The Innovation Hub

for Affordable Heating and Cooling

Report #LLHC3-2

Healthcare Living Laboratories: Fernhill Residential Aged Care – Baseline Data

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QUEENSLAND UNIVERSITY OF TECHNOLOGY

About i-Hub

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

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

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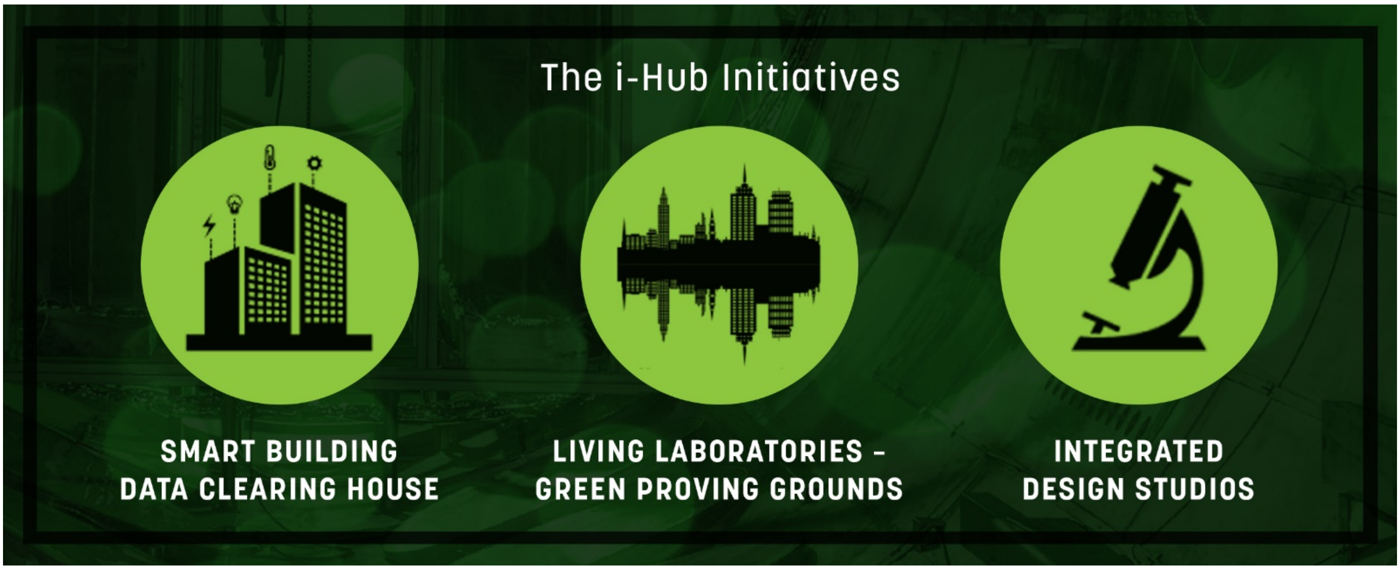

Healthcare Living Laboratories: Fernhill Residential Aged Care – Baseline Data

The Living Laboratory at Fernhill Residential Aged Care (Fernhill) will support the aged care sector to transition to a net-zero energy/demand future. In particular it will validate the impact of emerging technologies in demand reduction, demand management, renewable energy and enabling technologies, in terms of core health services (patient and worker health and comfort), building maintenance and operations, environmental impact and financial management (including participation in energy markets). An estimated 30% reduction in energy/demand (from sector wide baselines) can be achieved through the incorporation new technologies relating to HVAC efficiencies and control, demand management, grid interoperability and renewable energy into aged care policies, plans, operating manuals and procurement processes. It will not only test innovative technologies and processes but will also evaluate the usefulness of new key performance indicators (KPIs) and metrics that link energy performance (especially peak demand, renewable energy and resilience) to core health services.

This report records baseline energy data for the Fernhill precinct.

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Queensland University of Technology (QUT)

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FERNHILL RESIDENTIAL AGED CARE - BASELINE DATA

This report includes baseline energy performance data for the Fernhill Residential Aged Care facility in Caboolture. After providing a brief international and national context, it reports historical energy use from the existing buildings (hostels and nursing home) plus expected energy use of a new building (a multi-storey modern residential aged care facility that replaces the existing buildings).

1 INTRODUCTION

The Australian government estimates that 80% of older people will access some form of government funded aged care services before death. In 2015-16 government expenditure in this sector was $12.9 billion, approximately 75% of the total sector expenditure. Sector-wide energy consumption is dominated by space heating and cooling, hot water services and lighting (at least 65% of total energy consumption). Power (kW) and energy (kWh) are strongly correlated to outside temperature, which accounts for 80% of variation in electricity consumption. These weather-induced impacts increase with extreme temperatures.

Energy consumption benchmarks typically relate to occupancy levels (e.g. number of beds), although there is much variation across sites. There is a need to develop more nuanced KPIs that incorporate the impacts of outdoor environmental conditions, changing society expectations of service levels with residential aged care (RAC), electricity network operations and market conditions. In particular there is a need to understand daily and seasonal energy demand profiles of different services within RAC and the impact these have on energy costs (for the facility), the local grid, the national electricity grid, and greenhouse gas emissions. Greater understanding in these areas can help drive investment decisions by aged care and retirement living providers and innovation diffusion by technology providers.

1.1 Aged care accommodation

A Residential Aged Care (RAC) facility in Australia is defined as facilities that cater to the needs of older persons who have low to high level of care needs, including lower levels of mobility and independence. Unlike retirement villages (housing states for predominantly healthy, mobile and independent people aged 55 and over), the number of type of services provided to residents is high, for example scheduled meal times and 24 h nursing on call. Occupants in RAC facilities tend to have higher average age, more health care needs and lower levels of personal mobility compared to retirement villages. RAC facilities are strongly regulated by national laws, in terms of occupancy and associated charges.

Within the RAC sector, there are perhaps four common ‘models’ of accommodation, reflecting different levels of resident health care autonomy and needs, and different cultural expectations of service levels, as shown in Table 1-1. Each of these accommodation models are within a precinct that offers other services such as communal facilities (for dining and recreation), medical and other services (e.g. pharmacy, allied health, hairdressing, café), and administration type services (offices, facilities management). Energy performance of aged care facilities tends to be reported on energy use (kWh) per bed, however this key performance indicator (KPI)does not reflect the different accommodation models nor the variety of services offered by each facility. It is therefore inadvisable to use this KPI for benchmarking and comparison purposes.

Table 1-1 RAC models of accommodation in Australia

Accommodation Model	Description
Independent Living Units (ILU)	Apartments or duplexes that are fully self-sufficient. These may be studio units or have 1-3 bedrooms and are typically occupied by a single elderly person or a couple. They can elect the level of care that they require. Supported Living Units (SLUs) are somewhat similar, but with residents requiring more home assistance (i.e. perhaps an occupant's stage between full independence and full dependence.
Hostels	"Share homes" with independent bedrooms, and shared common spaces. Bathrooms may be ensuite or shared. Each hostel has a low number of residents (e.g. about 10).
Nursing Home	Old style, 'hospital ward' like buildings
Multi-storey 'modern' residential aged care	"Resort style" accommodation where each resident has their own room and ensuite. A variety of shared facilities (e.g. dining, lounge, recreation etc) is provided (similar to a holiday resort). Full nursing care is also be provided.

There are trends in aged care that will likely impact on energy productivity. One trend is the policy direction of "Aging in Place", a policy that aims to keep aging Australians at home for as long as possible, providing the appropriate level of health and personal services in their own homes. This means that Residential Aged Care facilities will increasingly become places for the very infirm, those who can no longer be supported at home. This may increase the energy intensity of such facilities.

Community expectations regarding the level of care provided in old age are also changing. Older modes of RAC accommodation, such as nursing homes and hostels, are generally no longer considered appropriate. The push is for more 'home-like' options, such as independent living units similar to the general market apartments, or high-rise 'advanced care' options similar to that being constructed at Fernhill (i.e. private rooms with ensuites, but within a facility that has a range of community services as well as full medical services).

1.2 Energy use in Aged Care - Internationally

There are very few detailed datasets published about energy use in residential aged care facilities. There is a plethora of publications about Aged Care, but these are predominantly focused on care service provision. Some literature discusses the indoor environment from a thermal comfort perspective, but this literature typically does not discuss the energy issues. Countries with ageing populations and increased service demands from that demographic are seeing increased financial pressures on providing appropriate levels of care services. Reducing overheads, such as through energy efficiency and renewable energy, are ways in which budgetary pressures can theoretically be reduced. Achieving this in a cost effective and systematic way, however, requires better understanding of how and when aged care facilities use energy. Reports from the UK, EU and Japan are described in this section.

The UK's Carbon Trust estimates that the largest proportion of energy use in primary healthcare is attributable to space heating (70%), as shown in Figure 1-1.

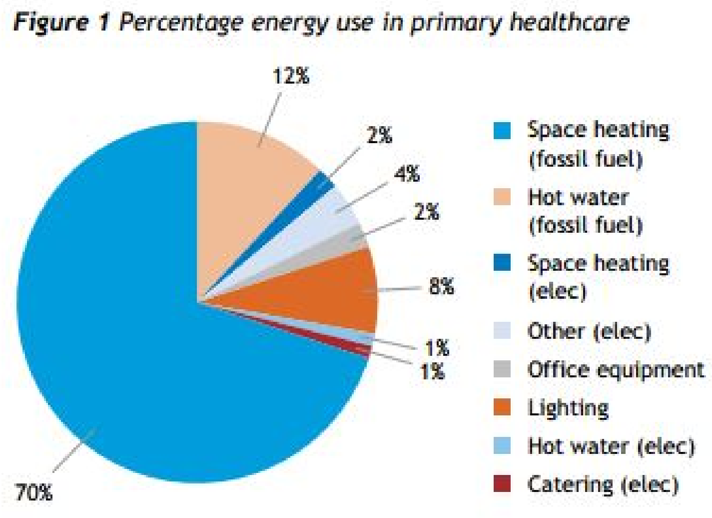

Figure 1-1 Energy use percentages in primate healthcare

Scotland has approximately 1300 care homes, with 916 homes for elderly people who require full time care due to age related health issues (so equivalent to Australia's residential aged care). These facilities are owned and operated by either private companies or local authorities. Care homes, similar to all buildings in the UK, are required by law to provide energy performance certificates (EPCs) indicating the energy 'efficiency' of the building envelope and fixed services. The typical U-values of building envelope elements is shown in Figure 1-2. About 40% of the energy demand for care homes is for space and water heating.

