The Innovation Hub
for Affordable Heating and Cooling

Technology Evaluation Report

DNA Energy:
HVAC Demand Response for Residential Aged Care Homes

May 2022

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.

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.

The information or advice contained in this document is intended for use only by persons who have had adequate technical training in the field to which the Report relates. The information or advice should be verified before it is put to use by any person. Reasonable efforts have been taken to ensure that the information or advice is accurate, reliable and accords with current standards as at the date of publication. To maximum extent permitted by law, the Australian Institute of Refrigeration, Air Conditioning and Heating Inc. (AIRAH), its officers, employees and agents:

a) disclaim all responsibility and all liability (including without limitation, liability in negligence) for all expenses, losses, damages and costs, whether direct, indirect, consequential or special you might incur as a result of the information in this publication being inaccurate or incomplete in any way, and for any reason; and

b) exclude any warranty, condition, guarantee, description or representation in relation to this publication, whether express or implied.

In all cases, the user should be able to establish the accuracy, currency and applicability of the information or advice in relation to any specific circumstances and must rely on his or her professional judgment at all times.

Lead organisation

University of Wollongong (UOW)

Project commencement date **31 August 2021**

Completion date **27 May 2022**

Date published

Contact name Georgios Kokogiannakis

Email gkg@uow.edu.au

Role Living Lab Activity Leader

Project website www.ihub.org.au

VERSION HISTORY

Revision	Version details	Prepared By	Revision Date	Reviewed By	Approval Date
1.0	For submission to AIRAH	M. Tibbs and D. Daly	27/5/2022	G. Kokogiannakis	27/05/2022
1.1	Revisions from DNA	M. Tibbs	31/5/2022	D. Daly	09/06/2022

This report should be read in conjunction with:

- Technology Evaluation Report: Flow Power Electricity Spot Price Trading. https://www.airah.org.au/Content_Files/iHub/2022/LLHC2_Technology_Evaluation_Report_Flow_Power_Electricity_Spot_Price_Trading.pdf

Cite as: Tibbs, M, Daly, D, Kokogiannakis, G, McDowell, C, Roth, J, Cooper, P. 2021. I-Hub Product Testing Evaluation Report: DNA Energy: HVAC Demand Response. I-HUB report, AIRAH.

Table of contents

1 EXECUTIVE SUMMARY

1.1 Warrigal Living Laboratory residential aged care facility

A ‘Living laboratory’ is a user-centred open-innovation, ecosystem within collaborative partnerships. Living Laboratories benefit both technology providers and technology users, addressing barriers to the uptake of innovation, such as lack of familiarity, risk aversion and distrust in supplier claims. The i-Hub Living Laboratories are flexible spaces where product suppliers can bring their technology for independent validation.

The Warrigal Shell Cove living laboratory established research-quality measurement and verification systems within an existing aged care facility. The living laboratory includes monitoring of HVAC services and occupant behavioural impact on indoor environmental quality (IEQ), in order to observe and evaluate technology upgrades within the context of the daily life of these facilities. The technologies trialled in this living laboratory were selected from promising renewable energy and enabling technologies and services that can increase the energy flexibility of aged care facilities, and deliver increased value for renewable energy, at the site and grid level.

The Warrigal Shell Cove living laboratory is a modern three-level residential care home. The facility includes a large 99 kWp array of solar panels. The heating and cooling needs of the building are served by Mitsubishi Electric City Multi heat recovery VRF (variable refrigerant flow) heat pump systems, with 258kW of demand response capable capacity. The thermally massive construction of the building provides significant thermal energy storage capacity with relatively stable indoor temperatures.

Evaluation of the baseline performance of the facility found appropriate levels of thermal comfort, a relatively high on-site consumption fraction of on-site renewable energy generation, and a daily site electrical load profile that was qualitatively aligned in profile with PV generation.

1.2 Demand response marketplace: HVAC for the aged care sector

A technology mapping exercise prior to this project identified HVAC demand response technologies as one of the most promising technologies currently available with the potential to improve the value of renewable generation in the aged care sector. However, it quickly became evident that the intersecting technological, social and financial systems in which demand response technologies and market services exist are extremely complex. Moreover, the technology and service capabilities within these ecosystems are evolving rapidly. Navigating and mapping the landscape of demand response markets and technologies became a key outcome of this report.

One of the key enabling technologies for HVAC demand response is energy retail agreements that expose the consumer to price fluctuations on the National Energy Market, and thereby incentivise changes to energy consumption behaviour. As a precursor to the present evaluation, a technology evaluation study was undertaken on an innovative energy retailer (Flow Power) offering a wholesale spot price agreement. This report (iHub, 2021c) provides relevant background to assist in mapping and quantifying market mechanisms, available incentives and the potential value that could be exploited by suitable demand response technologies

The Flow Power evaluation compared the total annual cost of electricity supply from a wholesale spot price agreement against the existing conventional electricity supply cost for the same consumption period. The wholesale spot price agreement resulted in significant variation in monthly energy cost. In months with more than the usual number of high price events, the Warrigal electricity bill could be substantially larger than it would be under a traditional offering (up to 120% higher than the conventionally priced monthly energy cost).

Analysis of the energy consumption and thermal conditions at Warrigal during these (typically short and infrequent) high price events indicated a substantial opportunity to reduce energy costs, if energy consumption were actively managed to reduce load during these periods. This evaluation highlighted the potential financial value of the use of demand response technologies to reduce HVAC consumption during price peak intervals. This present technology evaluation combines the Flow Power pass-through offering with active control of the HVAC system.

Alongside the wholesale spot price market, significant potential was also identified in the Frequency Control and Ancillary Services (FCAS). These frequency response markets, particularly the FCAS Fast and Slow Raise markets, were highlighted as additional potential income streams that also align well with the requirements of the aged care sector. These demand response markets are outlined in some detail in Section 2.1 and summarised in Table 1.

Accessing these markets requires enabling technologies that can effectively utilise the HVAC capacity by controlling devices to switch off or time-shift HVAC electrical loads without compromising thermal comfort. This grid-interactive HVAC control 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.

DNA Energy’s Demand Response Mode (DRM/DRED) HVAC control technology was subsequently chosen for evaluation at the Warrigal Living Laboratory. DNA Energy’s DRM-enabling HVAC control interfacing technology appeared to be a suitable candidate technology for evaluation since it could potentially respond quickly enough to participate in not only the RERT market, but also the spot price and FCAS markets. Further, DNA Energy's DRM technology was also seen to be potentially flexible enough to enable DRED-equivalent responses for the majority of HVAC equipment in commercial buildings that are DRM-capable, though not necessarily compliant with Australian DRM standards.

The current evaluation explored the use of DNA Energy's DRM technology to reduce energy consumption during 5-minute spot price peak intervals using several methods, and the impact of this on thermal conditions within the Warrigal facility. Additional evaluation was also undertaken of the potential value of providing services to the FCAS Fast and Slow Raise markets, with the key consideration being the reliable response time of the combination of DNA devices and the existing Mitsubishi VRFs.

A key advantage of the DNA Energy HVAC demand response technology offering is the unique combination of wireless DRM controls being applied to the HVAC industry (where they are more typically being rolled out with grid-scale batteries at present) and having integrated market interfacing to both the wholesale spot price market and to FCAS Raise markets.

1.3 **Results**

The evaluation was undertaken using HVAC consumption and internal environment data for the Warrigal Shell Cove facility between 1 September 2020 and 25 May 2022, and Australian Energy Market Operator 5-minute data for the same period, as well as device specific data from DNA energy devices. There were significant restriction imposed on this evaluation due to COVID-19. Supply chain issues in provision of devices resulted in a relatively short active evaluation period, and restrictions on access to the facility (as a Warrigal risk management strategy) limited the evaluation techniques available.

This evaluation has demonstrated that automated temperature set point adjustments are a promising method to implement HVAC load flexing control with the wholesale spot price forecasts. This can deliver significant value to Warrigal by pre-conditioning spaces with elevated HVAC loads during periods of lower spot price (typically when there is significant renewable energy input to the grid) and reducing loads during higher spot price. A HVAC load response was identified of order 30 minutes, making these predictive temperature flexing adjustments well-suited to gradual HVAC load flexing over extended periods. However, the slow load response time to the temperature set point adjustment limits the utility of this mechanism for rapid modulation of HVAC loads (i.e. within a five-minute trading interval).

The thermal mass of the Warrigal facility was shown to provide adequate thermal stability to allow HVAC demand response control actions (both DRM controls and temperature set point flexing) to be sustained for multiple 5-minute trading intervals without any sudden or significant impact on indoor thermal comfort expected.

An analysis was also undertaken of the wholesale spot price market since it has changed from 30-minute settling to 5-minute settling (October 2021). Typical peak spot price events were shown to be relatively brief and characterised by sharp rates of price rise above $300/MWh. Approximately

70% of spot price events that settled at greater than $500/MWh were only sustained for a single trading interval (5 minutes). Only three of these high spot price events were sustained for greater than 50 minutes during the period from October 2021 to May 2022. This suggests that the use DRM1 control calls (i.e. turn off) to condensers can avoid most high spot price events. An indication of potential grid-interactive HVAC load flexing and curtailment is illustrated in Figure 1-1.

The current program of evaluation has identified that three independent, complementary grid-interactive HVAC control technology/market value streams are practically feasible, and appropriate for the aged care sector.

1. The slower response load flexing by predictive adjustment of temperature set point could be used effectively with a reasonably robust spot price forecasting tool with a wholesale spot price retail agreement.
2. Supplementary to predictive temperature set point load flexing, DRM controls may be used to curtail HVAC electricity consumption for the ensuing five-minute spot price trading interval immediately after a sudden unexpected spike in the spot market is settled.
3. DRM controls may be independently used to trade new value streams on the FCAS Raise markets through an aggregator.

This highlights the complementary important potential roles of both of these grid-interactive HVAC control technologies across two separate market mechanisms. Further development work would be required to demonstrate and refine the more complex predictive control strategies for this site.

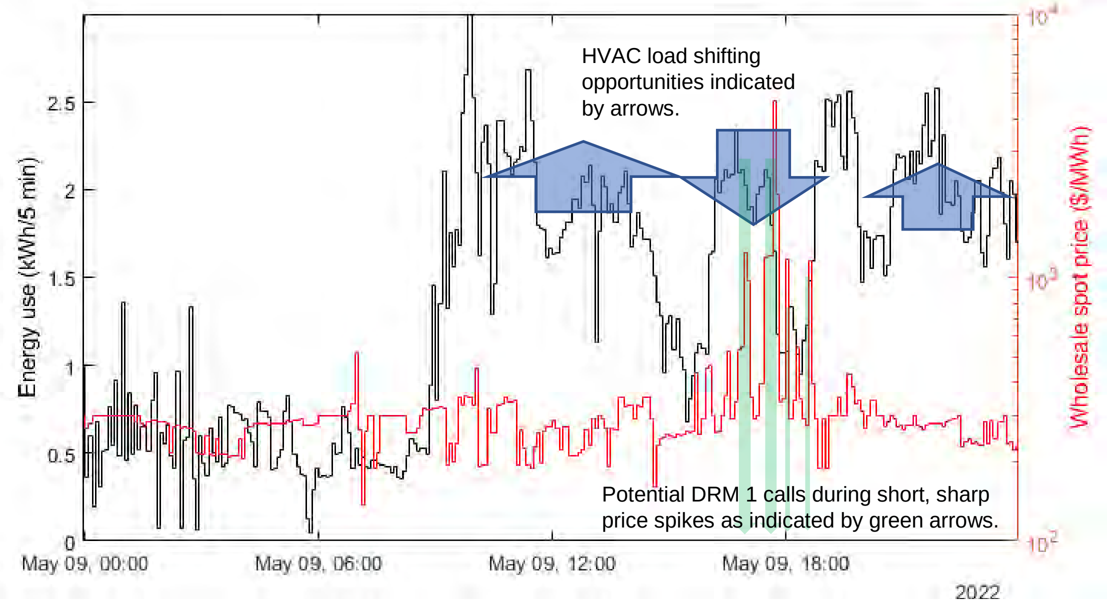


Figure 1-1. Aggregated condenser consumption overlaid on wholesale spot price for one day – high loads coincident with high spot price intervals.

2 INTRODUCTION

New and emerging technologies and services are creating opportunities for energy flexible buildings, that is, buildings that can 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). Heating ventilation and air conditioning (HVAC) systems are a major energy load in buildings, so their control and integration with renewable generation, both on-site and off-site, is an essential consideration for energy flexible buildings.

Whilst the enabling technologies are reaching maturity, there are many factors relating to their successful deployment in buildings and uptake by the health care sector that requires further investigation. There are three items of particular relevance to the current report:

1. *Technical implementation issues:* There are many ways in which HVAC can be controlled to improve the value of renewable generation, including load shifting (i.e. time-shifting HVAC loads through pre-conditioning spaces), demand-response (i.e. applying short term power limits to HVAC equipment), and demand flexing (i.e. modifying control settings such as temperature set-point during certain periods to indirectly shift HVAC loads). 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. *AEMO market incentives and regulatory realignment*: 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. Adjustments to the regulatory frameworks can unlock opportunities for service providers and consumers to be rewarded for more active participation in demand response markets, so that the outcomes negotiated between consumers and generators may better facilitate shared benefits.
3. *Social license for active management of distributed energy resources:* 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. Consumers are at the centre of this transition as the client, as distributed generator, and as potential demand response participants. For consumers to allow a more active control of their HVAC services to be more responsive to the dynamic costs of the electricity grid, the energy industry will need to build relationships of trust and understanding of shared values.

As such, a detailed understanding of the energy market in Australia and the ways in which the different energy flexibility services are rewarded is required in order to effectively evaluate these technologies. This section first presents a review of the demand response mechanisms within the National Energy Market, detailing a range of specific sub-markets of relevance to grid-interactive control of HVAC, then overviews the relevant demand response technologies, including the implications for thermal comfort in an aged care facility.

2.1 Demand response in the National Electricity Market

The National Electricity Market (NEM) operated by the Australian Electricity Market Operator (AEMO) is one of the world's longest interconnected power systems spanning five states from Queensland in the north, South Australia in the west and Tasmania in the south.

The NEM is undergoing rapid transformation moving closer towards world-first levels of renewable generation. AEMO projects that there could be sufficient renewable resources available as soon as 2025 to meet 100% of underlying consumer demand in certain periods (AEMO 2021). A key focus of AEMO is on managing an accelerating transition towards high instantaneous penetration of renewable generation, accelerating exit of coal, increasing electrification of heating and transport, and the introduction of 'green' hydrogen consumption. This increasingly dynamic balance of supply and demand in this marketplace is disrupting the conventional, relatively stable market with 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 2-1, noting that electricity prices are bid and set on separate, interlinked wholesale spot price markets for each state.

In order to balance demand and generation 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 is set for each 5-minute trading interval based upon generator bids and the AEMO forecast of total consumer demand for each interval.

For each five-minute interval, generators submit their price and capacity bid to AEMO who create a "bid-stack" to sort these offers in ascending order of price. AEMO will then dispatch the cheapest collection of generators needed to meet expected consumer demand. The price for the five-minute interval is set by the marginal generator offer, that is, the price of the most expensive generator needed to meet consumer demand. This price is paid to all generators who were dispatched to produce power in that interval and is paid by energy consumers who used energy in that interval.

Energy consumers have not previously been able to actively bid into the wholesale market as large generators do, with the exception of some very large hydro pumps. However, note the new Wholesale Demand Response Mechanism described in Section 2.1.3. Because energy consumers do not generally bid into the wholesale market, they are not part of the process of setting the wholesale price. However, there is the opportunity for wholesale price exposed consumers to change their demand in response to the forecast price, thus reducing their exposure to higher wholesale prices.

Price responsive consumers can also influence 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.

The market trading interval was reduced from 30 minutes to 5 minutes in October 2021 to provide a better price signal for investment in faster response technologies (AEMO 2021a).

