The Innovation Hub

for Affordable Heating and Cooling

Technology Evaluation Report

Flow Power
Electricity Spot Price Trading

19 November 2021

University of Wollongong

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.

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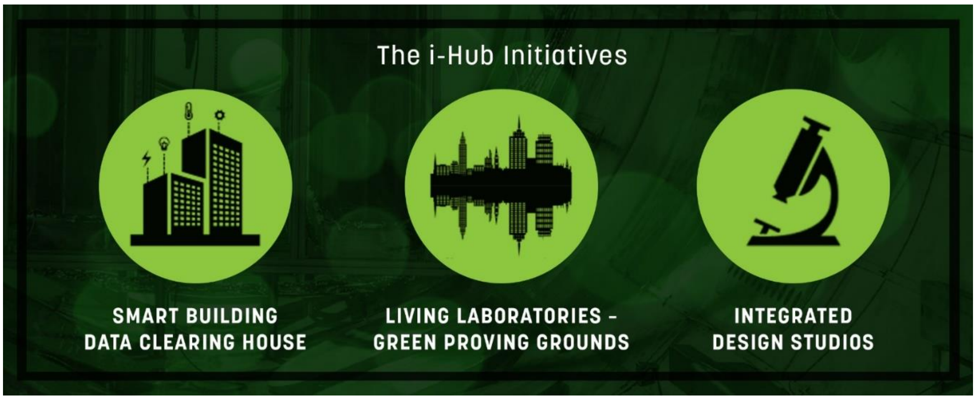

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This report should be read in conjunction with:

- Living lab manual: https://cloudstor.aarnet.edu.au/plus/s/ynVAcN9PhZY5CVk/download.
- REETSEF: KPIs and methods of evaluation: https://cloudstor.aarnet.edu.au/plus/s/J5TE6le6NnK5uIR/download

Table of contents

1 Executive summary 5
2 Introduction 7
2.1 Background 7
2.2 Problem statement 14
2.3 Technology overview 14
2.4 Objective 15
3 Test description...16
3.1 Site information 16
3.2 Description of tested enabling service: Flow Power Pure Wholesale Pass-through 18
4 Methodology 20
4.1 Test Approach and Description 20
4.2 Instrumentation Plan 21
5 Test Results 22
6 Summary Findings and Conclusions..30
6.1 Overall Technology Assessment 30
6.2 Barriers and Enablers to Adoption 30
6.3 Recommendations 31
7 References...32

1 EXECUTIVE SUMMARY

The Warrigal Shell Cove residential Aged Care living laboratory is a modern facility constructed in 2017, with a large (99kWp) solar array and efficient HVAC system utilising heat recovery ventilation and VRF (variable refrigerant flow) heat pump systems with demand response capability. Evaluation of the baseline performance of the facility identified appropriate levels of thermal comfort, and high self-consumption rate for on-site generation. The clearest opportunity to improve the value of renewables in this i-Hub living laboratory was identified as time-shifting of HVAC loads to better align with renewable generation.

There are many ways in which the operation of heating, ventilation and air-conditioning (HVAC) can be integrated with renewable generation, both on-site and off-site, in order to maximise the utilisation value of the renewable generation. However, this is an emerging technology and service area, and it is not currently clear what the most appropriate approach is for an aged care facility, with a need for high standards of thermal comfort. In identifying appropriate technologies for evaluation within this living laboratory, a balanced approach to risk and incentive was necessary.

Demonstration of a market mechanism that could provide an attractive incentive for aged care facilities to implement active demand response controls was identified as a key enabling service. The following demand response markets were reviewed in consultation with a variety of service providers and intermediaries: the Reliability and Emergency Reserve Trader (RERT) market, the Wholesale Demand Response Mechanism (WDRM), Frequency Control and Ancillary Services (FCAS) markets and the Wholesale Spot Price Market. The wholesale market presented the most promising alignment with HVAC demand flexing capabilities to increase the value of renewable generation. The current technology evaluation report provides an evaluation of a retail electricity agreement that would enable the Warrigal facility to benefit from improved alignment between their loads and typical periods of renewable energy generation through direct exposure to the wholesale spot price market signals.

Flow Power is an innovative energy retailer, offering customers direct exposure to wholesale electricity spot market. This demonstration project will consider Flow Power's pure pass-through wholesale product, in which customers are directly charged the wholesale spot price each 5-minute interval, plus a margin. The wholesale spot price is influenced by the amount of renewable generation in the grid (as well as aggregate demand), and on a typical day will have minimum prices during periods of highest generation.

The current evaluation has identified that during most months in the evaluation period (14 of 19), the Warrigal site would have lower energy costs under the wholesale pass-through. However in certain periods with more than the usual number of high price events, the Warrigal bill could be substantially larger than it would be under a traditional offering (up to 220% of the monthly energy cost). These high costs are typically caused by consumption during a small number of extremely high price events, where the wholesale price increased by several orders of magnitude. In the month with the highest estimated bill under the wholesale pass-through (Jan-20), 57% of the energy cost was caused by consumption during 5.5 hours with wholesale spot prices above $5,000/MWh, which is more than fifty times the average volume-weighted spot price in NSW of around $80/MWh. For comparison, the average fixed price for the existing supply contract was $104/MWh.

Analysis of the energy consumption and temperature profile in the Warrigal living lab during these high price events indicates substantial opportunity for HVAC demand response to reduce electricity costs in these periods. This could take the form of simple scheduling of loads, utilisation of the latent demand response capacity within the existing AC units, or through advanced controls based on forecast wholesale spot pricing. A second technology evaluation is currently underway, in which the Flow Power pass-through offering is combined with active control of the HVAC system by a third-party technology provider based on forecast wholesale spot process. This would be expected to yield substantial cost savings for the living laboratory and demonstrate substantial benefits to the grid if implemented sector-wide.

2 INTRODUCTION

New and emerging technologies are creating opportunities for energy flexible buildings, that is buildings that have the ability to actively manage demand and generation in accordance with local climate conditions, the needs of occupants, and conditions in the broader energy network (Jensen et al, 2017). As a major building load, the control of heating, ventilation and air-conditioning (HVAC) and its integration with renewable generation, both on-site and off-site, is an essential consideration for energy flexible buildings. Whilst the enabling technology is reaching maturity, there are many factors relating to their deployment in buildings that requires further investigation. There are two items of particular relevance to the current report:

1. There are many ways in which HVAC can be controlled to improve the value of renewable generation, including load shifting (i.e. through pre-conditioning), demand-response (i.e. switching off or ramping down HVAC equipment for short periods), and demand flexing (i.e. modifying controls setting such as temperature set-point during certain periods). The most appropriate of these various options, and the limits within which they can be applied, will vary substantially according to building types and sector.

2. The interaction of these technologies with the broader energy network is not just a technological issue, but involves substantial consideration of socio-technical issues in the broader energy market. The specific ways in which various energy flexibility services can be contracted and valued by the broader energy market will have important implications for their value to a building owner.

As such, a detailed understanding of the national energy market and the ways in which the different energy flexibility services are rewarded is required in order to effectively evaluate these technologies. This section presents a review of the National Energy Market, and a range of specific sub-markets of relevance to grid-interactive control of HVAC.

2.1 Background

2.1.1 National Electricity Market (NEM)

The National Electricity Market (NEM) operated by the Australian Electricity Market Operator (AEMO) is undergoing transformation with increasing dependence upon renewable generation sources. Balancing generation supply and consumer demand in this dynamic marketplace is requiring significant adjustments to market mechanisms, including the increasing prevalence of negatively priced power during periods with high renewable generation. A snapshot of the NEM wholesale spot prices during a negative price event is shown as Figure 1.

