Australia's National Science Agency

Built-Environment Flexible-Demand Resource Assessment

Discussion Paper for the RACE CRC

B4 Flexible Demand Opportunity Assessment

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April 2021

Citation

Goldsworthy M, Brinsmead T, and White S (2021) Discussion Paper for the RACE CRC “B4 Flexible Demand Opportunity Assessment”, CSIRO, Australia.

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Contents

1. Background

For just 3% of the year, demand for electricity in the National Electricity Market (NEM) increases by 20%. This is equivalent to the generation capacity of the two largest coal fired power stations in Australia combined (1).

The RACE for 2030 Cooperative Research Centre's B4 "Flexible Demand and Demand Control Technology and Development" Theme, focuses on helping Australian businesses to develop and implement *load-flexibility* as a means of both (i) reducing the number and severity of these peak demand events and (ii) managing the impact of increasing levels of variable renewable energy generation entering the electricity system. Accessing flexible demand from Australian businesses could make a significant contribution to reducing the need both for costly infrastructure investment upgrades and for reducing price volatility in energy markets; each putting downward pressure on electricity prices.

RACE for 2030 commissioned the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Energy Efficiency Council (EEC), Royal Melbourne Institute of Technology (RMIT), the Australian Alliance to Save Energy (A2EP), University of Technology Sydney (UTS) and Energetics Pty. Ltd. to conduct an Opportunity Assessment to identify potential high impact research in the field of Flexible Demand and Demand Control Technologies.

Amongst other work in the B4 Flexible Demand Opportunity Assessment project, this discussion paper reports on modelling done to quantify the technically feasible amount of flexible demand that could be obtained from prospective loads in the built-environment sector. The prospective loads considered here are

- Residential loads
  - Airconditioning
  - Hot water
  - Swimming pool pumps
- Commercial and institutional building loads
  - Airconditioning

Flexible demand could be obtained from a variety of other potential loads, but these were not considered prospective (at least in the context of an initial scoping study). For example, commercial building hot water was not investigated because, typically, it is either in relatively small quantities or heated by gas. Food storage requirements suggest that fridges are not well suited to relatively unsupervised load shifting. Loads from other appliances and plug loads are considered either too adhoc or non-shiftable for providing meaningful flexible demand.

The demand models, in this study, aim to estimate the magnitude of each of the candidate loads in each substation across Australia (with the exception of the Northern Territory), at various points in time (month, day), and under various levels of coincident demand on the substation (minimum, average, peak).

The models also enable the amount of flexible demand to be estimated based on either (i) load shedding or (ii) nudging thermostat set points by 2°C (in the case of airconditioning).

The demand models are presented as two online Tableau databases that can be interrogated to understand the temporal, spatial and technology opportunity for sourcing flexible demand in the built environment. Importantly, loads are presented in the context of ***coincident*** levels of overall demand on the network. In this way, the user can identify what loads are on the substation at the point of interest (eg peak demand)

2. Methodology & Data Sources

a. Residential and Commercial Building Airconditioning

Voluntarily reducing the amount of air-conditioning being used in buildings can prevent extreme peak demand, while still maintaining the comfort conditions inside buildings within acceptable tolerances. Activating this voluntary air-conditioning flexible demand takes advantage of the cool thermal energy stored in the building fabric. The amount and duration of flexible demand available can be further enhanced by the addition of supplementary thermal storage capacity.

Air-conditioning flexible demand can cover a range of time scales and market services including i) Frequency Control Ancillary Services (FCAS), ii) wholesale energy market, iii) network support and, iv) emergency load shedding. While fast response FCAS is an attractive future target for investigation, this study focuses on assessing the potential of slow (i.e. ≥30 minute) flexible demand.

Estimates of total airconditioning load and flexible demand potential, on each substation, were calculated by top-down disaggregation of half-hourly electricity zone substation data, combined with commercial and residential building stock data sourced from the NEAR data platform (https://near.csiro.au/).

The model covers approximately 2000 substations across 14 Distribution Network Service Provider (DNSP) regions from the period 2013 – 2017.

The temperature dependent (cooling) electrical demand was first estimated from total sub-station demand. Next a statistical model was fit to decompose the temperature dependent component into separate components corresponding to commercial and residential buildings. The model for disaggregating substation load into airconditioning electricity demand was validated against detailed residential monitoring data.

Finally, models of available flexible demand fraction (as a function of the outside temperature and time of day) were applied, based on a flexible demand strategy that implements a 2°C thermostat set-point adjustment to the air-conditioned zones. The flexible demand capacity was estimated for each substation and half-hour interval. Further details can be found in (2).

Results can be visualised at Air-conditioning demand response atlas v1.04 - Mark Goldsworthy | Tableau Public. It should be noted that much higher flexible demand potential would be available by simply switching off airconditioners in an emergency, but this would impact on comfort conditions. Hence the 2°C thermostat set-point adjustment threshold is seen as a *market-responsive* resource (as opposed to switching off airconditioners which could only be used as an *emergency* resource).

Space heating was not modelled, on the expectation that the peak demand and minimum demand events of interest would be occurring in Summer and late Spring respectively.

b. Residential Hot Water and Swimming Pool Pumps

Residential hot water has been used extensively as a source of flexible demand using off-peak controls and associated tariff structures. In the traditional off-peak 'ripple control' application, participating electric hot water elements across the network are switched on at night using a central command signal and switched off during the day. Sufficient heat is stored in the hot water tanks to tide through the day, and peak day-time demand on the network is reduced. This control paradigm is increasingly being challenged by more responsive digital control technologies, and the emerging need for more day-time demand to offset solar PV production. Other water heating technologies (gas instantaneous, gas storage, continuous electric, heat pumps and solar hot water) also comprise parts of the national stock, but do not currently contribute to flexible demand.

Residential hot water electricity demand calculations were based on a bottom-up approach;

- Estimating the type and size of hot water systems, and their allocation across geographic and demographic cohorts, utilising data from the Australian Bureau of Statistics. This accounted for state and city-based differences in fuel type (electricity/gas) and hot water system technology preferences. It also accounted for household size (number of occupants) and its impact on hot water system size.

- Determining daily electricity consumption based on usage and climate zones from AS/NZS4234, assigned to each hot water system size (from above), and heating performance efficiency of each hot water system type. Electricity consumption was assumed to be uniformly spread across the daily operating cycle of the technology type (continuous or off peak)

- Estimating the number of dwellings (and hot water systems) in each substation by mapping substation geometries to 2016 SA1 geometries.

Further details on the methodology can be found in Appendix A. As a cross check, the total national annual residential hot water electricity demand estimated here is 41.8PJ which compares favourably with the Commonwealth residential energy baseline study value of 38.8 PJ.

The estimated hot water loads on each substation can be visualised at Residential end use demand viewer v0.1 - Mark Goldsworthy | Tableau Public

Noting that, theoretically at least, a hot water system can be switched off completely for a number of hours (giving 100% of load as the available flexible demand), no attempt has been made to calculate a separate value for flexible demand from hot water systems.

Swimming pool pumps are a discretionary load that can ostensibly be turned off for a number of hours, without meaningful impact on overall function. A number of trials have been conducted to investigate the potential of obtaining flexible demand from swimming pool pumps, and one company specialises in this technology with over 1,600 pools under management.