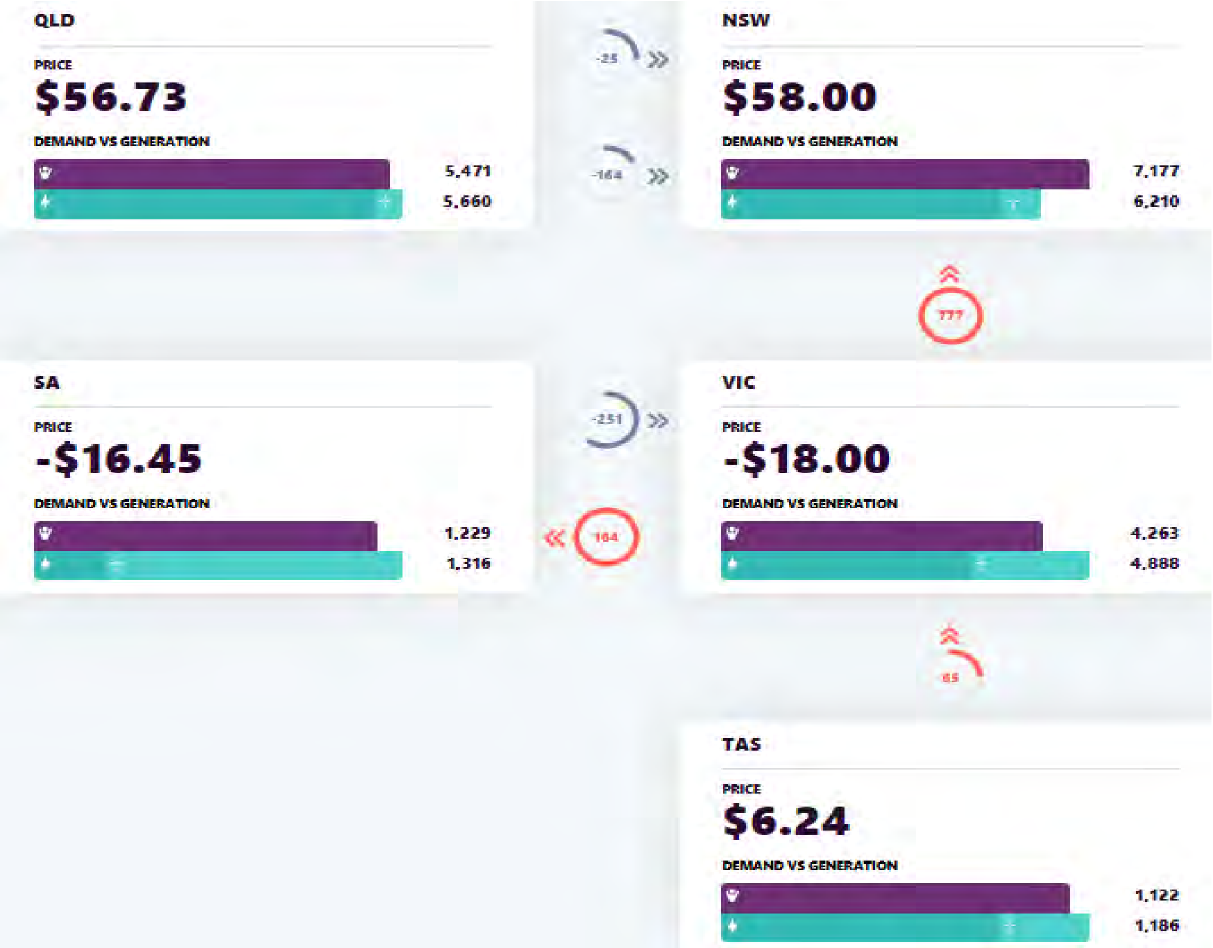


Figure 2-1 - The AEMO dispatch overview page showing current spot price for each connected state, with total demand, generation and energy transfers between states.

This wholesale spot price market manages the supply-demand balance at the 5-minute time interval. Shorter-term fluctuations in supply-demand are managed and costed in the separate Frequency Control and Ancillary Services (FCAS) markets. Extreme seasonal peak demand events, where the electricity grid is approaching full capacity and prices are spiking, are managed by the Reliability and Emergency Reserve Trader (RERT) market. These three separate demand response markets present alternative and additional income stream opportunities for consumers to participate in with their active demand response capacity.

2.1.1 Frequency Control and Ancillary Services (FCAS) markets

The purpose of the FCAS markets is to balance short-term generation and demand fluctuations that disturb grid frequency. For example, an unplanned sudden failure of major generation unit would cause a decrease in system frequency. Just like driving a car and coming to a steep hill without changing the accelerator position, the car will slow down (grid frequency decreases from 50 Hz) due to the increased load (total grid demand) upon the engine (power generators).

FCAS markets are operated by AEMO independently to the wholesale spot price market, however, market forces will tend to produce correlations between FCAS prices and wholesale spot prices. 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 markets are for major generators to modulate generation in response to minor grid frequency fluctuations. The 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 unscheduled loss of a generation unit, a major industrial load or a large network transmission element.

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

The timing and ramping of ideal FCAS Raise demand responses is graphed in Figure 2-2 for a total available demand response of 3 MW for each of the Fast, Slow and Delayed Raise FCAS markets. AEMO dispatches the agreed demand capacity under FCAS market contracts for the present five-minute trading interval. This demand capacity must be ready on standby to ramp down by a guaranteed 3 MW over a set time-period then ramp back up more slowly. The total portfolio DRED-enabled HVAC load is initially operating well above 3 MW, as a buffer in case this total available demand response decreases during the trading interval. A Fast Raise demand response sheds load within six seconds, then ramps back up to the previous load over one minute. A Slow Raise demand response does nothing for six seconds, then ramps down within one minute of the event trigger before ramping back up to unrestricted load after five minutes. The Delayed Raise response does nothing for one minute, then ramps down over the next four minutes, before ramping back up to full load after ten minutes. Notice the load shedding profile for 3 MW dispatched on both the Fast Raise and Slow Raise markets simultaneously.

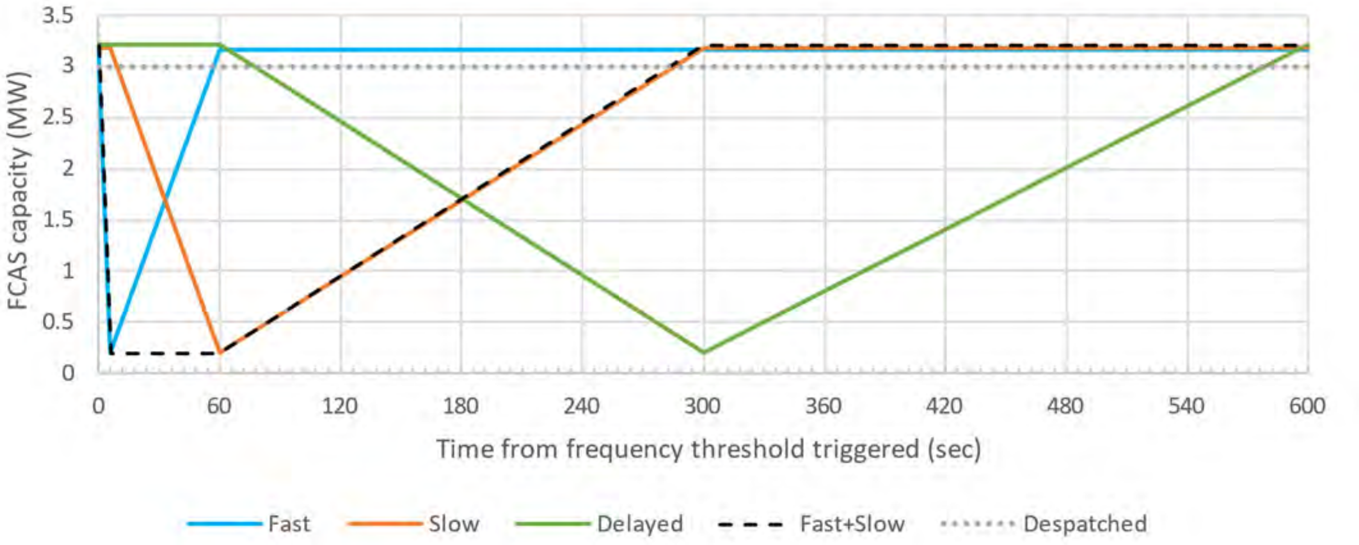


Figure 2-2 – Ideal FCAS market response ramps for a 4 MW contracted demand response.

These FCAS responses are triggered when the grid frequency, measured by an approved meter on site, drops below the *normal operating limit* of 49.85 Hz. A grid frequency disturbance response is illustrated in Figure 2-3 with a typical deployment of FCAS reserves to manage this excursion (AEMO 2019). The total rotating inertia in the grid limits the initial rate of change of frequency (ROCOF). The ‘Primary’ system response block indicates a combined FCAS Fast Raise and Slow Raise response by a generator with standby capacity ramping up within 6 seconds. Tertiary/rescheduling demand response is managed by the five-minute spot price market and within the Regulation FCAS markets.

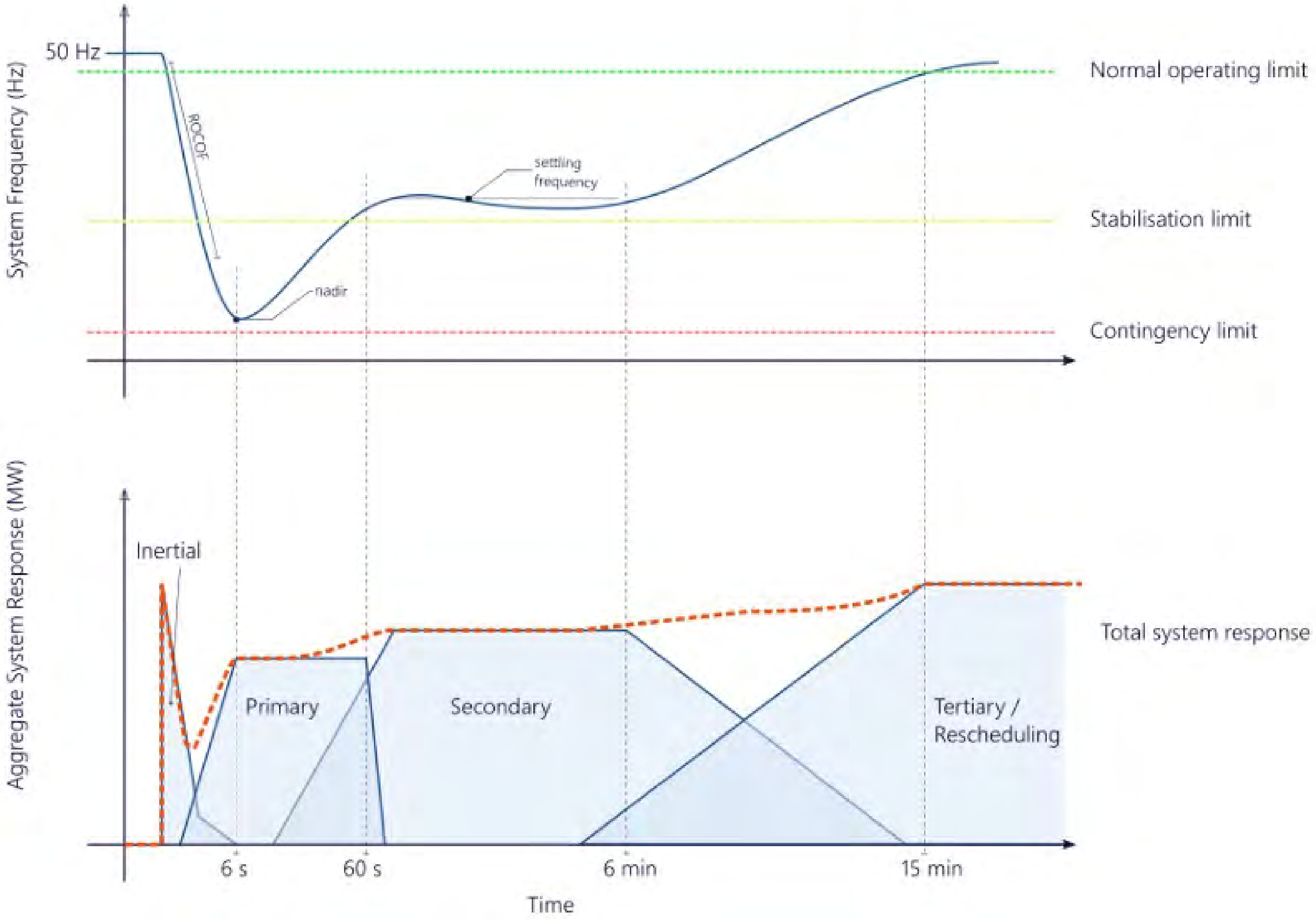


Figure 2-3 - idealised system response to a generation contingency (AEMO 2019).

FCAS trading is bid and settled for each 5-minute trading interval alongside the spot price market. Bids may be made for multiple FCAS markets simultaneously, as assessed by AEMO. Once AEMO dispatches an offer for the next trading interval, this involves a contractually binding commitment by the Demand Response Service Provider (DRSP) to have the promised demand response capacity on standby for automated and immediate response to emergency events. Failure to provide contracted FCAS services when required would be non-compliant with the National Electricity Rules, so FCAS commitments are typically conservative reserves of loads that may be quickly reduced for FCAS. To avoid FCAS penalties a minimum base load needs to be reserved for FCAS demand response commitments. For example, if a consumer is trading demand response concurrently on FCAS and other demand response markets, then demand response capacity commitments may be compromised if FCAS and other demand response control actions coincide.

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. High-speed sub metering is required on site to verify that FCAS providers met their commitments. This data is randomly audited by AEMO for compliance checks.

FCAS market prices are highly variable, and offers are made for every 5-minute interval, similar to the wholesale market. The Contingency Fast Raise and Contingency Slow Raise markets tend to be the highest value due to the 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.

As the energy market transforms, the nature of frequency control services in the NEM is also changing. The high rotating inertia of synchronous generation machines (such as coal and gas) naturally resists the rate of change of frequency following a disturbance on the power system. As synchronous generation is displaced by inverter-connected generation (such as wind and photovoltaics), the installed inertia of the power system reduces, meaning that the rate of change of frequency is expected to also increase in response to supply-demand disturbances. AEMO identified fast frequency response (FFR) services as a potential option for managing high rate of change of frequency in a lower inertia grid (AEMO 2017).

The Australian Energy Market Commission has announced two new markets to be implemented in October 2023 with generation and loads that can change capacity in two seconds or less (AEMC 2021). These will be *very fast raise* and *very fast lower* and will operate in conjunction with the existing FCAS markets. This new rule is introduced in response to the early retirement of synchronous generators and is intended to ameliorate the increasing cost pressure on the fast raise and fast lower markets.

Commercial-sized HVAC demand response has not been widely traded on FCAS markets. The technology has not been widely available. Also, contingency markets trade in 1 MW increments such that HVAC loads would need to be aggregated before being eligible to trade. Trade of HVAC demand response is becoming more readily facilitated through (typically third party) aggregators, who operate Virtual Power Plants (VPPs) to manage a distributed network of generation and demand response assets.

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 assets 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 nominally from November to March, with typically between zero and four RERT events in each season, each of typically 30 minutes to three hours duration. 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. RERT contracts are engaged by direct email or SMS contact to the site representative to confirm presently available RERT capacity leading up to each anticipated event. So this market is best suited to major loads or standby generators with manual controls that may benefit from rare activation on some extremely hot summer evenings. 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.

The calculation to settle delivered demand response for a major standby generator or battery is simply the net energy delivered from the standby source during the period. In contrast, commercial pre-commitments and settling on delivered demand response from HVAC is more complex, since HVAC is not a fixed determinate load. The CAISO 10 method (AEMO 2021b) may be used to establish a baseline for demand response capacity determination based upon a series of similar recent days from the same time.

Commercial-sized HVAC demand response has not been widely traded on the RERT market. The technology has not been widely available. Also, the RERT market trades in 1 MW increments as per FCAS Contingency markets. Trade of HVAC demand response is becoming more readily facilitated through (typically third party) aggregators, who operate Virtual Power Plants (VPPs) to manage a distributed network of generation and demand response assets.

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 through demand response service providers. AEMO then dispatches the least expensive option of increasing generation or reducing demand.

WDRM differs from RERT in that it is integrated into the spot price market for every trading interval and so it is not limited to the relatively rare RERT events, which need to be activated by AEMO. Consumers engage in the spot price market through the WDRM by submitting their demand response capacity and activation price threshold to AEMO for each trading interval. This may be conducted through virtual power plants that trade aggregated demand response on the wholesale 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 help mitigate 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 eligible for the initial rollout of this new mechanism, but this is worth monitoring for future opportunities for consumers with conventional electricity agreements.

2.1.4 Transmission and distribution network costs and constraints

The demand response market mechanisms detailed above are all designed to manage the balance of value between offers from the presently available generators and the anticipated consumer demand. In between the generators and consumers on the NEM is the high voltage *transmission network* to transmit the energy from major generators to major consumption nodes. This includes the major transmission interconnectors that transfer energy between the distinct state networks. The local low voltage *distribution networks* then distribute the energy to individual site metering points.

