POWER, ENERGY & CLEAN TECHNOLOGIES

seminars

Dr Wendy Miller

Living Lab Test Facilities in Queensland

Innovation Hub for Affordable Heating and Cooling (i-Hub)

Parties: Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH), CSIRO, QUT, Uni Melbourne, Uni Wollongong + Industry

Objective: support the broader HVAC&R industry with knowledge dissemination, skills-development and capacity-building

Disclaimer: *AIRAH receives funding from ARENA under its 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.*

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ARENA

Australian Government
Australian Renewable Energy Agency

THE INNOVATION HUB
HUB
FOR AFFORDABLE HEATING AND COOLING

AIRAH

Living Laboratories - Healthcare

Purpose: validating impact of RE-EE-HVAC integration

Two Living Labs in QLD – QCH and Fernhill

Sector wide - Quantifying performance and additional benefits nationwide

Benchmarks and KPIs (existing and new)

IEA Annex 80 Resilient Cooling in Buildings

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ARENA

Australian Government
Australian Renewable Energy Agency

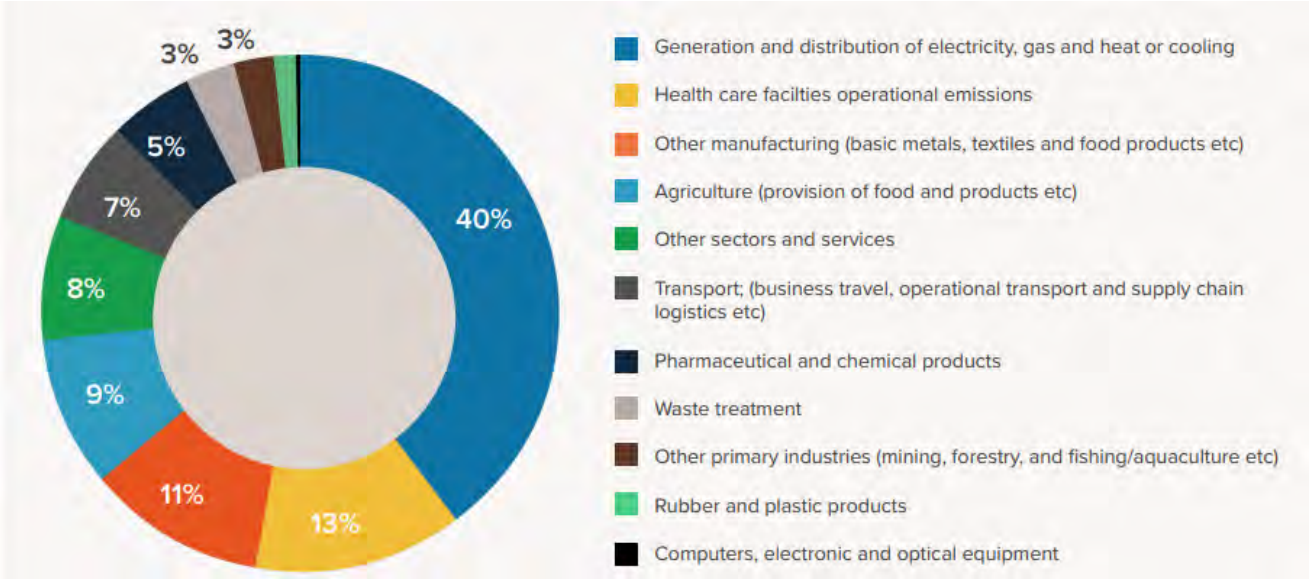
QUT

Global health care emissions

4.4% of global net emissions

29% of these emissions directly related to care facilities and vehicles

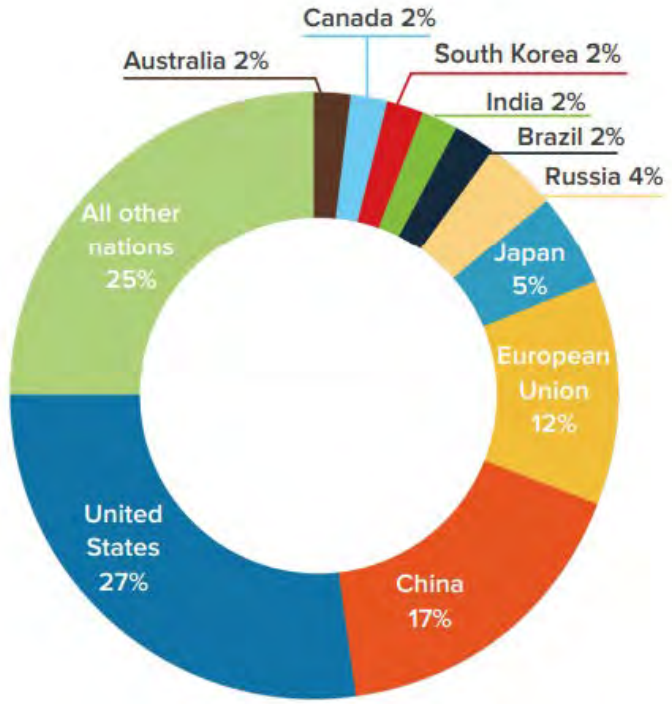
Energy use accounts for more than half of sector emissions



R. Karliner J, Slotterback S, Boyd, B. Ashby, K. Steele. (2019) *Health Care's Climate Footprint: How the Health Sector Contributes to the Global Climate Crisis and Opportunities for Action.* Health Care Without Harm Climate-smart health care series. Green Paper Number One.