A similar bottom-up approach was taken to modelling swimming pool pump electricity demand, utilising data on (i) swimming pool pump ownership from Roy Morgan (2018), (ii) swimming pool pump operating hours from Woolcott Research & Engagement (2016) and (iii) swimming pool pump performance from the E3 Equipment Energy Efficiency Committee (2018). In the absence of better information, swimming pool pump operation was spread uniformly across a 24 hour day.

Further details on the methodology can be found in Appendix A. As a cross check, the total national swimming pool energy demand is estimated here to be 4.65PJ which compares favourably with the E3 Equipment Energy Efficiency 2012 Consultation Regulation Impact Statement value of 5.4 PJ.

The estimated swimming pool pump loads on each substation can be visualised at Residential end use demand viewer v0.1 - Mark Goldsworthy | Tableau Public

Noting that swimming pool pumps can be switched off completely, for the duration of likely peak demand events (giving 100% of load as the available flexible demand), no attempt has been made to calculate a separate value for flexible demand from swimming pool pumps.

3. Understanding the Tableau Data Bases

a. Residential end use demand viewer

An example of the Residential end use demand viewer v0.1 - Mark Goldsworthy | Tableau Public visualisations is illustrated in Figure 1 below, overlayed with coloured boxes in order to highlight relevant features.

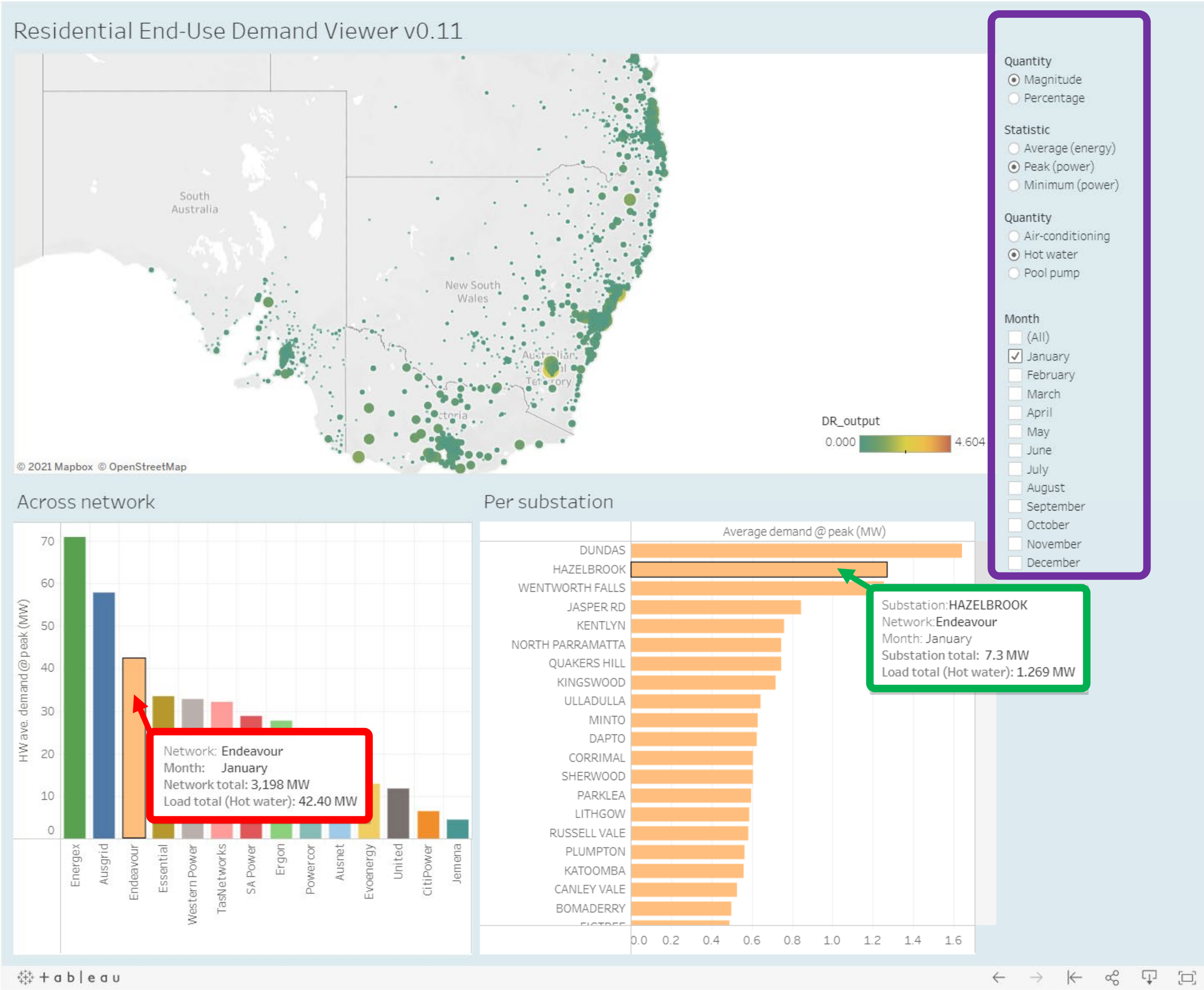

Figure 1 Example Tableau visualisation of hot water usage during peak demand events in January in Endeavour Energy's network area.

The **purple box** highlights the available selections that can be made, simply by clicking the relevant radio buttons/checking the relevant boxes. For example, in Figure 1, radio buttons/check boxes have been selected to extract data relating to the average hot water load on each substation when the given substation is experiencing peak load (99.5th percentile) in January.

In response to this request, the tableau database looks at each half hour period in January, where the substation is at peak demand, and it then averages the hot water load occurring in each of those peak half hour periods.

Hovering the mouse over a network (bottom left plot), brings up the **red box** which shows (i) the sum of the average total loads on network area substations (which is not necessarily the peak on the entire network as some substations peak at different times) and (ii) the sum of the average hot water loads; from each of the substations in the selected network area. For the selected example conditions (inside the purple box) in Figure 1, the sum of the average peak load on each substation in Endeavour Energy's network area in January is 3,198 MW, of which the sum of the average hot water load during these peak periods is 42.4MW (1.3% of total).

Double clicking on a given network (in the bottom left plot) will bring up all the substations in that network area. In the Figure 1 example, Endeavour Energy has been selected and all the substations in Endeavour Energy's area appear in the bottom right plot.

Hovering the mouse over a substation (bottom right plot), brings up the **green box** which shows (i) the average total load for the selected events and (ii) the average hot water loads in the given substations. For the selected example conditions (inside the purple box) in Figure 1, the average demand (over each of the peak demand events) in the Hazelbrook substation, in January, is 7.3 MW, of which the average hot water load during these peak periods is 1.269MW (17.3% of total).

The Hazelbrook substation appears to be far more prospective for obtaining flexible demand from hot water than the average across the Endeavour Energy network (17.3% compared with 1.3% of total load). It is noted that the bottom up nature of the calculation has some potential for misallocation of stock, and the substation load data itself is subject to factors such as changing supply areas and loads over time as well as data quality issues. Requesting results to be returned from the Tableau database as percentages and also comparing results over multiple months or with substations that are expected to be similar can help identify outliers (eg Figure 2 suggests that Hazelbrook is not the only prospective substation for hot water flexible demand).