In order to balance demand and supply on the network, the Australian Energy Market Operator (AEMO) will dispatch the cheapest collection of generators needed to meet expected consumer demand through the wholesale spot price market (AEMO 2012). The wholesale spot price market is set for each 5-minute trading interval[1] based upon generator bids and the AEMO forecast of total consumer demand for each interval. Every five minutes, generators (such as coal fired power stations and wind farms) make offers to AEMO to supply customers and AEMO will create a “bid-stack” that sorts these offers. The cheapest generation offers are lower in the bid stack and the more expensive offers are at the higher end. AEMO will then dispatch the cheapest collection of generators needed to meet expected consumer demand, starting with the generators with the lowest priced offers. The price for the five-minute interval is set by the marginal generator offer. That is, the price of most expensive generator needed to meet consumer demand. The price for the interval is the price paid to generators who produced power in that five-minute window, and paid by energy consumers who used energy in that five-minute window.

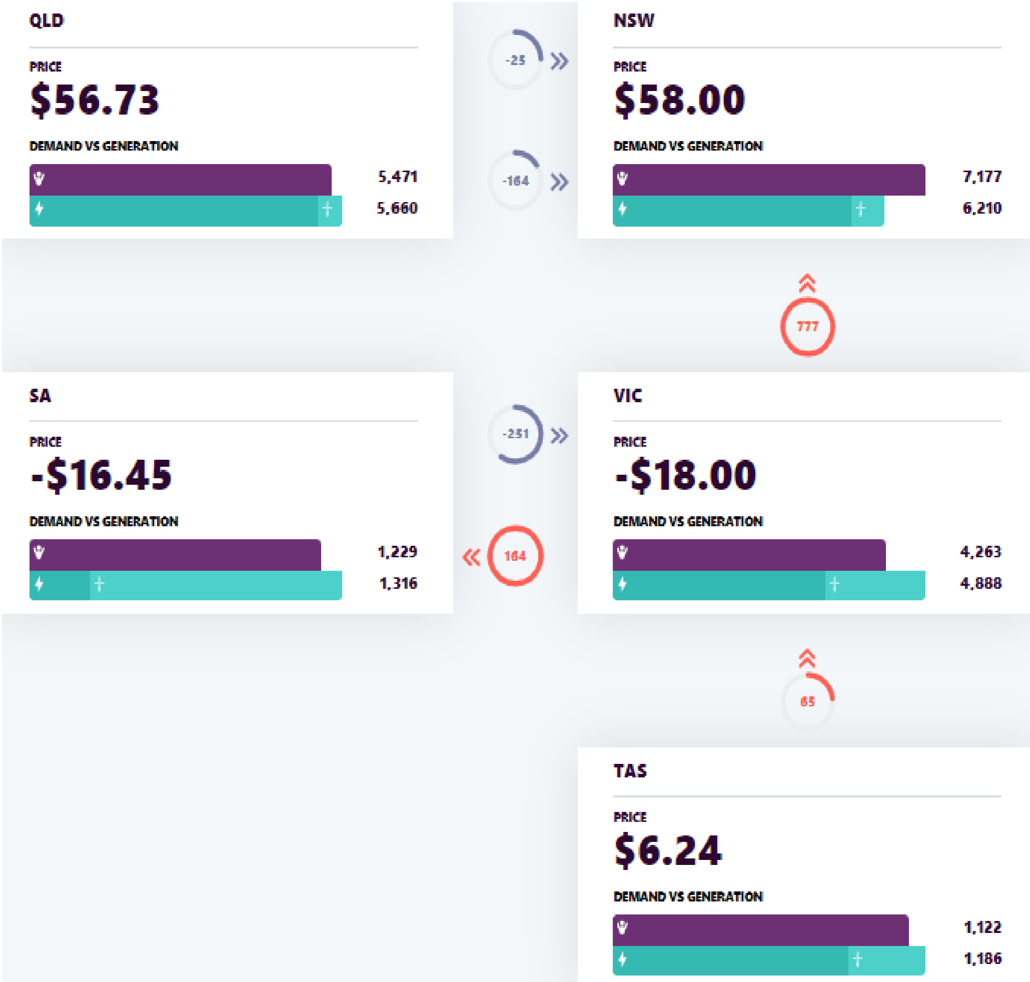

Figure 1 - The AEMO dispatch overview page showing current spot price for each connected state, with total demand, generation and energy transfers between states.

Almost all energy consumers do not actively bid into the wholesale market as large generators do (the exception being some very large hydro pumps). Because energy consumers do not bid into the wholesale market, they are not part of the process of setting the wholesale price. However,

[1] The trading interval was 30 minutes prior to October 2021.

there is the opportunity for consumers to change their demand in response to the forecast price. Doing so can lead to positive outcomes for energy consumers, e.g. reducing their exposure to higher wholesale prices.

Price responsive consumers can also reduce future wholesale prices. If consumers reduce energy use in response to high wholesale prices, AEMO will then adjust the total grid demand estimate for the next trading interval. Lower aggregate demand can lead to wholesale prices decreasing, which completes the feedback loop from consumer demand response to spot price.

This spot price market manages the generation-demand balance at the 5-minute time-frame. Shorter-term fluctuations in supply-demand are managed and costed in the Frequency Control and Ancillary Services (FCAS) markets. Extreme seasonal peak demand events are managed with the Reliability and emergency Reserve Trader (RERT) market. These separate demand response markets present additional income stream opportunities for consumers to participate in with their active demand response capacity.

2.1.2 The Reliability and Emergency Reserve Trader (RERT) market

RERT is a separate grid peak demand market designed to manage controlled shedding of major grid loads or to activate standby generation during extreme peak demand events where otherwise whole suburbs would need to be disconnected from the grid. For the climate and load profiles of the NEM, RERT events are typically triggered when major generation assets have unscheduled outages on very hot summer afternoons around 5:00 pm to 7:00 pm (when household AC loads are often at peak on weekdays).

The RERT season is typically from November to March, with typically between zero and four RERT events in each season. RERT pricing and capacity offers are submitted by standby generators and major consumers at the start of each RERT season. AEMO rules establish the required RERT capacity for each interval, which sets the threshold price for that interval. The spot price market forecast is a key indicator of impending RERT events and the RERT market is effectively designed to cap the wholesale spot price for these extreme events.

2.1.3 Wholesale demand response mechanism (WDRM)

The WDRM is a new market mechanism introduced in October 2021 to enable consumers to trade their demand response capacity on the wholesale spot price market.

WDRM differs from RERT in that it is integrated into the spot price market and does not depend upon AEMO to activate the opportunity. Consumers engage in the spot price market through the WDRM by submitting their demand response capacity and activation price threshold for each trading interval. This is typically conducted through a third party operating a virtual power plant (VPP) who then trades aggregated demand response on the spot price market. Granular metering is required and a demand response capacity calculation method needs to be pre-established in order to settle commercially on this market.

The WDRM will tend to pre-empt RERT events. However, increased reliance upon renewable generation sources will increase fluctuations in generation capacity. Eligible demand side participants for the initial trading trials include large backup generator sets and large battery systems (around 5 MW minimum capacity). HVAC demand response is not be eligible for the initial rollout of this new mechanism.

2.1.4 Frequency Control and Ancillary Services (FCAS) markets

FCAS markets are operated to balance short-term generation and demand fluctuations that disturb grid frequency. Just like driving a car and coming to a steep hill without changing the accelerator position, the car will slow down (grid frequency decrease) due to the increased load (total grid demand) upon the engine (power generators). Eight separate FCAS markets provide the price signals to incentivise grid frequency control services as listed below:

- Regulation Raise
- Regulation Lower
- Contingency Fast (6 seconds) Raise
- Contingency Fast (6 seconds) Lower
- Contingency Slow (60 seconds) Raise
- Contingency Slow (60 seconds) Lower
- Contingency Delayed (5 minute) Raise
- Contingency Delayed (5 minute) Lower

FCAS 'Raise' markets trade capacity to raise frequency by increasing generation or shedding loads. 'Lower' markets trade capacity to lower grid frequency by decreasing generation or increasing loads. The regulation FCAS markets are for major generators to modulate generation in response to minor grid frequency fluctuations. Contingency markets are more open to demand side customers as well as generators and are designed to manage sudden unexpected disturbance to grid frequency caused by the loss of a generation unit, a major industrial load or a large network transmission element.