Type of element	Area weighted average U-value for all elements of the same type (W/m²K)	Individual element U-value (W/m²K)
Wall	0.27	0.7
Floor	0.22	0.7
Roof	0.2	0.35
Windows/doors, roof windows and roof lights	2	3.3

Figure 1-2 Typical U-values of building areas in Scotland[1]

The EU's Save Age project[2] analysed the energy consumption patterns and energy efficiency measures of 100 residential care homes in 10 countries. It was the EU's first move to establish energy benchmarks for Residential Care Homes for Elderly People (RCHEP). The project involved the collection and analysis of a range of data from each facility:

- Three continuous years of monthly energy use data (2007 – 2010)
- All energy sources (electricity, natural gas, district heating, biomass and fuel)
- Climatic conditions: heating degree days (HDD 15 °C) and cooling degree days (CDD 20°C)
- Building envelope characteristics (based on year of construction and/or retrofit)
- Floor area
- Number of residents
- Number of staff

All energy data were converted into a common unit (kWh). Heating (space heating and water heating) was the major energy user. All facilities had central heating systems, of different types and running on different energy sources (refer to Table 1-2). Winter set points ranged from 15 °C in Italy to 26 °C in Greece. The control of set points was usually managed centrally, by staff. Few facilities enabled individual control over indoor air temperature.

Space heating accounted for >50% of total energy use in Spain, Italy, Greece, France and Czech Republic, and 40-45% in the other countries. Apart from climatic differences, space heating was considered to be impacted by the building envelope (e.g. the level of insulation and air tightness), set point temperatures, types of controls, and occupant habits. Space cooling (air conditioning) was not common in all countries. Where it was provided, it was typically applied to common areas only.

[1] Resource Efficient Scotland, Resource Efficiency Guide: Care Homes| 2, (n.d.). https://www.resourceefficientscotland.com/sites/default/files/downloadable-files/Resource Efficiency Guide_Care Homes_FINAL.pdf.

[2] SAVE AGE: A Project on Energy and Cost Reduction in Care Homes for the Elderly, (n.d.). http://www.saveage.eu/.

Table 1-2 Energy sources used for space heating in EU care homes

Country	Electricity	Natural Gas	District Heating	Biomass	Fuel
Czech Republic		X	X		
Germany		X	X		
France		X		X	
Greece	X	X		X	X
Italy	X	X			X
Netherlands		X			
Portugal	X	X			X
Slovenia		X	X		X
Spain	X	X			X
Sweden	X	X	X		X

Space heating consumption in the RCHEP project used two different Energy Use Intensity (EUI) metrics: heating kWh per m2 and per resident (per year). The baseline was given by the average consumption in the summer months (June, July, August), and the heating energy calculated from disaggregation of metered energy data.

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Energy sources for water heating also varied, as shown in Table 1-3. This shows wide use of solar thermal and natural gas, and no use of district heating or biomass.

Table 1-3 Energy sources used for water heating in EU care homes

Country	Electricity	Natural Gas	District Heating	Biomass	Fuel	Solar thermal	PV
Czech Republic	X	X				X	
Germany		X				X	
France	X	X				X	X
Greece					X	X	
Italy		X				X	
Netherlands		X				X	
Portugal	X	X			X	X	
Slovenia	X	X			X	X	
Spain	X	X			X	X	
Sweden	No information available						

The research team used a multivariate linear-regression model approach to correlate EUI with factors that may influence the energy consumption of a building. The variables included HDD, number of residents, number of employees, year of construction and year of retrofit. Occupant variables such as behaviour, awareness and maintenance practices were not included, as they were considered too difficult to quantify or evaluate. The data were then used to provide benchmarks specific to each facility, and to compare each facility's benchmarks to their actual performance. Four key performance indicators (KPIs) were used to report results. The mean values and the range of values for each of the KPIs are shown in Table 1-4.

Table 1-4 Energy KPI results for EU care homes

KPI	Metric	Mean value	Range (min / max)
EUI1	kWh/m²/yr	252	46 to 551
EUI2	kWh/resident/yr	11711	2215 to 36349
EUI3	kWh heating/m²/yr	129	To 333
EUI4	kWh heating/resident/yr	6109	To 20556

Two Japanese studies [3,4] have sought to quantify energy and water use in nursing homes in order to develop fundamental design data to inform the enhancement of facilities and equipment to improve quality of life of the residents. The two nursing homes studied had an occupant capacity of 51 and 77 respectively, and each had dining rooms, recreation rooms, bathrooms, private rooms and laundries. The studies focused on understanding seasonal, daily and hourly consumption patterns for hot and cold water. The average daily water use for each facility did not vary significantly between summer and winter, but the amount of energy used to heat the water did (refer to Table 1-5). These researchers also found that the purpose of hot water usage changed seasonally (e.g. the ratio of use between the kitchen and the bathing room). Their research demonstrated that, for this cultural context, energy use (for water heating) in nursing homes is dependent on both the type of equipment used for bathing, and the bathing style of elderly people.

Table 1-5 Hot water energy use in 2 Japanese nursing homes

Nursing Home	Hot water energy source	Hot water type	Water heating energy
Facility 1	Electricity and LPG	Heat storage with heat pump	2640.65 MJ/d winter 1972.86 MJ/d summer
Facility 2	Electricity and LPG	Boiler and storage tank	2860.08 MJ/d winter 1011.74 MJ/d summer

1.3 Energy use in Aged Care – Australia

The 2014 NSW government Energy Saver Aged Care Toolkit[5] discusses the findings of 15 energy audits in NSW aged care facilities. Major energy uses are noted along with potential energy saving measures to address specific energy loads. The report does not offer any specific values for benchmarking. Most of the values presented in this report are allocations of total use, rather than

[3] N. Daisaku, M. Saburo, T. Hiroshi, I. Takanori, A Study on the Water and Energy Consumption in Nursing Homes for the Elderly, (n.d.) 3–14. http://www.irbnet.de/daten/iconda/CIB6835.pdf.

[4] S.M. Daisaku, Nishina, A Study on the Water and Energy Consumption of the Bathrooms in a Nursing Home for the Aged, CIB W062 36th International Symposium. (2010) 71–80. https://doi.org/10.1177/014362449902000306.

[5] New South Wales Department of Environment and Heritage, Aged-care toolkit, (2014) 36.

energy use per bed[day]. The report shows total energy use, then electricity and gas proportions. Figure 1-3 shows a typical data representation, in this case for electricity.

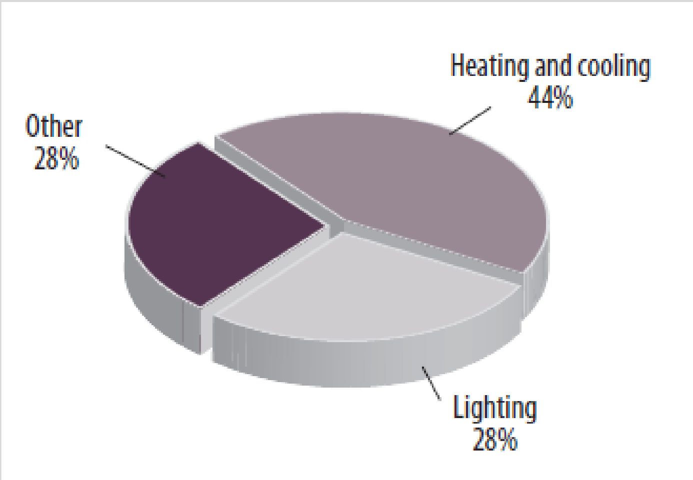

Figure 1-3 NSW Energy Toolkit allocation of electricity end use

This report discusses energy cost as well as energy consumption. This is particularly important as this section includes references to network related costs. Many energy efficiency programs only consider energy use reduction (kWh), not power (kW). This may be because in many jurisdictions, particularly abroad, there is no kW demand charge.

Table 1-6 shows a summary of the key variables recorded for audited sites. These parameters are related to energy and give an indication of the variation in the physical size of the sites. The value's precise nature suggests a detailed raw data set was collected for each site as part of the audit process. Pooling ranges of data prevents assessment of energy performance of any individual site, and therefore comparison between the audited sites and any others. It is not clear why the data are presented in this manner. This format significantly reduces the potential effectiveness as a benchmark against which to compare future findings. The discussion related to facility benchmarking does not offer any energy values, instead introduces 'degree cooling days' (CDD). While this importantly recognises the relationship between energy use and outdoor weather conditions, there is no discussion on how this may be applied.

Table 1-6 Site characteristic – range of results (adapted from Table 2.1[6])

Variable	Range: Lower - Upper	Units
Gross floor area	3,100 - 11,764	m^2
Number of beds	40 - 180	Beds
Occupancy	56 - 100	Percent
Annual electricity consumption	291 – 1,482	MWh
Annual gas consumption	66 - 3,507	GJ

[6] New South Wales Department of Environment and Heritage, Aged-care toolkit, (2014) 36.

The NSW Energy Saver Toolkit offers several variables against which energy could be benchmarked and the level of correlation. As seen in Table 1-7, occupied bed days is the most closely aligned, however the report does not give any indication of typical 'per bed day' energy values against which another facility can be compared.

Table 1-7 Benchmark variable correlation, data recreated from NSW toolkit.