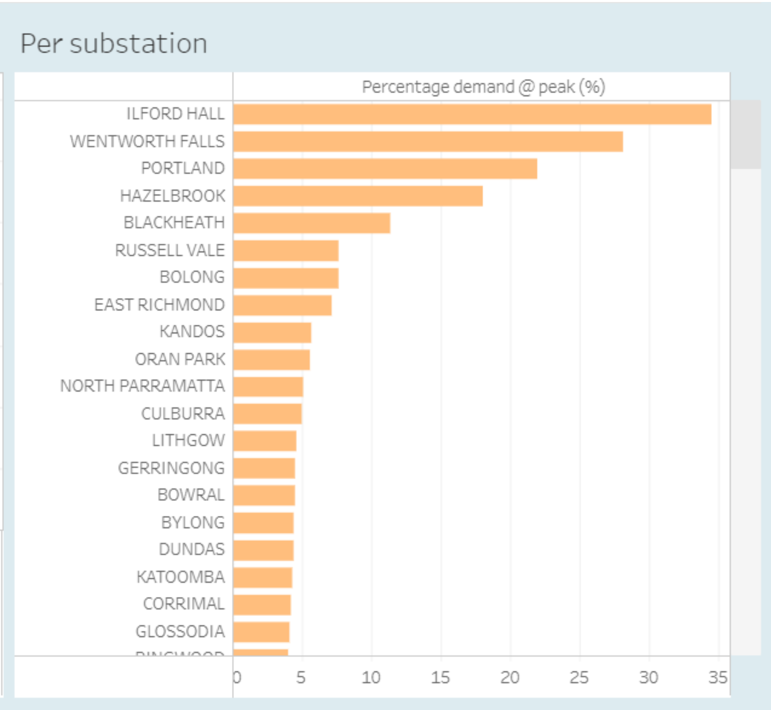

Figure 2 Percentage of peak demand attributed to hot water usage during peak demand events in January in substations in Endeavour Energy's network area .

Similarly, (utilising the relevant radio buttons in the purple box section illustrated in Figure 1) the Residential End-Use Demand Viewer can be used to examine the contribution of airconditioning and swimming pool pumps in substations around Australia during peak demand events, minimum demand events and averaged across all selected events.

It should be noted that the airconditioning loads presented in this visualisation are *total* airconditioning loads - not the amount of flexible demand available from nudging thermostats. Flexible Demand from nudging thermostats is presented in the National Airconditioning Demand Response Atlas (next subsection). Also, the Residential End-Use Demand Viewer does not provide any information on commercial building HVAC. Information on commercial building HVAC is presented in the National Airconditioning Demand Response Atlas (next subsection).

b. Air-conditioning demand response atlas

An example of the Air-conditioning demand response atlas v1.04 - Mark Goldsworthy | Tableau Public visualisations is illustrated in Figure 3 below, overlayed with coloured boxes in order to highlight relevant features.

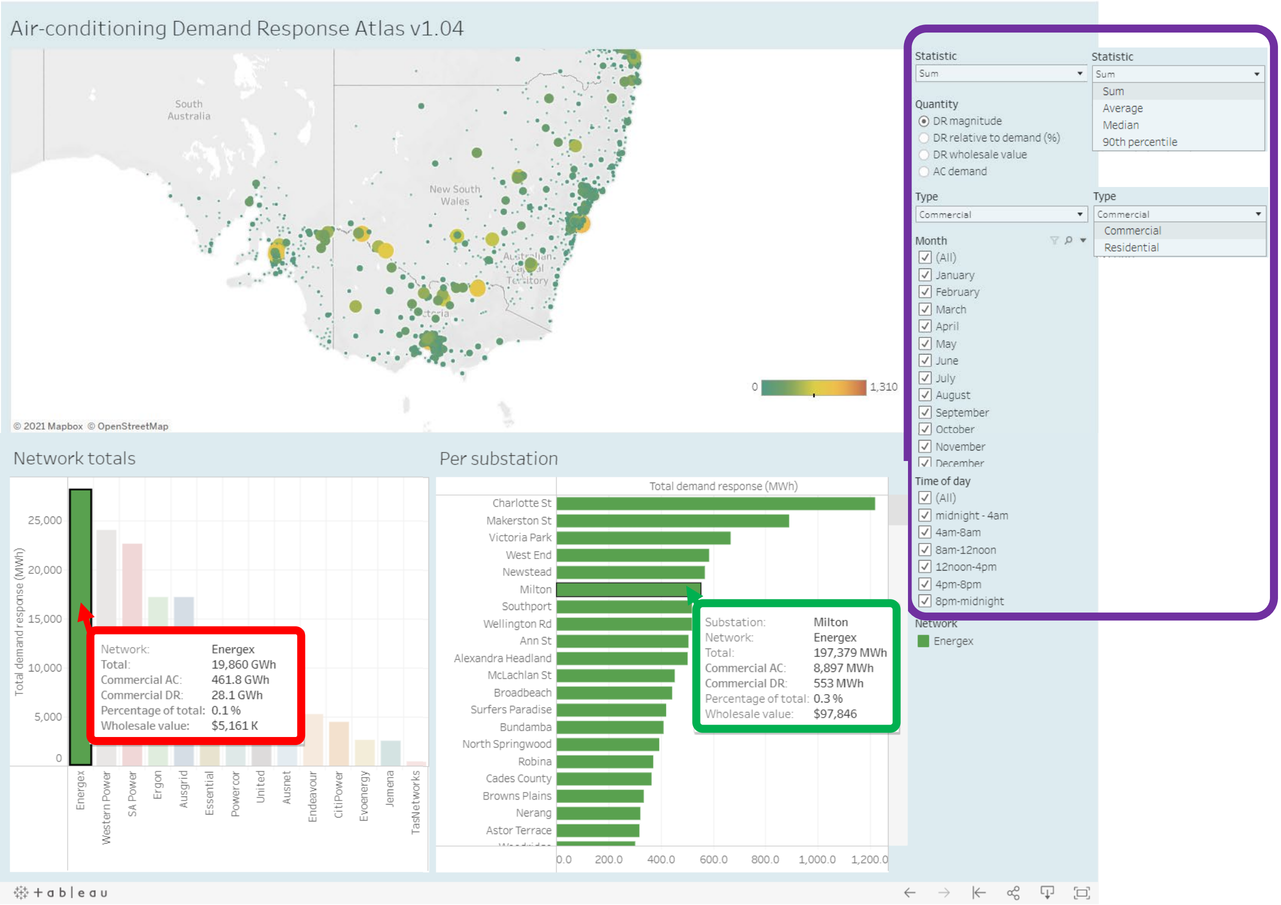

Figure 3 Example Tableau visualisation of potential annual demand response volumes available from commercial buildings across an entire year in the Energex network area.

Similar to the Figure 1 Residential End-Use Demand Viewer example, the **purple box** in Figure 3, highlights the available selections that can be made, simply by clicking the relevant radio buttons/checking the relevant boxes and selecting from the two drop down menus.