An ‘ideal’ transmission and distribution network with infinite capacity, zero energy losses and zero cost would enable the supply-demand markets to engage any generator or consumer on the NEM to provide the lowest cost demand-response services. However, the real network capacity, losses and costs add a further layer of complexity to the management of the NEM, imposing local power transmission limits and localized cost variations. This is most evident in the distinct wholesale spot price markets for each state, where an ‘ideal’ network would provide for a single spot price market for the whole NEM. Interconnector capacity limits and transmission losses require a separation of the NEM into state-wide trading regions.

Network transmission and distribution costs are explicitly listed on energy billing arrangements for commercial customers. Additionally, the energy charges on the bill are adjusted for the high voltage transmission network Marginal Loss Factor (MLF) and, where applicable, the low voltage distribution network Distribution Loss Factor (DLF) applicable to each location in the network. These static nominal loss factors are recalculated each year as average loss factors for each node. These billing tariffs are designed to help drive network upgrade decisions.

Network feeder capacities are presently designed for the anticipated peak annual demand. A network-interactive demand response solution could be more cost effective than a network capacity upgrade. Such a solution would need to incorporate network-interactive demand response technology, a pro-active network service provider and willing demand-side customers. Distribution Network Service Providers may increasingly offer programs to incentivise cost-competitive solutions to capacity constraints for specific feeders on their network. Such incentives may supplement abovementioned demand response income streams from network-interactive HVAC solutions. HVAC network capacity demand response is not part of this present trial

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, that is, 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, based on expectations of future average spot prices. These hedging products 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 by the energy retailer from the wholesale spot price market (see below) for each trading interval.

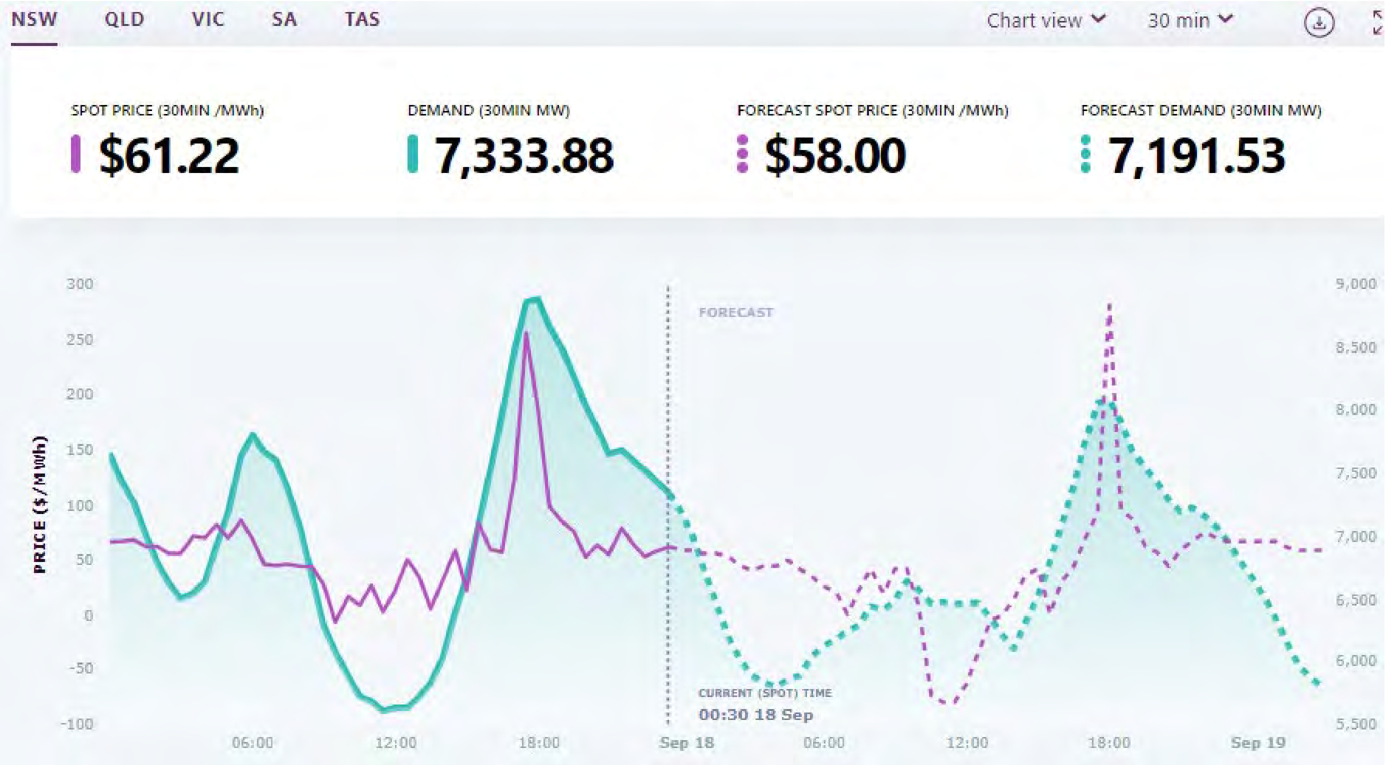
The FCAS and RERT markets are funded on a user-pays model where costs are distributed to consumers through retailers along with network transmission and distribution costs, metering costs and environment levies. Conventional electricity retail customers with managed demand flexibility can separately and concurrently trade this capacity on the various FCAS and RERT markets (and potentially on the wholesale spot price market through the WDRM) through third party aggregation services (VPPs).

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). However, for 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, however, electricity agreements do not typically enable the direct exposure of consumers to the wholesale spot price market.

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 2-4, 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.



SPOT PRICE (30MIN /MWh) $61.22

DEMAND (30MIN MW) 7,333.88

FORECAST SPOT PRICE (30MIN /MWh) $58.00

FORECAST DEMAND (30MIN MW) 7,191.53

Figure 2-4 - 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 offer price capping agreements or other hedged wholesale products that soften the wholesale market volatility in various ways for customers. However, if the short-term pricing volatility is reduced, then the potential pricing incentives are also softened for active demand response consumers and hedging products will incur additional background costs.

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. RERT events will almost always coincide with extremely high spot price intervals when a wholesale demand response controller will already be calling for minimal HVAC energy consumption, so this potential conflict needs to be managed.

Wholesale electricity agreements are considered to offer substantial potential to demand responsive HVAC operators due to the simplicity of interaction with the market and the facility to be constantly optimizing for HVAC energy costs according to forecast prices.

2.1.7 Summing up the applicability of NEM demand response markets for HVAC systems.

Exposure to the wholesale spot price market is identified as the most financially attractive and suitable for grid-interactive HVAC control for the aged care sector. Participation requires a virtual power plant operator or an innovative retailer to access the wholesale spot price as a replacement of an existing conventional electricity agreement, however, with this commercial arrangement in place this market mechanism is the simplest, most flexible and with 48-hour price forecasts available to flag high price events to avoid and lower price events to take advantage of for pre-conditioning. The five-minute trading intervals for this market provide excellent flexibility, however, extended curtailment of HVAC loads during high price events may significantly impact indoor thermal comfort if not properly managed. More complex predictive controls can provide continual cost optimisation whilst also actively managing indoor thermal comfort.

Frequency control (FCAS) Fast Raise and Slow Raise markets are highlighted as an attractive additional income stream with minimal operational interruption. The FCAS markets are remarkably volatile markets and they present challenging compliance and aggregation regulations for grid-interactive HVAC participants to meet. However, these value streams can be very attractive at times and contracts are paid on dispatched standby capacity per trading interval regardless of the likelihood that this demand response may not be actually called upon for weeks at a time and then only for very short durations. So thermal comfort impacts will be negligible.

The Wholesale Demand Response Mechanism is still in the process of being rolled out and is better suited to large standby generators, for example at hospitals.

The RERT market is simplest but is not considered to be attractive to grid-interactive HVAC control due to the scarcity of occurrence and the inflexible conflicting requirement to turn HVAC systems off for extended periods during the most extreme high temperatures of the year.

With the above background of demand response trading mechanisms on the NEM, the following section will outline the technologies that enable HVAC systems to create and manage demand responsive control.

Table 1 - Summary of demand response markets operated within the National Electricity Market.

AEMO market	DR duration	Commercial complexity	Replaces existing agreement?	Min trading MW	Indicative pricing $/MWh	Relative annual value	Comment
RERT	0.5 - 4 h	Annual contract. Simple manual operation.	Separate income stream.	5 to 15 MW depending upon state	$10,000 to $15,000	**$**	Conflicts with greatest need of HVAC load. 0 – 20 h/y. Simple manual activation. Best for major standby assets.
WDRM	5 min+	5 min bid/settle	Separate income stream	1 MW per state	$0 to $15,000	N/A	Trading complexity; HVAC ineligible.
Wholesale Spot Price	5 – 30min	No scheduled commitment, price-taker	Yes	No limits (+/-)	-$100 to $15,000	**$$$$$**	Simple, flexible, tech complex, avoid short forecast spikes.
FCAS	1s - 10min	5min bid/settle, compliance	Separate income stream	1 MW per state	$0 to $15,000	**$$$$**	Very brief, ~1 event/month, aggregation

2.2 Demand response enabling technologies – an overview

Demand response is the voluntary reduction or time-shifting of electricity loads by consumers. The various needs for demand response in the grid are associated with the AEMO demand response market outlined above.

The survey of market mechanisms highlighted limitations to the use of *‘demand response’* as a descriptor of the matrix of technologies and market mechanisms under consideration. *“Grid-interactive HVAC control”*—is offered as a clarifying definition to more explicitly embrace predictive controls (not just a passive *response* to market control signals). *“Grid-interactive consumer flexible assets”* would furthermore integrate energy storage and generation resources that are not strictly *“demand”* control.

Demand for electricity in the NEM steps up by around 20% for very hot summer afternoons, which represent just 3% of the year (Goldsworthy 2020), as illustrated in Figure 2-5. This demand increase is associated primarily with residential air-conditioning, so it makes sense to explore demand response solutions in the HVAC industry. These HVAC demand response capacity projections were made based upon a 2 °C temperature set point adjustment to enable demand flexing of HVAC loads away from grid peak events. Existing thermal mass of buildings is noted as assisting thermal comfort during these periods of voluntary demand reduction.

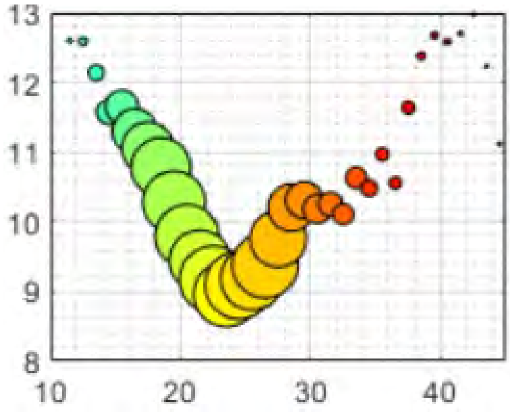


Figure 2-5 - Median electricity network demand as a function of outdoor temperature for NSW in the period 2006 to 2019, where marker size indicates time proportion (Goldsworthy 2020).

There are many ways in which HVAC, and other more conventional flexibility assets, can improve the value of renewable generation through a more grid-interactive control. The various grid-interactive technologies may be categorized as:

- *Demand-response enabled devices* -- Applying short term power limits to equipment.
- *Load shifting* – Time shifting of loads.
- *Demand flexing* – Dynamically adjusting control settings such as temperature set-point.

The most appropriate of these various options, the limits within which they can be applied, and the most suitable AEMO markets will vary substantially according to building types and sector.

2.2.1 Demand response enabled devices (DRED)

Demand response enabled devices (DRED) were designed to interact with the RERT market to enable trading of aggregated demand reduction as an alternative to providing additional standby generation capacity. The term ‘demand response’ sometimes more restrictively refers to DRED-specific technology, which allows automated activation of short-term power capacity limits to demand response enabled equipment.

Australian Standard AS 4755.3 specifies a method by which AEMO or a third-party operator can remotely switch DRED-enabled appliances to request a different power-limited state during grid peak demand and minimum demand events. A ripple is passed through the grid which triggers an automated pre-determined response. The standard was originally designed to enable large scale introduction of DRED embedded into domestic AC units. Residential HVAC systems were identified as having much greater demand response potential when compared to commercial buildings (Goldsworthy 2020).

DRED can demand various levels of response, including:

- DRM0 is operate the disconnection device (e.g. directly cut power by a contactor).
- DRM1 is minimum load (e.g. HVAC compressor off).
- DRM2 must not exceed 50% of rated power.
- DRM3 must not exceed 75% of rated power.
- DRM4 increase load where possible.

Implementation of DRM1 is the minimum requirement to meet AS4755.3.1. DRM2 and DRM3 are options introduced to make DRED more flexible and more palatable to consumers. DRM 5 to 8 are also available to provide corresponding requests to control grid feed-in from generation and storage devices.

DRED is being mandated over the coming years for specified appliances including air conditioners, electric storage water heaters (resistive), pool pump controllers, electric vehicle charger/discharger units, energy storage systems and distributed energy generation inverter systems. Some potential issues with this mandated system have been listed as lack of flexibility and lack of interoperability with existing international demand response standards, and consumer concerns about compulsory handing over of control of their households' appliances to third parties (Kuiper, 2021). For air conditioners this third-party controlled demand reduction is being mandated at the specific time of the greatest need for cooling, with potential implications for the health and well-being of occupants.

This highlights the importance of developing a relational social license based upon a mutual understanding with appropriately valued shared benefits and needs met.

Applicability of DRED to commercial HVAC systems is dependent upon the following factors:

- DRED-compliant HVAC **loads can be directly limited**.
- The demand response capacity from DRED control is **not easily pre-determined**, since HVAC demand is constantly varying with outside air temperature (impacting the sensible heat load) and outside air humidity (impacting the latent heat load), especially for ventilated systems that introduce outside air. Also, proprietary HVAC controller algorithms and feedback sensors are typically unknown.
- **Building thermal capacities** are unlikely to **maintain occupant thermal comfort** within acceptable limits for extended periods of a typical RERT event if major curtailment limits are applied, however, DRM2 or DRM3 may provide acceptable HVAC service in most cases.
- HVAC demand **response times** are not well defined, especially within the HVAC manufacturer's systems, which may limit the suitability of HVAC DRED control for FCAS trading. This may be addressed by installing contactors to enable direct cut-off of power to the condenser.
- Commercial HVAC systems with more customizable DRED functionality, including a greater range of power limit settings and fast determinate response, may be effectively used to

trade demand response value on the **RERT and FCAS markets, which may provide useful additional income streams** for astute electricity account managers, and especially those with a sensibility to environmentally and financially sustainable outcomes.

2.2.2 Load shifting

Load shifting refers to time-shifting HVAC energy consumption away from peak demand intervals and more towards low or negative spot price intervals. Load shifting is applicable to flexibility assets with directly controllable load and with some standby capacity that allows time flexibility to offset the operating period. Managing the timing of a large pump is a simple example, where a storage tank provides the energy flexibility capacity.

Energy storage technologies such as large battery systems are being traded on RERT, FCAS and WDRM markets to provide improved stability to the electricity grid. The demand response capacity of these systems is a determinate amount that is reliably available for pre-committed trading on FCAS markets and may alternatively be sustained for periods of several hours or more for the RERT or wholesale spot price markets (potentially through the WDRM).

Applicability of load-shifting technologies to commercial HVAC systems is dependent upon the following factors:

- **HVAC loads cannot be directly controlled** at an individual asset level**,** since DRED does not set a fixed load but only sets demand limits. That is, DRM cannot request a particular condenser to decrease load by 3kW on demand, however, DRM controls coordinated by portfolio-level demand response management software could be capable of directly reducing HVAC loads.
- DRED systems for HVAC **cannot typically increase HVAC loads** (this capability would be indicated by DRM4).
- Creating and managing HVAC demand response capacity by direct load-shifting would require decoupling the control from temperature set-point and could **negatively impact occupant thermal comfort**. HVAC controllers do not typically provide this option.

So, load shifting is not as simple and appropriate to implement for HVAC systems, however, pre-conditioning a building prior to a forecast peak demand event will have a similar effect (see Section 2.2.3 -- Demand flexing).