Variable	Regression analysis results (degree of correlation %)
Annual occupied bed days	74%
Number of beds	52%
Gross floor area	28%
Age of facility	No correlation

Table 1-8 shows a typical high level of ambiguity of information presented. Energy values are presented with no time parameters (e.g. are the figures related to annual energy use) or bed numbers. There is no way to reference these energy values to any other information, such as the 'kWh/bed/day' values shown in Figure 1-4.

Table 1-8 Energy values shown in energy saver toolkit[7]

End Use	GJ per bed	kWh per bed
Hot water and drying	14	50
Heating and cooling	11	40
Lighting	7	25
Total		115

This report, while presenting some potentially useful information, highlights the need for clarity and consistency in the selection of KPIs and in the presentation of data. It is important to clearly articulate whether the KPIs are to allow for benchmarking across the sector or are intended for benchmarking within a specific facility.

The Sustainable Living Tasmania (SLT) report[8] [29] discusses the findings of nine 'Level 2' energy audits in Tasmanian aged care facilities. Sites are anonymised, however energy consumption and cost data are presented with consistent identification codes throughout the report. Figure 1-4 shows data collected and processed into 'per bed per day' energy values.

[7] Data from Figure 3.1 in NSW Energy Saver Toolkit

[8] A. Vikstrom, R. Boyle, S. Harkness, J. Hargraves, A. McKinnon, Summary of Energy Audits (Level 2) – Aged Care Facilities, 7000 (2015) 1–15.

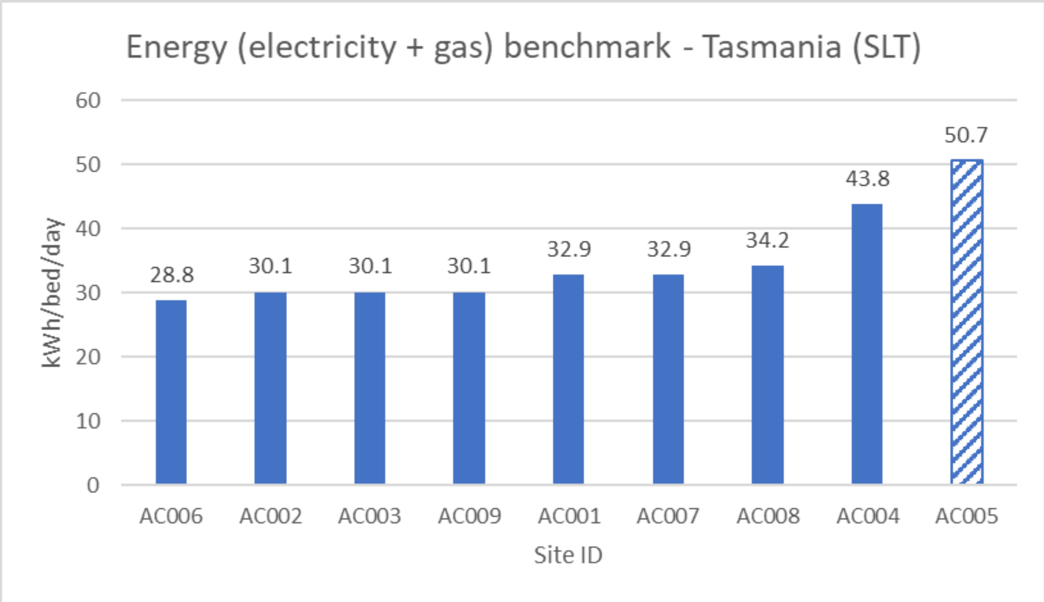

Figure 1-4 Benchmarking values for 9 sites (Sustainable Living Tasmania Energy Audit)

The report naming convention has been transferred to Figure 1-4. Both electricity and gas are combined, using the common unit kWh. Individual energy sources for each site were not presented in the report summary. All sites, with the exception of AC005, have kitchen and laundry facilities. AC005 is recorded as having a swimming pool. Although not specifically noted in the report, it is not uncommon for facilities to share, or even outsource services such as kitchens (cook chill vs cook fresh) or laundries.

Tariffs discussed in this report generally relate only to energy use (kWh), not power (kW). Only one tariff has a kVA demand charge listed. Seven different electricity tariffs were summarised as being used at audited sites. Direct tariff comparison is noted as being notoriously difficult as low unit energy charges may be offset by higher network or equipment maintenance costs. Figure 1-5 shows the variation between the audited sites. No explanation was offered in the report to account for this variation. On several occasions in both audit reports, there can be mismatches between the same data. In this case, the minimum value of ~29kWh is higher than 24kWh quoted elsewhere in the same report. Figure 1-5 shows that bed numbers, and therefore size of the site, does not appear to have a strong underlying relationship to energy use per resident. This aligns with the NSW government findings as shown in Table 1-7.

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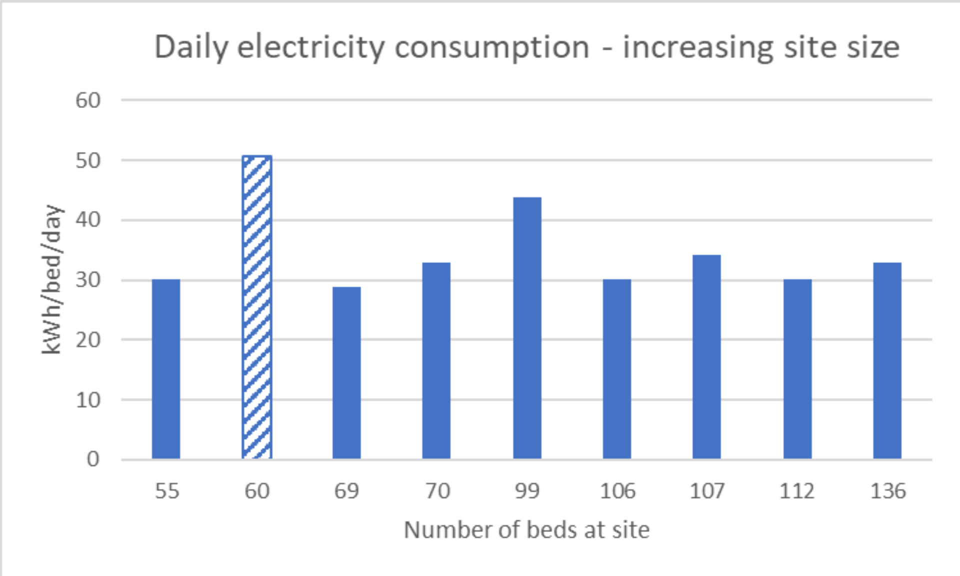


Figure 1-5 Electricity consumption by bed numbers

1.4 Bolton Clark

Bolton Clarke is an Australian provider of aged care services predominantly in the form of retirement living communities, Residential Aged Care (all four models of accommodation) as well as Home Care visits. The company owns and operates facilities throughout Australia, with expanding offshore interests in New Zealand, the United Kingdom and China. The Australian residential facilities are predominantly located in Queensland, with a presence in most other states. The 2019 annual report indicates Bolton Clarke cared for over 3,400 residents across 25 Residential Aged Care facilities, and around 2,500 residents chose to live in 25 retirement living communities. Additionally, there were also over 3.9 million home care visits for over 52,000 clients. The company's expansion plans discussed in 2019 include 450 new retirement living units and 825 residential aged care beds, predominantly around south-east Queensland.

The Living Lab at their Fernhill site will not only enable the testing of innovative technologies and processes, but it will also 'test' the potential usefulness of new key performance indicators (KPIs) and metrics that link energy performance (especially peak demand, renewable energy and resilience) to core health services (e.g. indoor environment quality, resident health, staff satisfaction). Outputs from this Living Lab will feed into the iHUB's Healthcare Sector Wide project (LLHC1).

2 SITE DESCRIPTION

Fernhill is a residential aged care facility (RAC) and retirement village (RV) on freehold property located at Caboolture, approximately 42 kilometers north of Brisbane's CBD. The RAC on the 6.6 hectare site consists of a 50-bed nursing home (twin and triple share rooms with shared bathrooms) and eight hostel cottages containing 114 single ensuite bedrooms (including 28 intensive care rooms). The site was earmarked for development because the spread-out nature of the hostel accommodation did not permit efficient staffing or facilitate the best possible level of care, and the shared bed wards and bathrooms of the nursing home did not meet the company's standards or community expectations. The Retirement Village comprises 87 independent living units.

The first stage of a multi-staged site development plan will see the construction of a new 162 bed 5-level RAC with communal facilities, allied health spaces, landscaped outdoor activity spaces and basement care parking. Once completed (August 2020), the existing nursing home will be demolished. The new RAC will be an i-Hub Living Laboratory.

More details about this site can be found in the Fernhill Residential Aged Care Living Lab Prospectus and Manual.

3 SITE BASELINE ENERGY DATA

3.1 Current energy use at Fernhill

Figure 3-1 shows the average daily energy use, per month, throughout 2016 at the current Fernhill site. As site daily activities are similar throughout the year, monthly variations can be attributed largely to air-conditioning loads in line with seasonal temperature variations.

Figure 3-2 shows several years of data, allowing patterns to be seen, such as the seasonality of the monthly average of daily energy use profiles. The main differences between years is during the late summer months, likely due to weather patterns. The winter months consistently show lower daily consumption, which is likely due to reduced air-conditioning loads during these cooler months. Note that the data ceased in September 2018 – when the site electricity connection to the mains was re-configured to enable deconstruction and construction work.