Top 10 healthcare emitters

	Healthcare country/region CO2-e ranking	Total country/region CO2-e ranking
1	United States	China
2	China	United States
3	European Union	European Union
4	Japan	India
5	Russia	Russia
6	Brazil	Japan
7	India	Brazil
8	South Korea	Canada
9	Canada	South Korea
10	Australia	Mexico
	Mexico (11)	Australia (17)



Health care emissions per capita by country				
Top emitters: (over 1t per capita)	**Major emitters** (between the 0.05t and 100t per capita)	**Higher than average emitters** (between global average .28t and .50t per capita)	**Lower than average emitters**	**Unknown**
Australia	Austria	Bulgaria	Brazil	Rest of World (ROW)
Canada	Belgium	Cyprus	China	
Switzerland	Denmark	Czech Republic	Croatia	
United States	Estonia	France	Hungary	
	Finland	Greece	India	
	Germany	Italy	Indonesia	
	Ireland	Malta	Latvia	
	Japan	Poland	Lithuania	
	Korea	Portugal	Mexico	
	Luxembourg	Slovenia	Romania	
	Netherlands	Spain	Slovak Republic	
	Norway	Sweden	Turkey	
	Russia	European Union		

Hospital key performance indicators (KPIs)

Energy use intensity (EUI) per floor area (kWh/m^2)

UK benchmark: 550 kWh/m^2; Good 445 kWh/m^2 (2004)

Wales: 622 kWh/m^2 (2003)

Scotland: 466 kWh/m^2 (2003)

USA: 1473 kWh/m^2 (mean energy intensity of 3200+ hospitals to 2013)

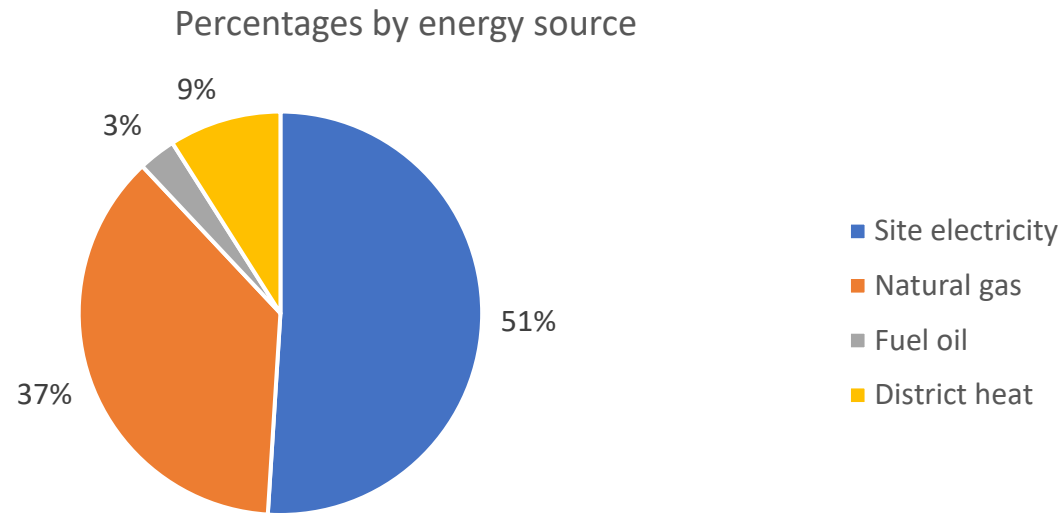
EUI per full time equivalent staff

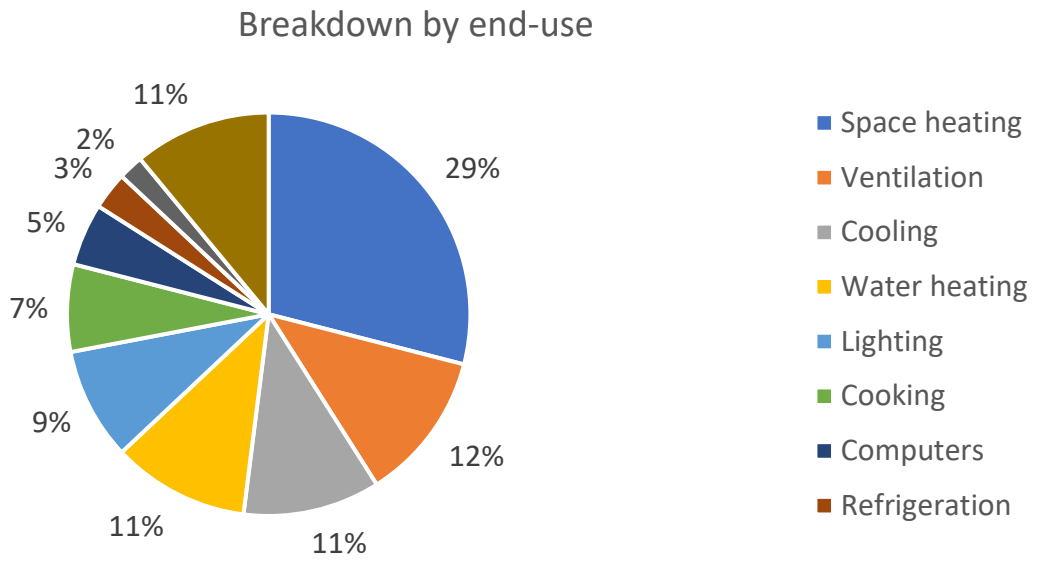
EUI per staffed bed per m^2

EUI per floor area correlated to cooling and/or heating degree days (CDD, HDD)