2.2.3 Demand flexing

Demand flexing refers to the predictive adjustment of control settings to indirectly increase or decrease the electrical load in response to forecast demand conditions (as distinct from load shifting, which directly controls the load). HVAC demand flexing is a very applicable example, where the temperature set-point is adjusted within acceptable limits in response to forecasted temperature and/or electricity spot price. For example, during a hot summer day with forecast peak price events and very hot weather in the late afternoon, rooms may be pre-cooled by offsetting the temperature set-point to lower-than-normal indoor temperatures during lower price intervals during the middle of a hot day. Then later, to reverse the set-point offsets to a little higher than normal temperatures during the peak intervals, typically in the late afternoon and early evening.

Demand flexing may be particularly well-suited to commercial HVAC systems for the following reasons:

- HVAC is **indirectly controlled to manage indoor temperature** within acceptable limits.
- Demand flexing can result in **either a HVAC load decrease or a load increase.**
- Temperature set-point flexing **response time is within a typical 5-minute spot market trading interval** as the market value mechanism.
- **Building thermal mass** and **occupant thermal comfort ranges** provide some **demand flexing capacity** that may be modulated within pre-agreed temperature limits for extended periods suitable for the daily diurnal temperature cycles and spot market price cycles.

The available demand response capacity depends upon the acceptable temperature limits, which requires careful consideration of thermal comfort models.

2.2.4 HVAC temperature set point models

Air-conditioned commercial buildings are generally operated with fixed temperature comfort bands, which provides consistent thermal comfort, however, this simplistic model does not provide adaptation to the natural daily and seasonal cycles of the outdoor environment, nor does it allow for other thermal comfort adaptive strategies.

More advanced temperature set point controls may be based upon body temperature heat balance models such as the predicted mean vote PMV model (ASHRAE 2017). The PMV considers mean radiant temperature, air temperature, air speed, clothing levels, and metabolic activity rate to provide a more detailed and flexible thermal comfort model for the specific building and occupant conditions.

Alternatively, buildings that are naturally ventilated or have mixed-mode (natural and mechanical) ventilation, may be operated according to adaptive thermal comfort models, such as (ASHRAE-55, 2017) as presented in Figure 2-6.

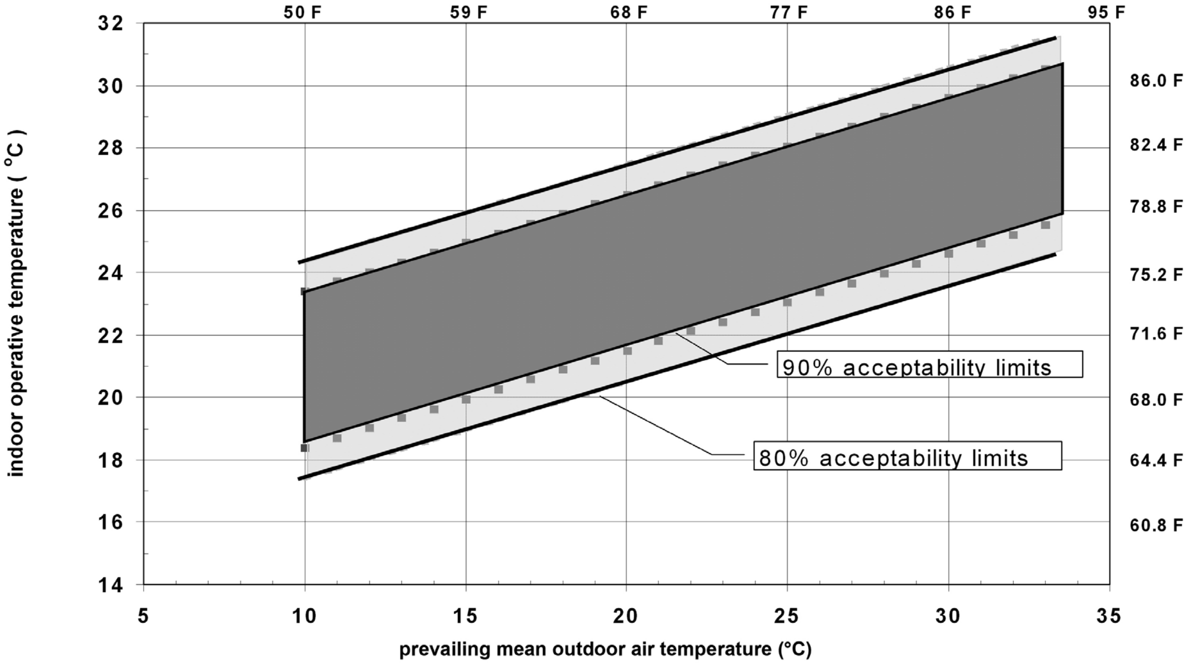


Figure 2-6 - Acceptable operative temperature ranges for naturally conditioned spaces (ASHRAE-55, 2017).

The ASHRAE-55 adaptive model is based upon data primarily from adults in office buildings and has not been validated for aged care facilities nor for mechanically ventilated buildings. (Forcada 2021) presents the results of 1921 adaptive thermal comfort questionnaires conducted in nursing home common rooms in the Mediterranean for both elderly residents and staff and were from a mix of natural and mechanical ventilation. Compared to the general adult population their proposed adaptive model for mixed mode aged care buildings provides some evidence that:

- Adaptive thermal comfort models have some applicability to aged care.
- The elderly prefer slightly warmer temperatures compared to the general adult cohort.

Advanced thermal comfort models allow for the natural adaptation to seasonal and daily weather conditions along with clothing and activity levels. They will tend to reduce the peak demand both in summer and winter and are likely to increase HVAC demand flexibility and hence demand response capacity. However, they are more complex to implement and monitor and there is still considerable debate in the academic literature about which model is most suitable for this scenario. This indicates that further research work is required before applying these models into such a HVAC demand response trial in aged care.

2.3 Summary of opportunities for HVAC demand response in the NEM

The National Electricity Market is undergoing rapid transformation to high penetration of low-cost renewable generation sources with more dynamic influences on the wholesale spot price through each day and an increased need for grid-interactive loads. Energy flexible buildings integrated with demand response market services provide a shared value trading basis between grid stability and capacity benefits with pro-active demand side customers. Demand flexing capacity of HVAC loads is available through predictive adjustment of temperature set-points within thermal comfort limits and utilizing the existing thermal mass of buildings. Innovative wholesale electricity agreements with spot price forecasting tools provide a cost attractive alternative market mechanism to trade this demand flexing value without the complexity of needing to pre-commit demand response capacities prior to each trading interval.

Demand-response enabled devices (DRED) may also be able to provide a considerable additional income stream through frequency control (FCAS) markets accessed through third party aggregators operating virtual power plants (VPPs).

When compared to other flexibility assets, such as batteries, these HVAC demand response technology and service packages are likely to be:

- Much lower capital cost, since buildings, HVAC equipment and the control platforms are existing with substantial demand response capacity. The main cost is incurred to implement and interface the grid-interactive control with existing systems.
- Much more widely dispersed and already connected into the electricity grid across the entire NEM, thus providing a large existing potential demand responsive solution not just at the grid and transmission level but also to support local distribution network constraints.
- More widely sharing the responsibility and rewards between generators and consumers to create a more grid-interactive, value-responsive energy eco-system at lower cost for the health care sector and at the lowest cost to society.
- More complex in terms of control strategy and limited by occupant thermal comfort constraints, requiring further work to optimize for electricity cost and HVAC service.

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 combination of HVAC demand response technologies and the demand response market services being demonstrated in this trial both facilitate and incentivise active demand flexing technologies for the benefit of the consumer, the grid and society. As such this innovative trial is considered a major enabling technology and service package for increasing the value of renewable energy through smarter demand response control of HVAC systems.

2.4 **Problem statement**

HVAC demand response has not been widely traded on demand response markets. 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 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.

Compared to these better-known flexibility assets HVAC demand response capacity is:

- Located in much smaller distributed loads across the whole network, thus requiring an aggregation mechanism to trade in RERT and FCAS markets.
- Less predictable and more difficult to pre-commit to FCAS Raise and RERT trading.
- More complex and less predictable for demand increase control.
- Generally not sustainable at high demand reduction levels for the typical RERT event durations of several hours, since these events are by their very nature the prime HVAC service demand periods.
- More constrained on frequent start-up and shut down cycling.
- Well-suited to forecasted wholesale spot price load shifting opportunities.

More substantial benefits of a wholesale electricity agreement may be achieved for HVAC loads when predictive control strategies are implemented, however, the potential costs savings of these innovative control strategies are difficult to estimate without real-world data.

The complex interactions between the various demand response markets are not well understood by building facilities managers and this demonstration project will help to explore and describe these complexities for a health care facility.

The magnitude of the practically tradeable HVAC demand response capacity at a site, portfolio, health care sector and state-wide level is not well understood.

This Living Laboratory trial, both separately and in concert with the Flow Power Electricity Spot Price Trading trial is an excellent facility to evaluate the combined cost impact of this complex suite of technologies and services.

2.5 Technology overview

DNA Energy is an innovative demand response technology provider, offering customers direct control of HVAC demand response technologies and other energy management solutions. Two distinct and complementary demand response technologies will be demonstrated in this trial.

1. DNA’s Demand Response Mode (DRM) switching technology works with DRED-compliant (AS4755) appliances in response to AEMO’s DRM standard signals. Two significant advantages of this technology are that it:
   a. Interfaces with many existing commercial/industrial HVAC appliances that do not strictly comply with AS4755 but have DRED-equivalent functionality, thus enabling DRM response for very substantial portions of existing installed HVAC energy capacity that would otherwise be unable to participate.

   b. Promises a fast enough response time to meet the stringent requirements of the FCAS and other markets, which provides potential benefits to the grid with a broader grid-interactive market offering and as an additional value stream for grid-interactive consumers.

2. Demand flexing using machine learning algorithms: This grid-interactive control technology is used to time-shift demand in response to forecast spot price and may be used with battery storage or other demand-flexible assets. For this project, temperature set point flexing controls use live forecasts of spot price and weather to flex indoor temperature set points to predictively increase or decrease HVAC loads to minimise total monthly spot price exposure whilst managing thermal comfort.

2.6 **Objectives**

The objective of this trial is to demonstrate and evaluate the benefits of DNA Energy's suite of HVAC demand flexing technologies for Warrigal Shell Cove Living Laboratory and the health care sector more broadly. Overall electricity cost savings and income generation potential will be evaluated across a range of demand response trading markets.

This evaluation will:

1. Determine the response times and practical demand response capacity of the DRED technology tradeable on the appropriate FCAS Raise market(s).
2. Determine the associated HVAC demand response capacity, initial response times and acceptable durations within the identified temperature flexibility constraints.
3. Evaluate the income generation potential of trading HVAC demand response on the FCAS markets.

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. 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. Renewable generation includes a 99 kW-p array of solar panels.

This Living Laboratory provides research-quality measurement and verification systems within 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 3-1 - Warrigal residential care home

Figure 3-2 - Roof top Mitsubishi City Multi VRF HVAC units

Figure 3-3 - Aerial view of the Living Laboratory with the 99 kW-p PV system and HVAC service on the roof.

3.1.1 HVAC and thermal comfort

Heat recovery VRF (variable refrigerant flow) heat pump systems serve the buildings heating and cooling needs. Both hot and cold refrigerant supply is piped to each indoor unit to provide the flexibility for adjacent rooms to be simultaneously heated and cooled respectively with heat recovery technology to reduce losses.

The ventilation for the Warrigal Shell Cove residential care home is mixed natural and mechanical mode design. The bedrooms are naturally ventilated with openable windows.

A ventilation design conflict in the National Construction Code (ABCB 2019) was identified with the design ventilation area of sliding windows being specified as the full openable area, whereas a safety regulation requires the fitting of window opening restriction to less than 100 mm, which limits practical natural ventilation.

In practice the ventilation for the 64 bedrooms on Level 2 is assisted by the toilet exhaust fans, which are running constantly. To balance the air pressure in the building from these toilet exhausts 100% outside air is supplied to the air conditioner serving the central lounge and dining common areas.

HVAC for the corridors is provided with an energy recovery ventilator (ERV) that recovers both sensible and latent energy from the exhaust air into the fresh air supply.

The common area HVAC operates in auto mode with temperature set points presently fixed for winter and summer seasons as below:

- Winter heating temperature set point is 21 °C, with cooling activated above 24 °C. Heating is activated when the temperature feedback reaches 20.5 °C and will turn off again when the temperature returns to 21 °C.
- Summer cooling temperature set point is 22 °C, with heating activated below 19 °C. Cooling is activated when the temperature feedback reaches 22.5 °C and will turn off again when the temperature returns to 22 °C.
- There is a minimum of 3 °C deadband between cooling and heating set points for a space.

Bedroom temperature set points may be adjusted by occupants and are currently constrained to be heating-only mode in winter and cooling only mode in summer to avoid excessive variations in performance demands.

The temperature time series plot in Figure 3-4 shows the operation for a cold week in April with the summer settings still implemented. Notice the common areas 107 and 111 are being cooled around 22.5 °C when indoor temperatures would otherwise be higher, and overnight, when temperatures fall below 19 °C, the spaces are heated. This highlights an opportunity to eliminate this counterproductive overnight heating energy and instead utilize the natural night purging opportunity, since this system is 100% outside supply air. This will tend to both reduce energy consumption overnight, as well as further reduce the thermal mass temperature overnight to better prepare for warm summer days.

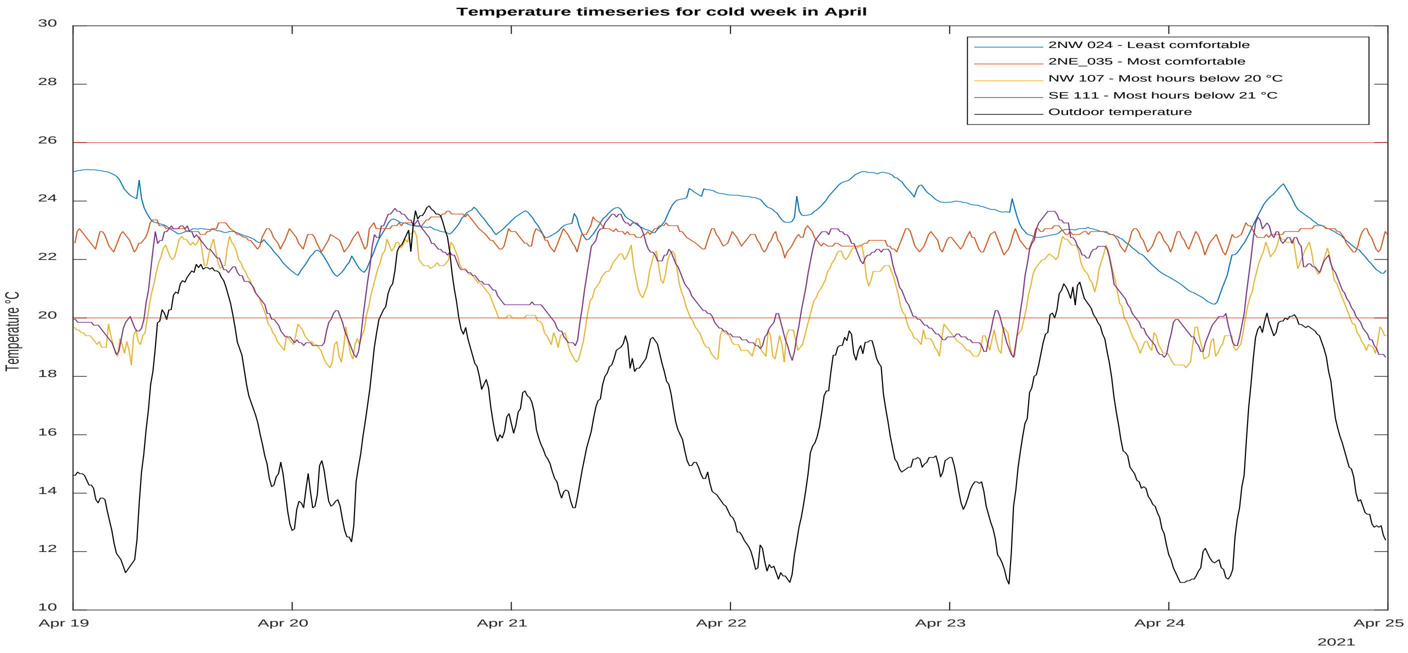


Figure 3-4 - Temperature trends from a cold week with winter settings.