FCAS trading involves a strict contractually binding commitment to have the promised demand response capacity on standby for automated and immediate response to emergency events. FCAS demand response is triggered by onsite grid frequency instrumentation. Failure to provide FCAS when required would be non-compliant with the National Electricity Rules, so FCAS commitments are typically conservative reserves of minimum base loads that may still be reduced for FCAS. High-speed sub metering is required on site to verify that FCAS providers met their commitments. FCAS capacity commitments are made in relationship to the instantaneous Unit MW Output. That is, the greater the energy usage on site, the greater the available capacity that can be turned off in response to a frequency disturbance.

FCAS Raise service costs are recovered from generators in proportion to their generation production whereas Lower market costs are recovered from consumers in proportion to their consumption. These FCAS costs are often explicitly listed on a commercial electricity bill.

FCAS prices are highly variable and offers are made for every 5-minute interval, similar to the wholesale market. Contingency markets trade in 1 MW increments. The Contingency Fast Raise and Contingency Slow Raise markets tend to be the highest value due to emergency responses to loss of major generation assets. These are coincidentally the most suitable FCAS markets for fast HVAC demand response control with minimal impact upon thermal comfort.

2.1.5 Conventional electricity agreements

Conventional electricity retailers often sell electricity to their customers at fixed tariffs. To offer a fixed price, these retailers establish hedging arrangements with generators (either by purchasing financial derivatives or through vertical integration i.e. owning and operating generation assets).

The financial hedges would normally involve buying the bulk (nominally around 60% or more) of their aggregated customers' base load daily profile through pre-purchased fixed price contracts. These fixed price contracts tend to be based on expectations of future average spot prices. Hedging products used are referred to as swap contracts and cap contracts, and can either be purchased on a central exchange operated by the Australian Stock Exchange (ASX), or purchase directly from generators (called over-the-counter (OTC) contracts).

The balance of their customers' aggregated energy demand needs to be procured from the wholesale spot price market (see below) for each trading interval.

The FCAS and RERT markets are funded on a user-pays model where costs are distributed to consumers through retailers along with network distribution costs, metering costs and environment levies.

Conventional electricity retail customers with managed demand flexibility can separately trade this capacity on the various FCAS, RERT and WDRM markets. This trade is generally conducted through (typically third party) aggregators, who operate Virtual Power Plants (VPPs) to manage a distributed network of generation and demand response assets on one or multiple of these various markets.

2.1.6 Wholesale electricity agreements

The NEM wholesale electricity market introduced above provides marginal cost signals to both generators and loads. Provision of this more agile generation on the margins may tend to be more costly on average than the predictable base load capacity. So for a consumer with no active demand response capability, a conventional fixed tariff structure may be the most cost effective agreement (noting the above comments linking fixed price to ASX future pricing and hedging options, which all come at additional costs). Whereas, consumers with active capability to reduce demand during peak price events and to productively consume extra energy during low and negative spot price periods, there may be an attractive cost advantage for participation in the wholesale market. This cost signalling and active participation is explicitly what the NEM is designed to achieve.

Innovative electricity retailers are emerging with a range of electricity agreement products that are designed to directly expose commercial and industrial consumers to the wholesale spot price. Consumers are provided direct access to the spot price settled for each trading interval, with a nominal fixed margin typically applied by the retailer. These wholesale electricity agreements could become major enablers for consumers with active demand flexing capability to effectively trade directly on the live spot price market without the forecasting and settling contractual constraints of the RERT and FCAS markets.

The AEMO price and demand is displayed in Figure 2, with 24-hour history and 24-hour forecast. The price is seen to spike dramatically when the demand reaches a certain dynamic threshold. This is a dynamic threshold that is approached when the lower cost generators are fully loaded, and demand is still increasing. This highlights the sensitivities of the marginal spot price.

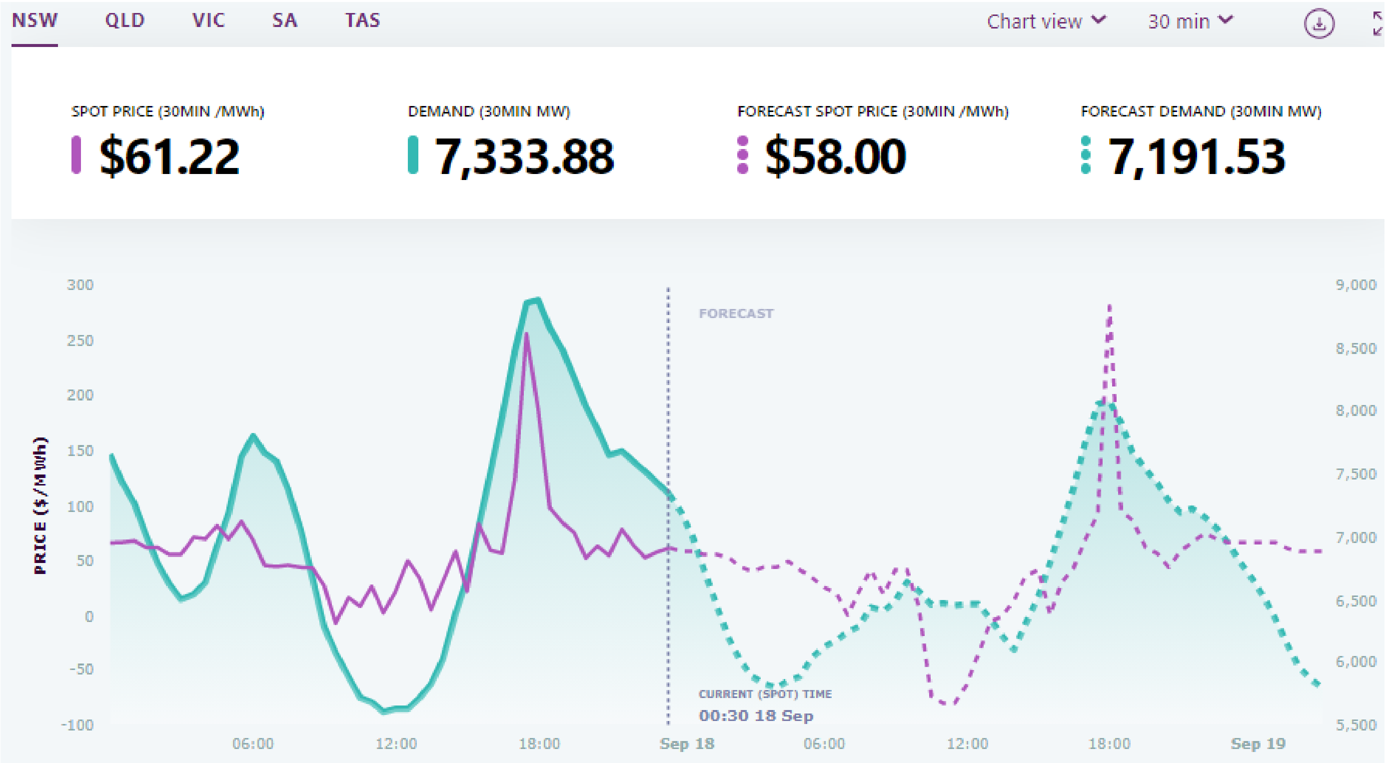

Figure 2 - AEMO price and demand trend and forecast

Proactive consumers who reduce demand during higher price intervals will reduce their exposure to spot price spikes. Conversely, with growing PV generation capacity in the NEM the wholesale spot price frequently settles at negative prices through the middle of the day. For these intervals spot price exposed customers are actually paid to use electricity and spot price generators must pay market price for the electricity that they feed into the grid.

Wholesale spot price market forecasting tools further enhance the potential of consumers to predictively control their demand flexibility to optimise for reduced electricity supply costs.

The risk of widespread catastrophic events disabling multiple major generation assets across the network for extended periods is a substantive risk to consider for wholesale customers. In such an event unhedged wholesale customers may be exposed to sustained high wholesale prices.