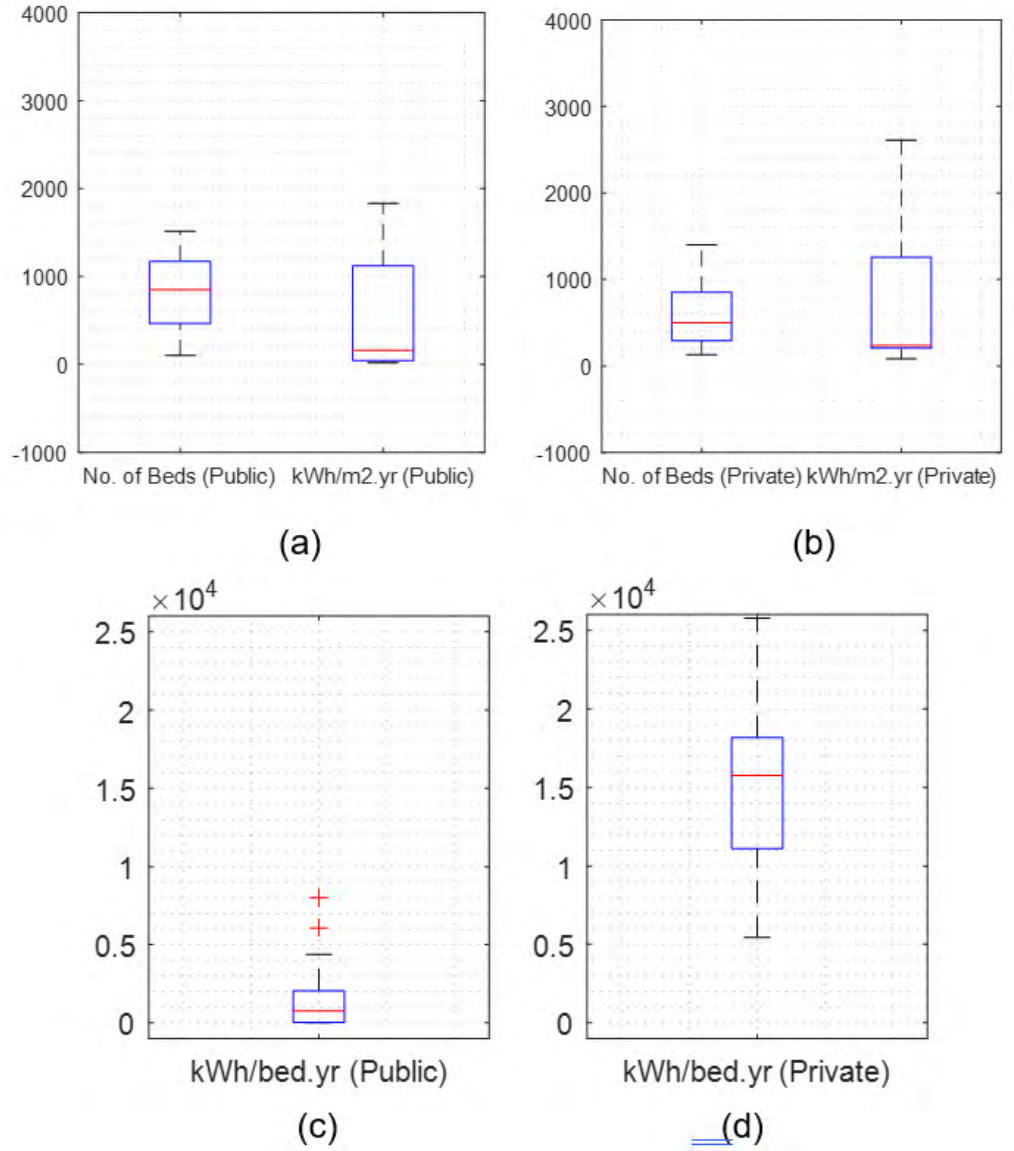
EUI per MRI per m^2

USA 2012 healthcare buildings energy source





India: public (17) and private(7) hospital KPIs



kWh/m² has limited usefulness

Country	kWh/m²
US	1473.2
Wales	622.2
UK (average)	550.0
Scotland	466.7
Australia (regional public hospitals)	460.3
UK (NHS benchmark)	445.0
Australia (capital city public hospitals)	393.1
India	~200.0
China (electricity only)	96.1

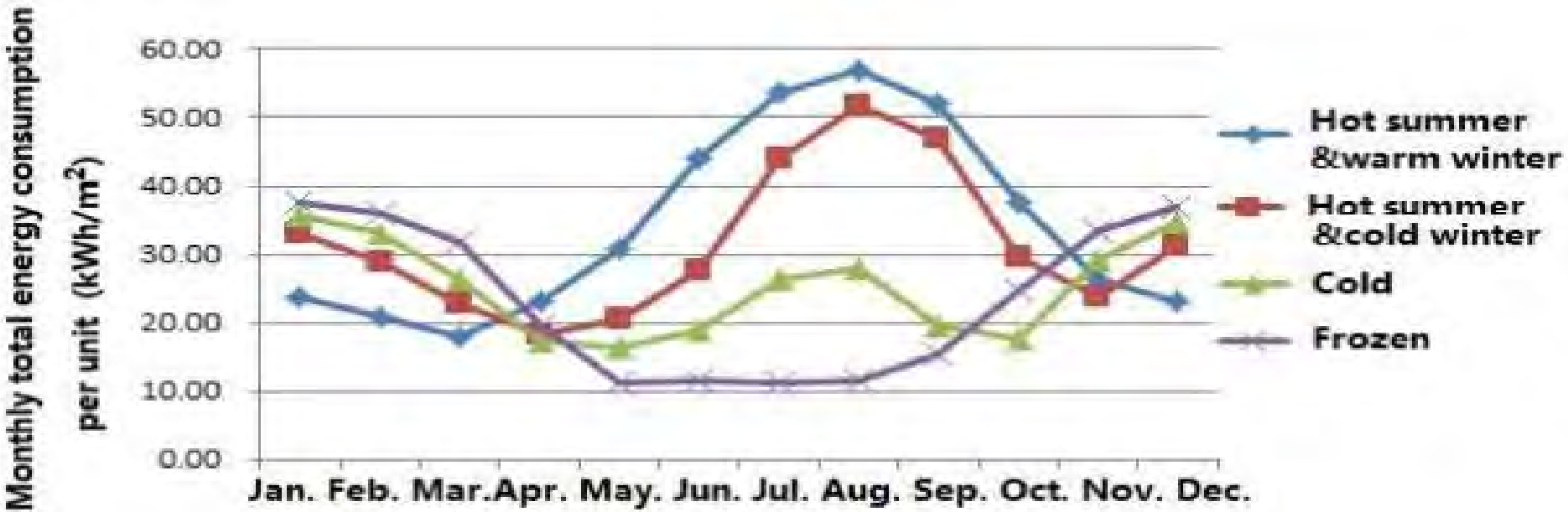
Climate and cultural expectations regarding indoor climate

