months of interval data made available and electricity tariff information obtained from the school's Origin Energy bills. Local weather and irradiance data was obtained for the Lismore airport weather station, which is the closest weather station to Nimbin. The two scenarios were with a 100kW and a 50kW solar PV system, and both with a 5kW, 10kWh battery storage system.
- The 100kW solar PV system resulted in an annual saving of $30,221 on the electricity usage and the corresponding saving for the 50kW solar PV system is $18,621.
- It is not known whether the school is subject to demand charges as this data was not available from the bills provided. This needs to be clarified and data will need to be included in the model if demand charges apply.
- Future simulation work will focus on determining optimal configurations/combinations of solar PV system and battery storage system sizes for the school. Optimal combinations may be different depending on goals, e.g. peak reduction, solar self-consumption, carbon emissions reduction. In order to obtain accurate modelling results, additional data required include:
    - Actual load demand data for a whole year, with at least hourly resolution;
    - Further electricity costs, e.g. demand charges, that the school is subjected to;
    - Actual costs, e.g. solar PV and battery storage system capital, installation and maintenance costs, associated annual depreciation;
    - Incentives, e.g. tax credits, government subsidies/rebates.

2.2 Preliminary evaluation of school electricity load data and approach to size solar PV & battery storage system using 'DER CAM' tool

The Distributed Energy Resources Customer Adoption Model (DER-CAM) is a powerful and comprehensive decision support tool that primarily serves the purpose of finding optimal distributed energy resource (DER) investments in the context of either buildings or multi-energy microgrids.

This model has been developed by the Berkeley Labs in the USA, and can be used to find the optimal portfolio, sizing, placement, and dispatch of a wide range of DER such as solar PV and stationary battery, while co-optimizing multiple stacked value streams that include load shifting, peak shaving, power export agreements, or participation in ancillary service markets. The model objectives include economic and environmental benefit increase by minimising cost and CO2 emission.

While the objective function of DER-CAM can be easily modified — or even replaced by a multi-objective analysis, it is most commonly defined a site's total annual cost of energy supply. This includes costs associated with both new and existing DER, operation and maintenance costs, fuel costs, but also all costs related to utility imports — either fixed, time-dependent, energy-based, or power-based. Additionally, all value streams associated with the optimal DER dispatch determined by DER-CAM are considered in the objective function, both in the form of avoided costs and market participation.

In the process of finding optimal DER solutions, several important questions are answered by DER-CAM:

- What is the optimal portfolio of DER that meet the specific needs of this microgrid?
- What is the ideal installed capacity of these technologies to minimize costs?
- How should the installed capacity be operated to minimise the total energy bill?

DER-CAM uses advanced mathematical modelling techniques to formulate the optimal multi-energy microgrid design problem as a mixed-integer linear program (MILP). Unlike simulation-based models or optimization models based on heuristic and non-linear formulations, this allows DER-CAM to quickly find globally optimal solutions to this highly complex problem. The key challenge lies in developing and implementing linear formulations that adequately represent different non-linear phenomena, and DER-CAM achieves this using a wide range of techniques.

DER CAM will use site's hourly end-use load profiles, electricity tariff, natural gas prices, and other relevant price data in the model.

2.2.1 DER CAM Inputs: Electricity Consumption Data for Nimbin CS

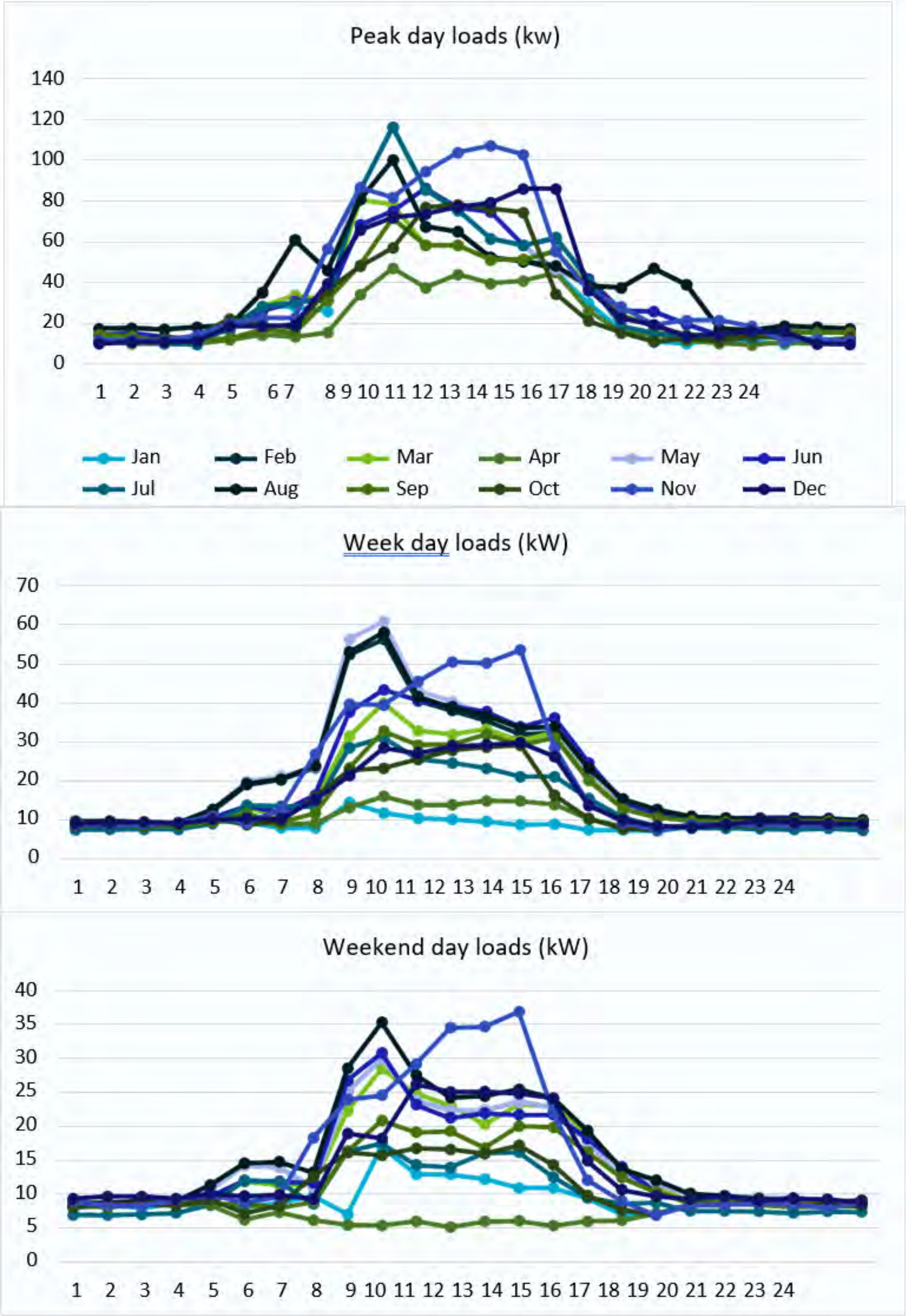

Figure 10 – Hourly electricity consumption data for Nimbin CS

The available load data (figure 10) reveals interesting usage patterns in the school. Weekday load data shows daily peak during winter happens between 9 to 10am whereas the peak load during November shifts to afternoon periods. Weekend load profiles also exhibited similar peaks. Moreover, it was observed that peak load during winter and summer (only November data) were of similar magnitude. It is also seen that the peaks happen consistently during the same time period irrespective of weekday or a weekend.