Conventional fixed price retailers would also need to recoup the portion of their wholesale exposed costs from their customers at some time, although a good hedge will protect them against this scenario.

Wholesale retailers may also offer price capping agreements or other hedged wholesale products that soften the wholesale market volatility to varying degrees for customers. However, by reducing the pricing volatility, the potential pricing benefits are also softened for active demand response consumers.

Since the wholesale consumer is taking the market risk on price fluctuations there should be a cost advantage even for an average consumer with no active demand response, noting the caveat above on the difference between the average marginal cost and base load cost. For proactive consumers who do much better than average through flexible demand management, the cost savings may be very substantial on a time-averaged basis.

Since WDRM is traded on the wholesale spot price market, the WDRM is not applicable to wholesale customers. However, wholesale agreement customers may concurrently trade their demand response on the RERT and FCAS markets.

2.1.7 Summary: HVAC demand response and the NEM

HVAC demand response has not been widely traded on the traditional demand response markets (RERT and FCAS). The reasons for this include: the large minimum trading capacities with respect to relatively small, distributed HVAC loads; the rigid standby delivery obligations with respect to HVAC demand capacity variability with weather and occupancy; the complexity of predictive HVAC controls to manage dynamic electricity costs within constraints of indoor thermal comfort; the lack of HVAC demand response technology; and the unfamiliarity of procurement managers with these more diverse and complex markets.

Commercial pre-commitments and settling on demand response from HVAC on the FCAS, RERT and WDRM markets is more complex than for standby energy sources such as batteries or backup diesel generators. The CAISO 10 method (AEMO 2021) may be used to establish a baseline for demand response capacity determination based upon a series of similar recent days from the same time. Whereas for a major standby generator or battery, the delivered demand response capacity is simply the net energy delivered from the standby source during the period.

The intent of the iHub living laboratory projects is to demonstrate innovative technologies and services that can increase the value of renewable generation through better alignment of the use of HVAC. The wholesale spot price electricity agreement in this trial provides the market mechanism to facilitate and incentivise active demand flexing technologies for the benefit of the consumer, the grid and society. As such this innovative service is considered a major enabling technology for increasing the value of renewable energy through smarter demand response control of HVAC systems.

2.2 Problem statement

HVAC demand response has to date not been commonly traded on the various demand response markets.

Active HVAC demand response has limited financial incentives through conventional commercial electricity agreements. Peak demand costs are calculated based on the 30-minute peak demand interval for each month and a fixed tariff rate ($/kWh). However, the timing of the consumer's monthly peak is not related to the concurrent grid spot price and as such is a relatively crude market signal. The effect tends to incentivise peak demand smoothing only for especially proactive consumers but does not provide a strong mechanism to incentivise or reward consumers for active demand response to the market signals.

Demand response service providers have tended to focus upon the larger and more predictable flexibility assets such as back up gensets, batteries, or large pumps. The magnitude of the potential HVAC demand response capacity at a site, portfolio, health care sector and state-wide level is not well understood.

HVAC demand response has a different demand response profile compared to these better known flexibility assets. HVAC demand response capacity is distributed in much smaller loads across the whole network. It is less predictable and hence more difficult to pre-commit to standby FCAS and RERT trade. It may generally not be sustained for hours without drastically impacting occupant thermal comfort.

Wholesale electricity agreements are relatively innovative products that provide clear market signals direct to retail consumers and also provide a simple financial settling arrangement direct to consumers to benefit from their active demand response actions. However, the prospect of comparing such diverse electricity agreements is complex and relies largely upon information provided by the wholesale retailers themselves.

Wholesale electricity agreements are an important enabling technology to allow a customer to easily access substantial financial benefits from advanced HVAC predictive control strategies. However, the potential costs savings of these innovative control strategies are complex to estimate.

This living laboratory trial, both separately and in concert with the forthcoming DNA Energy demand response trial, is an excellent facility to evaluate the combined cost impact of this complex suite of technologies and services. The current report provides an evaluation of the impact of moving from a traditional electricity supply contract to a wholesale electricity agreement, and an analysis of the potential for additional benefit to be realised through active control.

2.3 Technology overview

Flow Power is an innovative energy retailer, offering customers direct exposure to wholesale electricity spot market pricing. This demonstration project will consider Flow Power's pure pass-through wholesale product. In this product, consumers are charged according to their consumption and the co-incident wholesale spot price, plus a retailer mark-up. This provides a clear price signal to use in the active management of energy consumption.

Flow Power's kWatch^{TM} controller connects directly to the utility meter and enables the trading of consumption, generation and demand response on the AEMO wholesale and RERT markets.

Live data streams provided by Flow Power include:

1. Granular consumption
2. Live spot price
3. Live dynamic spot price forecast

2.4 **Objective**

The objective of this trial is to evaluate the overall electricity cost savings potential for Warrigal Shell Cove living laboratory for Flow Power's pure wholesale pass-through product compared to the existing conventional electricity agreement.

The evaluation will first compare the electricity supply costs without any demand response control action. The evaluation must consider the relative costs over a period that adequately represents the wholesale market volatility.

A separate evaluation will later be conducted to evaluate the cost savings of the combination of the wholesale market agreement and the active demand flexibility controls implemented by DNA Energy.

3 Test description

3.1 Site information

The Warrigal Living Laboratory is situated in the innovative coastal community village of Warrigal Shell Cove, in the Illawarra region and was opened in 2017 (Figure 3). This facility integrates aged care and independent living units into the local community and offers a range of villas and apartments suiting relaxed low maintenance living. At the centre of Shell Cove is The Quay, featuring shared spaces and a range of hospitality and wellbeing amenities on Ground Level. Warrigal Shell Cove's residential care home, situated on Levels 1 and 2 of The Quay, provides a range of high quality residential care, including 126 beds and 6 serviced apartments. This living laboratory focusses on Level 2 of the residential care home which consists of 64 beds and communal spaces. Heat recovery VRF (variable refrigerant flow) heat pump systems serve the buildings heating and cooling needs (Figure 4). Renewable generation includes a large array of solar panels (Figure 5).

This living laboratory provides research-quality measurement and verification systems within the this existing aged care ecosystem to test and evaluate the benefits of emerging HVAC&R, renewable energy and enabling technologies in the context of daily life.

Further description of this facility is provided in the Living Lab Operations Manual (iHub 2021).

Figure 3 - Warrigal residential care home

Figure 4 - Roof top Mitsubishi City Multi VRF HVAC units

Figure 5 - Aerial view of the living laboratory with the 99 kWp PV system and HVAC service on the roof.

3.2 Description of tested enabling service: Flow Power Pure Wholesale Pass-through

Flow Power's Pure Wholesale Pass-through product is a wholesale electricity agreement where the spot price is passed through direct to the customer with a transparent mark up. All other costs (network, environment, FCAS, metering, etc) are passed through at cost.

Capped spot price plans are available with some hedging included for customers who are comfortable with performing better than average but not ready for automated demand flexing control. These capped/hedged plans weaken the control signals and incentives for active demand response and were considered as less appropriate for this trial-especially in conjunction with the demand response trial. An alternative hedging offering, Power Active, is also available. This is designed to pass-through the undiluted wholesale spot price signal, whilst limiting the average monthly spot price that the customer will pay.

A comparison of electricity supply cost components between Flow Power's wholesale electricity agreement and Warrigal's existing conventional electricity agreement is outlined in Table 1.

Table 1. Comparison of electricity agreement tariffs.