Age (and EE) of building, infrastructure and equipment

Degree of medical specialisation

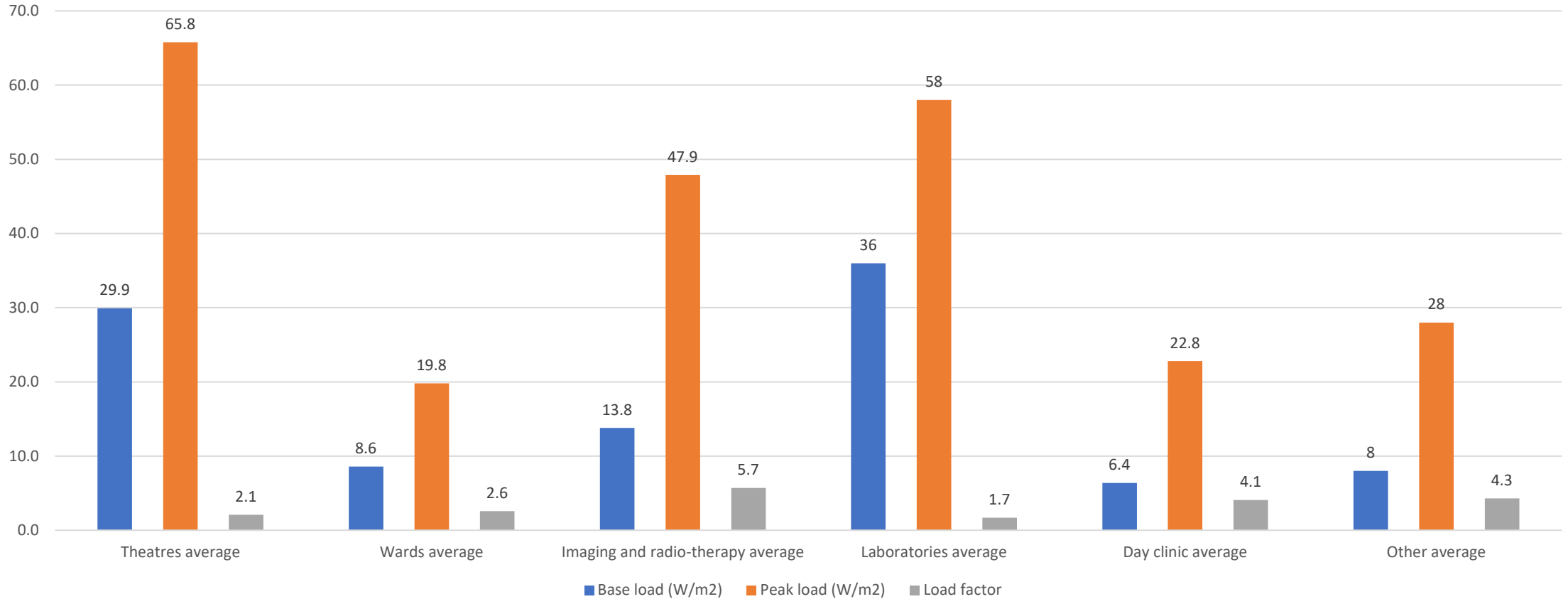
Building size and configuration

National and regional healthcare budgets



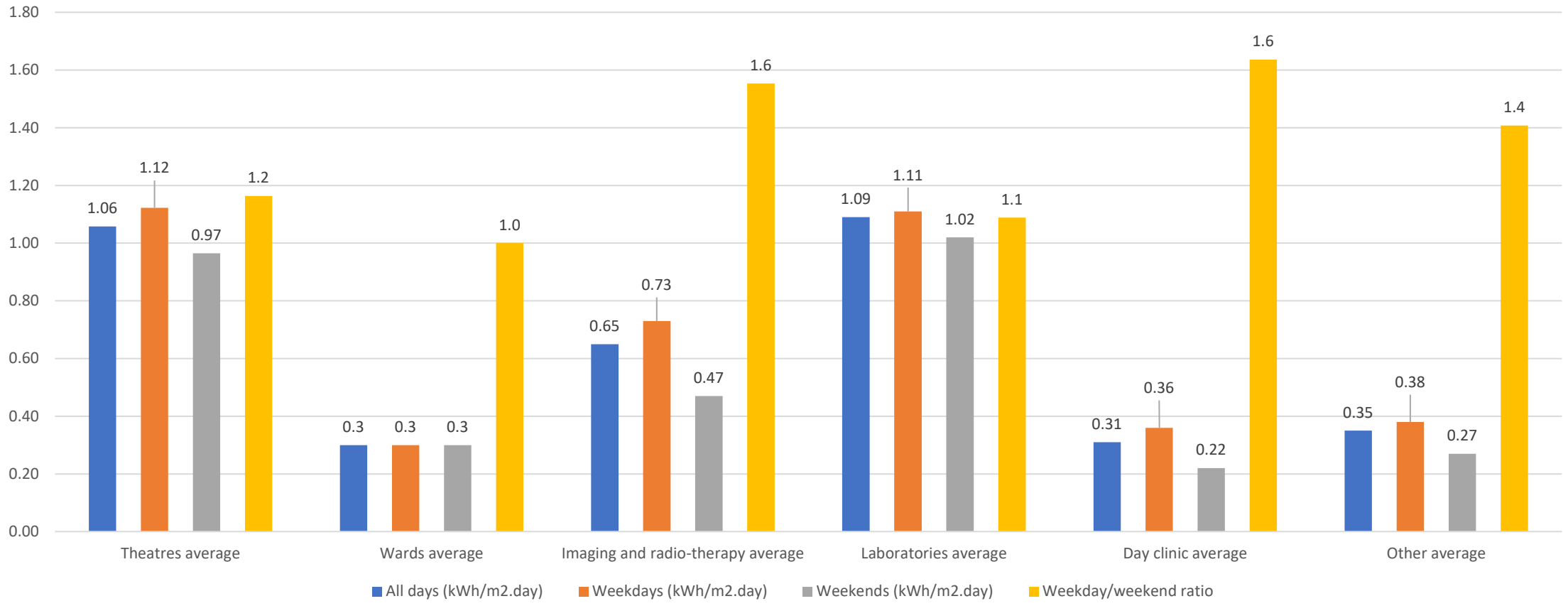
CHINA

Seasonality



Department base load and peak load

UK medium to large general acute hospitals



Time of use

UK medium to large general acute hospitals

Healthcare trends

Blurring of lines between facilities

Not just a ‘hospital’, but medical / surgical / allied health hubs +++

Keep hospitals for critical / specialised care

Replace with local clinics and home after-care (e.g. Denmark)

Technology

More energy intensive medical diagnostic equipment

More energy efficient building services technology

Electrification

Displacement of gas?