3.1.2 Demand response opportunities

HVAC net loads, with PV generation offset, for the Warrigal Living Laboratory follow typical daily and seasonal profiles as illustrated in Figure 3-5. These net consumption profiles are sometimes referred to as the ‘duck curve’, like the shape of a duck’s back due to PV generation during the day, and typically higher loads at the start and end of the day. The winter loads display peak consumption in the cold mornings. Summer loads are lower on average than winter loads due to more comfortable outdoor air temperatures for natural ventilation and higher PV site generation contribution, especially through the middle of the day. However, the summer peak demand is through the late afternoon and evening and will dramatically increase in proportion to the indoor-outdoor temperature difference on the extremely hot evenings that will coincident with grid peak event times. This highlights some key opportunities for demand flexing to reduce energy cost, increase the value of renewable generation, and improve grid stability.

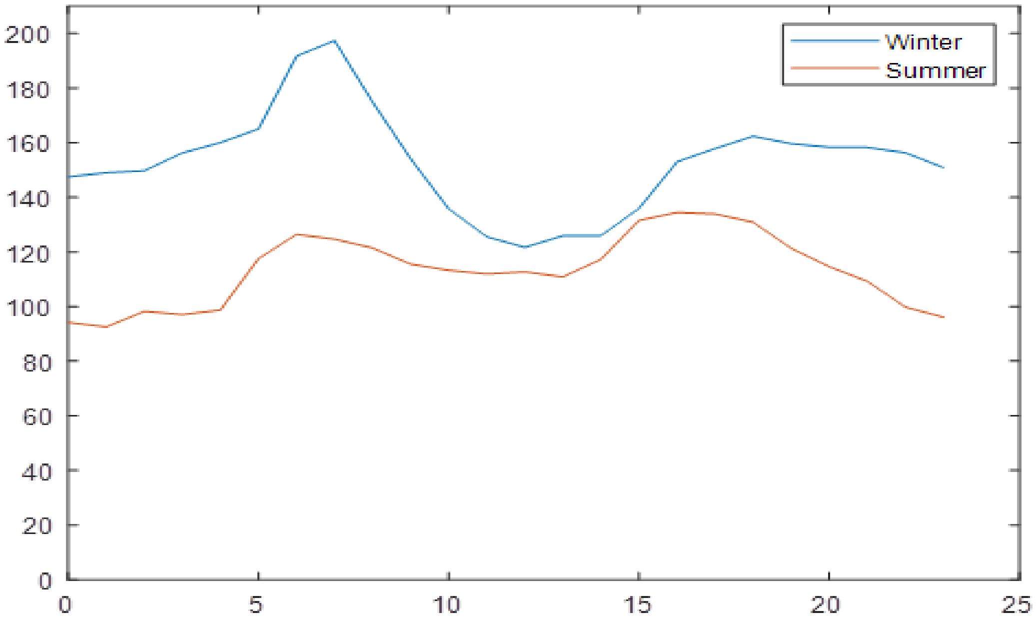


Figure 3-5 - Total site net consumption for Warrigal residential care home - seasonal comparison.

3.2 Tested item description

DNA Energy's DRED technology integrates with the existing demand response capable Mitsubishi City Multi VRF HVAC system on site for fast demand response with equipment details provided in Table 2. This very short-term demand response component for trading on FCAS markets for example will have negligible impact upon thermal comfort.

Table 2 – Technology component descriptions

Technology component	Description
Smart Integrated Device (SID) 	AS 4755 compliant Demand Response Enabling Device (DRED, with DRM1-4 – newer systems have DRM1-8 available); controls and meters most assets via RJ45 or analogue 4 pin output or multiple industry and bespoke built control adaptors; asset level single phase CT and power metering; timer control; Object-Oriented Organic 900Mhz MESH network comms with up to 8 hops back to IoT gateway (approx. 35ms per hop)
Mitsubishi DRED adapter PAC-SC36NA	Manufacturer supplied non-DRED interface card required to operate step demand control functionality in Mitsubishi 'City Multi' range

DNA Energy relay board (Mitsubishi) 	Bespoke built relay board to connect SID to Mitsubishi PAC-SC36NA
Mitsubishi City Multi VRF PURY-PxxxYxLM-A condenser units	The existing Mitsubishi condenser units on Level 2 of the facility have step demand capability that largely mirrors the AS 4755 demand response standard, limiting load to 75% (DRM3), 50% (DRM2) and 0% (DRM1).
IoT gateway 	Wireless mesh network gateway for SIDs; hosts DNA Energy software (including controls and BACnet interface); Organic mesh network firmware; 4G router included in device; Modbus TCP/IP; Modbus RS485; API direct from cloud server.
Electricity meter	Ceta PMC-340B IEC 62053-21 Class 1 for 100A Direct Input IEC 62053-22 Class 0.5S for 5A CT Input Modbus RTU output
DNA cloud server	Dual hosting of DNA Energy software (including cloud APIs, machine learning model, analytics program).
DNA dashboard	Real-time monitoring and control of all metered and controlled points.
Existing conventional retail electricity agreement	
Wholesale electricity agreement	Tariff data provided by Flow Power
FCAS market data	Sourced through Flow Power and Endeavour Energy

A single line diagram of the connected devices is presented in Figure 3-6.

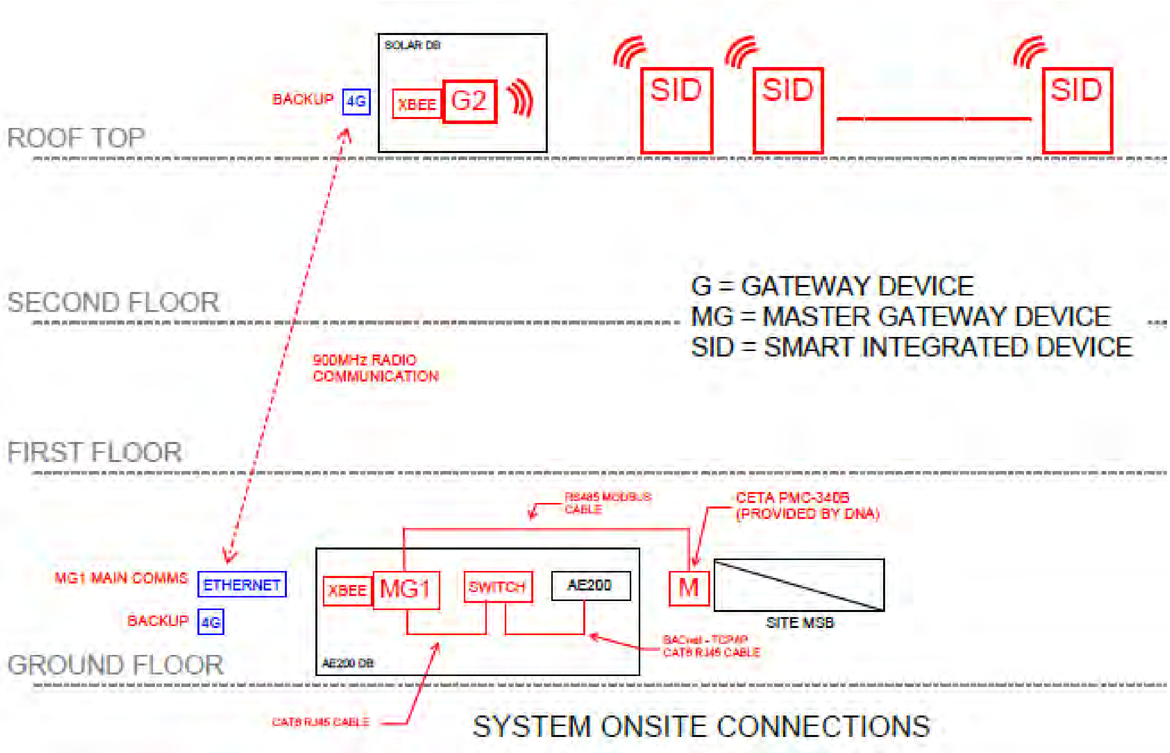


Figure 3-6 - Single line diagram of technology installation

Electricity metering requirements are more granular for trading of site consumption, generation and demand response on the AEMO wholesale and FCAS markets. DNA installed a meter immediately downstream of the existing site utility meter to provide the required granularity of consumption data.

This technology trial has important interdependencies with the Flow Power Electricity Spot Price Trading technology trial (iHub 2021c). DNA Energy were provided the following live data streams from Flow Power:

1. Live spot price
2. Live dynamic spot price forecast

These data streams are available from Flow Power’s application programming interface (API).

Demand flexibility is created by the predictive rule-based controls identifying HVAC load shifting opportunities within established thermal comfort practices. The predictive control strategies pre-condition HVAC zones in anticipation of high spot price events. Additionally, HVAC loads may be boosted during low or negative spot price events to super-condition building thermal mass. At a sector-wide scale this technology would benefit not only consumers with lower costs but would also provide an active matching mechanism of grid generation and demand.

Spot price forecast feeds into the predictive controls to optimise for energy cost within acceptable thermal comfort tolerances. This control is achieved through BACnet link with the existing Mitsubishi AE200 HVAC controllers to provide the temperature feedback and set point control for each conditioned zone. The spot price forecasts & machine-learning model forecasts/predictions are used to set rules. These rules are initialized on the DNA Dashboard. These rules are then stored on the master gateway device. When a rule is triggered the configured control commands are issued and a data log of each event is initiated. The BACnet interface on the master gateway device sends control commands to the AE200 and receives indoor temperature and operational feedback from the HVAC controller.

An energy dashboard is provided for monitoring energy and temperatures. This dashboard also provides a manual override control of temperature set points. This provides the site facilities manager with direct control capability in the event of thermal comfort complaints and also provides a feedback mechanism to the project if required.

4 METHODOLOGY

The framework of the test methodology is outlined below:

4.1 Background performance tests

4.1.1 Time response tests - DRED controls

The objective was to confirm that the time response for the DRED-equivalent system with the existing HVAC is compliant with the requirements of the FCAS Contingency Raise markets. A statistical analysis of a large sample of DRM 1 responses was undertaken.

4.1.2 Time response and demand capacity tests - predictive temperature flexing controller

The objective of this test was to provide a preliminary assessment of the response times of HVAC electrical energy and indoor temperatures to step changes in temperature set points to assess the suitability of the temperature set point flexing controller for the FCAS Raise Slow, Raise Delayed, Lower Slow and Lower Delayed responses. Indoor temperature stability was also assessed during various demand response control actions. Finally, demand response capacity and indicative durations for the predictive temperature controller actions within the identified temperature constraints were also assessed.

4.2 Electricity cost saving and income generation evaluations

4.2.1 FCAS income evaluation

The available site aggregated capacity is to be collated against the FCAS market price set for each 5-minute settling period.

4.3 Instrumentation Plan

DNA Energy use their proprietary electrical energy monitoring devices, data logging system and dashboard for control and self-evaluation. The Mitsubishi temperature sensors are available to DNA Energy via a BACnet interface. The existing Living Laboratory sensors for electrical energy and indoor environment quality monitoring were used to independently evaluate the cost saving potential comparing the implemented technology performance with the baseline data.

Table 3: Sensor list and specifications

Criteria	Specification
Electrical utility meter	EDMI, True RMS, IEC62053-21 Class 1 Instrument
Condenser energy	Wattwatchers Auditor 6M
Indoor Environment Quality sensors	Nube iO and Elsys wireless LoRa IoT sensors (iHub 2021).
Local weather station	Davis Pro (6328AU)

5 TEST RESULTS

This evaluation has been undertaken using HVAC consumption and thermal comfort data for the Warrigal Shell Cove facility between 1 September 2020 and 25 May 2022, and Australian Energy Market Operator 5-minute data for the same period. Prior to October 2021 the AEMO markets were trading at 30-minute intervals.

5.1 Thermal and energy response for grid-interactive HVAC flexing controls

A series of preliminary tests was carried out to gain an indication of the thermal dynamics of the building and HVAC system. These tests were conducted on the tandem (master 20M/slave 20S) condenser unit serving all the level 2 common areas are presented in Figure 5-1.

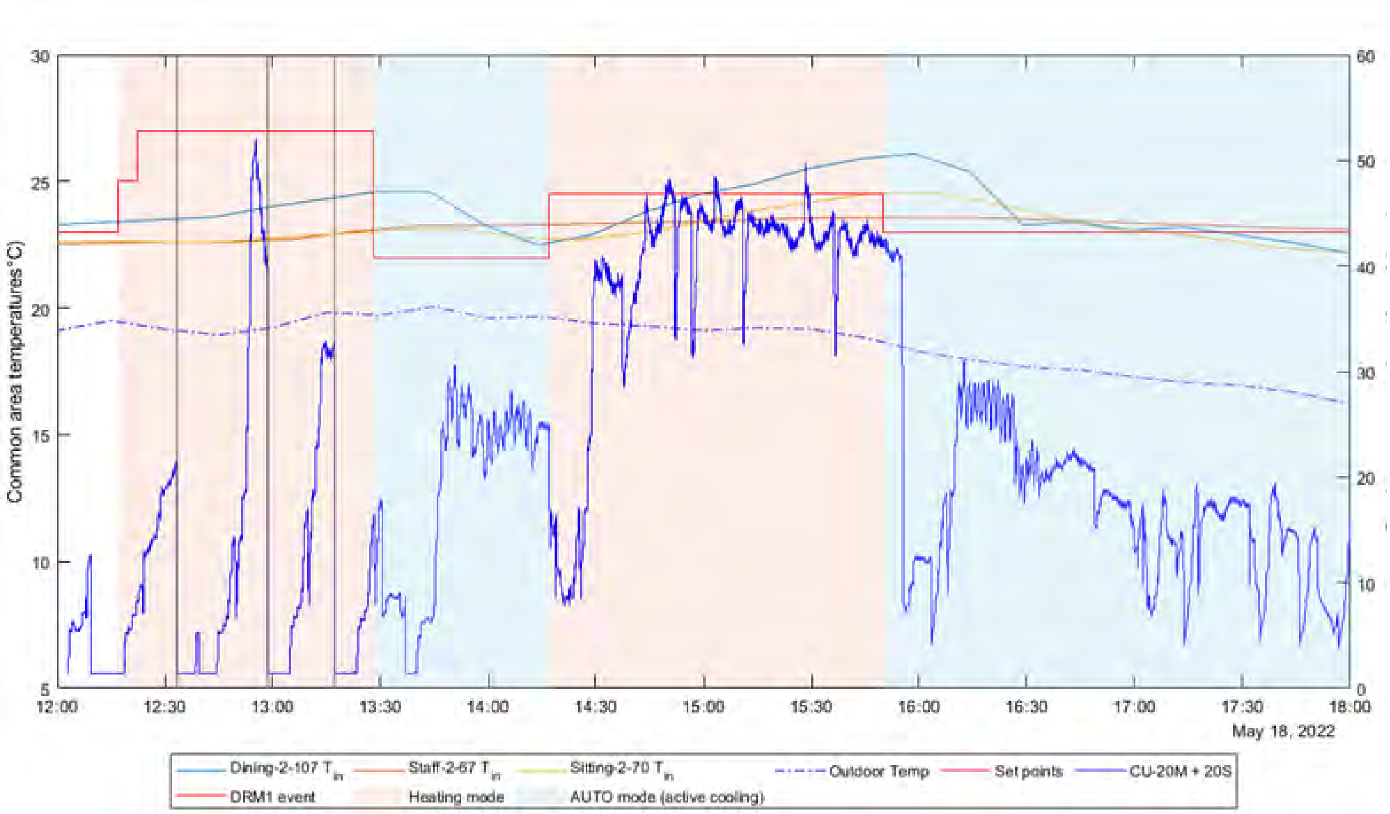


Figure 5-1 – Preliminary temperature and HVAC energy dynamic performance checks – 18/5/2022.

5.1.1 Temperature set point flexing control principle demonstrated

The temperature set point was stepped up at 14:17, 18th May from 22°C (auto mode with an active cooling load) to 24.5°C (heating-only mode). In response the condenser electrical load increased, and the indoor temperatures gradually increased to reach the new set point in approximately two hours. Again, when the temperature set point is adjusted back down to 23°C (auto mode with active cooling) the condenser load settles at a lower level and the indoor temperatures are driven back down over approximately one hour.

The response of the condenser load to a temperature set point step change appears to first switch to a lower energy state of around ten amps for five to ten minutes, perhaps while the control sequence reinitiates for the heating mode cycle, then the load ramps up gradually over the next 10 minutes before settling at the higher steady load of approximately 45 amps after around 30 minutes. A similar slow condenser load response is displayed when the temperature set point is stepped back down to 22°C.