DER CAM will use site's hourly end-use load profiles, electricity tariff, natural gas prices, and other relevant price data in the model.

DER CAM outputs include:

1. optimal selection and capacity of DER, namely, solar PV and stationary battery, to be installed
2. when and how the available DER should be dispatched (both to maximize economic performance and meet reliability targets)
3. detailed cost breakdown of supplying end-use loads
4. detailed breakdown of carbon emissions associated with supplying end-use loads

Once annual hourly load data becomes available DER CAM modelling will be carried out with various optimisation objectives.

2.3 Evaluation of comfort metrics for schools

HVAC systems, from single residential-size heat pump systems to larger ducted and packaged systems, serve as flexible loads offering additional opportunities for demand management and participation in the VPP market. Temperature set point control either directly or indirectly (via AS 4755 Demand Response signalling for example) is seen as a viable approach that can assist in reducing HVAC demand during peak summer days. However, this load reduction is often traded-off with indoor thermal comfort conditions.

In order to identify the potential for temperature set-point based HVAC control in pilot schools, the CSIRO has developed a cloud-based comfort calculator that implements the ASHRAE 55 Standard – Thermal Environmental Conditions for Human Occupancy[1]. This standard specifies analytical methods to determine thermal environmental conditions in buildings and other spaces that a significant proportion of the occupants will find acceptable, based on site specific real-time and historical data. The ASHRAE comfort models provide a more dynamic approach to determining comfortable operating conditions in real-time, as opposed to industry guides or ‘rules-of-thumb’ that are often static in nature across all seasons. For example, the Cooler Classrooms project control functionality manual stipulates 22.5 ± 3oC as the operating conditions for air conditioning units.

Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment. Because there are large variations, physiologically and psychologically, from person to person, it is difficult to satisfy everyone in a space. The environmental conditions required for comfort are not the same for everyone. Extensive laboratory and field data have been collected that provide the necessary statistical information to define conditions that a specified percentage of occupants will find thermally comfortable.

The ASHRAE 55 - Adaptive Comfort Model shown in Fig. 11 (one of two models defined in the standard) was originally formulated based on analysis of 21,000 sets of data compiled from thermal comfort field studies conducted in 160 buildings located on four continents in varied climate zones. Detailed physical measurements, along with responses to questions about thermal sensation, acceptability, and preference were analysed to determine the

---

[1] ASHRAE, ASHRAE/ANSI Standard 55-2017 Thermal environmental conditions for human occupancy. 2017, American Society of Heating, Refrigerating, and Air-Conditioning Engineers: Atlanta, GA.

relationship between optimum indoor temperature and outdoor temperature. It is becoming a widely adopted standard globally for designing and operating buildings that are naturally ventilated, or the occupant has some form of control over their thermal environment.

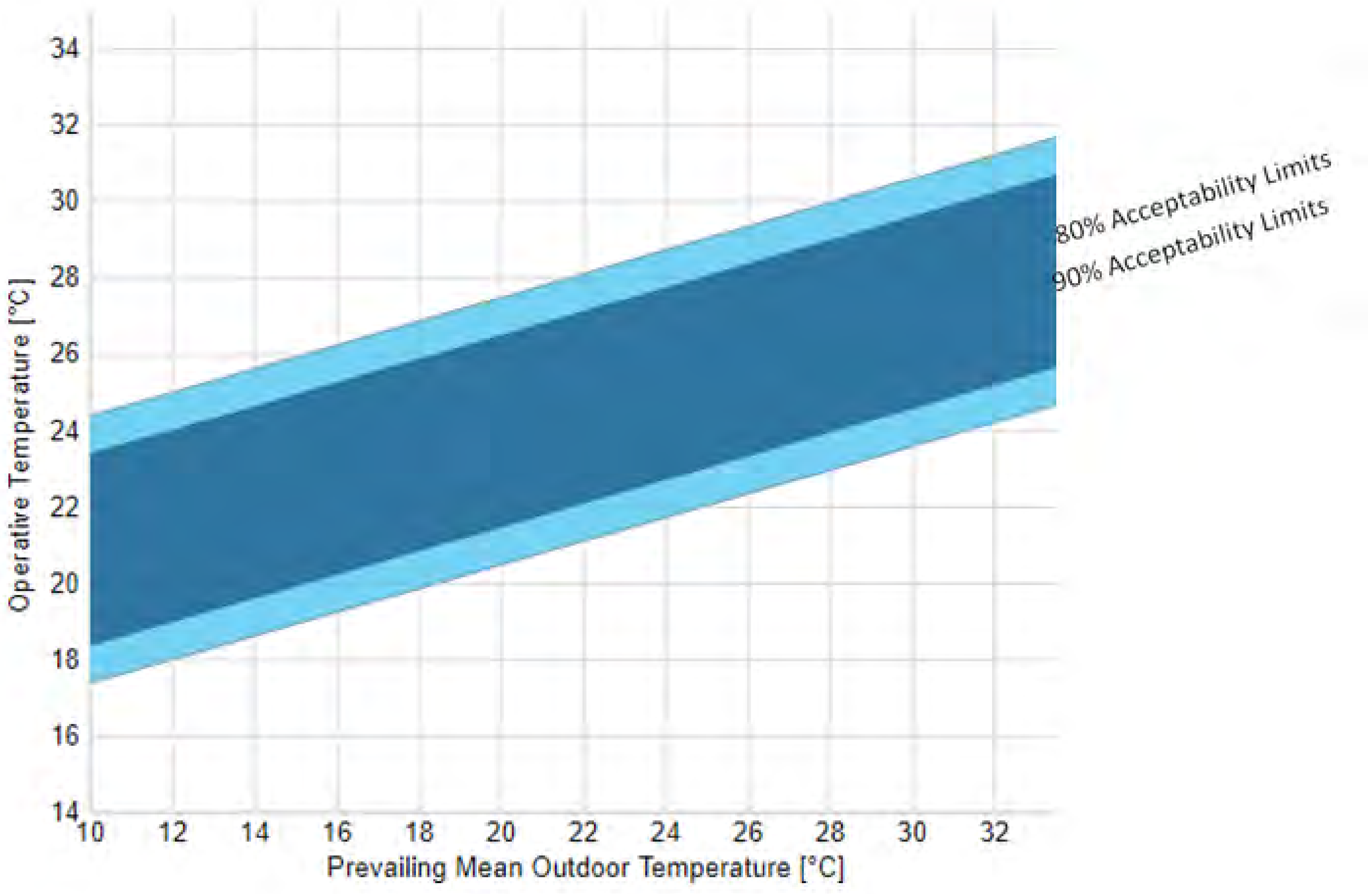

Figure 11 – ASHRAE Standard 55 - Adaptive Comfort Model comfort band (source: CBE Thermal Comfort Tool).