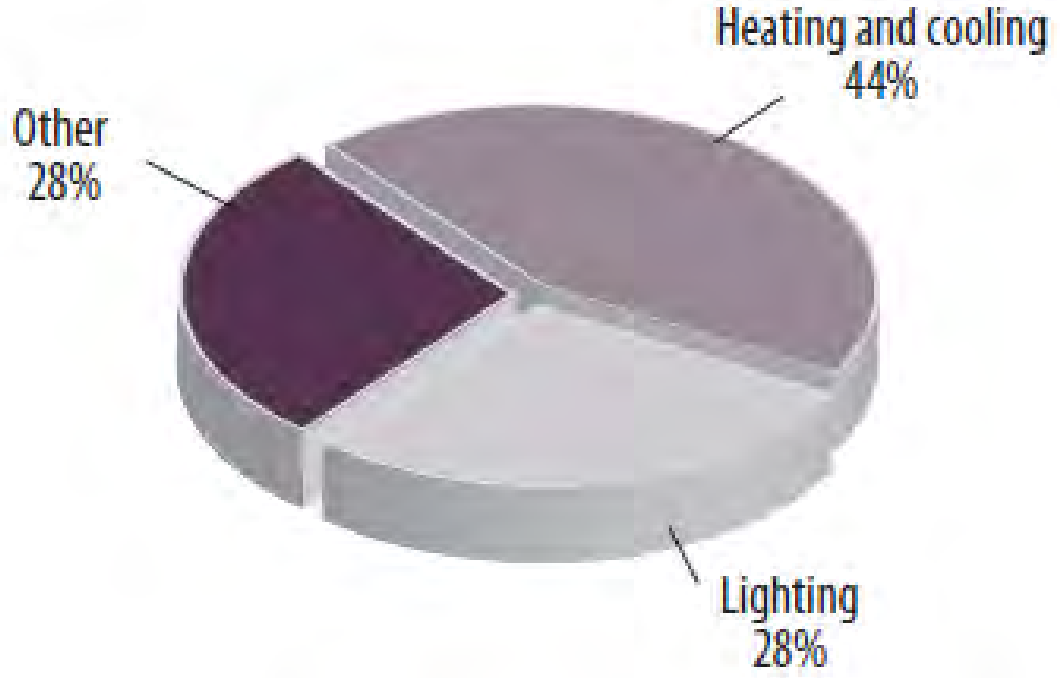
Electric transport

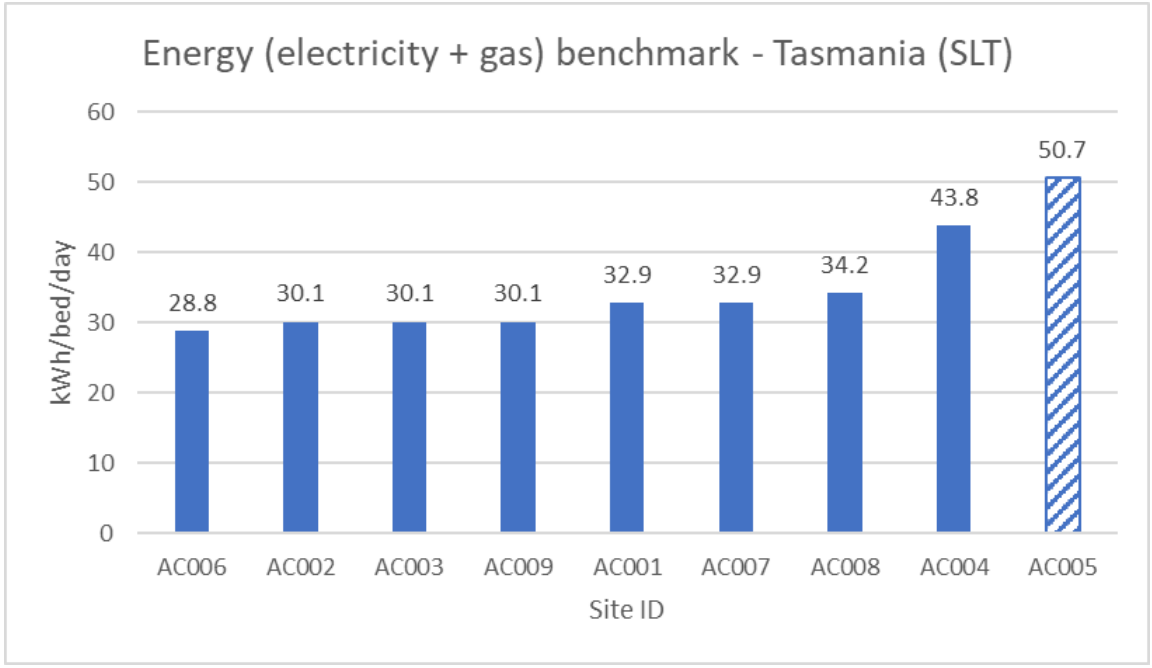
100 Care Homes EU – energy sources and KPIs

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

KPI	Metric	Mean value	Range (min / max)
EUI1	kWh/m^2/yr	252	46 to 551
EUI2	kWh/resident/yr	11711	2215 to 36349
EUI3	kWh heating/m^2/yr	129	To 333
EUI4	kWh heating/resident/yr	6109	To 20556