This test demonstrates that **temperature set points adjustments may be used for grid-interactive HVAC load flexing control with the wholesale spot price forecasts by pre-conditioning spaces with elevated HVAC loads during periods of lower spot price and reducing loads during higher spot price. Since the HVAC load response is around 30 minutes, these predictive temperature flexing adjustments are well-suited to gradual HVAC load flexing over extended periods of the order of 30 minutes to several hours, which is well suited to the wholesale spot price market. However, the slow load response time to the temperature set point adjustment will not enable modulation of HVAC loads within a five-minute trading interval**.

DRM controls could be used to achieve this faster demand response control to curtail HVAC loads within a 5-minute price spike event. So, a combination of these two technologies may be required to manage HVAC energy costs most effectively on a wholesale spot price agreement within the constraints of acceptable temperature comfort bands.

5.1.2 Thermal storage capacity and stability of indoor temperatures during HVAC demand control

Temperature set point step change response times for these common areas of Level 2 are quite slow at one to two hours. Even at 16:00 (Figure 5-1) when the temperature set point calls for active cooling while the outdoor temperature is also aiding the decline in indoor temperature the temperature response time is around one hour.

From 12:30 to 13:30, three DRM1 calls were made to this condenser within a one-hour period. Despite these repeated disturbances of cutting the condenser power to zero for 60 seconds at a time, there was no noticeable compromising of indoor temperature, which was steadily rising during this period.

The above test period of 18th May is presented alongside the previous two days in Figure 5-2 to confirm that indoor thermal comfort is not suddenly nor dramatically impacted by multiple DRM 1 calls compared to similar periods during the previous days where no DRM1 calls were being made.

These observations clearly indicate that this Warrigal Shell Cove facility has very substantial thermal inertia adequate to provide indoor temperature stability to ride through HVAC load disturbances such as demand response control actions.

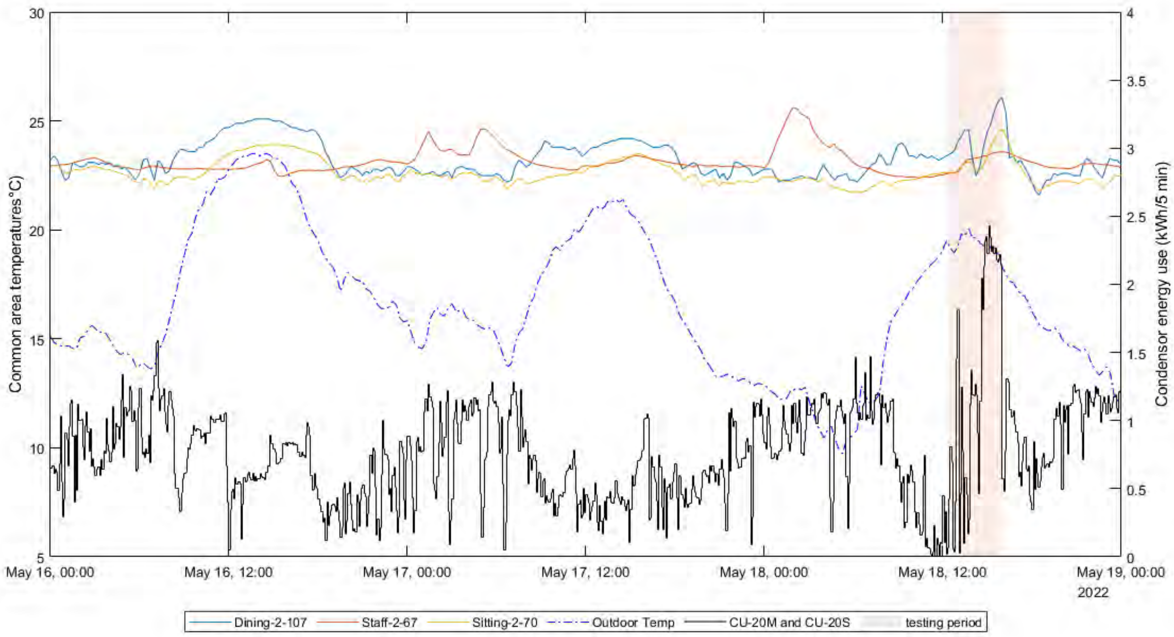


Figure 5-2 – Comparison of thermal comfort during the 3 days leading up to including the above tests.

Consequently, from May 20th for several days a large number of repeated DRM 1 calls were made to all of the level 2 condenser units. The purpose was to capture a large sample of DRM 1 response events for statistical analysis of the response time compliance for FCAS Fast Raise trading. This test period was also used to check the thermal comfort impact during an unrealistically excessive period of demand response control actions (Figure 5-3).

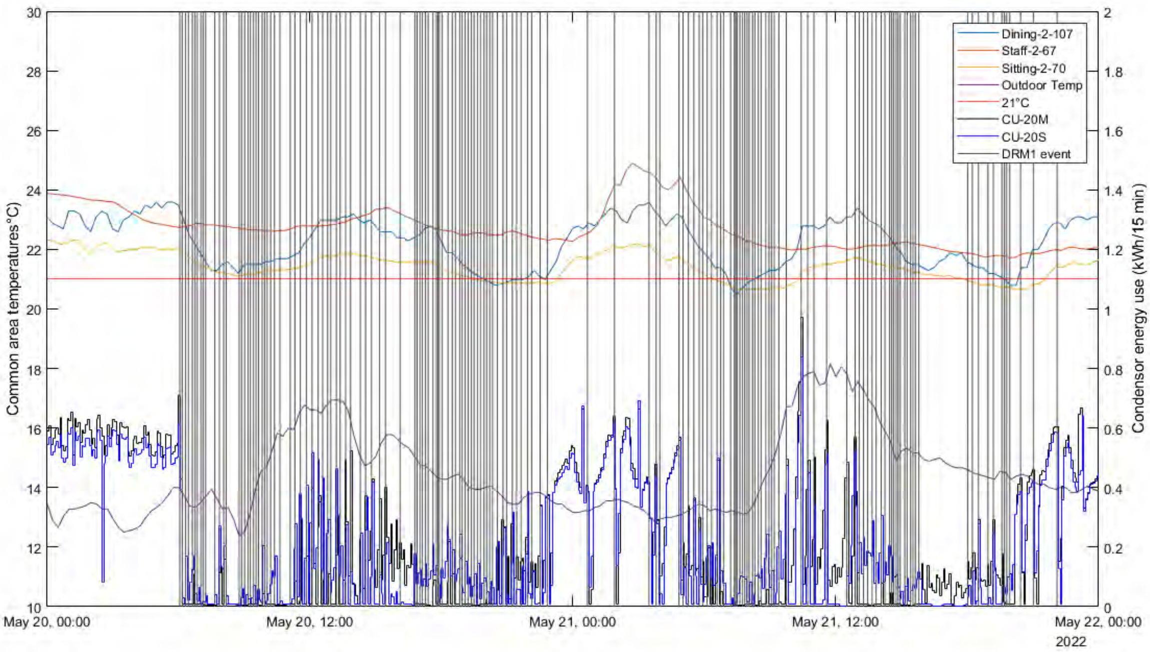


Figure 5-3 – Intensive DRM 1 response testing period highlighting the minimal impact upon thermal comfort.

The thermal mass of the building provides adequate thermal stability to allow HVAC demand response control actions (both DRM controls and temperature set point flexing) to be sustained for multiple 5-minute trading intervals without any sudden or significant impact on indoor thermal comfort expected. Much more work is required to robustly define these performance boundaries and dynamic control characteristics, however, this is a very promising preliminary assurance of an excellent in-built thermal storage resource that may be more broadly available throughout similar building stock.

The next question is to consider the typical required duration of grid-interactive control events for this spot price market to compare against the thermal comfort stability indicated here.

5.1.3 Wholesale spot price volatility

The wholesale spot price is plotted in Figure 5-4 for the period since the 5-minute settling interval was introduce in October 2021, on a logarithmic scale. This summer of 2021-2022 was unusually wet and mild and correspondingly there are unusually few high spot price events over this RERT season. The typically lower spot prices throughout the warmer months when the sun is much higher in the sky tends to provide much greater PV generation, while greater heating loads and lower PV generation in winter tends to place upward pressure on the spot price.

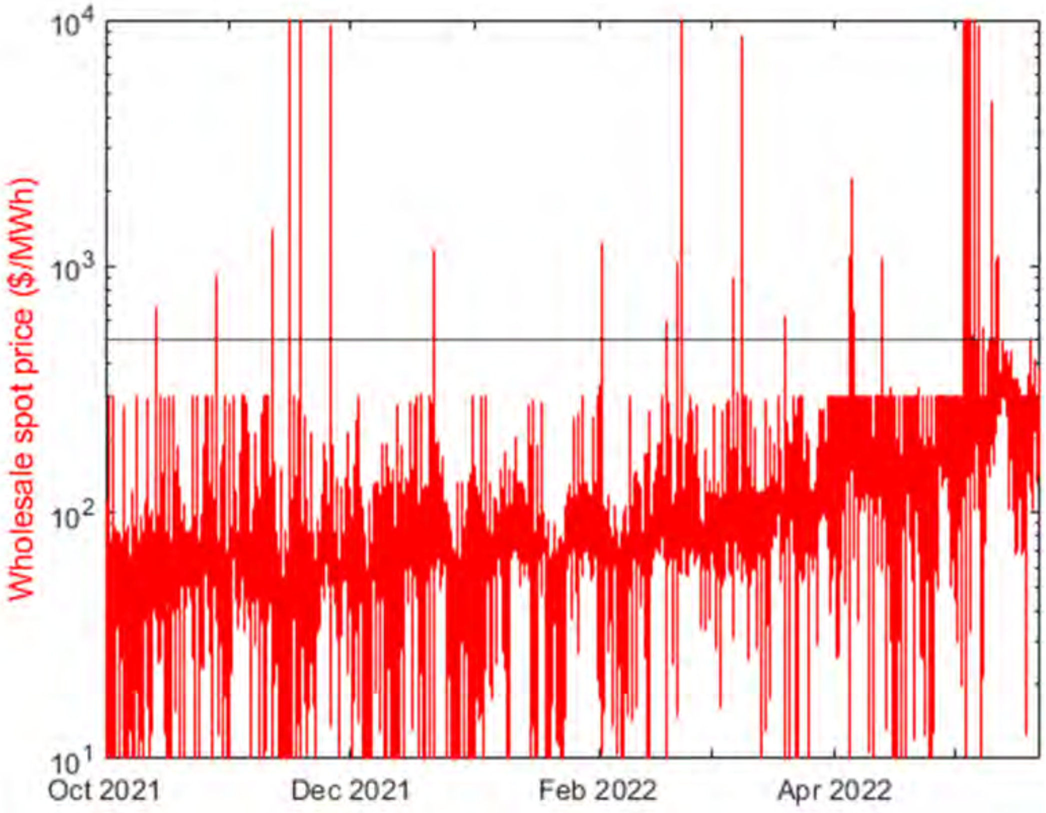


Figure 5-4 - Wholesale 5-minute spot price on a logarithmic scale

A distinct price clamping affect at $300 /MWh is clearly apparent in Figure 5-4, which is due to specifics in the contracting of energy supply, and recent increases in the marginal cost of generation. A cumulative frequency distribution of the spot price from the whole period is presented in Figure 5-5. This plot is useful to estimate what proportion of five-minute intervals are settled at or below a certain spot price for the period. For example, the spot price is negative approximately 2% of the time and is greater than $300 /MWh only 2% of the time and greater than $500 /MWh <1% of the time or on average around 15 minutes per day.

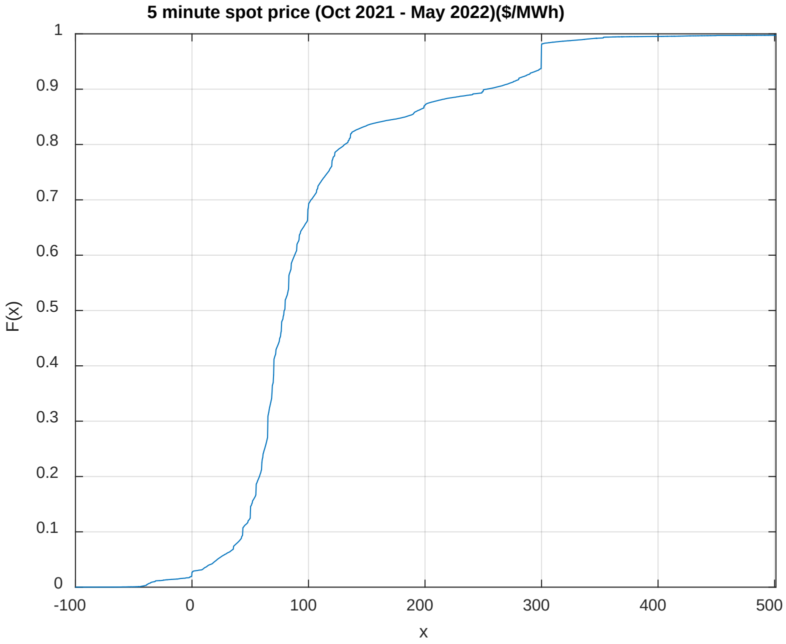


Figure 5-5 – Cumulative frequency distribution of wholesale spot price.

To confirm the duration of high spot price events a frequency distribution of the count of five-minute intervals is presented in Figure 5-6. **Approximately 70% of spot price events that settled at greater than $500 /MWh are only sustained for a single trading interval. Only three of these high spot price events from the period October 2021 to May 2022 were sustained for greater than 50 minutes. The spot price tends to rise quite dramatically once it exceeds $300 /MWh.**

This combination of market characteristics suggests that an effective energy supply cost control strategy with a wholesale spot price agreement could be to utilise fast DRM 1 control calls to the condensers to execute time-determinate and HVAC load curtailment-determinate response to these more cost-sensitive trading intervals.

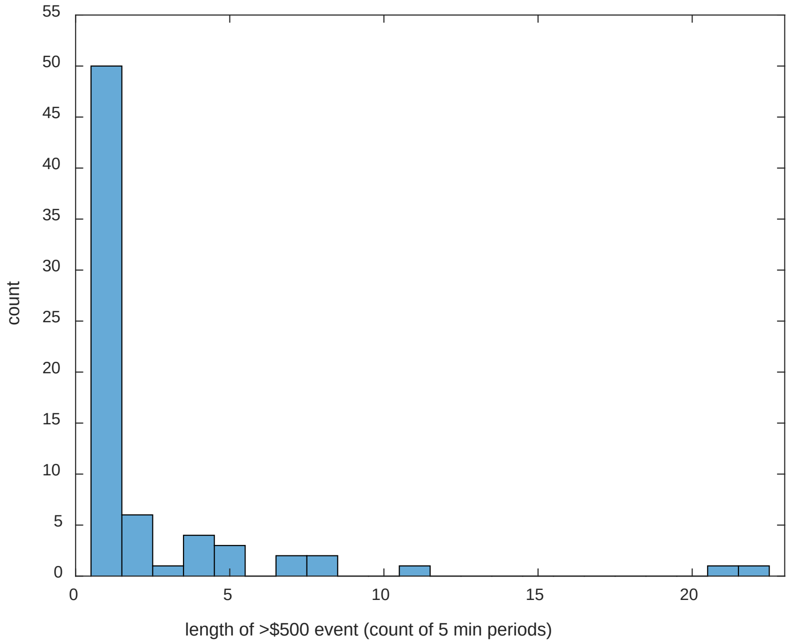


Figure 5-6 – Frequency distribution of the duration of spot price intervals greater than $500 /MWh.

5.1.4 Alignment of daily HVAC load profiles at Warrigal against spot price fluctuations

The following figures now look more closely at time series energy and spot price data to assess the potential to implement grid-interactive HVAC load controls in conjunction with the spot price market for a number of real scenarios from the Warrigal Living Laboratory.

Firstly, one week of spot price data is plotted with the Level 2 total HVAC consumption overlaid in Figure 5-7. This is for a relatively sustained high spot price often locked into the $300 /MWh. Notice the daily profile of the wholesale spot price that has a marked dip through the middle hours of every day while PV generation is typically highest on the overall grid, whilst the spot price peak intervals tend to occur at around early evening at this time of year. This is most likely largely due to workers returning home to cold homes in the evening and turning on electrical heating and cooking appliances.

Interestingly, the high price intervals often coincide with low HVAC consumption levels for this week. Conversely, the lower price periods typically seem to already align with higher HVAC consumption. This means that predictive HVAC load flexing control may not provide any substantial scope for improving spot price market costs during such periods as this. There is naturally a highly variable conjunction of spot price and HVAC consumption scenarios changing hourly, daily and throughout the seasons of each year.