The Adaptive Comfort Model calculates a dynamic operating temperature band deemed comfortable by 80% of occupants (the light blue band in Fig. 11) and is more closely aligned by average ambient (outside) conditions and seasonal changes, as opposed to indoor environmental conditions and static design-time guides and ‘rules of thumb’, such as 22.5 ±3°C. By adjusting the operating temperature set-point towards the upper and lower bounds of the comfort band (depending on season), energy efficiency and cost savings can be achieved, whilst maintaining thermal comfort conditions.

The CSIRO has analysed the Adaptive Comfort Model output and created a live dashboard to visualise the dynamic operating comfort band based on either a 7-day or 30-day ambient temperature average data as specified by the standard.

Using historical BOM observations data from AWS weather stations located near the three school pilot sites, the CSIRO generated seasonal operating comfort bands based on the ASHRAE 55 Adaptive Comfort Model. An annual comfort band for the Nimbin CS based on historic air temperature data from the Lismore AWS is shown in Fig. 12. The comfort band is between the upper and lower temperature bounds shown be the orange (upper) and green (lower) trend lines. The hourly ambient air temperature BOM data is shown blue.

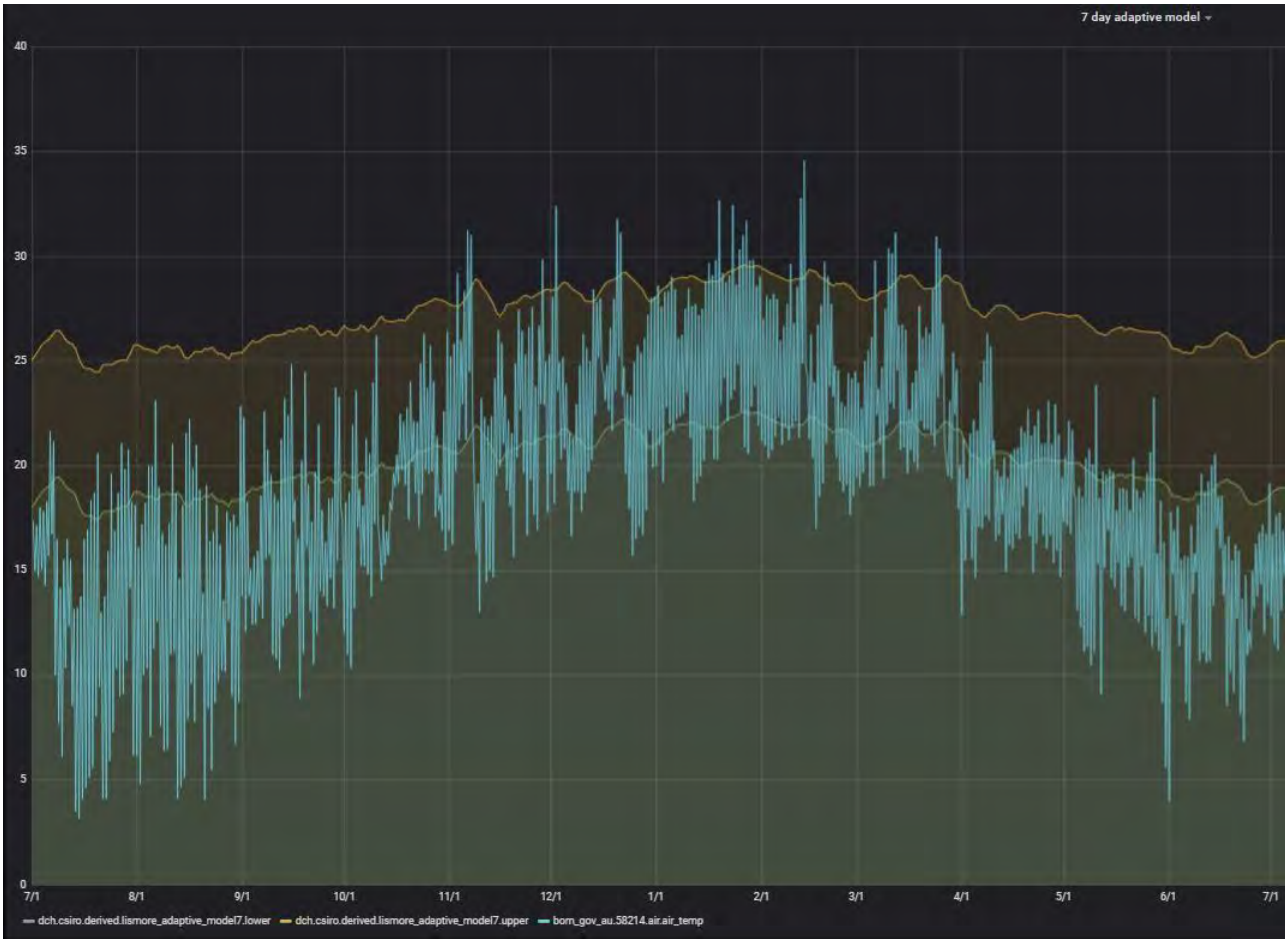

Figure 12 – Adaptive Comfort Model - comfort band for Nimbin (Lismore AWS) from July 2018 - June 2019.

Analysis of the comfort band for Nimbin CS over the 2018-2019 summer period (Dec – Feb 2019) showed comfortable operating conditions on average between 21.8-28.8^{o}C. As a comparison, the 22.5 ±3^{o}C static design rule has operating conditions between 19.5-25.5^{o}C. This provides potential further opportunity for changing HVAC temperature set points to manage peak loads summer months, without compromising comfort.

The next section of the document outlines the site visit reports completed by Buildings Evolved required to:

- identify, and record onsite technical infrastructure across the three sites to inform contractors, commissioning agents and the project team; and
- plan for key project activities, solar PV system, battery and component sizing and communication/control strategies, design and commissioning activities.

2.4 Site & Engineering Reports

2.4.1 Singleton High School

2.4.1.1 *Site Visit*

Field	**Details**
Site name	Singleton High School
Site address	75-81 York Street Singleton NSW 2330
Site ID	
Date of visit	1 Apr 2020
Duration of visit	3hrs
Visitor	Arne Hansen
Hosted by	Darren Brasington, General Assistant; Karen Feeney, Business Manager

2.4.1.2 *Site Description*

Singleton High School is located 70km NW of Newcastle in NSW.

2.4.1.3 *Report Objectives*

Report objectives include:

1. Review *Cooler Classrooms* plant and equipment
2. Review *Cooler Classrooms* control systems and communications
3. Review existing Solar PV inverters
4. Review existing communications infrastructure
5. Inspect main switchboards, sub-boards and transformers
6. Review any existing metering or sub-metering equipment and communications
7. Identify possible locations for battery installation
8. Provide a summary of findings and recommendations
9. Inform stakeholders about site conditions

2.4.1.4 Asset List Details

2.4.1.5 Site Plan – Singleton High School

Plan	**11303**
	

Figure 13 – Singleton HS - Aerial Photo Taken During Site Visit

2.4.1.6 Cooler Classrooms

Singleton HS mechanical control centres (MCC) are miniaturised and located in each learning area. Therefore, there is a 1:1 relationship between learning areas and the MCC.