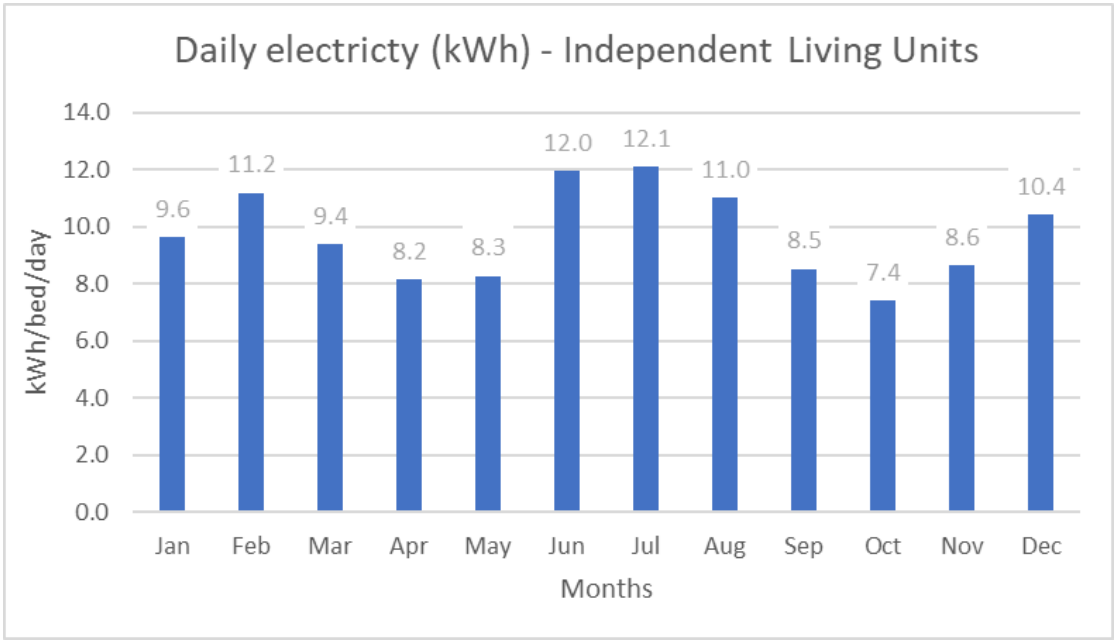
Australia: NSW (15) and Tasmania (9)

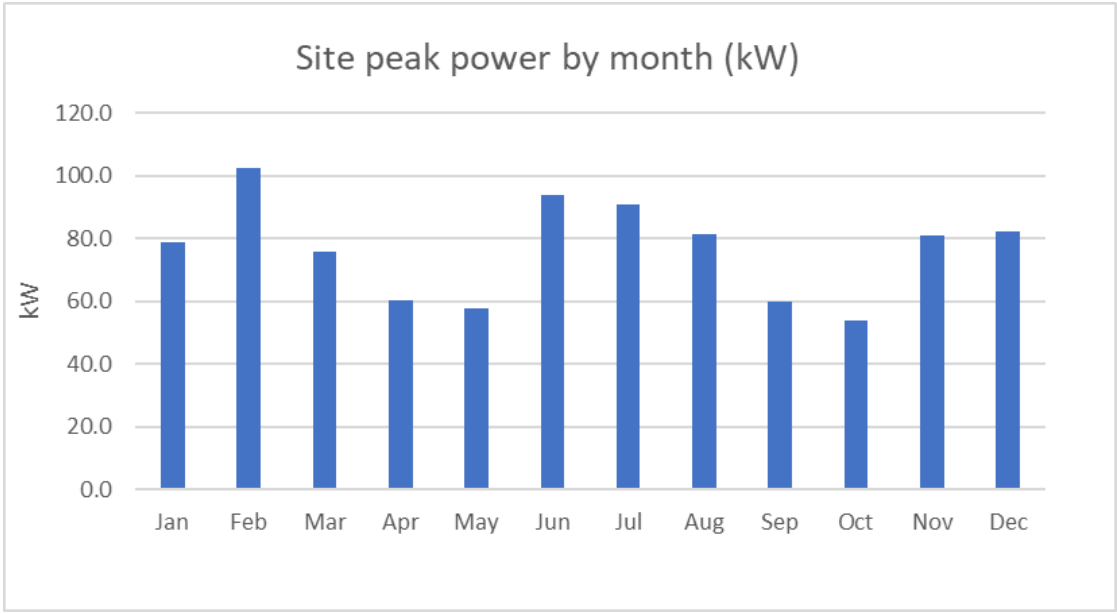




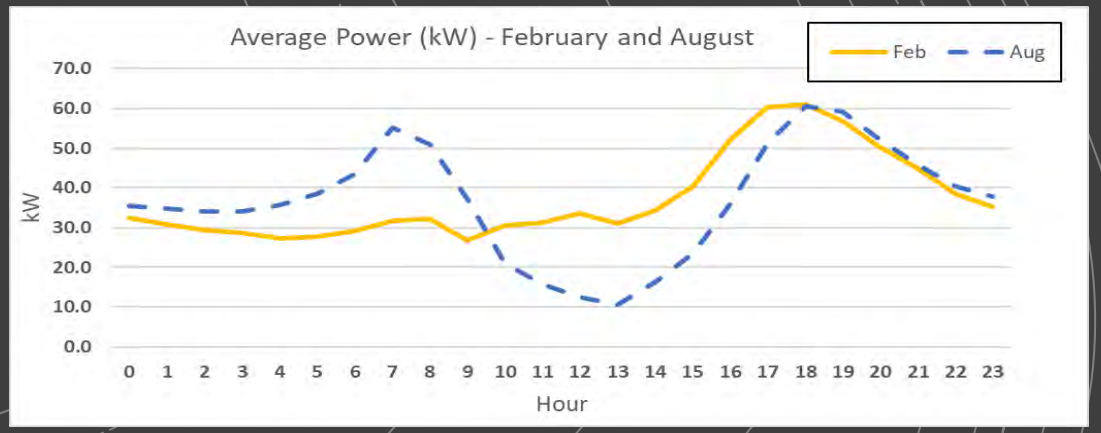
Models of Residential Aged Care in Australia