The HVAC load peaks for late Autumn are expected to be through the cool night-times and early morning hours when residents are sleeping and then rising for the new day with brisk outdoor conditions. However, it is expected that for typical summer peak price events, the HVAC consumption in the late afternoon would tend to coincide with typical RERT event timing and the associated extreme spot price intervals. Such scenarios as that provide many substantial spot price cost reduction opportunities for HVAC load flexing controls.

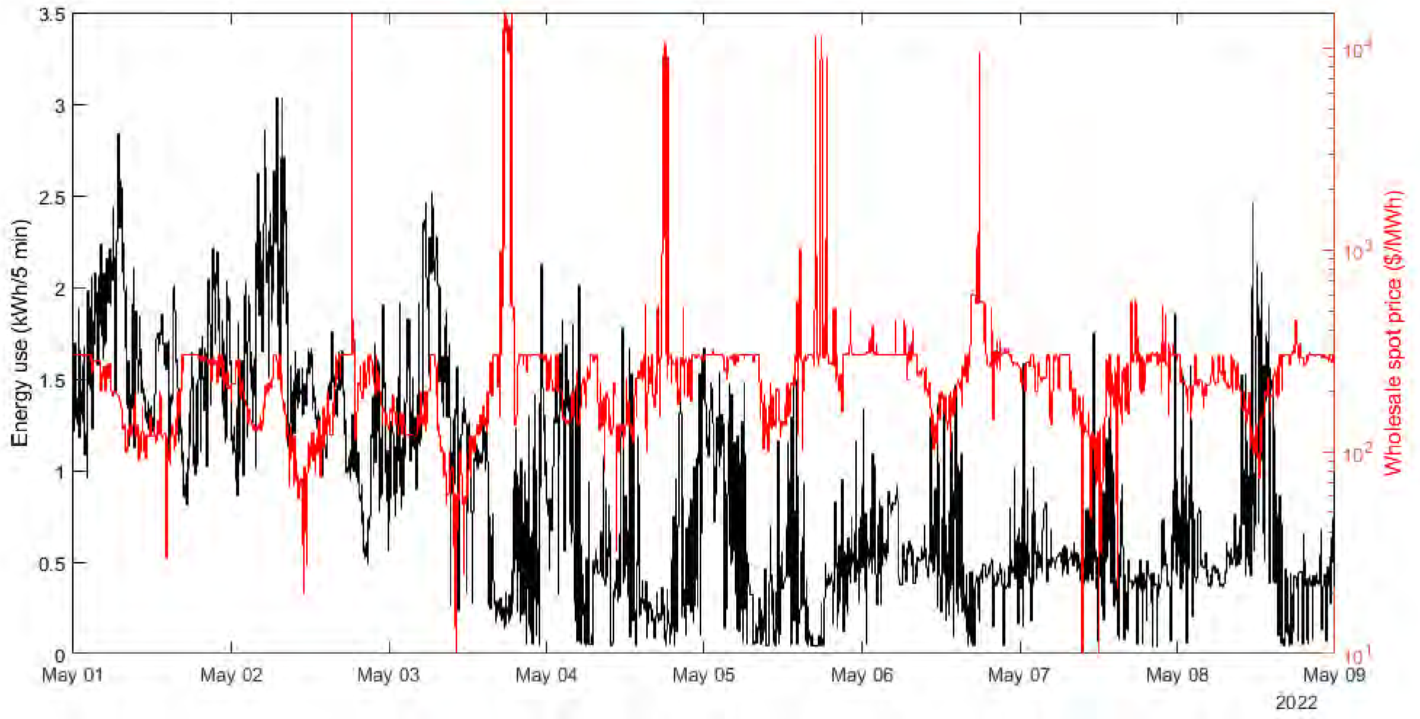


Figure 5-7 - Aggregated condenser consumption overlaid on wholesale spot price for one week in May.

To more closely observe the variability of specific HVAC load flexing and DRM curtailment opportunities with a wholesale spot price agreement, two separate 24-hour periods in May 2022 are presented. These two days represent a reasonably indicative range of the durations of spot price spike events.

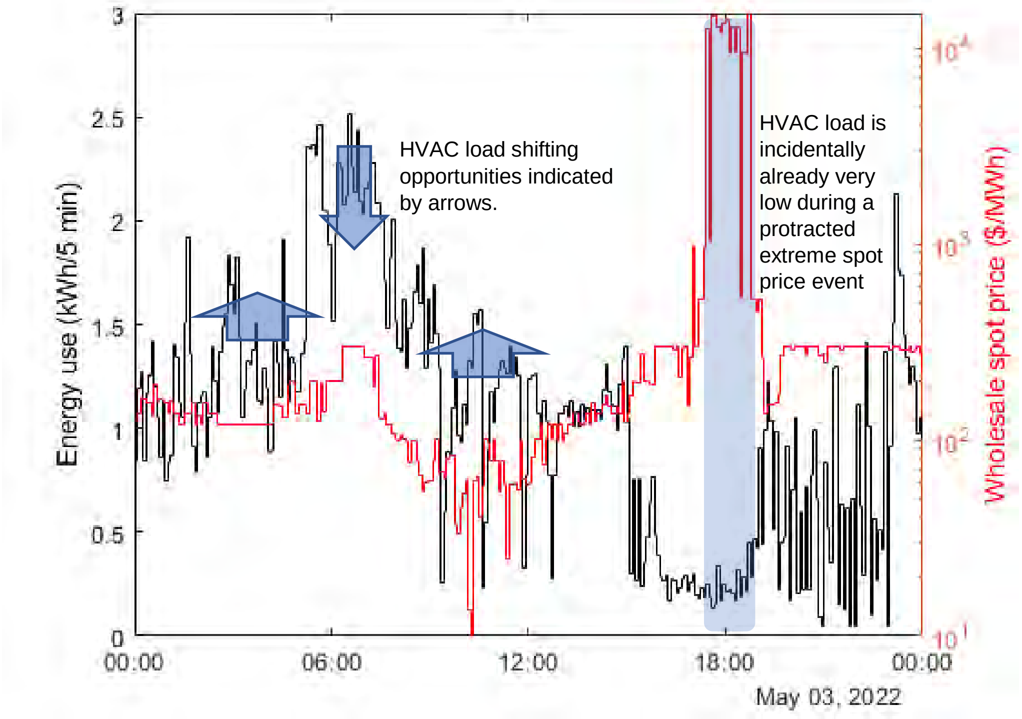


Figure 5-8 – Aggregated condenser consumption overlaid on wholesale spot price for one day – extreme spot price event already coincident with very low HVAC consumption.

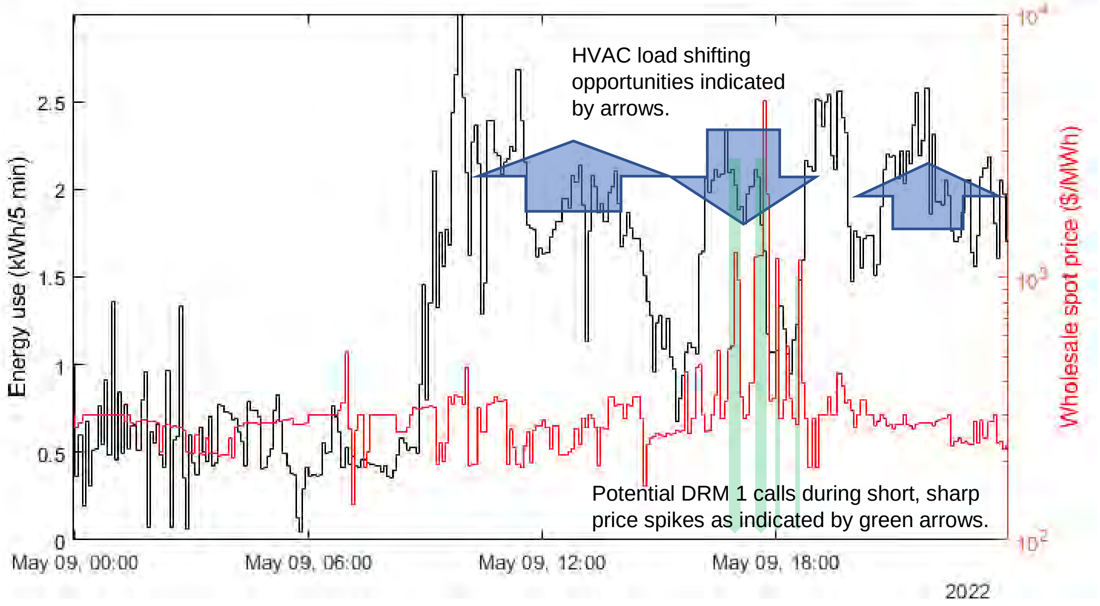


Figure 5-9 - Aggregated condenser consumption overlaid on wholesale spot price for one day – high loads coincident with high spot price intervals.

The first day (Figure 5-8) shows an extreme spot price period of just under two hours around 18:00. This is analogous to a typical summer RERT event in duration with a similarly sustained extreme spot price, except that RERT events will tend to hold the spot price at the regulated maximum limit of $15,000 /MWh. This price peak event happens to coincide with an already very low HVAC consumption, so very little could have been done in this case to further reduce the exposure to this spot price event. This is what an effective predictive grid-interactive HVAC load flexing control might look like on the evening of this day.

The morning of May 3rd presents a clear opportunity for a more gradual shifting of HVAC loads as indicated by the transparent large arrows. Notice how the aggregated HVAC consumption from midnight through to around 15:00 more or less follows the wholesale spot price trend. Consumption generally rises when the price rises and consumption tends to fall when the price is also lower. A predictive temperature set point flexing controller, based upon the short-term spot price forecast provided via the Flow Power API, could for example slightly increase the temperature set point (within agreed thermal comfort boundaries), in heating-only mode, during the early hours of the morning to increase the load during this lower priced period (~$120 /MWh) to pre-condition the building thermal mass prior to residents rising for the morning. Then during the period of approximately 90 minutes around 7:00, when the price steps up $300 /MWh, the temperature set points could be automatically dropped by the predictive controller to a set point lower than the now warmer pre-conditioned indoor temperatures so that HVAC loads would be substantially reduced in general across the site. The HVAC loads could then be boosted again to capture energy consumption during the price valley through the late morning and middle of the day to fully soak the building with slightly elevated temperatures.

The previous temperature time response plots of Figure 5-1 indicate that this residential facility has more than adequate thermal inertia to store this energy and maintain normal stable indoor temperatures. A similar grid-interactive energy cost and thermal comfort management strategy is indicated by the arrows on Figure 5-9.

Although the spot price variations over the morning of May 3rd are much more modest, varying between $10 /MWh and $300 /MWh, this load flexing scenario is expected to be available for a high proportion of trading intervals throughout each day of the year, so the energy cost abatement potential is still expected to be quite substantial.

The second sample day of May 9th (Figure 5-9) shows a high spot price period in the evening that does coincide with higher HVAC consumption, so that a more focussed cost abatement opportunity exists. Notice the different spot price axis range of this plot with price spikes that are less extreme but are also less sustained and more volatile. An effective potential control strategy for this scenario could be to use modest temperature set point flexing to generally shift the HVAC loads away from this extended period of sporadically high prices, noting that more substantial HVAC load shifting may likely start to noticeably impact thermal comfort over such a sustained period as this. So, the supplementary use of DRM 1 calls to trigger immediately upon notification of a sudden price spike being settled on the five-minute market will boost the cost abatement for these few intervals of between 5 minutes and 30 minutes as indicated by the green arrows.

These two days illustrate the highly variable and complex pricing and consumption scenarios at each site and demonstrate that a simple, regular scheduling of HVAC set points or load curtailment would not be reliably effective. Rather, **two grid-interactive HVAC control strategies may be considered. The slower response load flexing by predictive adjustment of**

temperature set point could be used effectively with a reasonably robust spot price forecasting tool. Alternatively, or additionally, a means of quickly curtailing HVAC electricity consumption immediately after a sudden unexpected spike in the spot price market is settled for the ensuing five-minute trading interval. This highlights the complementary important potential roles of both of these grid-interactive control strategies for the spot price market mechanism. This will require further development work to demonstrate and refine these more complex predictive control strategies for this site.

If DNA Energy DRM technology was implemented for this whole building the total demand response capacity would be on average approximately 38% of the total site load.

5.2 DRM response times and FCAS value streams

Firstly, the potential value of the Fast Raise and Slow Raise FCAS markets were evaluated for the Warrigal Living Laboratory to help provide focus for the relative potential value of these market options. Note that these two FCAS markets are separate but demand response capacity can be traded concurrently on multiple FCAS markets as described in Section 2.1.1 and Figure 2-2.

The total HVAC energy for the Living Laboratory on Level 2 of the building for each five-minute trading interval of the evaluation period was scaled up to estimate the FCAS trading capacity for the whole building. A minimum FCAS trading threshold of 50kW was set so that no FCAS trading was calculated for any trading intervals where the projected site HVAC consumption was not worth offering to an aggregator. The remaining capacity was further multiplied by 80% as an allowance to guarantee the delivered capacity availability throughout a five-minute interval. A further 80% multiplier was applied to allow for instances where an aggregator cannot utilise the site’s available FCAS capacity offered. These factors are based upon a site being a part of a larger portfolio of FCAS demand response being offered to an aggregator with a very large portfolio of FCAS demand response partners. This reduced total site tradeable capacity for each interval was then multiplied by the corresponding historic settled FCAS market price to obtain an estimate of the market value that could have been achieved for this site for each interval and these were accumulated for the whole evaluation period, as presented in Table 4.

It can be seen that the FCAS Fast Raise market offers the most value due to it having the most challenging time response requirements. Any HVAC system that can comply with the Fast Raise market requirements would also be able to comply for concurrent trading on the Slow Raise market. So, the practical market trading options are either concurrent Fast and Slow FCAS, or Slow Raise FCAS only. Hence, it can be seen that HVAC DRM controls that can comply with Fast Raise FCAS requirements could be expected to yield approximately three times the market value compared to systems that are only capable of Slow Raise FCAS.

Table 4 - Potential FCAS market value streams for Warrigal

FCAS market		
Slow Raise	**$**	**17,137**
Fast Raise	**$**	**34,550**
Slow and Fast Raise combined	**$**	**51,686**

DNA Energy's DRM control enabling systems are potentially capable of facilitating aggregated trading of HVAC load curtailment on the FCAS Contingency Fast Raise and Slow Raise markets. Accordingly, the time response of the DNA Energy DRM control systems in concert with the Warrigal Shell Cove HVAC condenser DRED-equivalent response times were assessed as part of this evaluation. It is noted that the response times presented below are a combination of communications delays, controller scan time limitations, and response times of both the DNA Energy technology and of the site-specific HVAC equipment as listed below:

- DNA Energy response time components, including:
    - Granular site meter to the gateway - Modbus
    - Gateway to the DRM Smart Integrated Devices – wireless mesh network
    - DRM Smart Integrated Devices to the Mitsubishi condenser controller
- Mitsubishi Electric condensers
    - Controller scan time
    - Condenser DRM control sequence initiation delays
    - Physical response of the power ramping down

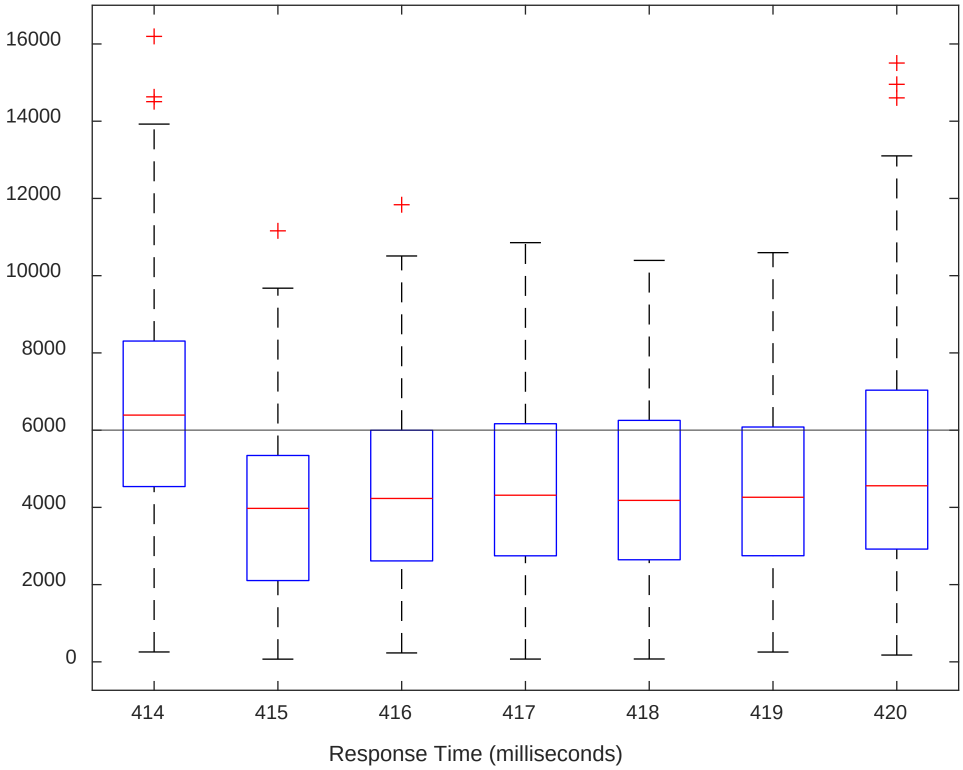


Figure 5-10 – Box plot of time responses of individual condensers at Warrigal's Living Laboratory site. Condenser number is shown on the horizontal axis with response time on the vertical axis.