Additional features available in this Tableau visualisation are

- The ability to drill down into specific 4 hour time periods (bins of event data). Whereas the Residential End-Use Demand Viewer is agnostic of time of day, this feature allows a diurnally targeted examination of flexible demand potential from airconditioning.
- The ability to aggregate the annual volume of flexible demand and the respective coincident wholesale spot market value for the available flexible demand. While potentially useful as an initial examination of annual potential (rather than just instantaneous capacity), this feature should be treated with caution because
    - Just because flexible demand is available does not mean that it is required or dispatched
    - Any re-equilibration of thermostats required after a flexible demand event (prior to being able to 'nudge' the thermostats again) has not been considered.

In the example, illustrated in Figure 3, the Airconditioning Demand Response Atlas has been used to estimate the sum of all the flexible demand (28.1 GWh) available from commercial buildings across the entire year in the Energex network area. This is compared with the total energy consumed in the network area (19,860

GWh) and energy consumed on commercial building HVAC loads (461.8 GWh). This suggests that Commercial building HVAC consumes only 2.3% of total electricity consumed on the Energex network and potentially available flexible demand volumes are only 0.14% of total electricity consumed through the network.

Looking at the flexible demand capacity available from commercial buildings during peak (90th percentile) events and city locations gives a different picture (Figure 4).

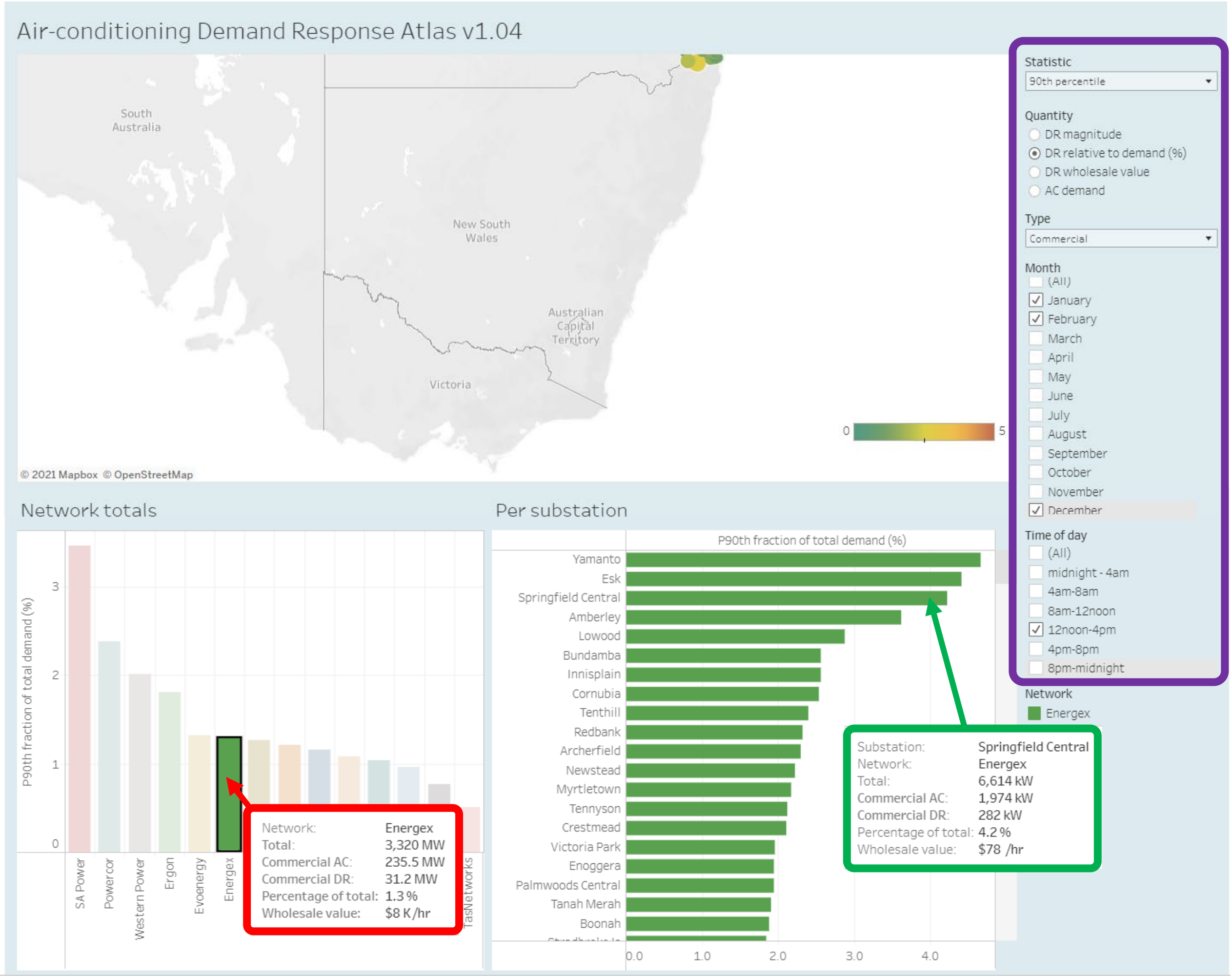

Figure 4 Example Tableau visualisation of average demand response capacity available from commercial buildings during early afternoon peak (90th percentile) demand events in summer in the Energex network area.

On average, during the peak demand events on the whole Energex network, commercial building HVAC is responsible for around 7.1% of peak demand and could provide around 1% reduction in peak demand through the nudging of thermostats.

Even more specifically, targeting a typical central city substation such as Springfield Central, commercial building HVAC accounts for around 30% of peak demand and could contribute a 4.2% reduction in substation load.

4. Key Results

The two Tableau visualisation tools (and the models underneath it) can be used to explore the quantity and potential usefulness of available flexible demand potential from the built environment.

a. Magnitude of candidate residential flexible loads at peak and minimum demand

The breakdown of each of the candidate flexible residential loads, during 99.5th percentile *peak demand* events, in summer, in each of the various network areas, is illustrated in Figure 5.