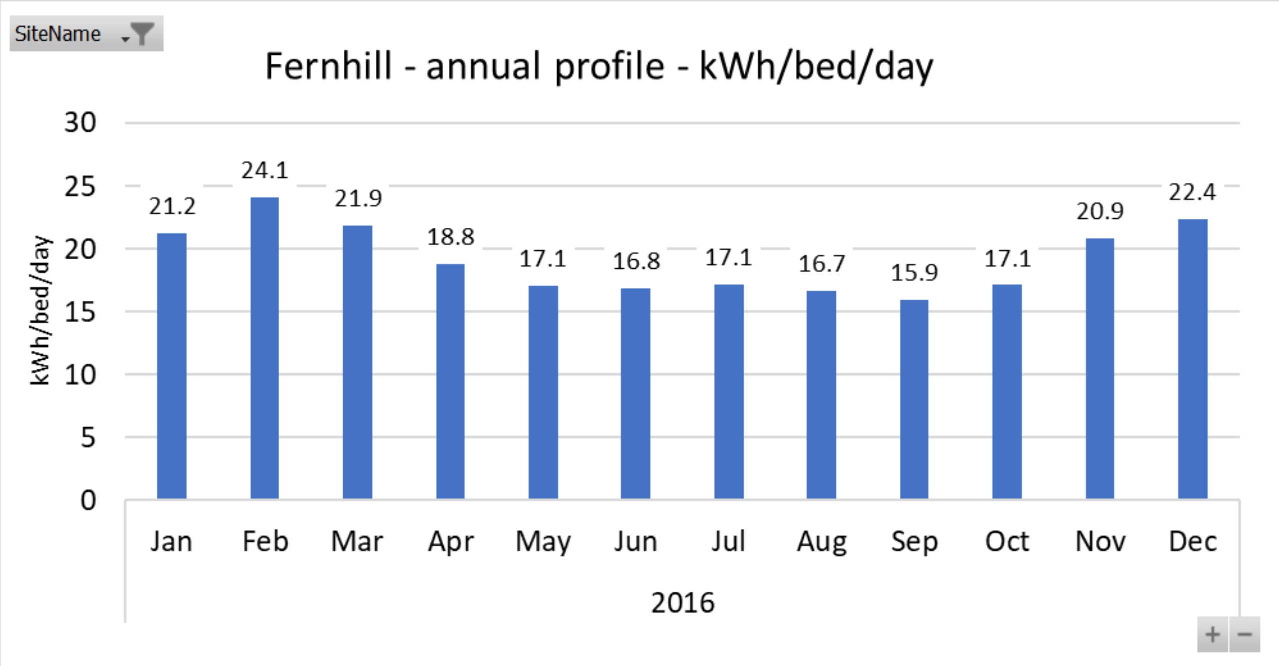


Figure 3-1 Fernhill energy consumption by month (2015-16 data)

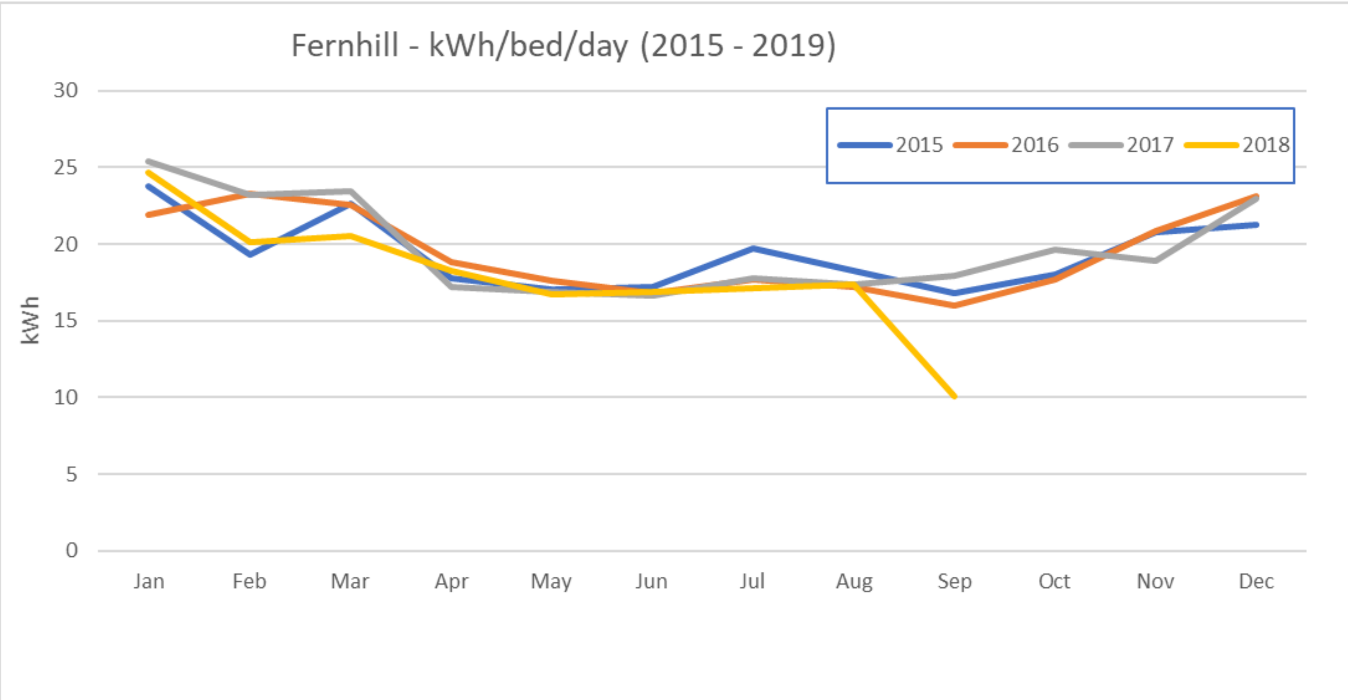


Figure 3-2 Daily per bed electricity readings by month 2015 – 2019, Fernhill Living Labs site

The average daily energy use profiles, however, are not granular enough to determine when the peaks occur. When considering peak demand, time of day is an important consideration for both load identification and assessing the potential suitability of renewable energy input. Figure 3-3 and Figure 3-4 show the daily profile for the 2018 summer and winter days which incurred the peak demand charge. The summer peak likely coincides with the hottest part of the day, and possibly lunchtime kitchen activity.

The typical summertime peak, not surprisingly, occurs during the time of highest heat load. This peak, or load levels near the peak, are maintained for several hours. The significance of this is to appreciate that interventions (embedded generation / storage or load shedding) should be designed to have enough capacity to meet both power (kW) and energy (kWh) requirements to meet a peak reduction target.

The peak winter event day shows the peak occurs early in the morning. Similar seasonal variations to those shown above are noted in the NSW government report. Acknowledging the variation in time of the peak event leads to acknowledging different solutions for renewable energy integration may be needed seasonally. The shorter peak duration, compared to the summer peak, is also of interest.