It can be seen in Figure 5-10 that most condenser units can effectively load drop most of the time within the 6 second threshold. Condenser 414 is a notable outlier; this is a slave unit that is controlled from unit 420, and this delay can be attributed to secondary communications delays between these two units. In future, this condenser unit would either be reconfigured to receive DRM 1 calls directly or excluded from the FCAS scheme. Notwithstanding this outlier, none of the condenser units recorded load drops reliably within 6 seconds. To offer capacity in the FCAS market it is necessary to have high confidence in the ability to reliably deliver a load drop capacity.

To further understand the slower than anticipated DRM response time, the condenser load response was explored in detail, for individual and aggregated condenser units. The load response curve for the aggregated condensers for one DRM1 call is shown in Figure 5-11. The clear and obvious stepping in condenser response is indicative of an issue with the granularity of the meter installed. As this was a desktop study, an FCAS compliant meter was not installed, and the alternative meter was not able to provide data with sufficient temporal resolution to accurately assess response time. The steps during the period of decreasing load are periods in which the device has not updated with new data, and is reporting data from a previous time step. Further, a meter with 1 second resolution still has a degree of error that becomes important when assessing response for FCAS purposes.

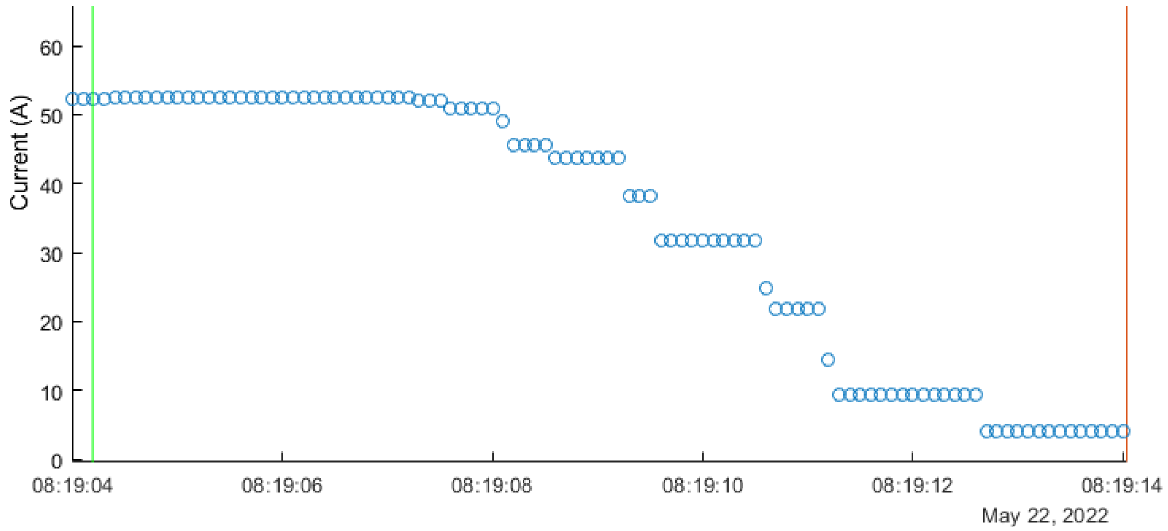


Figure 5-11 – Time response of the aggregated Level 2 condenser loads for a single DRM 1 call.

A cumulative distribution function of response times is provided in Figure 5-12. This shows the distribution of response times across the controlled condenser units, with the slave unit (CU-20S, 414) excluded. The measurement error in each response time was calculated incorporating both the limit of 1 second resolution, and the meter granularity issue identified above. The shaded band indicates the uncertainty of response time: between 75% and 95% of the time the condenser units were able to respond within 6 seconds.

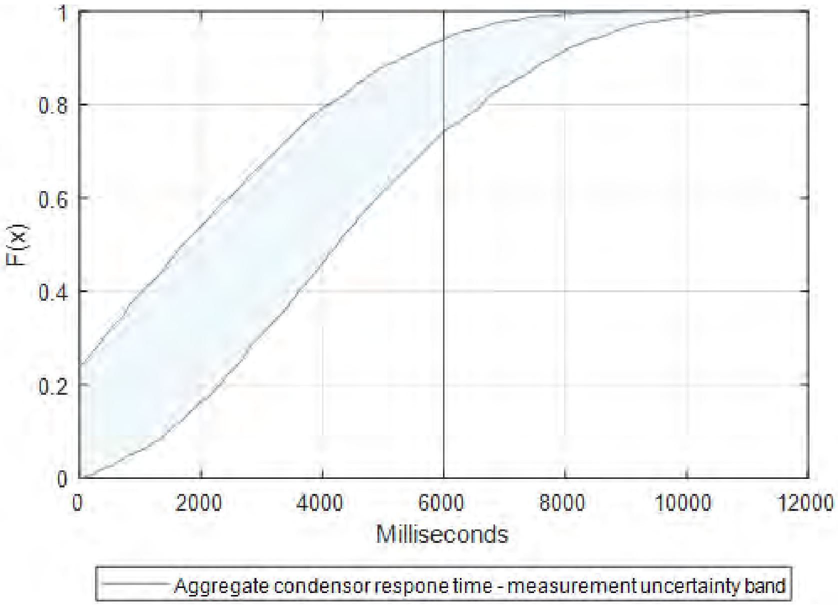


Figure 5-12 – Cumulative distribution frequency plot of all the response times of aggregated Level 2 condenser loads to DRM 1 calls during the test period, showing measurement uncertainty.

Whilst this DRM 1 response time would preclude the tested condensers from reliably participating in the FCAS Fast Raise market directly, the risk of slow response time from an individual condenser can largely be mitigated through aggregation of a large portfolio of device, and appropriate risk margins. Alternatively, the DNA Energy DRM control signal could be sent directly to an additional contactor that directly cuts power to each condenser, thus eliminating the site-specific HVAC DRM control response delays.

Whilst further evaluation is recommended to understand and quantity the contribution of the various possible sources of delay to the overall response time, there remains substantial potential for DRM 1 calls from DNA Energy Smart Integrated Devices to deliver significant load drops within the 6 second threshold of the Fast Raise market.

5.3 Further potential value streams

Monthly demand response charges on a conventional electricity agreement may be actively managed with DRM controls to cap the peak monthly site load at a target value. The DRM controls could similarly be used to limit site load to a capacity limit on the main switch board or sub-station as an alternative to a costly upgrade.

6 SUMMARY FINDINGS AND CONCLUSIONS

6.1 Overall Technology Assessment

There is significant latent potential for demand response capable HVAC equipment to improve the value of renewable energy at both a site level and grid level through aggregation of building portfolios. However, the technological, social and financial systems in which these technologies and market services exist are extremely complex and rapidly evolving. The current technological evaluation report has provided detailed mapping of the complexity of this landscape. Two potential markets have emerged as most promising for HVAC demand response: namely the wholesale spot price market, and the Frequency Control and Ancillary Services markets. Accessing these markets requires enabling technologies that can effectively utilise the HVAC capacity by controlling devices to switch off or time-shift HVAC electrical loads without compromising thermal comfort.

The current report has evaluated DNA Energy's Demand Response Mode (DRM/DRED) HVAC control technology in terms of the capacity to control HVAC load in response to wholesale spot price variation, and the ability to deliver FCAS into the Fast Raise and Slow Raise markets. There were significant restrictions imposed on this evaluation due to COVID-19. Supply chain issues in provision of devices resulted in a relatively short active evaluation period, and restrictions on access to the facility (as a Warrigal risk management strategy) limited the evaluation techniques available.

This evaluation has demonstrated that automated temperature set point adjustments are a promising method to implement HVAC load flexing control with the wholesale spot price forecasts, with response times appropriate to existing forecasting of spot prices, and minimal impact on thermal comfort within the duration of typical high price events. The thermal mass of the Warrigal facility was shown to provide adequate thermal stability to allow HVAC demand response control actions, even when an unrealistically large number of DRM1 events were artificially introduced in a short period.

Evaluation of the potential value of delivering FCAS market services using DNA Energy DRM systems found that the total potential FCAS market value of the Warrigal site during the specific evaluation period was $51,686 for concurrent Fast Raise and Slow Raise markets. Between 75% and 95% of the time the condenser units were able to respond within the required 6 seconds for the Fast Raise market. The risk of slow response time from an individual condenser may be mitigated through aggregation of a large portfolio of devices, appropriate risk margins, or by installing contactors for direct power cut-off response to DRM calls, so there remains substantial potential for DNA Energy DRM enabling technology to deliver significant value on FCAS Fast and Slow Raise markets. Income from this value stream would be shared by Warrigal with the aggregator depending upon the risk. Even a minor portion of this value stream may be attractive for a site that has an annual electricity bill of approximately $100,000.

The current program of evaluation has identified that three independent, complementary grid-interactive HVAC control technology/market value streams are practically feasible, and appropriate for the aged care sector.

1. HVAC load flexing by predictive adjustment of temperature set point with a spot price forecasting tool for a wholesale spot price retail agreement.
2. Supplementary to predictive temperature set point load flexing, DRM controls may be used to quickly curtail HVAC electricity consumption for the ensuing five-minute spot price trading interval immediately after a sudden unexpected spike in the spot market is settled.
3. DRM controls may be independently used to trade new value streams on the FCAS Raise markets through an aggregator.

This highlights the complementary important potential roles of both of these grid-interactive HVAC control technologies across two separate market mechanisms. Further development work would be required to demonstrate and refine the more complex predictive control strategies for this site.

Four key advantages of the DNA Energy HVAC demand response technology offering are:

1. Wireless DRM control architecture reducing installation disruptions and costs,
2. DRM enabling technology being applied to the HVAC industry, where they are more typically being rolled out with grid-scale batteries at present,
3. DRM technology for HVAC being applied to FCAS Raise markets, and
4. Integrated market interfacing to both the wholesale spot price market and to FCAS Raise markets.

6.2 Barriers and Enablers to Adoption

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

- DNA Energy’s wireless implementation format (compared to hard-wired solutions) is a key enabler for both implementation cost control and to minimise site operational disruptions during installation.

- Low capital cost of this suite of technologies and market services removes a common financial barrier to implementation compared to other energy storage and demand response solutions. These innovative technologies leverage existing energy storage of the thermal mass in buildings without the capital-intensive equipment component of batteries or generation equipment. Demand response capacity is enabled and released by these control technologies from existing HVAC loads without the need to generate additional energy, further removing barriers to implementation.

- The highly distributed existence of demand response capable HVAC systems throughout the electricity network acts as an enabler by being ubiquitous throughout local distribution networks. However, this distribution also poses a barrier by requiring large and potentially complex aggregation services to trade on FCAS markets.

- Thermally massive building construction with good thermal envelope performance substantially improves the resilience of thermal comfort to short-term demand flexing control actions.

- DRM response time of the whole system, from the DNA Energy triggering technology but more significantly through to the existing HVAC response time to DRM calls, may preclude the compliance for Fast Raise FCAS markets for some HVAC manufacturers.

- The lack of robust adaptive thermal comfort models validated for the aged care sector in Australia poses a barrier to establishing and trialling predictive temperature set point flexing controls in these facilities.

- Model predictive controls are known to provide excellent cost optimisation solutions for energy flexible buildings. However, the site-specific implementation complexity and ongoing support remains a substantial barrier to this solution being rolled out at scale. Model Predictive Controls with self-learning optimisation tools are being investigated to ease this development burden. Simpler rule-based controls may be used with machine-learning algorithms to capture a substantial proportion of the available value streams.

6.3 Recommendations

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

- These Living Laboratories offer very substantial ongoing potential value to industry and a broader range of building sectors to accelerate the development and implementation of grid interactive technologies. Ongoing funding streams are recommended to maintain and extend the operation of key Living Laboratory facilities.

7 REFERENCES

AEMC, 2021. Fast frequency response market ancillary services. Final determination published for fast frequency response. Information Sheet: https://www.aemc.gov.au/rule-changes/fast-frequency-response-market-ancillary-service, July 2021. Accessed 11/3/2022.

AEMO, 2012. Treatment of Loss Factors in the National Electricity Market. Australian Energy Market Operator, Systems Capability, accessed 25/10/2021, https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Loss_Factors_and_Regional_Boundaries/2016/Treatment_of_Loss_Factors_in_the_NEM.pdf

AEMO, 2017. Fast frequency response in the NEM: Working paper – Future power system security program.

AEMO, 2019. Contingency Frequency Response in the South West Interconnected System (SWIS): A proposal for system modelling and security limits for use in the Wholesale Energy Market Ancillary Service framework design, July 2019.

AEMO, 2021. 2021 Electricity Statement of Opportunities, Aug 2021,

AEMO, 2021a. The National Electricity Market, AEMO, Dec 2021. https://www.aemo.com.au/-/media/Files/Electricity/NEM/National-Electricity-Market-Fact-Sheet.pdf, accessed 14/2/2022.

AEMO, 2021b. WDRM – BASELINE METHODOLOGY REGISTER, 4 June 2021.

AS/NZS 4755.3.1:2014. Demand response capabilities and supporting technologies for electrical products – Operational instructions and connections for air conditioners.

ASHRAE Standard 55-2017, Thermal Environmental Conditions for Human Occupancy,

Australian Building Code Board (ABCB, 2019). National Construction Code Volume 1, Building Code of Australia 2019 Amendment 1.

Daly D, Kokogiannakis G, Tibbs M, McDowell C, Cooper P, 2020, i-Hub Education Renewable Energy and Enabling Technology and Services Evaluation Framework, AIRAH. bit.ly/3a5YWmh.

Forcada, N., Gangolells, M., Casals, M., Tejedor, B., Macarulla, M., Gaspar, K., Field study on adaptive thermal comfort models for nursing homes in the Mediterranean climate. Energy and Buildings, Vol. 252, Dec 2021.

Goldsworthy M, Sethuvenkatraman S and White S (2020) Air-conditioning demand response resource assessment, Summary Report. CSIRO, Australia.

iHub, 2021. Living Lab Operations Manual: Warrigal Residential Care Home. Innovation hub for affordable heating and cooling, Report LLS1 #XXX.

iHub, 2021a. Whole of life assessment guide for HVAC technology replacement decisions: Education Sector. Innovation hub for affordable heating and cooling, Report LLS1 WOLKPI.

iHub, 2021b. Technical Report: Warrigal residential care home Living Laboratory monitoring and baseline data analysis. Innovation hub for affordable heating and cooling, Report LLHC1 WOLKPI.

iHub, 2021c. Technology Test and Evaluation Plan: Flow Power Electricity Spot Price Trading. Innovation hub for affordable heating and cooling, October 2021.

Kelly D, Personal communications, Flow Power, 2022.

Kuiper G, Gill M, 2021. Mandating AS4755 Ignores Households and Widely Supported International Solutions—Modern Demand Response Should Be Consumer-Centric, Data-Driven, and Verifiable, Institute for Energy Economics and Financial Analysis, August 2021, accessed 21/2/2022 from https://ieefa.org/wpcontent/uploads/2021/08/Mandating-AS4755-Ignores-Households-and-Widely-Supported-International-Solutions_August-2021.pdf

Y. Yao, D.K. Shekhar, State of the art review on model predictive control (MPC) in Heating Ventilation and Air-conditioning (HVAC) field, Build. Environ. 200 (2021) 107952. https://doi.org/https://doi.org/10.1016/j.buildenv.2021.107952.