Cost component	Existing conventional agreement (average)	Flow Power's wholesale pure pass-through agreement
Usage - Peak **- off-peak**	10.4 c/kWh 7.2 c/kWh	Co-incident wholesale spot price
Peak demand	$9/kVA	-
Spot Pass-through Margin	-	0.834 c/kWh
Daily service charge	$0.82/day	$4.90/day
Metering charges	$1210/year	$945/year
CT Compliance Testing Levy	-	$110/year
Network access charge	$22.01/day	Passed through at cost
Network charge - Peak **- Off-peak**	3.8 c/kWh 2.2 c/kWh	Passed through at cost
Environment Charges	1.8c/kWh	Passed through at cost
AEMO charges (RERT/FCAS)	0.07 c/kWh	Passed through at cost
Feed in Tariff	0.00 c/kWh[2]	Spot price – 0.834 c/kWh

Flow Power's kWatch™ Intelligent Controller is installed free of charge for all Flow Power customers and connects directly to an existing or replacement smart electricity meter via Modbus communications. The kWatch™ offers a range of demand response control actions suitable for flexibility assets such as batteries and large pumps that can be switched ON/OFF remotely with

[2] Note: this site has almost 100% self-consumption of on-site generation, therefore negligible solar export.

relatively simple logic checks. The management of HVAC demand response while maintaining the thermal comfort of occupants is more complex and will be achieved in partnership with DNA Energy as a separate technology trial in close association with this project.

Flow Power can offer RERT trading options and anticipate offering FCAS agreement in the near future, but neither of these were considered for the current evaluation, since there is not yet any active demand response capability.

Warrigal's existing conventional electricity agreement is in place until June 2022 and for this current evaluation Warrigal have not entered into any electricity agreement with Flow Power and a kWatch controller was not installed. Rather, an evaluation is being undertaken based on historical data to compare energy costs directly, to undertake a risk/benefit analysis as well as to make direct comparisons with the living lab measurements of individual condenser units at the facility.

4 Methodology

4.1 Test Approach and Description

The methodology of the test is detailed below. The current report covers the first test (4.1.1), and the second evaluation report will cover the second test. Comparing the enabling service (wholesale supply contract) separately to the technology evaluation (DNA energy demand response) will establish a baseline by which to attribute the additional benefit of the demand response.

4.1.1 Side-by-side electricity agreement evaluation – no demand response

- Start date and time: 1 January 2020
- End date and time: 31 October 2021

A side-by-side comparison method is used based upon historic 30-minute interval data. This evaluation compares the existing electricity supply agreement costs against the Flow Power pure wholesale pass-through agreement costs. There will be no demand response control action implemented for this evaluation, however the measurements from the facility’s condenser units are used to analyse the relevant opportunities and risks.

4.1.2 Live wholesale evaluation with DNA Energy demand response trial

- Start date and time: 1 December 2021
- End date and time: 30 April 2022

This upcoming technology evaluation will be conducted to evaluate the cost savings of the combination of the wholesale market agreement and active demand flexibility controls implemented by DNA Energy. The contents of this evaluation component will be in common material with the DNA Energy Technology Test Plan Report, with a focus on discerning the particular contribution of Flow Power’s technologies and services to the collaborative outcomes.

4.2 Instrumentation Plan

Table 2. Sensor list and specifications

Criteria	Model and specifications
Electrical utility meter	Warrigal’s existing meter provided the interval data for the site for the evaluation period.
Electrical energy at circuit level	Wattwatchers A6M devices (True RMS, kWh/5min, IEC62053-21 Class 1) were installed in the living laboratory to monitor every HVAC circuit on Level 2 of the building.
Internal temperature for individual rooms	**Nube iO droplet** ±1°C **Elsys ERS-CO2** ±0.2°C
Local weather station	Davis Pro (6328AU)

5 TEST RESULTS

This evaluation has been undertaken using metered site data for the Warrigal Shell Cove facility between 1 January 2020 and 31 July 2021, and wholesale spot prices from the Australian Energy Market Operator for the same period. During this period, Warrigal electricity supply was provided by a tier 1 energy retailer, with negotiated tariff structure. The tariff structure, averaged over the evaluation period, is summarised in Table 3.

Table 3. Detailed structure of existing energy supply tariff

Category	Charge	Average Rate	Percentage of energy cost	Included in evaluation?
Energy Charges	Peak	10.4 c/kWh	55%	Y
Energy Charges	Shoulder	10.4 c/kWh		Y
Energy Charges	Off-peak	7.2 c/kWh		Y
Market Charges	Participant Charge	0.04 c/kWh	0.4%	N
Market Charges	Ancillary Services	0.03 c/kWh		N
Metering and Other Charges	Meter Charge	332 c/day	0.9%	Y
Metering and Other Charges	Retail Supply Charge	82 c/day		Y
Environmental Charges	SRES Charge	0.8 c/kWh	12%	N
Environmental Charges	NSW Energy Saving Scheme	0.2 c/kWh		N
Environmental Charges	LRET Charge	0.7 c/kWh		N
Network Charges	Network Access Charge	2,202 c/day	32%	N
Network Charges	Peak Energy (DST)	3.8 c/kWh		N
Network Charges	Off Peak Energy (DST)	2.2 c/kWh		N
Network Charges	Demand Charge	900 c/kVA		N

The comparative evaluation will only consider a subset of these tariff categories, namely Energy Charges and Metering and Other Charges. It has been assumed that Market, Network and Environmental charges will be comparable between energy retailers. The comparison charges for the Flow Power offering are shown in Table 4

Table 4. Flow Power tariff structure

Category	Charge	Average Rate	Included in evaluation?
Energy Charges	Time of use tariff	AEMO wholesale price, average of 6.80 c/kWh during evaluation periods	Y
Energy Charges	Spot Pass-through Margin	0.834c/kWh	Y
Metering and Other Charges	Meter Charge	289 c/day	Y
Metering and Other Charges	Retail Supply Charge	490 c/day	Y

For the evaluation period, Table 5 summarises the actual energy charges for the Warrigal living laboratory facility from the current tier 1 retailer, and the theoretical energy charges for Flow Power using the pure wholesale pass-through offering. As can be seen from the monthly costs, the wholesale pass-through offering is substantially more variable in costs that a traditional offering. With the existing retailer, the energy cost was relatively fixed, varying between 8 and 10 c/kWh over the evaluation period. In contrast, the monthly average retail price per kWh for wholesale pass-through ranged between 4c/kWh (Feb-21) and 15 c/kWh (Jan-21).

For the majority of the evaluation period (14 of the 19 months), the potential benefits of direct exposure to the wholesale market is illustrated in substantially lower energy costs of up to 45% reduction. However, the risks inherent in exposure to spot price variation are also clearly illustrated in the extremely high cost in several months, notably over double for Jan 2020 and Jun 2021.

Table 5. Evaluation of monthly energy costs for existing retailer and Flow Power wholesale offering

Period	Consumption (kWh)	Existing retailer		FlowPower			Comparison	
		Energy Charges	Metering and Other Charges	Average Wholesale price	Energy Charges	Metering and Other Charges	$	%
Jan-20	**95,979**	**$9,216**	**$128**	**$0.15**	**$20,201**	**$242**	**$11,098**	**119%**
Feb-20	85,472	$8,193	$120	$0.06	$5,923	$242	-$2,148	-26%
Mar-20	77,800	$7,500	$128	$0.05	$4,324	$226	-$3,078	-40%
Apr-20	70,019	$6,670	$124	$0.04	$3,488	$242	-$3,065	-45%
May-20	96,670	$9,131	$128	$0.04	$4,987	$234	-$4,039	-44%
Jun-20	110,681	$10,529	$124	$0.05	$6,326	$242	-$4,085	-38%
Jul-20	114,393	$9,459	$128	$0.05	$6,549	$234	-$2,805	-29%
Aug-20	113,983	$9,217	$128	$0.05	$6,812	$242	-$2,292	-25%
Sep-20	87,639	$7,138	$124	$0.04	$4,442	$242	-$2,579	-36%
Oct-20	73,402	$5,961	$128	$0.06	$5,024	$234	-$832	-14%
Nov-20	69,113	$5,629	$124	$0.06	$5,103	$242	-$408	-7%
Dec-20	**75,001**	**$6,203**	**$128**	**$0.07**	**$7,232**	**$234**	**$1,135**	**18%**
Jan-21	80,773	$6,558	$128	$0.04	$3,949	$242	-$2,497	-37%
Feb-21	71,403	$5,934	$116	$0.04	$3,130	$242	-$2,678	-44%
Mar-21	77,446	$6,483	$128	$0.04	$3,738	$218	-$2,655	-40%
Apr-21	74,157	$6,087	$124	$0.06	$4,960	$242	-$1,010	-16%
May-21	**94,695**	**$7,749**	**$128**	**$0.12**	**$13,216**	**$234**	**$5,572**	**71%**
Jun-21	**108,604**	**$8,913**	**$124**	**$0.16**	**$19,537**	**$242**	**$10,741**	**119%**
Jul-21	**114,322**	**$8,826**	**$128**	**$0.12**	**$16,046**	**$234**	**$7,326**	**82%**
Subtotal		**$145,394**	**$2,392**	**$0.07**	**$144,984**	**$4,503**	**$410.30**	**101%**
		$147,787		**$149,487**				

Whilst being exposed on the spot price market allows for demand flexing and demand response, it also means that 100% of energy is being purchased at the marginal cost of generation, and that short term price spikes can result in substantial costs.