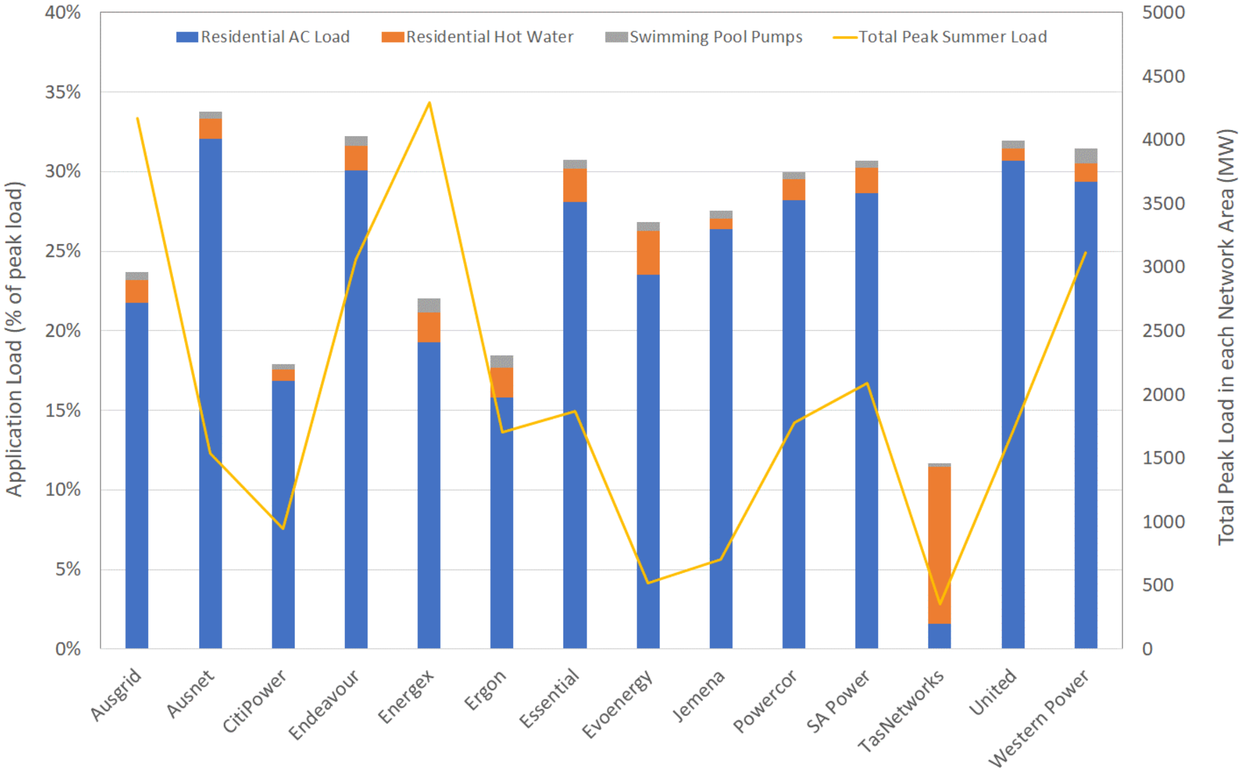

Figure 5 Magnitude of potentially flexible residential loads during summer peak demand events

Airconditioning is the dominant residential load during peak demand events, being responsible for 16 to 32% of all demand in each of the mainland network areas. Hot water systems and swimming pool pumps are relatively minor loads in all but the TasNetworks network area, where hot water is significant.

In theory, these three residential flexible loads could be switched off by a central controller (similar to ripple control) leading to 18% to 34% reduction in peak demand. Switching off airconditioners would have a significant amenity penalty for users, so could only be an emergency (not market) source of flexible demand.

The breakdown of each of the candidate flexible residential loads during *minimum demand* events, in spring, in each of the various network areas, is illustrated in Figure 6.

In contrast to summer peak demand events, the most significant flexible residential load on the networks during minimum demand events is hot water. In southern states, where gas is used extensively for hot water heating, hot water represents 6 to 15% of minimum demand. In NSW and Queensland hot water represents 21 to 36% of minimum demand.

Hot water loads during peak and minimum demand events may be higher than that modelled, if heating periods are more concentrated than assumed (in this scoping study, water heating was assumed to be evenly split across each technology's inherent operational period eg 24hrs per day for continuous electric water heaters). This could mean that there is potentially more flexible demand available at certain times, than that shown in Figure 5 and Figure 6.

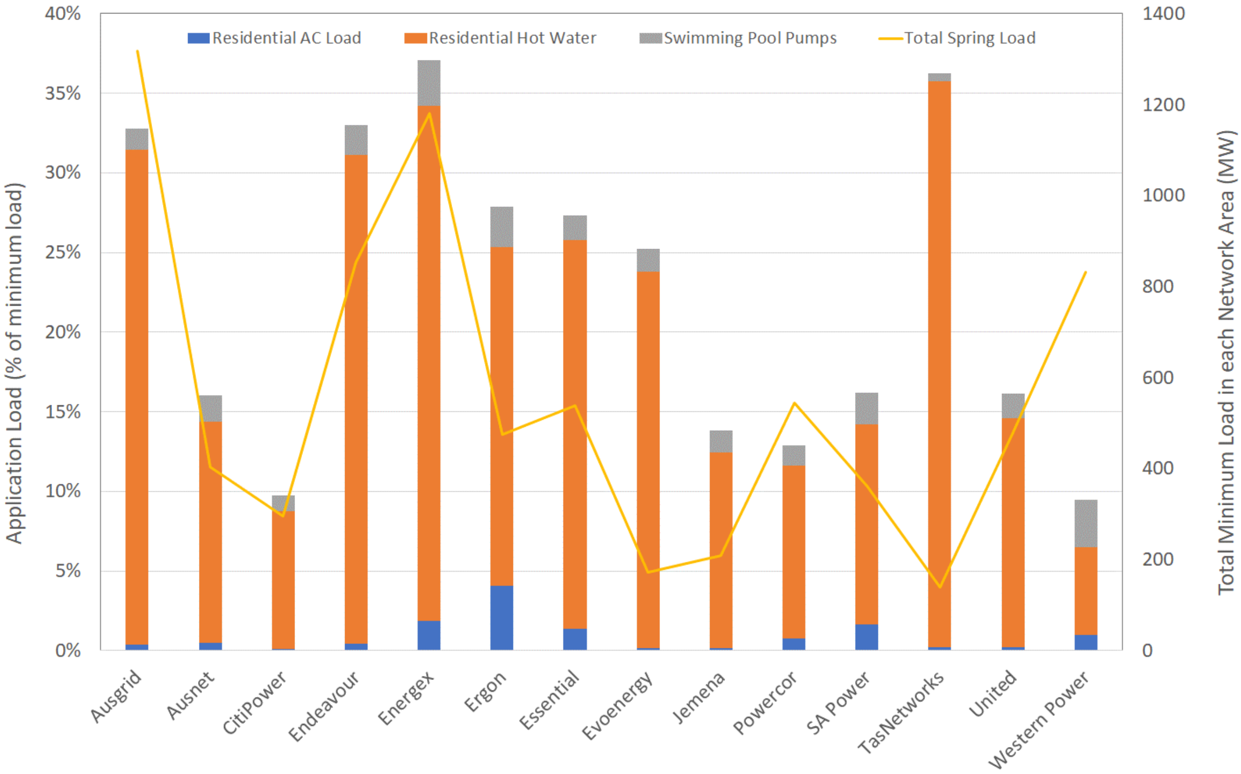

Figure 6 Magnitude of potentially flexible residential loads during spring minimum demand events

b. Opportunities for boosting residential loads during minimum demand events

The quantity of flexible demand available from residential loads, that could be used to increase demand during minimum demand events, is not directly quantified by the model and Tableau visualisations – and is not in the scope of the opportunity assessment. However, some indicative relativities can be deduced. The following rough estimations are based on the entire stock being made controllable:

- If continuous hot water systems contribute 1700MW to minimum demand when load is spread evenly across a 24 hour day, then much higher hot water loads could be achieved by concentrating that same load into a smaller targeted time-window using a central controller (similar to ripple control). Assuming coordination of the national fleet of 2.2 million continuous electric hot water systems, each of 3kW load, then hot water demand could grow to 6600MW; an increase network demand by more than 60% during a minimum demand event. Heating element size would seem like a very low cost way of addressing transmission level minimum demand.
- If the assumption in the model (of spreading swimming pool pump load evenly across a 24 hour day) leads to swimming pool pumps contributing around 1% to 3% to the minimum demand on a network, then concentrating that same load into a 6 hour window that is centrally controlled (similar to ripple control) could increase network demand by 3% to 9% during a minimum demand event. The ability to concentrate pool pumps to 6hrs is more about coordination than ability to 'work harder'.
- If residential airconditioning contributes 20 to 30% to peak demand events and minimum demand events are approximately 30% of peak demand, then turning on all the residential airconditioners (with low thermostat setpoint) may be able to increase network demand by roughly 50% to 100% during a minimum demand event. Of course, turning on airconditioners on a mild day could potentially over cool some homes. Further work would be required to understand if this approach had any merit.

c. Market responsive flexible demand from thermostat controls

The prevalence of commercial building HVAC and residential airconditioning loads on network substations, and the potential to extract flexible demand from these loads (by nudging thermostats) is illustrated in Figure 7. This technology is selected for deep dive because airconditioning is the single biggest contributor to peak demand on network substations.