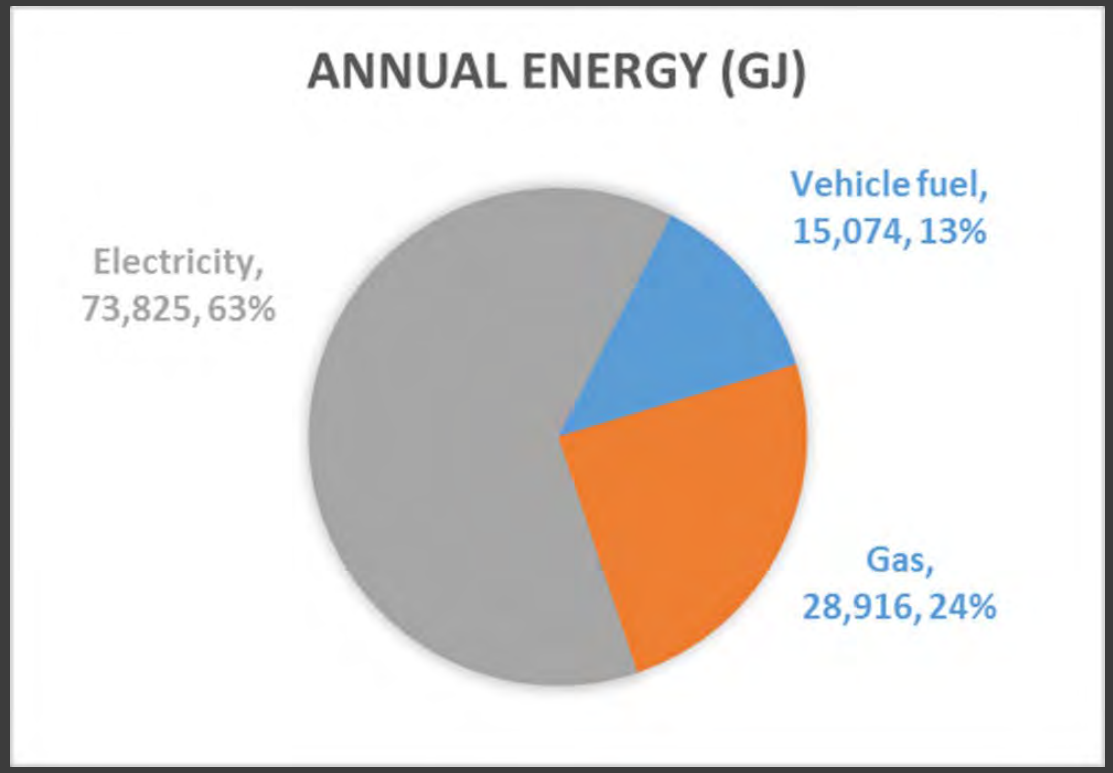
Accommodation Model	Description
Independent Living Units (ILU) (and supported living units SLUs)	Apartments or duplexes that are fully self-sufficient. These may be studio units or have 1-3 bedrooms and are typically occupied by a single elderly person or a couple. They can elect the level of care that they require.
Hostels	"Share homes" with independent bedrooms, and shared common spaces. Bathrooms may be ensuite or shared. Small 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) are provided (similar to a holiday resort). Full nursing care provided.