The controllers used, Distech ECB-103, are networked using BACnet MS/TP over a two-wire RS485 serial bus. The extent and topology of networking between classrooms is unknown as this is not documented. However, we can safely assume that to meet the control performance specification, each classroom will need to be networked to gather external sensor data (common to each block). Logically, each block would be its own network – but this will have to be confirmed. For the purposes of this report and associated analysis, we will proceed on the likely scenario.

To uplift the MCCs, the following is required:

1. Addition of a BACnet MS/TP communications gateway (by Mech contactor)
    a. One end connected to the existing drop-bus
    b. Other end connected to a network switch in each block communications rack
    c. Commissioning of BACnet MS/TP gateway to configure IP addresses/supply MAC address to ITD.
    d. Possible recommissioning of MCC PLC to publish BACnet points if not already configured to do so.

The above summary is common for all *Cooler Classrooms* blocks listed below.

2.4.1.7 General Comments

Of note is the following outcomes that may not match original program intent.

- Fans are either on or off
- Due to the on/off nature of operation, the noise is very noticeable when in operation
- Fans noise has generated significant numbers of complaints to the mechanical contractor
- HVAC units are set to “Auto” mode permanently
- HVAC units are only on or off – there is no setpoint control
- Set points have been changed by staff by directly interfacing with the vendor control panel

2.4.1.8 Recommendations

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

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

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

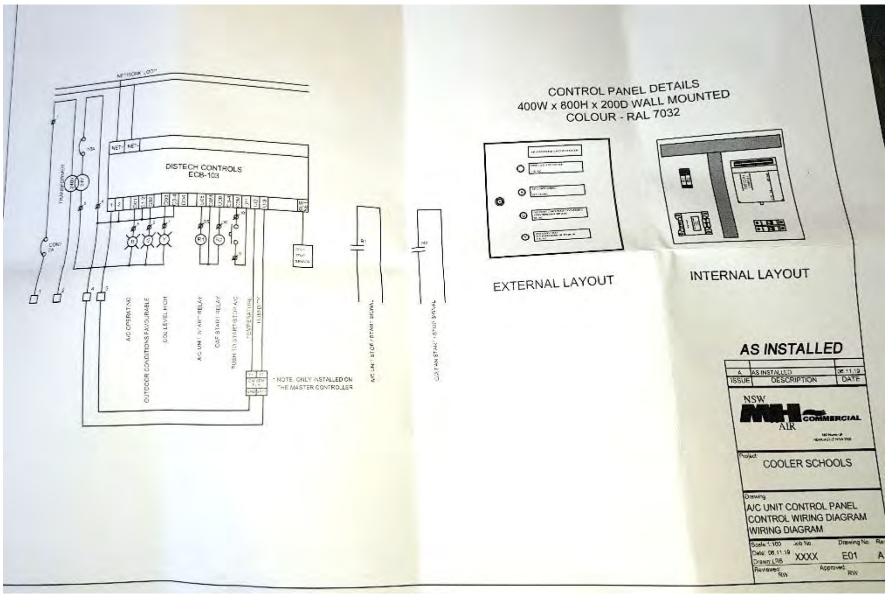

Figure 14 - Wiring Diagram for a Typical PLC (from a photograph taken of site documentation)

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

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

It is recommended that the fan begin operating at lower concentration levels, and that the fan continue to ramp in speed as it approaches 1200ppm CO2 in a manner shown in Figure 3. Not only does this better manage CO2 levels, it ensures that noise is minimised.

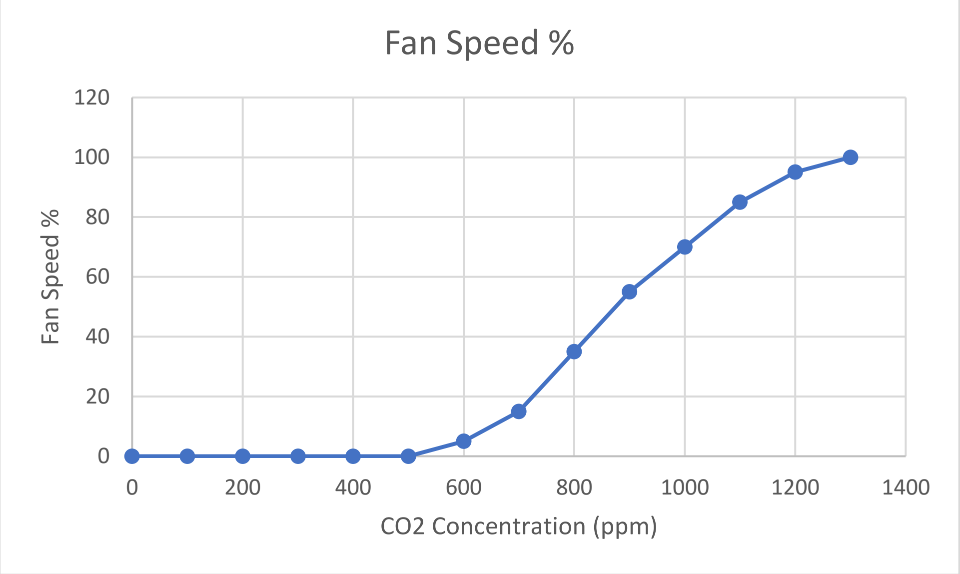

Figure 15 – Typical fan speed based on CO2 concentration

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

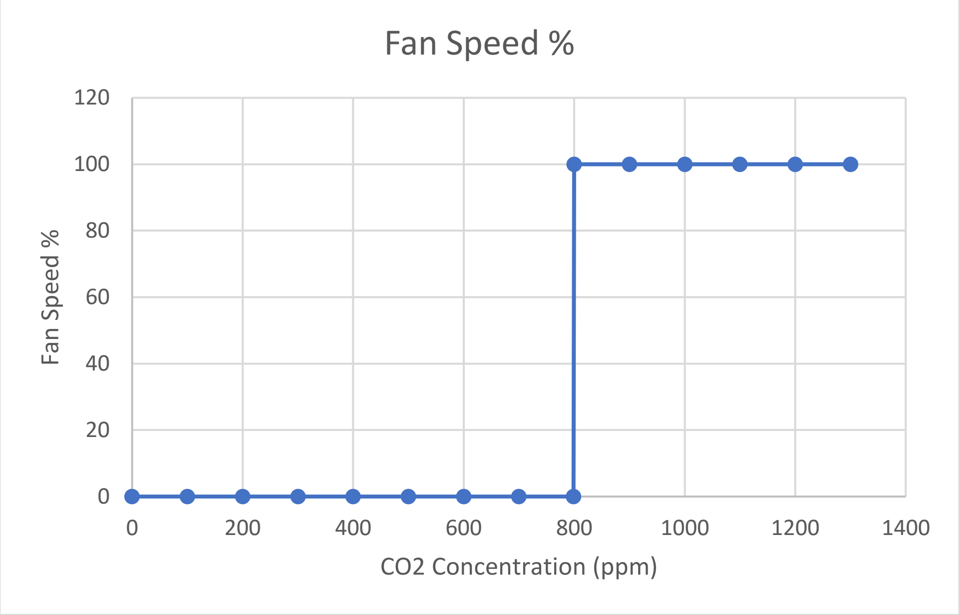

Figure 16 – Current Fan Speed Control Scenario

2. PLCs are wired to the Schools Network per the scope of works, and that BACnet control functionality is tested by the contractor at a central point on the schools network.
3. The Mitsubishi HVAC systems installed as part of CCP receive a control upgrade.