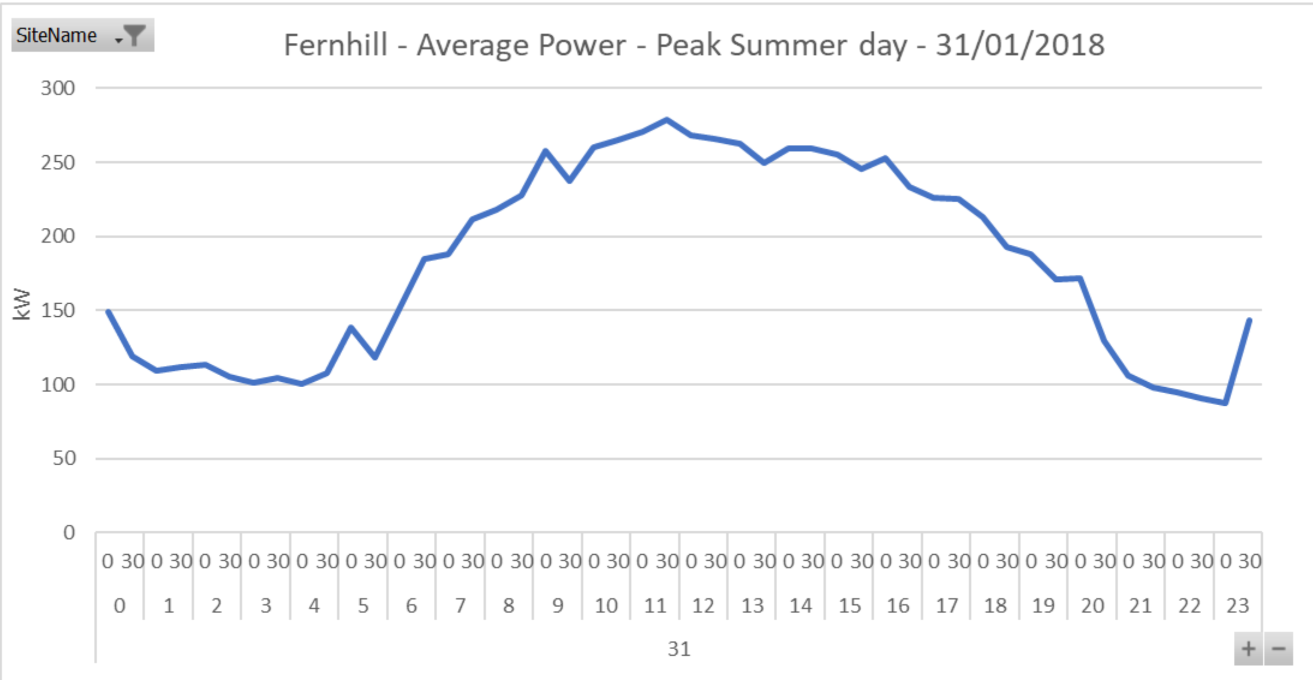


Figure 3-3 Fernhill summer daily electricity profile

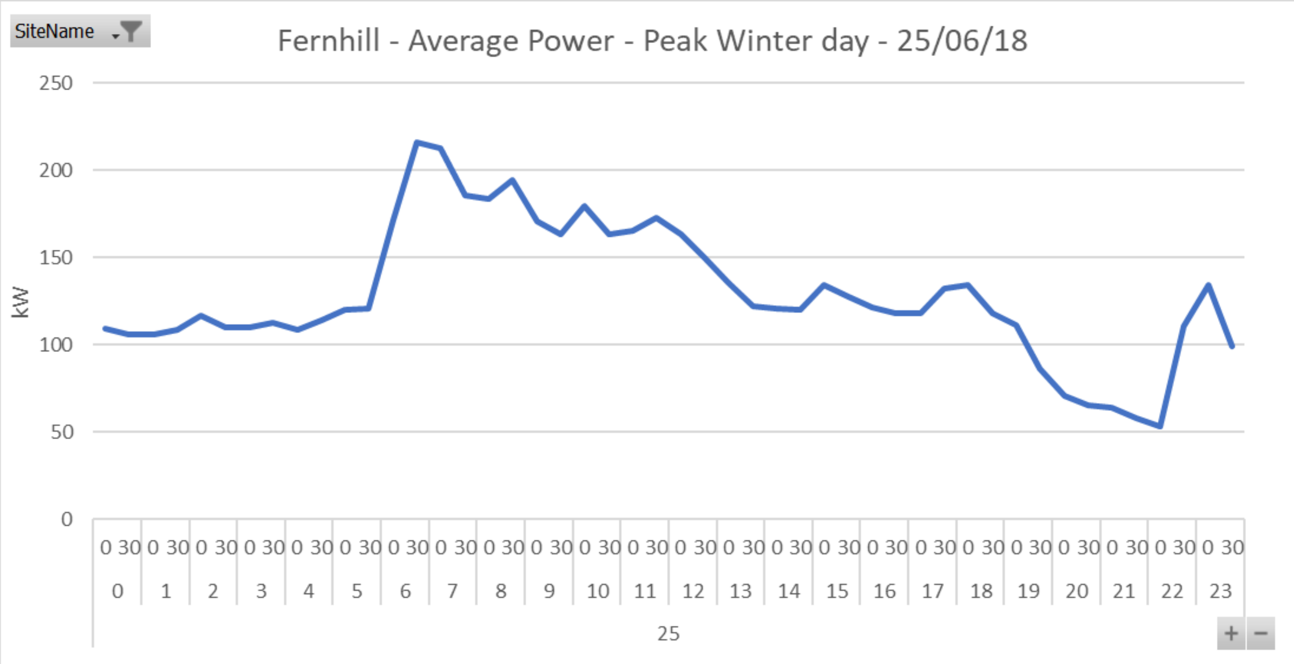


Figure 3-4 Fernhill winter daily electricity profile

Figure 3-5 and Figure 3-6 compares temperature to energy use patterns of years 2019 and 2020. The graphs show that energy use follows temperature patterns, indicating that the majority of energy consumption is for heating and cooling purposes. Energy use in summer is almost the double of energy use in winter. Energy use drops during winter when external temperature is between 15 to 20 degrees, it however rises when the temperature dops below 15 degrees. This highlights that reliance on air-conditioning during winter is less than in summer despite having temperature below the comfort threshold.

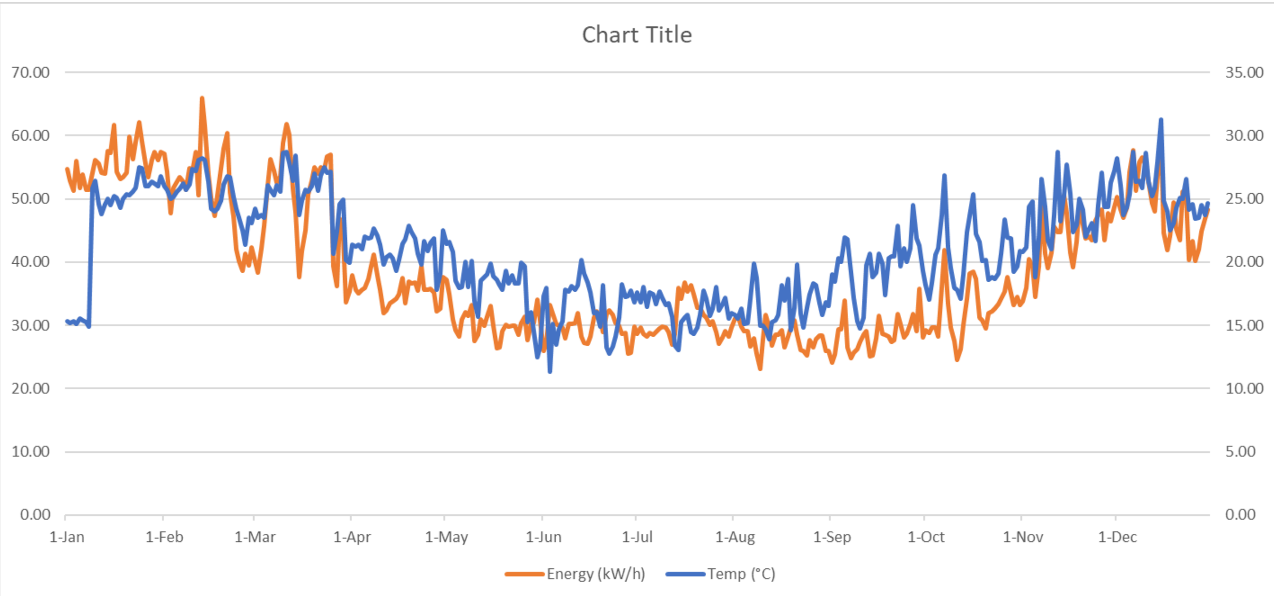


Figure 3-5 Daily temperature vs Energy use 2019

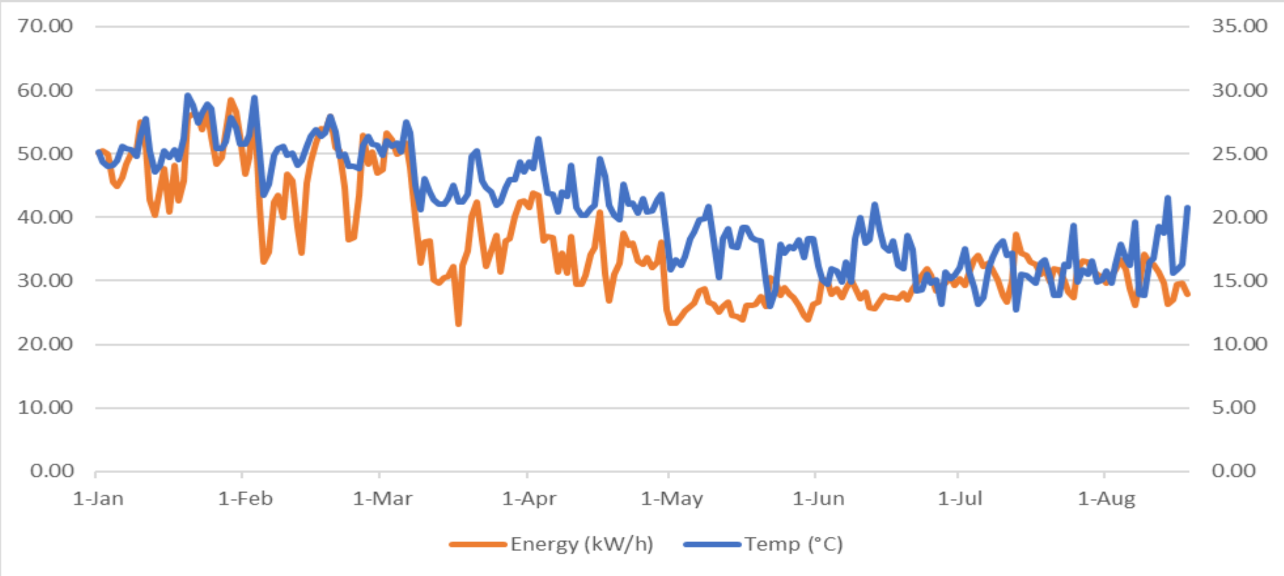


Figure 3-6 Daily temperature vs energy use for 2020

The impact of external temperature on energy use is supported by the significant correlation coefficient shown in Table 3-1 . The significant correlation across years 2015 to 2020 also shows that construction activities at Fernhill in 2019-2020 had a minor impact on the energy use.

Table 3-1 Correlation between temperature and energy use

	2020	2019	2018	2017	2016	2015
Pearson CC	0.827	0.779	0.82	0.779	0.887	0.852

There is no detailed sub-metering data available for this site. Analysed sub-metering data from other Bolton Clarke RAC facilities are reported in the i-Hub's Healthcare Sector Baseline and KPI report. That analysis sought to understand what services contributed to energy use and power loads, the profile of those services, and who had control of those services.

3.2 Current Key Performance Indicators (KPIs)

The most utilised EUI KPI is kWh/bed/year. This KPI is effective in that the data required to report on this KPI are relatively easily gained. However, as demonstrated in the case studies presented in the previous sections, such a KPI has limited usefulness as an industry benchmark and does not enable detailed evaluation of the energy efficiency of the site and its systems and services. It also doesn't allow for evaluation of energy uses that contribute to peak demand, nor analysis of options for renewable energy and energy storage solutions.

The Healthcare Living Lab projects will investigate the feasibility and usefulness of additional KPIs that could be useful for enhancing the energy productivity and renewable energy potential for RAC facilities. As the main energy use in RAC facilities is space heating and cooling, a focus will be on

KPIs that address cooling energy loads, peak demand and renewable energy and/or energy storage potential.

3.3 Current Building Envelope Properties

The building envelope performance was tested through comparing external to internal temperature for a 40 hour period in September 2020. Rooms 405, 406, and 408 were tested through putting out temperature sensors in the middle of all rooms and in the balcony of room 405 (Figure 3-7). Rooms 405 and 408 are corner rooms facing North/east and north/west respectively, with glazing on both orientations, therefore they are more effected by solar heat gain and by heat conduction in general since the façade to floor ratio is larger than room 406.