In order to balance the risk of exposure to these high price events, Flow Power offer a number of hedging options that can effectively limit the maximum cost that a consumer will be charged per kWh. Of particular relevance is the Power Active offering[3], which uses a price efficiency factor to pass-through an undiluted wholesale price signal, whilst effectively limiting the average monthly wholesale price per kWh that a consumer will be charged. This hedging option has not been explored in the current evaluation, however it is worth noting that offerings are available to manage the risk identified in Table 5.

Given the sensitivity of the wholesale pass-through, further consideration is provided below of the evaluation period, relative to longer term trends, and the co-incidence of loads at Warrigal with high spot prices. The AEMO wholesale price time series data shown in Figure 6 shows half-hourly price information since 2016, with the current evaluation period shown in red. It is clear that the current evaluation period has occurred during a time with a greater than normal number of high price events.

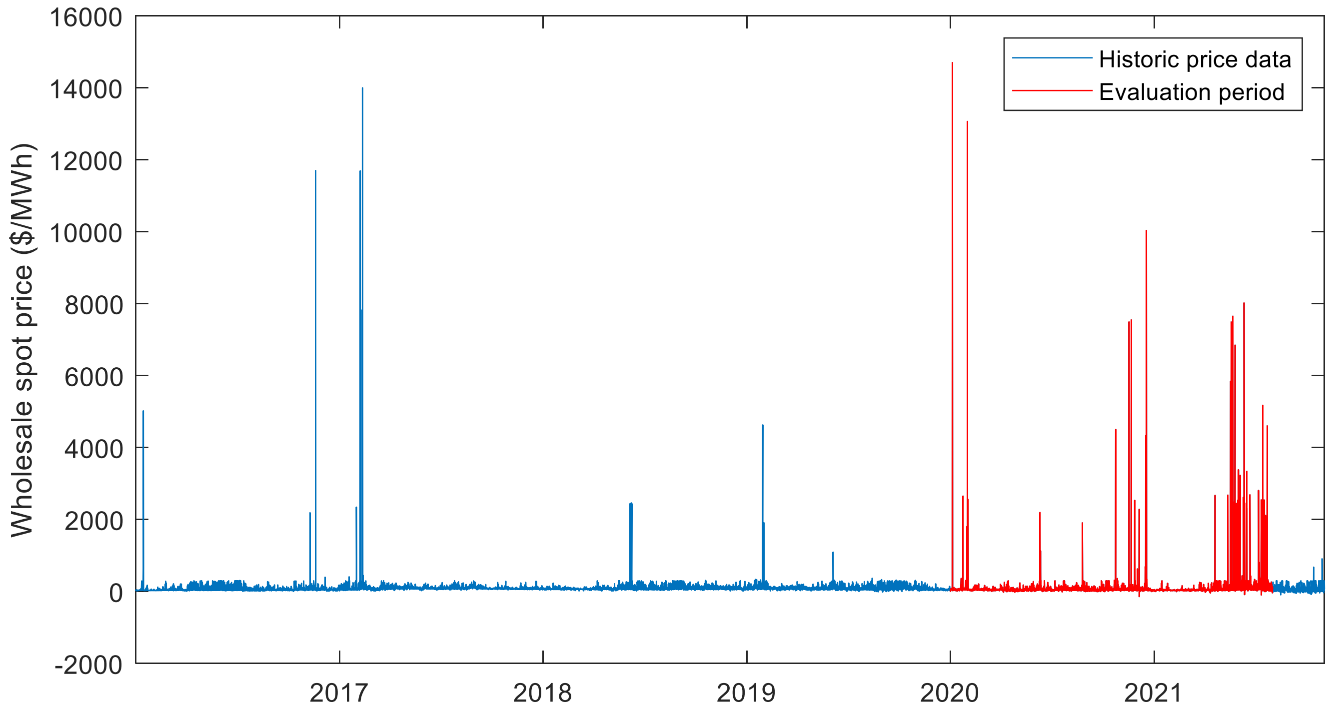

Figure 6. Historic wholesale spot price data from AEMO, showing the evaluation period in red.

The historically high number of high price events evident in Figure 6 is quantitatively summarised in Table 6. Both 2020 and 2021 had substantially more half-hourly periods with a wholesale spot price greater than a range of high price threshold values considered. For example in the years

[3] https://flowpower.com.au/power-active/

2016 – 2019, price events over $1000/MWh occurred for an average of 3.6 hours (2.5 to 7 hours); in 2020 and 2021 there were 18.5 and 33 hours with a spot price above this threshold, respectively.

As the NEM is in a period of transition, it is difficult to forecast the extent to which historic price trends will continue, or whether the frequency of high price events in the evaluation period is likely to continue. Adding to the complexity is the shift from 30-minute settlement to 5-minute settlement in October 2021. Regardless, it is clear form the price weighted fractions shown in Table 6 that high price events would be expected to have a substantial impact on energy costs during the evaluation periods.

Table 6. Quantitative summary of wholesale spot price

Year	Count of 30 min periods with wholesale spot price above				
	$500/MWh	$1,000/MWh	$2,000/MWh	$5,000/MWh	$10,000/MWh
2016	8	5	2	2	1
2017	15	14	6	6	4
2018	5	5	0	0	0
2019	5	5	0	0	0
2020	**42**	**37**	**16**	**16**	**7**
2021*	**79**	**66**	**9**	**9**	**0**
Year	Price weighted fraction*				
	$500/MWh	$1,000/MWh	$2,000/MWh	$5,000/MWh	$10,000/MWh
2016	3%	2%	2%	2%	1%
2017	6%	6%	6%	4%	3%
2018	1%	1%	1%	0%	0%
2019	1%	1%	1%	0%	0%
2020	**20%**	**20%**	**19%**	**15%**	**9%**
2021*	**21%**	**20%**	**19%**	**6%**	**0%**

*equation is (sum of price> threshold)/sum of all price. This is equivalent to what proportion of a bill would be caused by these price spike assuming a constant load.

**1/1/2021 to 31/07/2021.

The specific impacts of these high price events during the evaluation period on the monthly energy costs shown in Table 5 are presented in Table 7. It can be seen that for the months in which the wholesale pass-through offering resulted in higher energy costs (shaded and bolded in Table 7), a substantial portion of the energy cost was the result of consumption during a relatively small number of hours. For example, in January 2020:

- 68% of the energy costs was due to 11 hours of consumption when prices were above $500/MWh;
- 57% of the costs was due to 5.5 hours of consumption when prices were above $5,000/MWh, and;

- 40% of the bill was due to 3 hours of consumption when prices were above $10,000/MWh

This concentration of energy cost in a small number of hours over a month suggests that were the facility to have demand response or demand flexing capabilities enabled, there is the potentially to substantially reduce energy costs with limited impact on building operations.

Table 7. Length and contribution to bill total of various high wholesale cost periods during the evaluation period.