Faults are not reported as each system is stand-alone. Faults should be rectified in a timely manner to ensure long life-span of the equipment. This has a material financial impact upon the CCP in the operational phase.

For the DCH Project, it is not ideal to remotely turn off HVAC systems for demand response/energy balancing. It is better from the user occupant experience for the set points to be manipulated discretely in response to control signals.

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

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

Therefore, the recommendation is to approach the contractor, M&H Air, to request a quotation for the above works and make an assessment as to whether to proceed or not on a cost/benefit ratio.

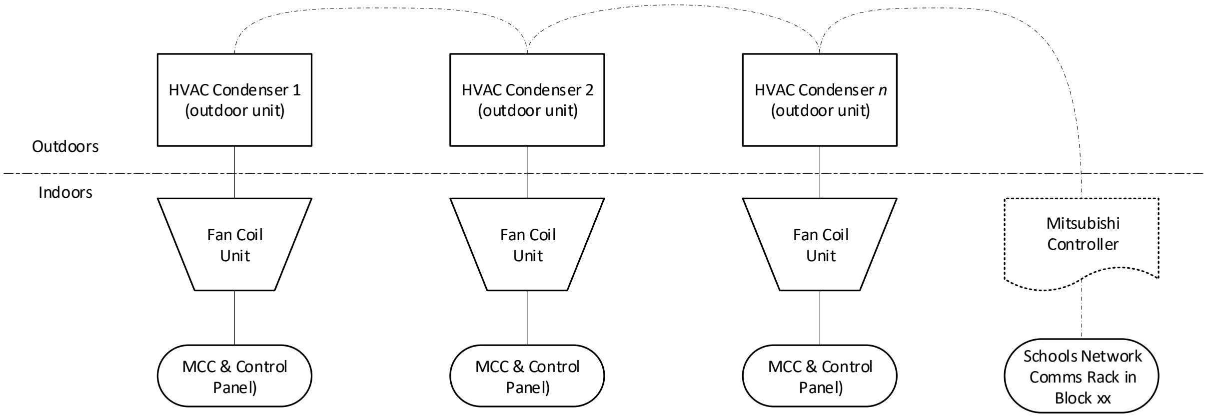

Figure 17 – Upgrading Mitsubishi Outdoor Units with Control System

More information can be found in the full version of the Site Visit Report by request.

2.4.2 Nimbin Central School

2.4.2.1 Site Visit

Field	Details
Site name	Nimbin Central School
Site address	23 Thorburn St, Nimbin NSW 2480
Site ID	
Date of visit	1 Apr 2020
Duration of visit	4hrs
Visitor	Arne Hansen
Hosted by	Alan Wraight, General Assistant

2.4.2.2 Site Description

Nimbin Central School is located 25km NW of Lismore in northern NSW.

2.4.2.3 Report Objectives

Report objectives include:

10. Review *Cooler Classrooms* plant and equipment
11. Review *Cooler Classrooms* control systems and communications
12. Review existing Solar PV inverters
13. Review existing communications infrastructure
14. Inspect main switchboards, sub-boards and transformers
15. Review any existing metering or sub-metering equipment and communications
16. Identify possible locations for battery installation
17. Provide a summary of findings and recommendations
18. Inform stakeholders about site conditions

2.4.2.4 Asset List Details

2.4.3 *Site Plan – 2751 Nimbin Central School*

Plan	**11757**

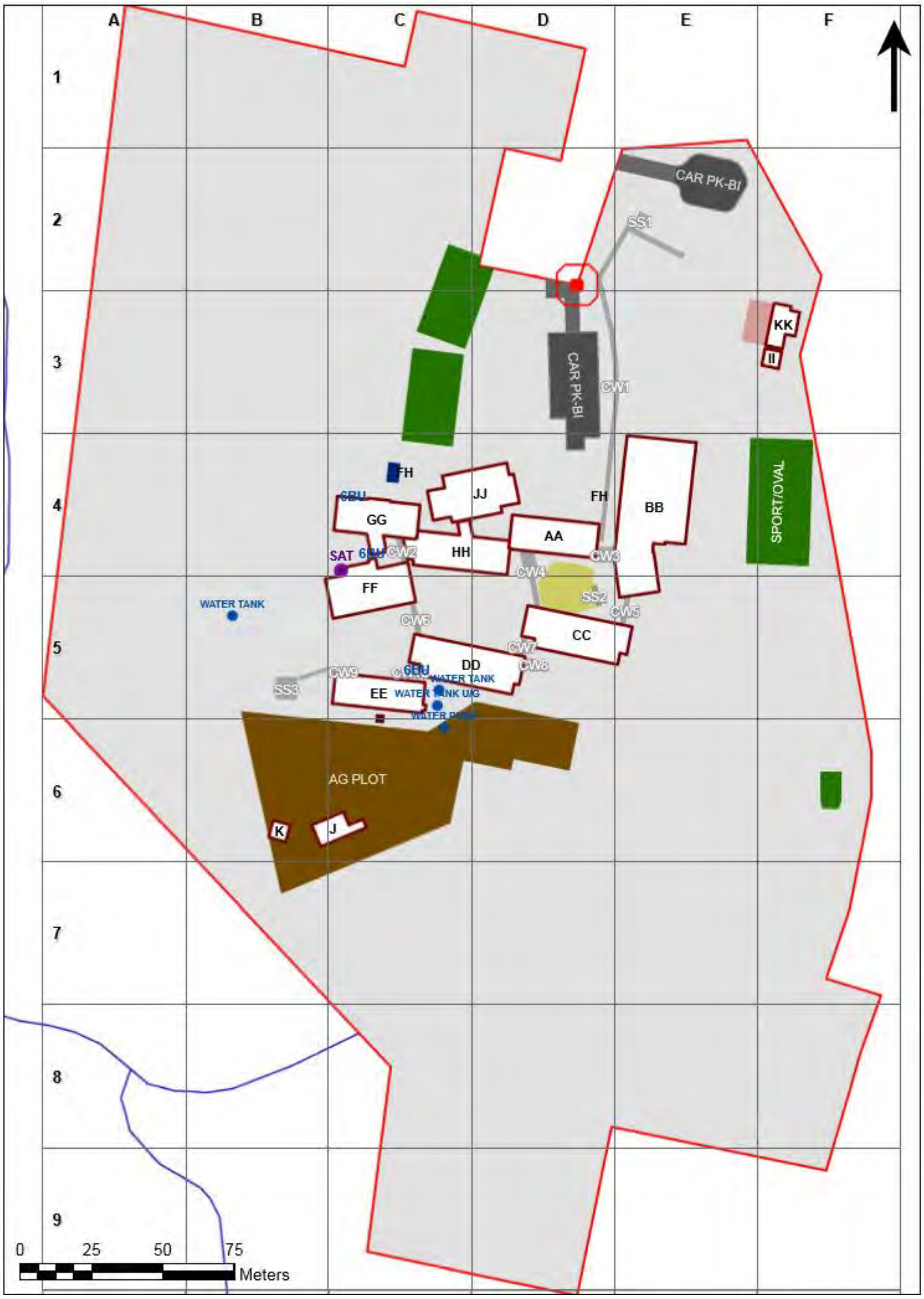

Figure 18 – Nimbin Central School – Aerial Photograph Taken During Site Visit

2.4.3.1 Cooler Classrooms

Typical Nimbin CS mechanical control board configuration are indicated in below sections. The MCBs have no network provision, but network is located in an adjacent room, or nearby.