Figure 7 illustrates the fraction of demand attributable to airconditioning both on average, and also in one of the most impacted substations in each network area (the substation with the 10th highest fraction of residential airconditioning and the substation with the 5th highest fraction of commercial building airconditioning). The more impacted substations were selected (i) to show the level of variability between average substations and substations with high levels of airconditioning and (ii) to highlight how airconditioning controls might be targeted at the most relevant substations (rather than applying to all substations).

On average, commercial building airconditioning is 5% to 9% of network demand during peak demand events, with the exception of the SAPN network area where commercial building airconditioning is 14.3% of peak demand. This is significantly smaller than residential airconditioning demand (16 to 32% of peak demand).

In selected substations with high commercial HVAC loads, commercial building airconditioning grows to 9% to 23% of network demand during peak demand events (with the exception of that in the SAPN network area where commercial building airconditioning is 36% of peak demand).

In substations with high residential airconditioning loads, residential airconditioning accounts for 37% to 54% of peak demand.

Rolling out a targeted thermostat-based flexible-demand program across all airconditioners in a prospective substation could deliver

- 2% to 6% demand reduction in target substations with high proportion of commercial buildings.
- 9% to 16% demand reduction in target substations with high residential airconditioning loads

Again, it is noted that these figures for thermostat-based flexible demand represent what could be achieved from regular, automated, market-driven implementation. This contrasts with the much higher demand reduction (~4 x factor) that could be obtained in emergencies as a result of switching off airconditioners (load-shedding).

Implementing thermostat-based air-conditioning DR across all commercial and residential buildings in the NEM (coincident with NEM peak demand), is estimated to reduce NEM peak demand by 1.2GW (~5.8%) and shift it forward in time by approximately 2 hours.

d. Opportunities for boosting commercial HVAC during minimum demand events

The quantity of flexible demand available from commercial HVAC loads, that could be used to increase demand during minimum demand events, is not directly quantified by the model and Tableau visualisations – and is not in the scope of the opportunity assessment. However, commercial building HVAC appears to have potential as a flexible demand resource to address minimum demand issues. While more investigation is required, some specific useful characteristics of this application include

- Individual commercial building loads are of sufficient scale (often in MWs) to justify automation, and some level of automation is already in place in many commercial buildings
- A high percentage of idle flexible-demand capacity is available on mild days
- Demand for airconditioning in commercial buildings is more closely aligned with solar production (midday to early afternoon), so any precooling/thermal storage can quickly be discharged back into the building once the event is over (for good round trip energy efficiency)

- Compared with load shedding, offering a period of free energy during minimum demand events can be perceived as giving ‘more service’ to the building rather than less (and is therefore may be an easier sell). Any precooling would need to be within comfort bounds.

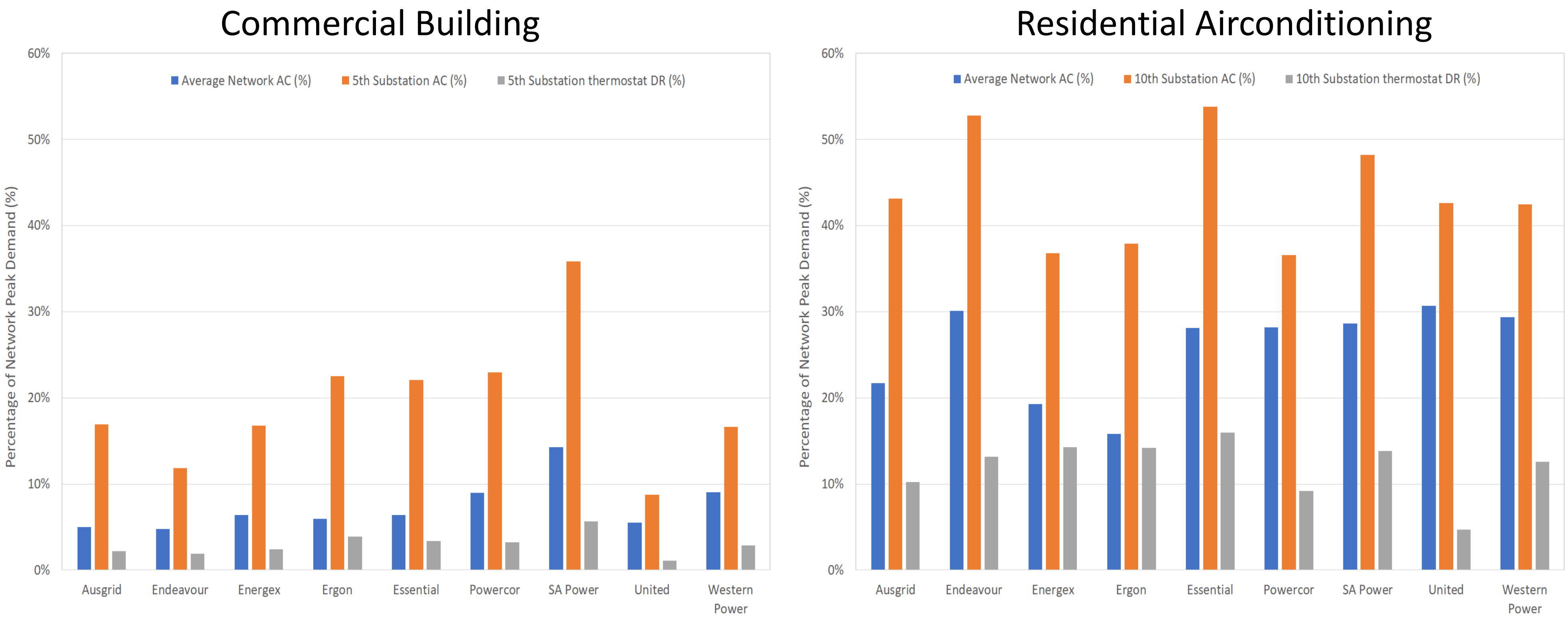

Figure 7 Fraction of demand attributable to airconditioning in commercial and residential buildings during peak network demand events (i) average across networks, (ii) for substations where airconditioning loads are high and (iii) contribution that thermostat-nudging flexible demand could make in substations with high airconditioning loads

Conclusions and Recommended Further Research

The analysis reported here is initial scoping study research aimed at gaining some initial estimates of the magnitude of the possible flexible demand resources that could be accessed from the built environment.