Period	Consumption (kWh)	Energy Charges	Duration and cost per MWh contribution of energy consumed with price above:							
			$500/MWh		$2,000/MWh		$5,000/MWh		$10,000/MWh	
			Hours (%)	% of bill	Hours (%)	% of bill	Hours (%)	% of bill	Hours (%)	% of bill
Jan-20	**95,979**	**$20,200.90**	**11 (1.5%)**	**68%**	**8.5 (1.1%)**	**65%**	**5.5 (0.7%)**	**57%**	**3 (0.4%)**	**40%**
Feb-20	85,472	$5,923.10	0.5 (0.1%)	5%	0.5 (0.1%)	5%	0	0%	0	0%
Mar-20	77,800	$4,324.20	0	0%	0	0%	0	0%	0	0%
Apr-20	70,019	$3,487.50	0	0%	0	0%	0	0%	0	0%
May-20	96,670	$4,986.50	0	0%	0	0%	0	0%	0	0%
Jun-20	110,681	$6,326.30	1 (0.1%)	4%	0.5 (0.1%)	3%	0	0%	0	0%
Jul-20	114,393	$6,548.60	0	0%	0	0%	0	0%	0	0%
Aug-20	113,983	$6,811.70	0.5 (0.1%)	2%	0	0%	0	0%	0	0%
Sep-20	87,639	$4,441.80	0	0%	0	0%	0	0%	0	0%
Oct-20	73,402	$5,023.60	1 (0.1%)	8%	1 (0.1%)	8%	0	0%	0	0%
Nov-20	69,113	$5,103.40	1.5 (0.2%)	18%	1.5 (0.2%)	18%	1 (0.1%)	15%	0	0%
Dec-20	**75,001**	**$7,231.70**	**5.5 (0.8%)**	**42%**	**3.5 (0.5%)**	**38%**	**1.5 (0.2%)**	**27%**	**0.5 (0.1%)**	**12%**
Jan-21	80,773	$3,948.50	0	0%	0	0%	0	0%	0	0%
Feb-21	71,403	$3,130.20	0	0%	0	0%	0	0%	0	0%
Mar-21	77,446	$3,738.20	0	0%	0	0%	0	0%	0	0%
Apr-21	74,157	$4,960.00	0.5 (0.1%)	3%	0.5 (0.1%)	3%	0	0%	0	0%
May-21	**94,695**	**$13,215.70**	**12 (1.7%)**	**44%**	**8.5 (1.1%)**	**40%**	**3 (0.4%)**	**22%**	**0**	**0%**
Jun-21	**108,604**	**$19,536.70**	**19.5 (2.8%)**	**42%**	**16.5 (2.2%)**	**39%**	**1 (0.1%)**	**6%**	**0**	**0%**
Jul-21	**114,322**	**$16,045.70**	**6.5 (0.9%)**	**17%**	**4 (0.5%)**	**14%**	**0.5 (0.1%)**	**3%**	**0**	**0%**

To further understand the potential for demand response or demand flexing to be implemented during the short high price periods identified, two case studies are considered below. These cases studies consider the measured energy consumption for the two large condenser unit at the Warrigal living laboratory serving the level 2 common areas, and the internal conditions in those spaces during two periods with a number of high price events.

- Figure 7 displays the week from December 2020 with the majority of high price events; the spot price exceeds $500 (per MWh) for 4.5 hours, $2,000 for 3 hours, $5,000 for 1.5 hours, and $10,000 for 0.5 hours.
- Figure 8 shows a week from June 2021 with the majority of high price events; the spot price exceeds $500 for 7.5 hours, $2,000 for 7 hours, and $5,000 for 1 hour.

In the summer period, it can be seen that during the two extreme high price events, both condenser units are operating at full capacity and measured temperatures are well within comfortable ranges. There are four distinct high price events, two last half an hour, one lasts 1 hour, and one lasting 2.5 hours. There is evident opportunity for load shifting to pre-cool these spaces during the morning period where prices are much lower, in order to reduce consumption during the two afternoon high price events. The shorter duration events occur earlier in the day, and it is likely that the spaces would be able to maintain comfortable conditions for the duration of the high price events.

In the winter period, the energy use profiles are less distinct. Heating is being supplied 24 hours a day, with slightly increased consumption during night time hours. There is an extended high price event, lasting 5 hours, that was likely related to strong winds and storms on the eastern seaboard at that time – which highlights the relationship between the wholesale spot price and local events (often unplanned). Again, there is clear evidence that active control of the HVAC equipment would likely have substantial cost implications. There are two clear examples, at 7:30 AM on 10/06/2021 and at 8:00 AM on the 11/6/2021, where short terms spikes in condenser energy consumption coincide with high price events. The relatively stable temperature observed in the dining zone, and the moderate energy consumption of the condenser units suggest that pre-warming spaces in anticipation of high price events would be achievable.

This analysis of sub-metered and internal temperature data collected from the Warrigal living laboratory supports the forthcoming evaluation of the wholesale price agreement in combination with demand response and load flexing (via DNA energy) as a promising technology combination.

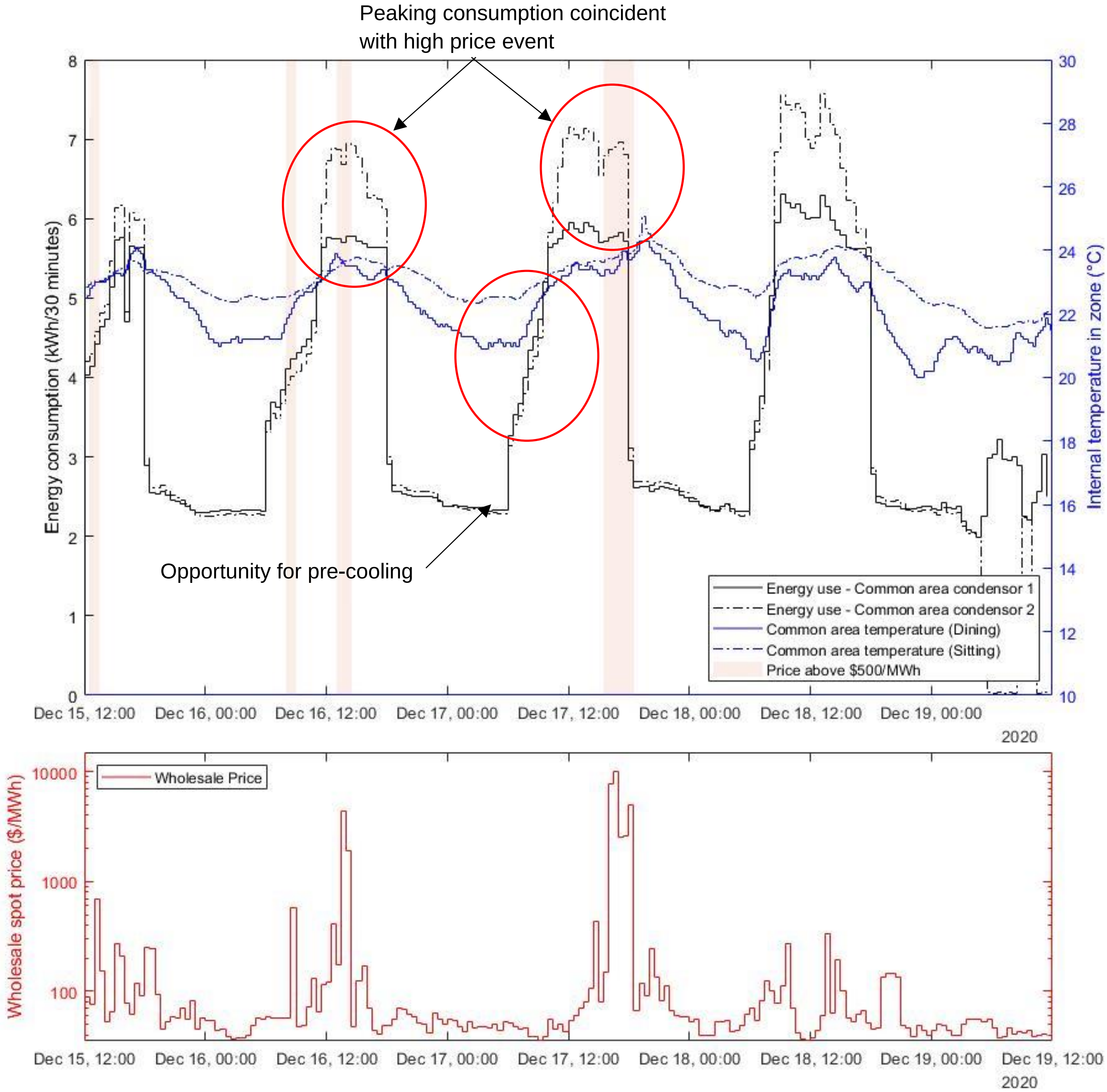

Figure 7.Summer time-series measured data form the Warrigal living laboratory showing energy use for individual condenser units, co-incident internal temperatures for a sample of the zones serviced by these units, and co-incident wholesale spot price during a period with a number of high price events.