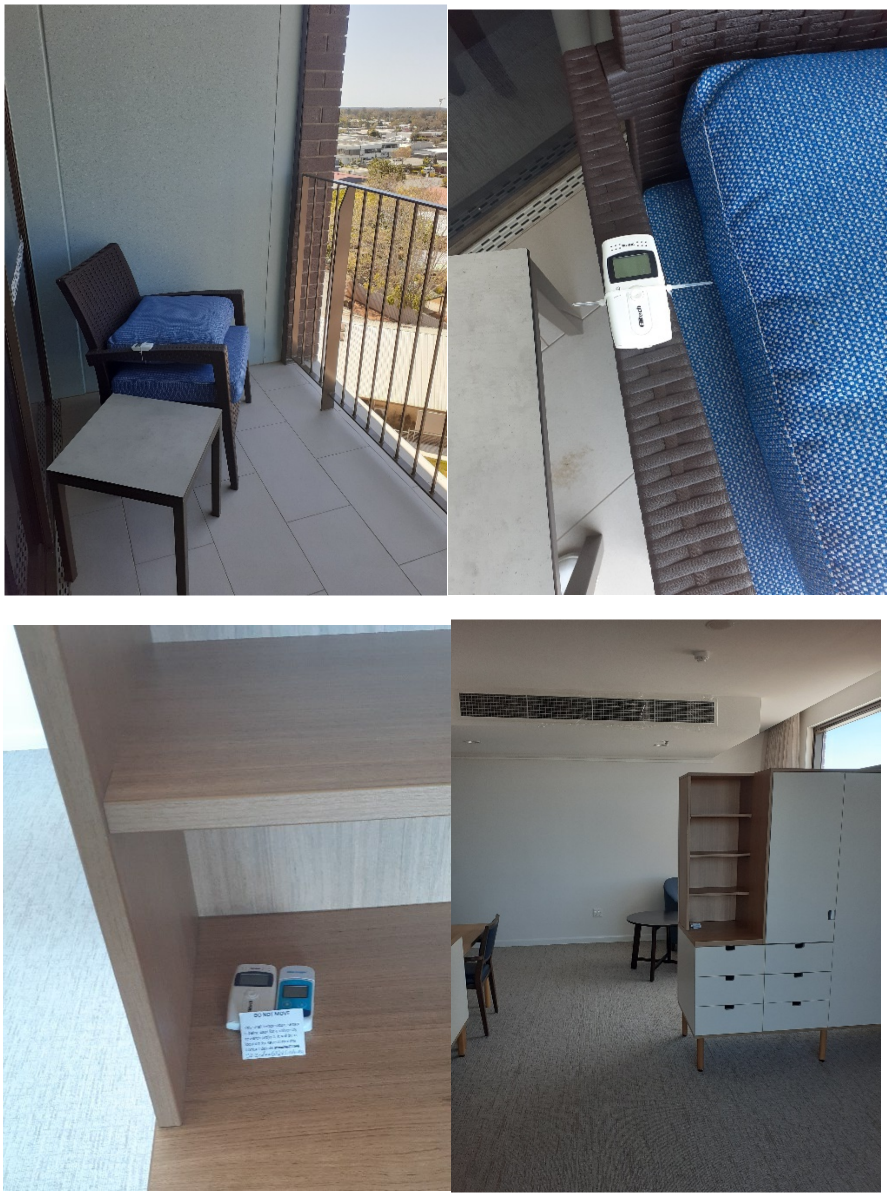


Figure 3-7 Locations of sensors

The rooms are located on top level, therefore they are more exposed to external conditions than the typical rooms on lower levels. Room 406 is facing north with one external wall and one window facing north (Figure 3-8). Data was collected every 30 minutes for around 40 hours, after the HVAC was turned off for the whole floor.

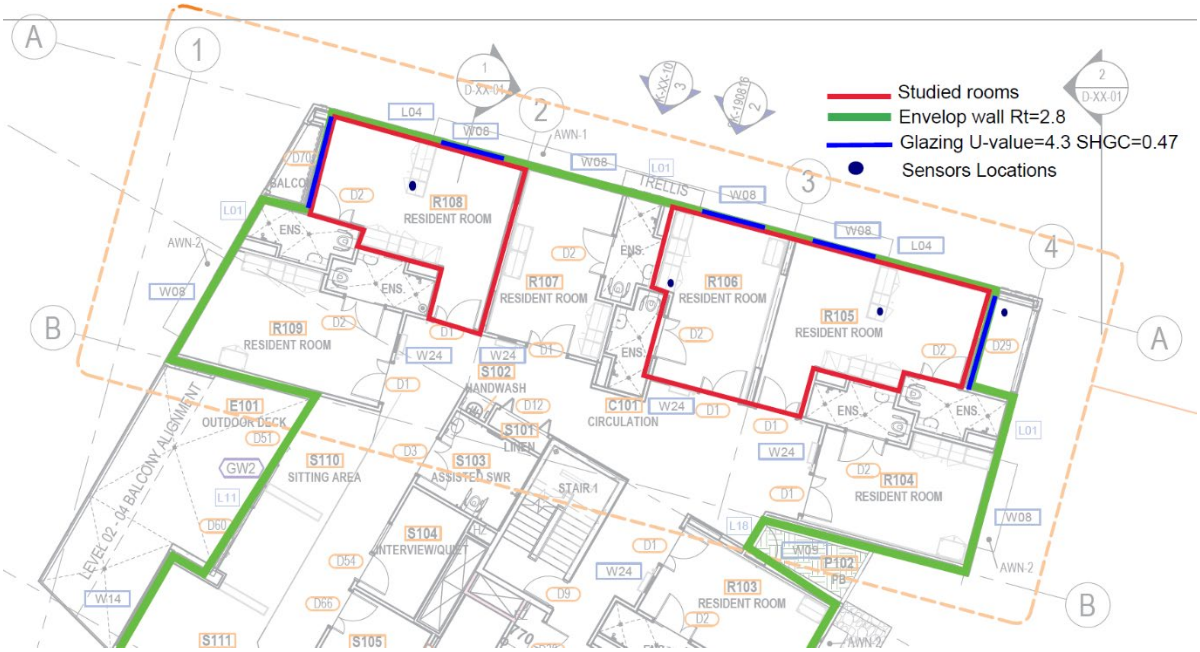


Figure 3-8 Studied Rooms

Figure 3-9 shows that the room internal temperature is mostly stable which indicates good insulation. The envelope performs better in colder weather and during night time with a total difference between internal and external temperature reaching 10.9 degrees just before sunrise. The internal/external temperature difference drops to 1.8 at midday. Room 405 (facing east) shows higher rise in internal temperature than room 406 at sunrise (between 7 to 10 am), which suggests that room 405 has more solar heat gain through the eastern facing glazing. In contrast to room 405, room 408 (facing west) shows higher internal temperature during sunset (between 4-6 pm). The graph demonstrates that room 408 is the worst performing room and most likely the room to consume most energy for cooling purposes due to its orientation. Additional tests will include heat flux sensors on the walls and glass to identify their thermal resistance. Note that all external window shading is via horizonal awnings, regardless of orientation.

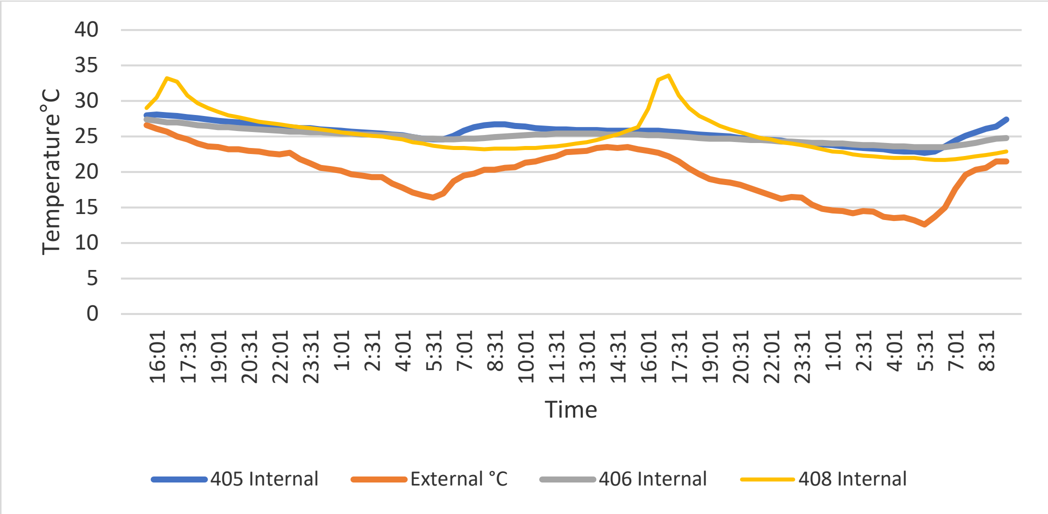


Figure 3-9 Comparing internal to external temperature

Figure 3-10 compares the 2 weeks external temperature data between rooms 405 and 408. The graph shows much higher external temperature at room 408, that reaches between 40 and 50 degrees, and occurred daily between 12:30 and 15:30 pm. This temperature difference could be attributed to the sun being directly on the dark surface which the sensor was fixed to (i.e. it is not a true reflection of the external ambient air temperature during this period).