The approximate resource potential, coincident with peak and minimum demand is

Technology/Sector	Emergency FD Resource	Market participation FD Resource
Coincident with peak demand		
Residential hot water	450MW	450MW
Residential swimming pool pumps	170MW	170MW
Residential airconditioning	6.9GW	970MW
Commercial HVAC	1.5GW	190MW
Coincident with minimum demand (rough estimate only)		
Residential hot water	4.9GW	
Residential swimming pool pumps	450MW	
Residential airconditioning	970MW	
Commercial HVAC	190MW	

Coordination of hot water systems during daytime minimum demand events looks like a very low-cost feasible approach to managing minimum demand. Airconditioning and hot water provide important opportunities for flexible demand participation in energy markets.

This resource assessment could be further developed by/to

- Further examine key assumptions (eg diurnal and seasonal operating profiles of hot water and swimming pool pumps) and conduct more detailed assignment of building/appliance stock to substations.
- Refine calculations of the magnitude, duration and post-event readjustment from thermostat-based flexible demand, through additional experimental research
- Explicitly evaluate flexible demand potential during minimum demand events.
- Develop modelling capability that enables scenario analysis of adoption rates of technologies based on policies and incentive programs.

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Appendix A: Residential Hot Water and Pool Pumps Methodology

1.0 Overview:

The purpose of the visualisation tool is to provide a break-down of estimated average, peak period and minimum period residential air-conditioning, hot water and pool pump demand per electricity zone-substation.

Average demand is shown as the estimated average daily energy use on a monthly basis, while peak and minimum period demands are the estimated average power use for the half-hour intervals above and below set percentiles. Peak demand is defined as the 99.5th percentile half-hourly demand in each month for a given substation. Minimum demand is similarly defined as the 0.5th percentile in each month for a given substation.

Residential air-conditioning demand estimates are derived from the total substation demand using the method outlined in [1]. Hot water and pool pump estimates are derived from a bottom up estimation using the methods outlined below. That is, the hot water and pool pump demand estimates are made *independently* of the substation data, and so in rare cases they can actually be higher than the substation demand for any given period. This is especially the case for the minimum demand period.

Results are based on up to 5 years of substation demand data from the period 2013 to 2017.

2.0 Method for residential hot water demand estimate:

Residential hot water demand estimates were based on a bottom-up approach combining data from Australian Standards [2], the Australian Bureau of Statistics [3,4] and other sources [5-7]. A detailed description is given below.

1. ABS data [3] on the fraction of residential dwellings $F_{s,l}$ with 4 types of electric hot water system (s=1,2,3,4) as a function of the household occupant classification (reproduced in Table 1) was used to estimate hot water system type ownership rates a function of the size of the hot water demand *l* (Table 2). This was based on the 4 hot water demand levels in AS/NZS4234 [2] and drawing on the results from Goldsworthy [5].

Table 1 Percentage of dwellings with specific types of electric hot water system by life cycle group. Taken from [3].

	Lone person aged under 35	Couple only, reference person under 35	Eldest child under 5	Eldest child 5 to 14	Eldest child 15-24	One parent with dependent children	Dependent & non-dependent children only	Non-dependent children only	Couple only, reference person 55 to 64	Couple only, reference person 65 and over	Lone person 65 and over
Continuous (storage or instant.)	39.4	30.0	22.4	17.1	10.8	23.4	13.5	13.0	14.2	12.8	23.2
Off-peak	19.0	17.6	21.8	21.0	24.2	28.9	26.9	26.4	30.9	33.0	36.3
Heat pump	0.1	0.7	0.7	1.9	1.5	0.3	1.2	1.4	1.9	1.3	0.1
Solar (all boost types)	3.4	6.7	8.1	11.2	14.2	5.0	11.7	12.5	11.7	13.9	5.4
Ave. number of persons in household	1.0	2.0	3.4	4.2	4.1	3.1	4.9	3.3	2.0	2.0	1.0
Inferred hot water load size	VS	S	M	M	M	S	L	M	S	S	VS

Table 2 Estimated percentage of dwellings with specific types of electric hot water system by hot water demand size.

	VS	S	M	L
Continuous (storage or instant.)	27.4	19.0	15.9	13.5
Off-peak	31.9	28.4	23.0	26.9
Heat pump	0.1	1.1	1.5	1.2
Solar (all boost types)	4.9	9.9	11.5	11.7

2. Next a location-based scaling factor S_g was calculated for each hot water system ownership type by scaling the relative hot water system ownership numbers across locations g (states and capital cities) using ABS data [3] and data on the relative ratio of electric boost solar to gas boost solar systems as a function of state [6].

Table 3 Estimated location-based scaling factor for prevalence of different types of electric hot water system

	Sydney	NSW	Melbourne	VIC	Brisbane	QLD	Adelaide	SA	Perth	WA	Hobart	TAS	Darwin	NT	Canberra
Continuous (storage or instant.)	1.2	0.8	0.4	0.5	1.6	1.4	0.7	0.5	0.8	0.8	4.3	4.0	3.0	1.3	2.0
Off-peak	1.6	1.2	0.4	0.7	2.0	1.2	0.8	1.5	0.0	0.0	0.2	0.1	0.0	0.0	0.7
Heat pump	1.0	1.6	0.5	0.4	2.4	0.7	1.0	1.3	0.1	0.6	4.7	0.9	0.0	0.0	1.2
Solar (electric boost)	0.6	0.8	0.1	0.2	3.2	1.8	0.7	0.7	0.7	0.6	1.6	0.7	13.7	9.0	0.0

3. The number of dwellings $N_{l,sub}$ corresponding to each hot water load size *l* for each substation zone *sub* was then calculated by area weighted scaling from the number of dwellings with specified numbers of people in each SA2 level based of ABS census NPRD data [4]. Substation geometries were mapped to 2016 SA1 geometries.
4. The AS4234 climate zone CZ_{sub} corresponding to each sub-station zone was found by mapping NCC climate zones [7] at SA2 level to AS4234 climate zones.
5. The peak daily thermal hot water load $Q_{l,cz}$ for each hot water load size and AS4234 climate zone and the seasonal (monthly) load multiplier L_m for month *m* were taken from [2].
6. An effective electric COP_s for each hot water system type was taken from [6] (see Appendix D) as a function of daily load and climate zone.

$$COP_{heatpump} = COP_{heatpump}(Q \times L, CZ)$$
$$COP_{storage} = COP_{heatpump}(Q \times L)$$
$$COP_{continuous} = 0.9$$
$$COP_{solar} = COP_{solar}(Q \times L, CZ)$$

7. The monthly average daily hot water electrical demand per substation was calculated as;

$$E_{sub,m} = \sum_s \sum_l N_{l,sub} F_{s,l} S_g Q_{l,cz} L_m / COP_s$$

8. Finally, the average daily hot water demand was converted to hourly demand assuming a uniform load throughout the day for continuous, heat pump and solar electric boosted systems, and a uniform load between 10pm and 6a, for off peak systems.

As a cross-check, the total annual residential hot water electricity demand was calculated as;

$$E_{total} = \frac{365}{12} \sum_{sub} \sum_m E_{sub,m} = 41.8PJ$$

By comparison, [6] report an estimated forecast value of 38.8 PJ for the year 2016 (whole of Australia). Figure 1 below compares the monthly residential hot water electricity consumption by system type with monthly estimated residential air-conditioning demand [8].