To uplift these locations, the following is required:

2. Network cable run between the two locations (MCC to ITD Network Switch)
3. Recommissioning of MCB controller to:
    a. configure IP addresses/supply MAC address to ITD.
    b. Publish BACnet points if not already configured to do so.

The above summary is common for all CCP blocks listed below.

2.4.3.2 General Comments

Of note is the following outcomes that may not match original program intent.

- Ventilation fan units situated above doorways
- Multiple ventilation vans located in the same position (typically two over a doorway)
- Fans are either on or off
- Due to the on/off nature of operation, the noise is very noticeable when in operation
- Fans have been reprogrammed since commissioning to make activation less sensitive due to noise issues
- HVAC mode (heat or cool) have to be manually selected from a vendor control panel located near each fan coil unit, meaning two trips per year to change the mode
- HVAC units are only on or off – there is no setpoint control
- Set points have been changed by staff by directly interfacing with the vendor control panel

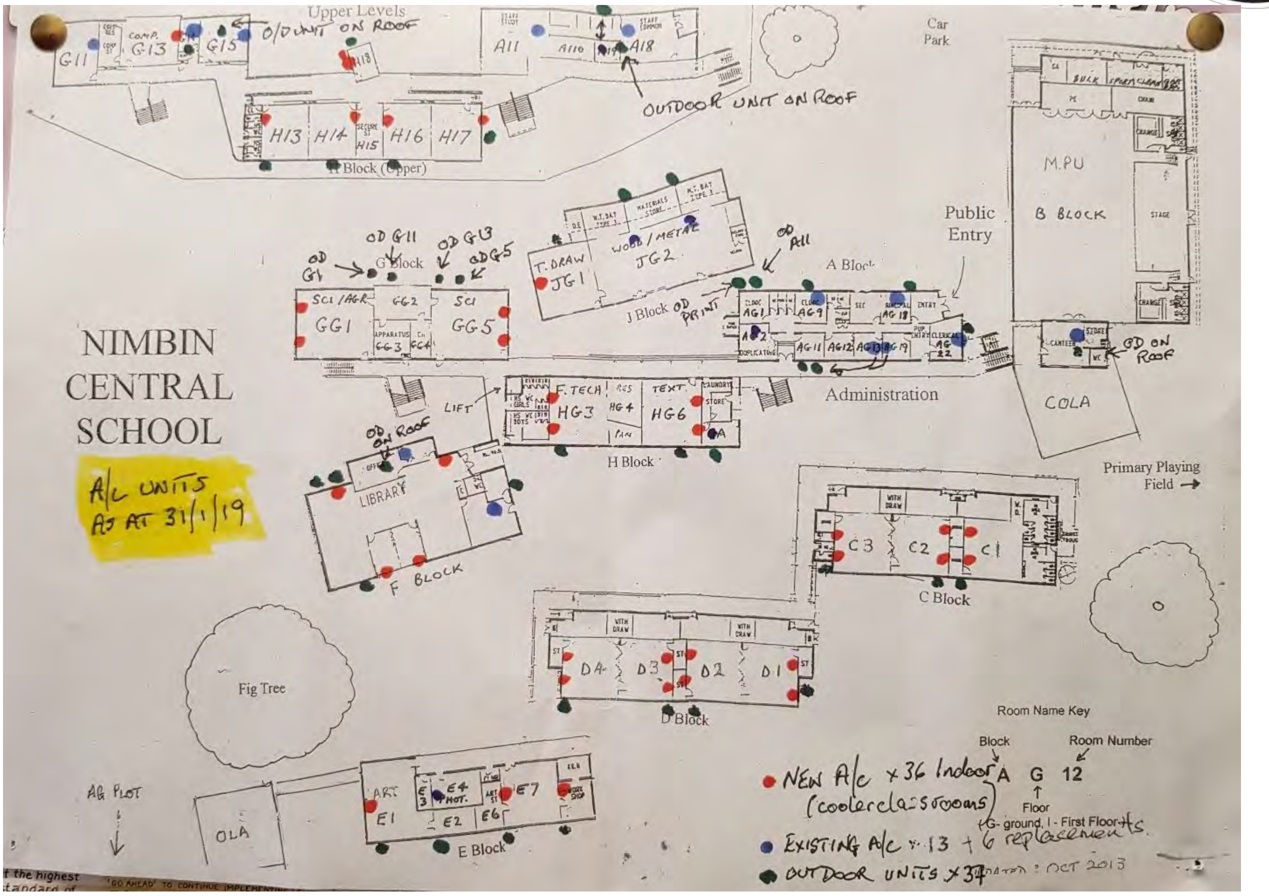

Figure 19 – Nimbin CS HVAC Map in GA Office Showing all Installed Units. Note 19x Non-CCP units in non-learning areas.

2.4.3.3 Recommendations

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

4. Change fan from on/off to variable speed – no additional equipment required

   The Innotech Omni C40 family of PLC as installed provides “universal input/output” meaning that each of the 40 channels can be tasked to analogue or digital/input or output. Each of the fans are connected as specified, using a relay or digital output to control the fan operation. Figure 20, a photograph of a document found on site shows the wiring to each of these channels and how they are configured for operation.