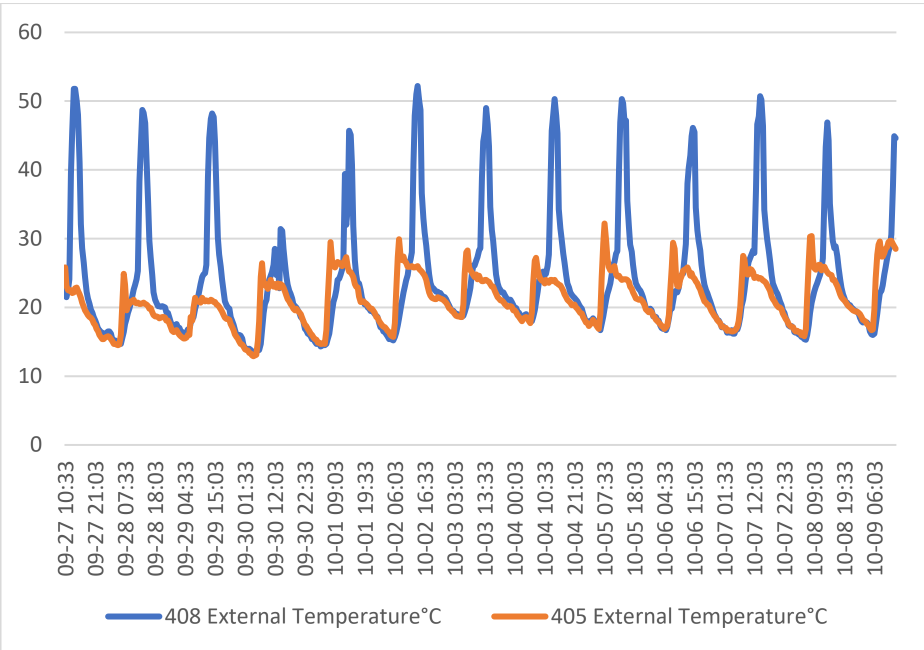


Figure 3-10 External temperature for rooms 405 and 408

Figure 3-11 shows Room 408 external vs internal temperature half hourly data for two weeks. The figure shows that there is about 10 degrees difference between the coldest internal and external temperature, and about 15 degrees between the hottest internal and external temperature. The graph shows that generally the building envelope helps protect the rooms from external weather conditions. However, Figure 3-12 shows that daily internal temperature of room 408 is above comfort threshold of 25 degrees for 9 hours (between 2:30 to 11:30 pm), and above 29 degrees for 2.5 hours (between 4:00 to 6:30 pm). The room temperature however does not fall below the comfort threshold of 21 degrees, which suggests that overheating of the room is due to high solar heat gain through large glazing on the north and west facades.

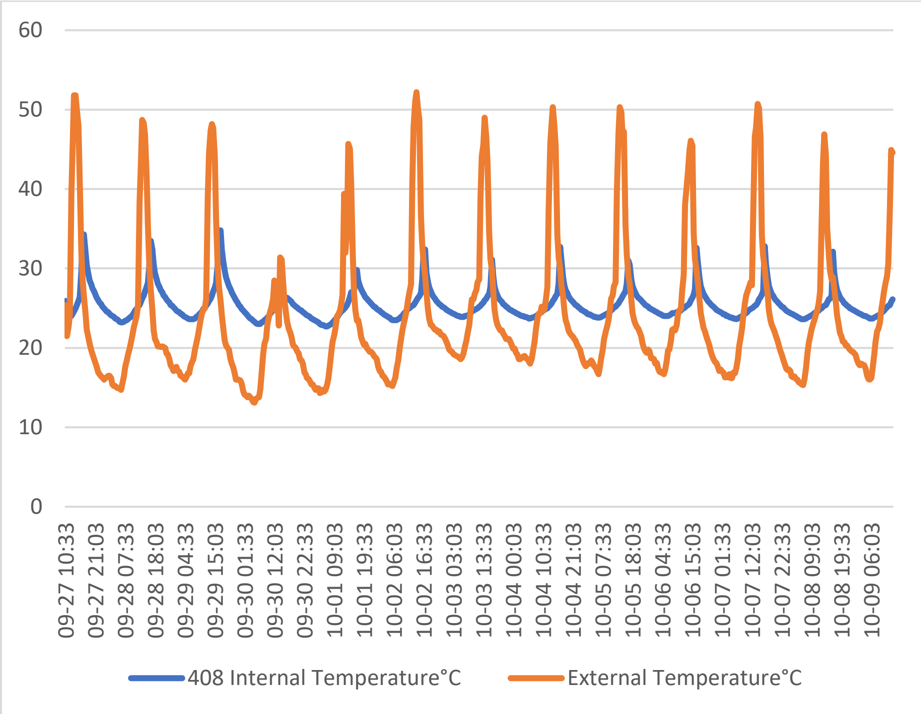


Figure 3-11 Room 308 internal vs external temperature

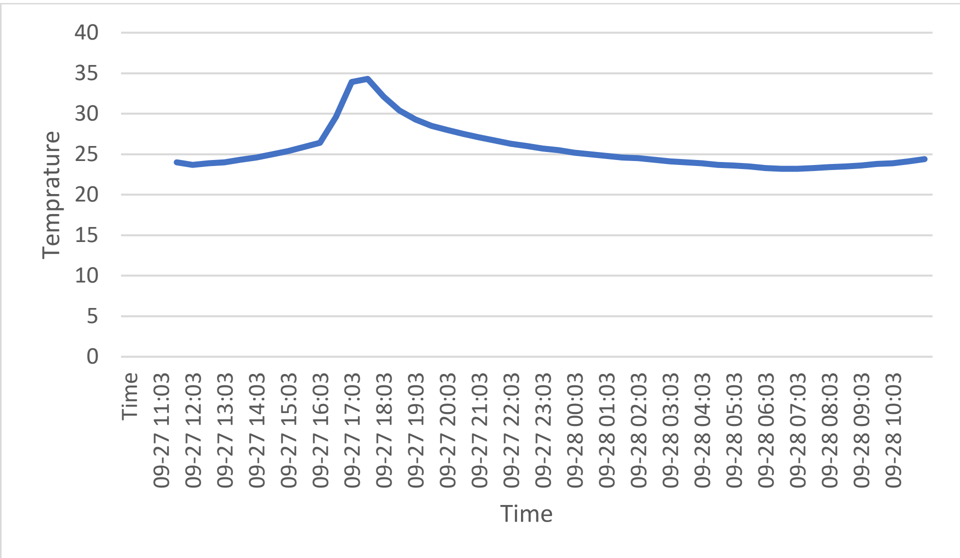


Figure 3-12 Room 408 daily internal temperature

3.4 Airtightness

Optimising the permeability of air through a building envelope has been shown to improve the energy efficiency and thermal comfort of sealed structures, and eliminate health issues resulting from condensation.

QUT engaged an airtightness ATTMA accredited professionals to conduct air tightness testing of the newly constructed building. The aim is to compare the actual air change rate of the building to the rate (1ACH.hr @ 50Pa) used in the JV3 energy efficiency modelling provided at the design stage. The actual air change rate can be used as a baseline to identify the effect of building sealing solutions on the overall permeability, energy efficiency and thermal comfort.

Originally it was planned for the whole building to be tested, however discussions with the builder showed that there is no feasible way of collectively sealing the on-floor exhaust system via damper isolation. Therefore, due to the large number (over 100 points) of exhausts/ header box systems, a decision has been made to conduct the test on one level only to be able to individually seal each exhaust fan (Figure 3-13) in a timely manner. This issue highlights the need for HVAC design that facilitates the possibility of airtightness testing, especially that it is now included in the National Construction Code. The test was conducted on level 4 (the top level) since it is likely the most prone to external air infiltration. The approximate envelope area for Level 4 is 6142 m^2

Figure 3-13 Sealing supply and exhaust

Methodology

In total six Retrotec fan units (Figure 3-14) were used in this project to achieve the necessary pressure differential, controlled by Retrotec digital controller gauges. Level 4 was pressurised from three locations. All locations were on fire escape doors and evenly spread over the floor (Figure 3-15).

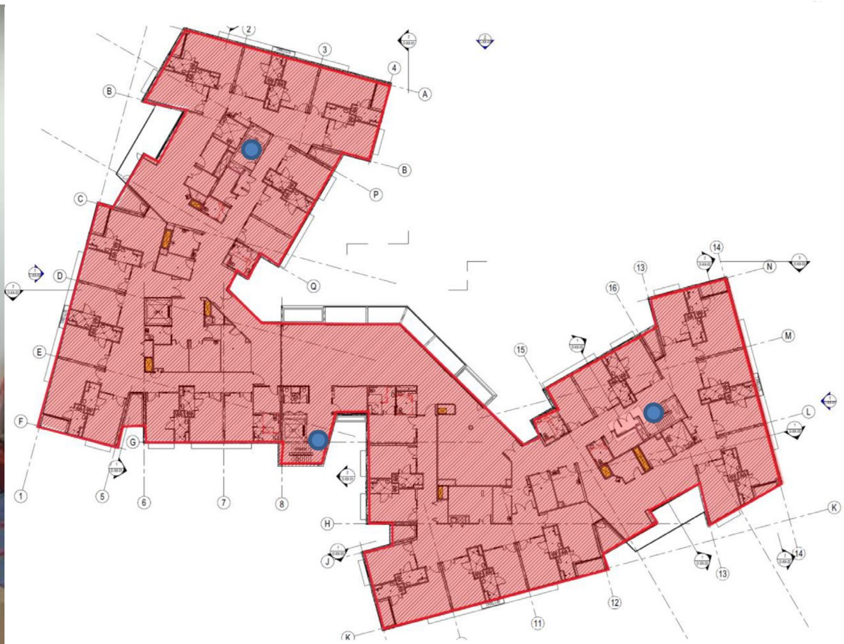


Figure 3-14 Blower door locations

Figure 3-15 Blower door setup

Each test space was prepared in general accordance with the AS/NZS ISO 9972:2015 Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method and ATTMA Technical Standard L2: Measuring Air Permeability of Building Envelopes (Non-Dwellings) (October, 2010) and summarised as follows:

- Test area: Select test area based on the air barrier and the conditioned space.
- All doors between internal areas left open.
- All external doors and lift doors closed but not artificially sealed.
- Openings to ‘permanently open uncontrolled natural ventilation’ temporarily sealed.
- Motorised smoke dampers closed.
- Building ventilation system serving the testing area shutdown during test. System artificially sealed.

Results

Fan speed was carefully adjusted incrementally up until the desired test pressure differential of approximately 30 Pa was achieved. The results have been summarised in Table 3-2.