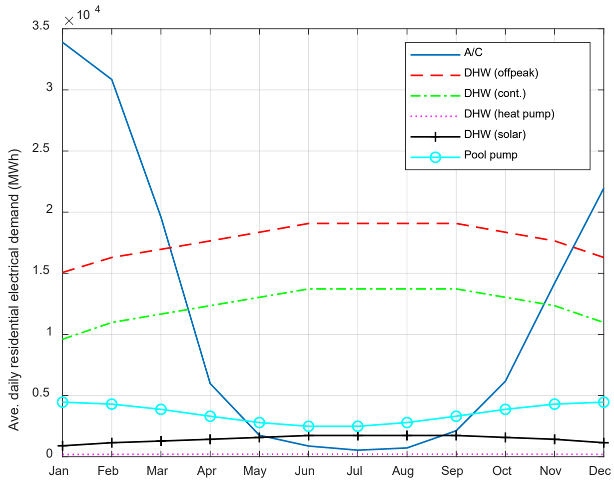


Figure 5 Estimated monthly variation of daily average residential electricity demand on the NEM for domestic hot water, air-conditioning and pool pumps.

3.0 Method for residential pool pump demand estimate:

The method to calculate residential pool pump demand is similar to that for hot water, although no recent pool related data from the ABS was found and so other sources were used. The method is outlined below.

1. First the fraction of dwellings with a pool F_g by state and capital/region was obtained from [8]:

Table 4 Percentage of households with a swimming pool Sep 2018. Taken from [8].

	Capital	Regional
NSW	15	10
VIC	9	9
QLD	18	20
SA	9	8
WA	19	7

TAS	4	3
NT	No data	
ACT	10	N/A

2. Next the number of dwellings per substation N_{sub} calculated from census data at SA2 level (ABS Census 2016) using an area weighted approach.
3. Average pool pump operation hours by season were taken from [9] as follows; Summer: 5.6hrs, Autumn: 4.1hrs, Winter: 3.3hrs [9]. These values were fit to cosine function: $H = b_1 + b_2 \cos\left(\frac{(m-1)2\pi}{11}\right)$ with $b_1 = 4.32, b_2 = 1.26$ to give a smoothly varying function of operation hours by month of the year. Given the absence of location specific information, these operation hours were applied to all locations.
4. Pool pump average efficiency existing values for single and multi-speed pumps were taken from [10] as 70% and 30% respectively. The average star rating of single and multi speed pumps was taken from [11] as 2.7 and 7.2 respectively. Pump power consumption was calculated from the star ratings using the function: P=2981.8exp(-0.3634*star) [11].
5. The monthly average daily pool pump electrical demand per substation was thus calculated as

$$E_{sub,m} = N_{sub} F_g H P_{ave}$$

6. Finally, this was converted to an hourly demand value assuming a uniform demand over 24 hours. Although many pool pumps may be operated exclusively at off peak times, for example, [9] report that 70% of pumps run on a timer, [11] report that 50% of pool pumps are likely to be operating during a/c induced peak events which contradicts this figure assuming the timers as set to avoid peak times.

As a cross check, the annual pool pump energy consumption across the NEM was calculated here to be 4.65PJ. By comparison, [7] report an estimated forecast national energy use value of 8PJ in 2020 which includes both pool pump and electric pool heating, while [12] report a national figure of 5.4PJ. The monthly variation of pool pump estimated energy consumption across the NEM is also shown in Figure 1.

4.0 Tableau visualisation

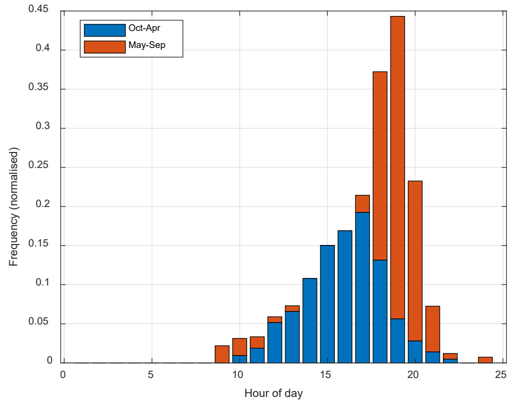
The Tableau visualisation can be used to view the daily average, peak and minimum average period total, residential a/c, residential hot water, and residential pool pump demand estimates by substation zone and by DNSP as a function of month of the year. These values can be shown in absolute terms (MWh and MW) and the residential demand values also as percentages of the total substation demand.

Percentage values are calculated as averages of hourly percentages, hence they are usually not the same as the percentage calculated from the ratio of the total sum of the end-use demand to the total substation demand. Also, as noted above, in some cases percentages sum to greater than 100%, or the raw individual percentage values were greater than 100% due to the way in which the hot water and pool pump estimates were calculated. Individual percentage values greater than 100% are shown as 100%.

5.0 Additional results

The underlying data-set can be used to produce additional results such as shown below. Figure 2 (left) shows the distribution of hour of the day when the peak demand hours on the Ausgrid network and Figure

2 (right) shows the distribution of the estimated fraction of the total substation demand due to residential air-conditioning, hot water and pool pump demand between October and April. Note that these plots are not available in the Tableau visualisation.



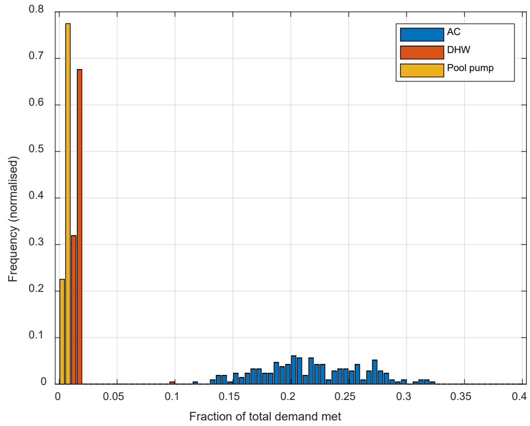


Figure 6 Left: Distribution of hour of the day when peak (99th percentile) demand occurs on the Ausgrid network. Right: Estimated distribution of fraction of peak demand due to AC (cooling), hot water and pool pumps (all Oct-Apr).

5.0 Potential next steps

The results here represent an initial estimate of the residential end-use demand values for hot water and pool pumps in particular. Further work is suggested to improve these estimates. In particular, the following may be considered.

- Investigating methods to rescale/normalise the hot water and pool pump demand estimates to the substation demand data to reduce the occurrence of implausibly high demand values relative to the total sub-station demand.
- Sourcing data on the daily operating pattern of continuous, heat pump and solar boost hot water systems and revising the assumed average daily operating pattern accordingly.
- Sourcing data on location specific seasonal pool pump usage patterns and daily pump operation and incorporating this into the pool pump demand estimates.

Additional areas to consider include;

- Estimating the demand response (load reduction) potential from hot water systems by combining the demand estimates with an estimate of the fraction of the demand that could be reduced, for example through set-point adjustments. This has been addressed previously only for air-conditioning [1], although those estimates were based on overseas data. Short term demand response from pool pumps is likely to involve a 100% demand reduction given the minimal loss of amenity from short term interruption.
- Estimating the demand increase that could be achieve from storage hot water systems at times of minimum demand via set-point temperature increases.

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