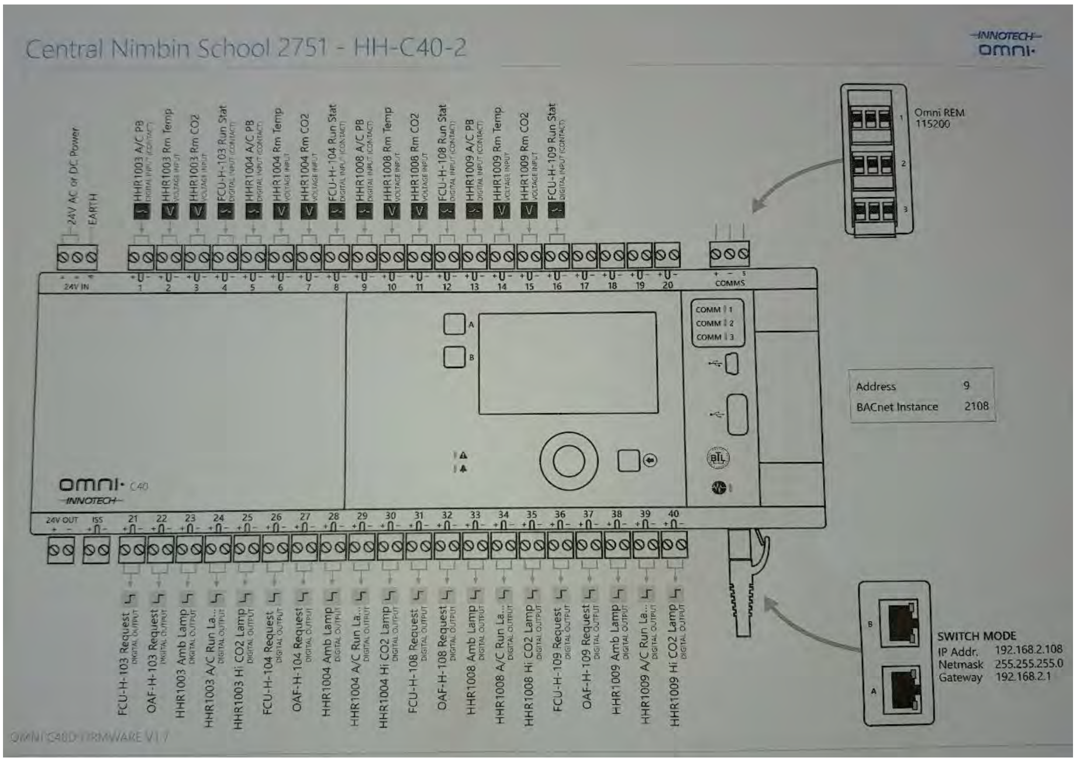

Figure 20 – Wiring diagram for a typical PLC from a photograph taken of site documentation

The ventilation fans, a Pacific HVAC FSW190-VEE model, provides a 0-10V input to allow variable fan speed control from a PLC such as the Innotech Omni C40 series.

The recommendation is to modify the programming of the PLC to provide a 0-10V signal to the fans and ramp the fans on depending on CO2 concentrations using a profile such as in Figure 21.

It is recommended that the fan begin operating at lower concentration levels, and that the fan continue to ramp in speed as it approaches 1200ppm CO2 in a manner shown in Figure 21. Not only does this better manage CO2 levels, it ensures that noise is minimised.

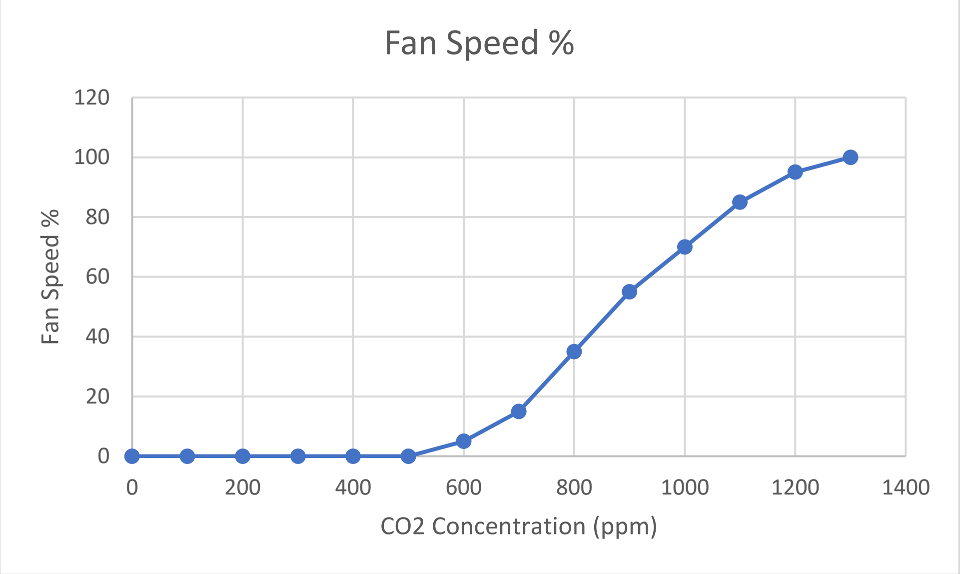

Figure 21 – Typical fan speed based on CO2 concentration

The present situation yields the following fan speed – producing a very noticeable sound for occupants (Figure 22.

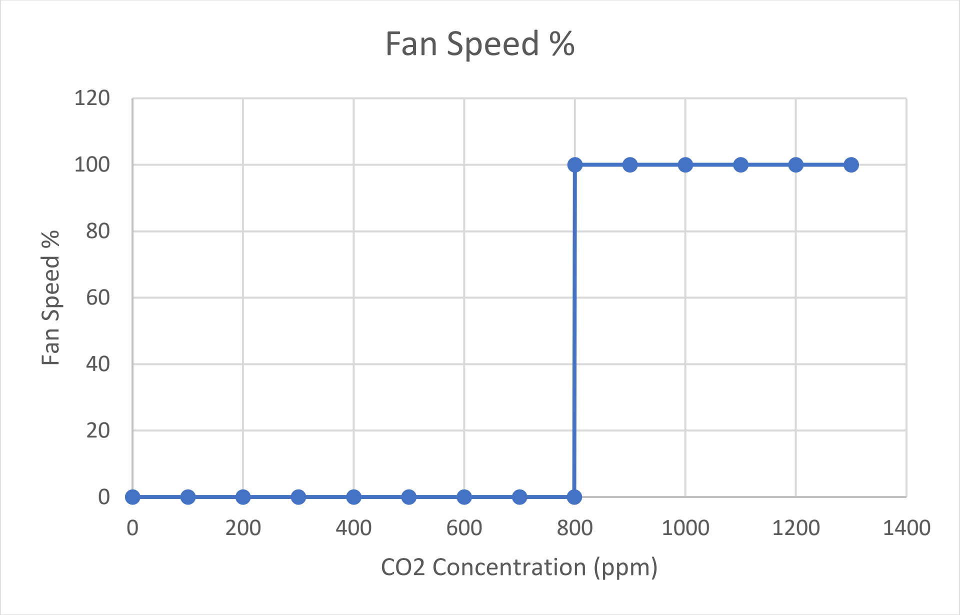

Figure 22 – Current Fan Speed Control Scenario

5. PLCs are wired to the Schools Network per the scope of works, and that BACnet control functionality is tested by the contractor at a central point on the school's network.
6. The Mitsubishi HVAC systems installed as part of CCP receive a control upgrade.

Presently, manual control of each and every unit has to be used to change from cool to heat and back. While this has been scheduled as part of HVAC maintenance, it is not ideal.

In addition, staff and students have changed setpoints on the vendor control panel, as reported by the General Assistant.

Faults are not reported, each system is stand-alone. Faults should be rectified in a timely manner to ensure long lifespans of the equipment. This has a material financial impact upon the CCP in the operational phase.

For the DCH Project, it is not ideal to remotely turn off HVAC systems for demand response/energy balancing. It is better from the user occupant experience for the set points to be manipulated discretely in response to control signals.

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

Therefore, the recommendation is to approach the contractor, Northern Air, to request a quotation for the above works and make an assessment as to whether to proceed or not on a cost/benefit ratio.