Table 3-2 Air leakage test results for level 4

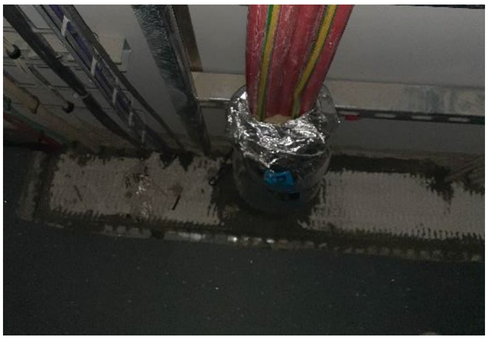
Location	Air flow rate m3/h @ 50Pa	Air leakage rate m3/h/m2 @ 50Pa	Equivalent Leakage Area m2	Air Change Rate m3/h/m3 @50pa	Correlation coefficient (R2)	Air flow exponent (n)
Level 4	83547.83	13.60	4.1666	9.85	0.9857	0.7315
Target	-		-	1	≥ 0.9800	0.5 to 1.0

Visual investigation of leakage points was undertaken during the site visit to determine where deficiencies in the façade were located. Minor Air leakage paths were observed, and were mostly located in the top and bottom of louver windows and between the sliding door panels (Figure 3-16).

Figure 3-16 Air leakage path in windows

Other leakage paths were observed in the ceiling space, however due to access limitations, the sizes/locations of the leakage areas above the ceiling were not identified. It was also not clear if the leakage is due to an opening to the roof or due to an unsealed shaft/riser connecting to lower levels. Other minor leakage paths included the lift shaft and garbage chute. Cable risers between levels were investigated using the smoke gun and found to be well sealed. Additionally smoke dampers were viewed as closed and drains were observed to contain water.





Test results shows that the actual permeability of the building is higher than expected. Sealing solutions/technologies could be tested as a part of the living lab to identify the reductions in the air leakage rate resulting from addressing some of the leakage paths outlined.

4 SITE POTENTIAL FOR ENHANCED ENERGY PRODUCTIVITY

This section outlines the site's potential for renewable energy and enabling technologies and services in line with the i-Hub objectives.

4.1 Potential technologies that could be in-situ tested

The energy plant load variation is most likely HVAC dominated. A range of new and emerging technologies could be applied to this site, such as technologies or applications that:

- Can be retrofitted to existing plant to improve the efficiency and performance of HVAC systems, such as water treatment, compression cycle efficiency, innovative heating-cooling mechanisms, filters;
- Can be retrofitted to the existing buildings to improve building envelope thermal performance (external thermal loads), such as roof or wall coatings, smart glazing, or internal/external shading devices;
- Can integrate with building management systems to optimise building operation, such as demand management, load shifting, predictive maintenance, and continuous commissioning;
- Can reduce internal heat loads, such as smart lighting controls
- Can provide onsite or neighbourhood renewable energy that can be utilised, stored and managed to meet site demands;
- Can enable demand response capability and other energy market trading mechanisms.

4.2 Renewable / Distribute Energy Potential

For billing purposes, only the magnitude of the monthly peak is considered. Load duration at, or near, the peak is not considered. This would however be a consideration when designing an embedded energy system. Two immediately obvious options are available to residential aged care sites:

- Solar PV
- Backup generator.

All RAC sites have emergency generators (a regulatory requirement) which could be operated for short periods to reduce grid demand at peak times. This is likely most effective in conjunction with the local grid operator and assumes a grid-synchronous generator.

Many existing sites, however, have also low set buildings, with a high roof to floor area ratio. Depending on building orientation, this makes rooftop solar a potentially ideal embedded generation solution. To demonstrate this potential, solar PV data from the University of Queensland's PV array at Pinjarra Hills[9] was applied to the electricity load of Bolton Clarke's Fairview RAC facility (also in Pinjarra Hills, adjacent to the solar array). Figure 4-1 shows a typical sunny day reducing the midday peak demand. The daily peak appears to be earlier (3-4pm) than

[9] 28.8kW capacity scaled to 100kW. Data freely available from https://solar-energy.uq.edu.au/

the typical evening peak expected from a ‘working household’. In this instance, solar may still be operating during a higher demand time of day.

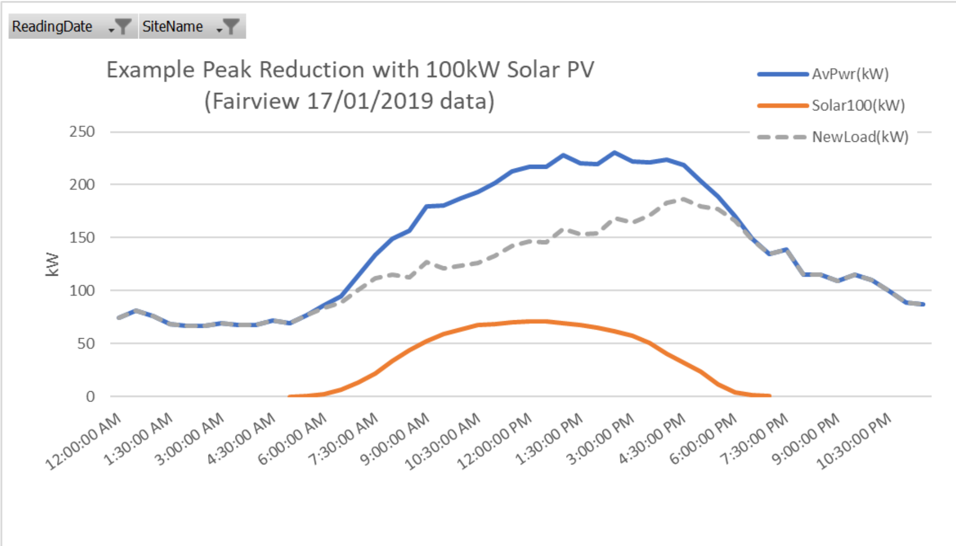


Figure 4-1 Fairview RAC facility load overlaid with adjacent UQ PV output

Savings made from solar installation may not be as simple as the difference between the peak load and peak solar. Often the two do not coincide, as evidenced in Figure 4-1. Obviously, solar can only reduce peak demand during daylight hours. Figure 4-2 shows the seasonal variation where solar is shown to only impact the peak demand during the months with daytime peak loads. Figure 3-4 in the previous section shows how the typical winter peak will occur before any significant solar generation takes place. In order to take advantage of solar generation for peak reduction, storage would be needed. Regardless of peak reduction, the solar will reduce grid energy consumption during the daylight hours.

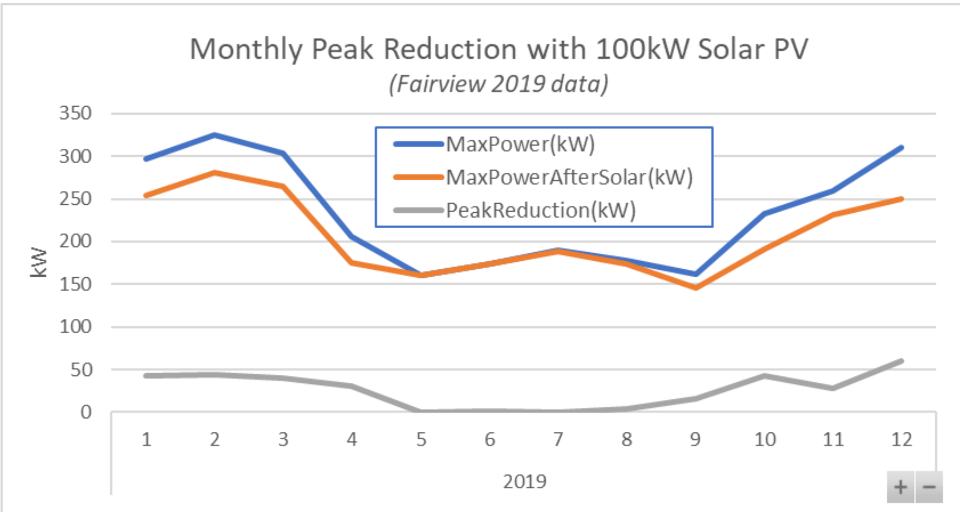


Figure 4-2 Fairview site with adjacent UQ research site solar data

4.3 Potential Key Performance Indicators

Current aged care sector KPIs are usually based on energy use per bed, as demonstrated in the previous section. To assist with energy management decisions, more detailed or purpose oriented KPIs may be needed. As indicated previously, RAC facility energy use and power demand are seasonal and likely highly correlated to HVAC. Therefore, monthly KPIs or HVAC related energy KPIs can be helpful. Some possible KPIs that may be examined are presented in Table 4-1. Additional KPIs may be identified and tested over time, including KPIs that relate to health outcomes.

Table 4-1 Potential KPIs for QCH

Sector	Benefit	Possible KPI
Site benefits	Energy bills saved	$ saved per month or per year
	Reduced energy intensity	kWh/m^2
	Increased load shifting capability	kW or kWh
	Predictive control of load	kW
	Self-sufficiency / Resilience	% of self-sufficiency rate Or N-X contingency
Renewable energy	Energy bill saved from locally generated renewable	$ saved per month or per year
	Increased value proposition	% of energy from renewable
Environmental benefits	Avoided greenhouse gas emissions	tCO2-e $/ tCO2-e
	Avoided air pollution (PM10, NOx, and SO2)	Reduction in (PM10)/MWh Reduction in (PM10) ppm
Network benefits	Peak 30 minute electricity demand	Peak kW/month (season, annual)
	Wholesale cost of peak 30 minute electricity demand	Wholesale $/KW at time of site peak demand
	Total self-consumption rate of local generation, e.g. renewable	%
	HVAC self-consumption rate of local generation, e.g. renewable	%
	Net Facility Load Factor	Peak demand to average demand ratio
	Demand response capacity	kW
Sector benefits	Energy cost reduced	$ per year
	Power Purchase Agreements - % of renewable energy	kWh of renewable energy purchased as a % of total PPA purchase
	Renewable energy fraction	kWh of renewable energy generated on precinct / neighbourhood