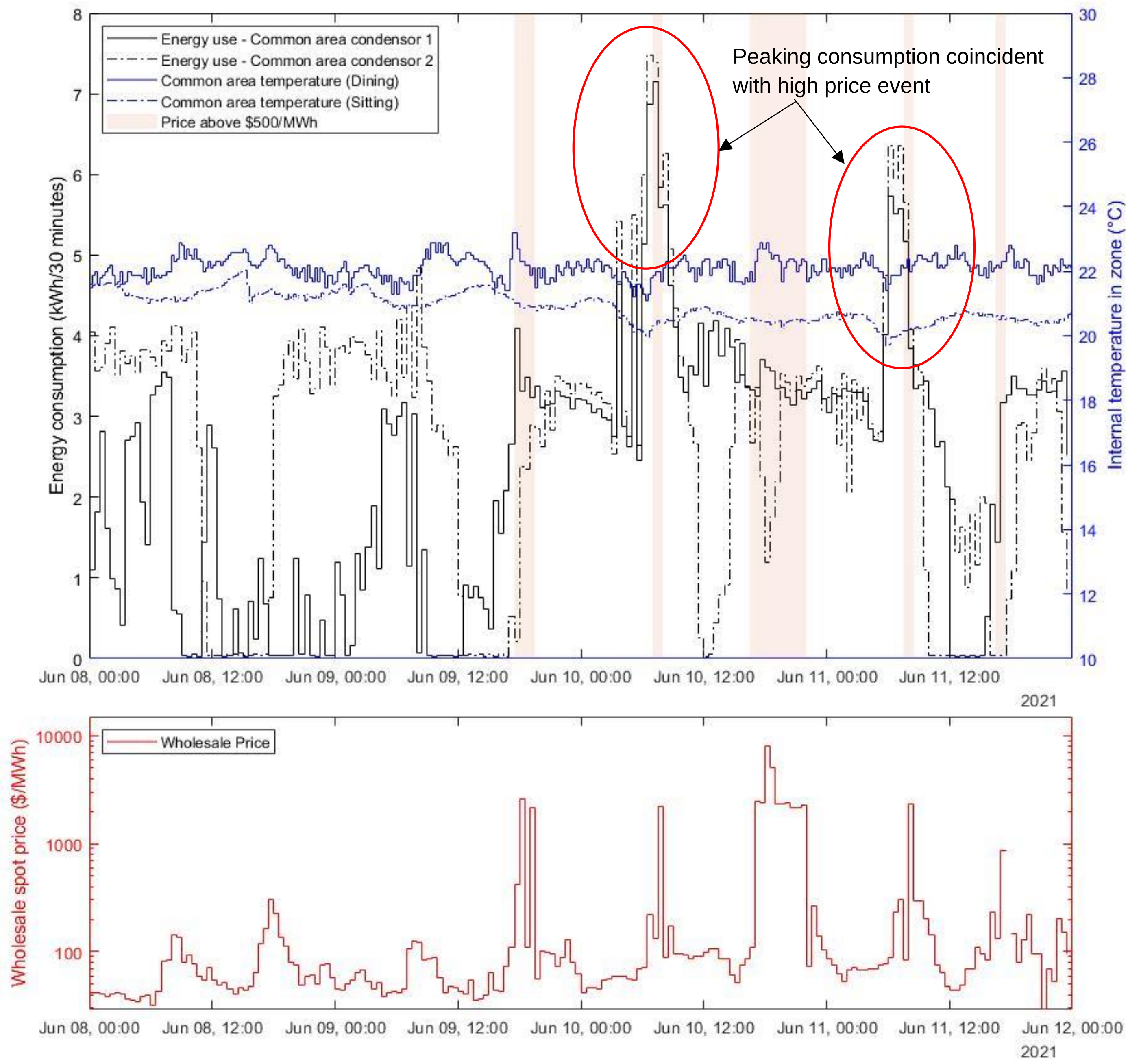

Figure 8. Winter time-series measured data form the Warrigal living laboratory showing energy use for individual condenser units, co-incident internal temperatures for a sample of the zones serviced by these units, and co-incident wholesale spot price during a period with a number of high price events.

6 SUMMARY FINDINGS AND CONCLUSIONS

6.1 Overall Technology Assessment

The current evaluation of the Flow Power Pure Wholesale pass through agreement has highlighted both the potential value and the potential risks of this enabling service. The use of this energy supply contract provides an effective price signal by which to incentivise better alignment of HVAC energy consumption with periods of lower wholesale prices, which are typically related to periods of high renewable generation (or lower aggregate demand).

Without the use of any active HVAC controls, the overall energy cost under the wholesale agreement for the period of this evaluation would have been very similar to the cost of energy under the current supply contract from a tier 1 retailer for the living laboratory facility ($410 or 1% greater). The period of evaluation also appears to have included an unusually large number of high price events, in comparison with historical data from AEMO.

However, there was substantial variation in the monthly energy cost under the wholesale agreement, from a maximum monthly cost of $20,201 (119% more than current bill) to a minimum of $3,130 (44 less than current bill). Further analysis revealed that the months with high energy costs were heavily influenced by a small number of high price events. These high price events typically occurred at periods that would be conducive to various forms of energy flexing to reduce loads, and thereby significantly reduce energy costs.

Participating on the wholesale spot price market through this form of energy supply agreement appears to be a promising method to monetise HVAC demand flexibility, by better aligning periods of HVAC consumption with periods of renewable generation and minimising the exposure to spikes in spot prices. This solution is relatively simple in comparison with other methods of monetising demand response (i.e. FCAS, RTE and WDRM)

6.2 Barriers and Enablers to Adoption

- Flow Power's wholesale electricity agreements have been identified as a potential key enabler and very promising incentive for HVAC demand flexing controls to engage value for the benefit of building owners and for the grid.

- There is an emerging market of service companies aiming to facilitate end-user interaction with these demand flexing market mechanisms.

- The National Energy Market is complex, with many different markets by which demand response enabled HVAC systems could potentially generate value. Understanding these systems and identifying the opportunities and risks of active participation in the various markets requires highly-developed energy literacy, and is a significant barrier to widespread adoption of these offers.

- Engaging with the wholesale market through a pass-through agreement is a fundamentally different way of purchasing energy, and the internal systems and processes within end-user organisation may not be sufficiently agile or confident to make this shift. Moving from a relatively predictable monthly energy bill, to a highly variable and hard to predict energy bill will challenge existing management processes and styles.

- The various hedging options offered by Flow Power are likely to be significant enablers to adoption. By effectively limiting the end-user risk whilst maintaining the clear price signal (i.e. the Power Active option), many of the anticipated adoption concerns from end-users can be addressed.

6.3 Recommendations

- Based on the results from the current analysis, it is recommended that the combination of a wholesale electricity agreement and predictive HVAC control for demand response be evaluated as a technological and enabling services combination as planned for the forthcoming Flow Power and DNA energy evaluation.

- Additional research and development is likely to be required to fully realise the potential of demand flexing of HVAC system based on wholesale spot price, as it requires bringing together diverse technologies and services to serve the needs of a specific sector

- The FCAS and RERT demand response markets should also be evaluated for HVAC demand flexing income generation potential.

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