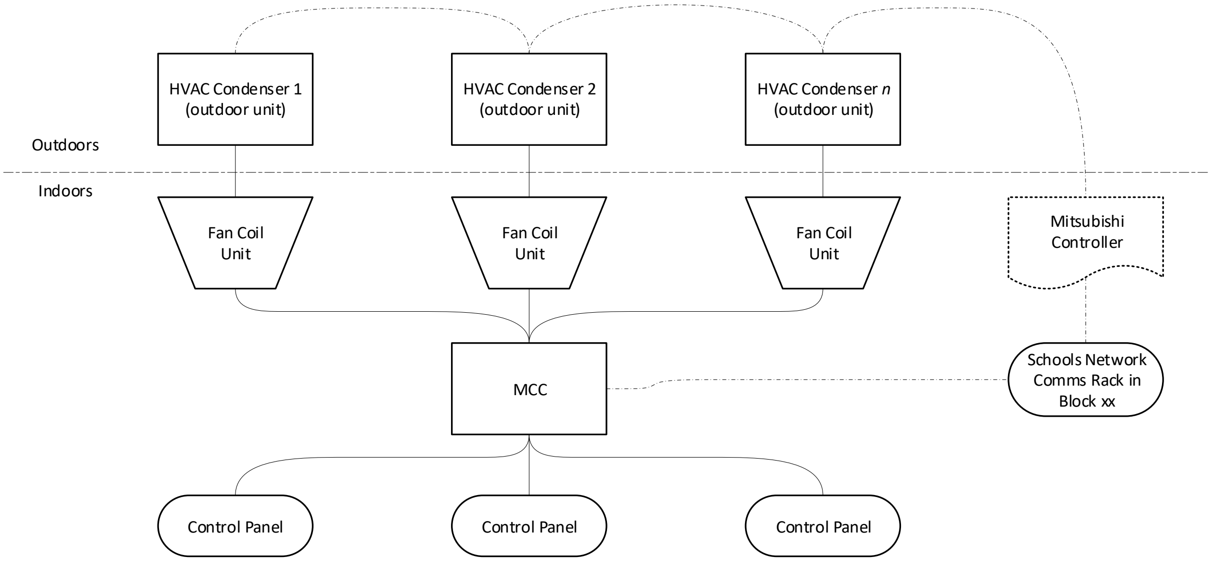

Figure 23 – Nimbin Central School – HVAC upgrade schematic

More information can be found in the full version of the Site Visit Report by request.

3 Conclusions

From desktop research, it has been found that the Australian energy market is ill-equipped to deal with the proliferation of solar energy systems in the national network and market. On one hand, the network is suffering from power quality issues due to base-load generation inflexibility. On the other, the market is suffering from the effects of negative pricing as a result of base-load inflexibility and, despite the potential of DER, offering poor outcomes for owners and operators of energy generating assets as a result.

In response, the network regulators, and operators along with a myriad of working groups and consultancies have published numerous studies and reports that outline the network and market problems and identify potential solutions. Subsequently, a literary review of studies and reports by the AEMC, AEMO, the ENA amongst others has been conducted herein to rationalise the potential benefits explored. From the literary review, it is posited that policy will likely be developed that is more reflective of and able to better realise the potential of DER in an emerging market.

The literary review identified the following key priorities for network and market reform:

1. Increased data access – consumer/prosumer rights to data ownership and access of their data by third parties and aggregators to increase competition and stimulate new markets and offerings.
2. A common value export methodology – prosumers can purchase firm export capacity to reflect network costs to incentivise efficient and effective pricing signal provisioning.
3. Cost-reflective tariffs – modelling of charges that is reflective of new services, network and market functions created by DER, predicating better and more accurate pricing and remuneration for services provided.
4. Provision for targeted and dynamic price signals to meet demand – the move to 5-minute market settlement and real-time data access on the network to improve market mechanisms, remuneration, network visibility and provision for DER functionality and services.

As these features are rolled out through policy reform and the required technology infrastructure is developed, SINSW has the potential to realise present and future benefit options quantified herein.

It is posited that SINSW can benefit by pursuing a smart controls strategy that capitalises on innovative and emerging energy technologies. It is anticipated that the DCH pilot will inform the application of smart controlled solar PV and battery systems in other areas of the SINSW portfolio.

In determining technical specifications and requirements necessary to realise the benefits of advanced controls strategies, the CSIRO has undertaken technical analysis covering component sizing, concept design and comfort level determination. The purpose of analysis is to ensure that the technical equipment is appropriately sized and capable of delivering on project objectives; to reduce energy costs and participation in the Demand Response (DR) wholesale market. Whilst ensuring that optimal temperature comfort levels are achieved in the Cooler Classrooms Program (CCP). The main activities and observations are:

1. Data gathering, review:

    a. Jamison High School (Jamison HS) has an existing 36kW solar PV system, while Nimbin Central School (Nimbin CS) has a 3.96kW system, and Singleton High School (Singleton HS) has a 35kW system. None of the schools have battery storage systems.
    b. Nimbin CS has 15-minute interval electricity load data for 5 months. Load data of other schools not available. Nimbin CS has electricity tariff information for nearly one-year period (10 months). Tariff information from other schools not available.

    c. Details of HVAC system installed in these schools are available. However, energy sub-metering and indoor conditions data are not available from these schools. CCP control functionality manual stipulates 22.5 ±3^{o}C as the operating conditions for air conditioning units.
    d. Details available regarding communication, control features of equipment available at the site(s) is insufficient. Further discussion with stakeholders or a site visit may be required to obtain this information.
2. Preliminary evaluation of solar PV & battery storage system sizing for Nimbin CS:
    a. The available weekday load data shows daily peak during winter happens between 9 to 10am whereas the peak load during November shifts to afternoon periods. Weekend load profiles also exhibited similar peaks. Moreover, it was observed that peak load during winter and summer (only November data) were of similar magnitude.
    b. Two scenarios were modelled using SAM, one with a 100kW solar PV system and another with a 50kW solar PV system, and both with a 5kW, 10kWh battery storage system. The 100kW solar PV system results in an annual saving of $30,221 on the electricity usage and the corresponding saving for the 50kW solar PV system is $18,621. Future simulation work will focus on determining optimal configurations/combinations of solar PV system and battery storage system sizes for the school, which may be different depending on goals (e.g. peak reduction, solar self-consumption, carbon emissions reduction). Additional data is required for accurate modelling results.
3. Evaluation of comfort metrics for schools. In order to identify the potential for set point based HVAC control in pilot schools, the team has developed a comfort calculator based on the ASHRAE 55 Standard. This standard specifies methods to determine thermal environmental conditions in buildings and other spaces that a significant proportion of the occupants will find acceptable.

The site visit reports conducted by Buildings Evolved functioned to identify, and record onsite technical infrastructure across the three sites to inform contractors, commissioning agents and the project team to plan for key project activities, solar PV system, battery and component sizing and communication/control strategies, design and commissioning.

From the site visit conducted at Singleton HS and Nimbin CS it is recommended for both schools that:

1. Outside air fans are changed from on/off to variable speed – no additional equipment required.
2. PLCs are wired to the school's network per the scope of works, and that BACnet control functionality is tested by the contractor at a central point on the school's network.
3. The Mitsubishi HVAC systems installed as part of the CCP receive a control upgrade.

From technical analysis and modelling conducted by the CSIRO and Buildings Evolved it is evident that, whilst there are some technical considerations there are no significant barriers or roadblocks to deliver on milestones or pose significant threat to project objectives and goals at this stage. Moreover, it is the opinion of Buildings Evolved consultants that the technical issues encountered are within the bounds of what is 'typical' for such infrastructure projects.