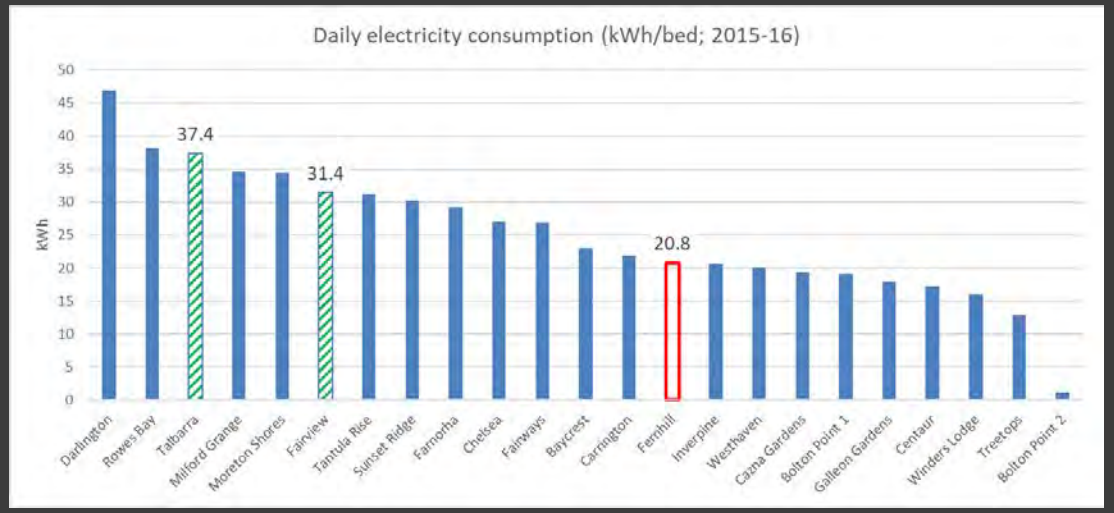




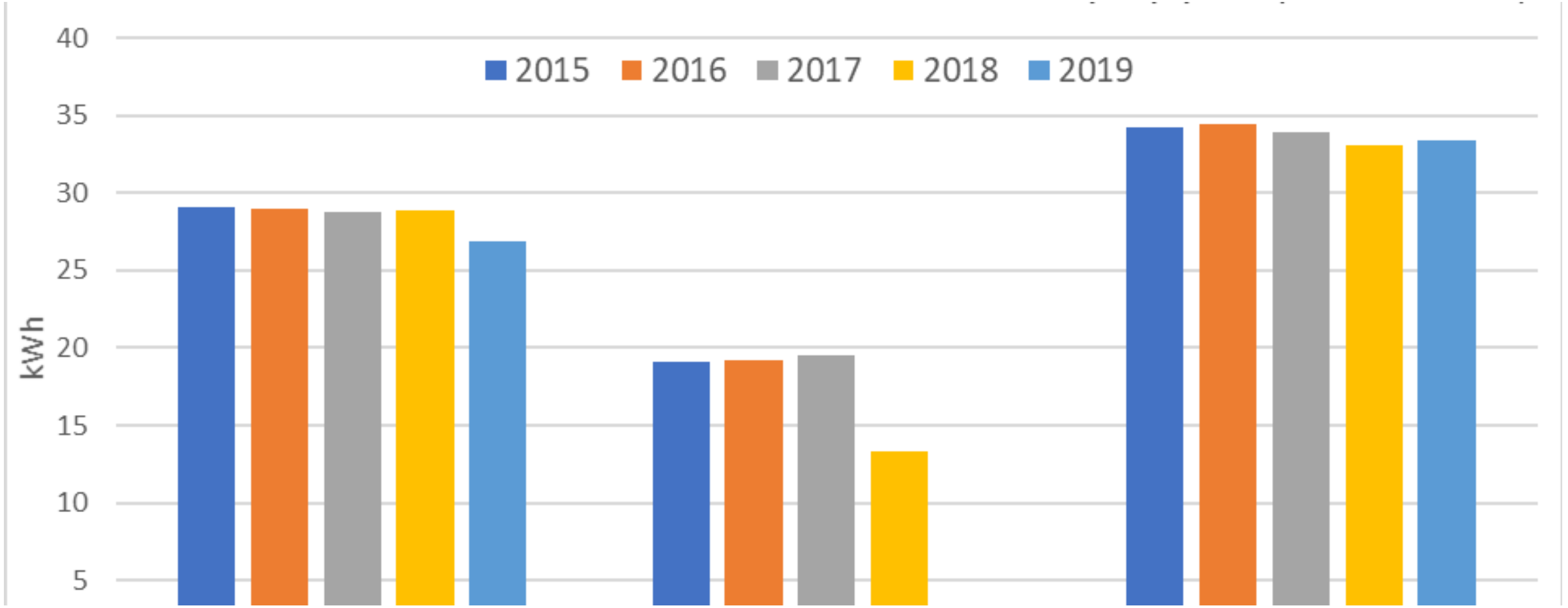
80 ILUs in south east Queensland, 2016



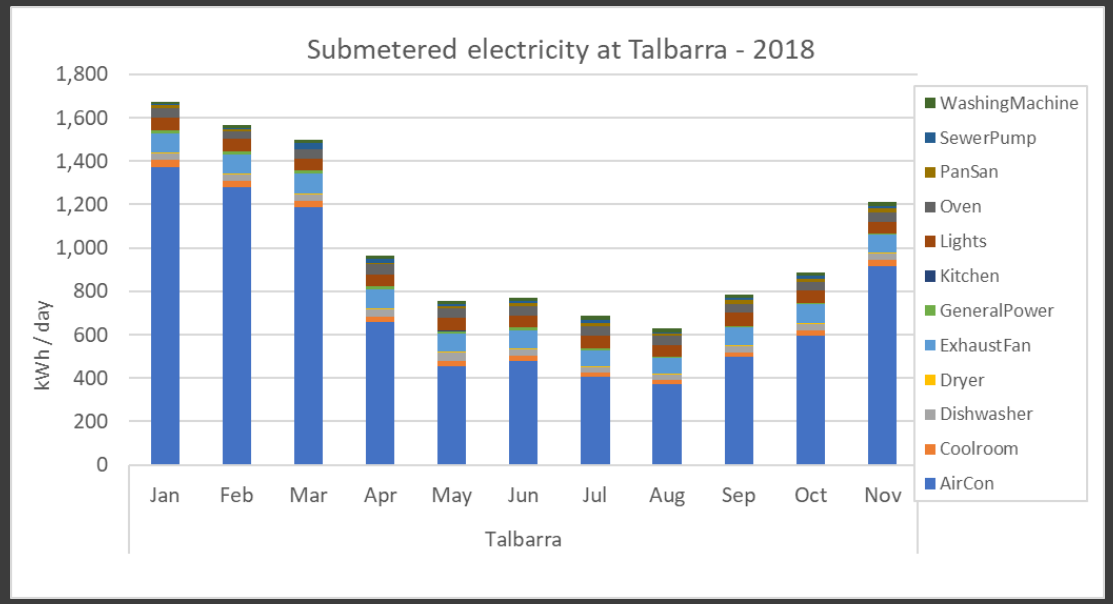


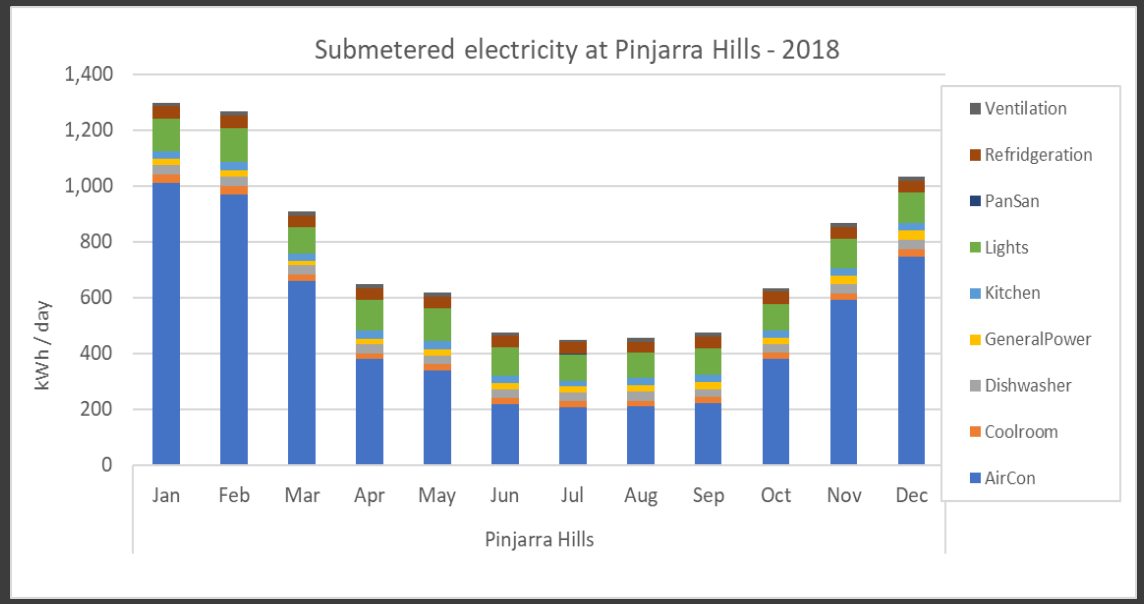


Bolton Clarke Portfolio Energy Use

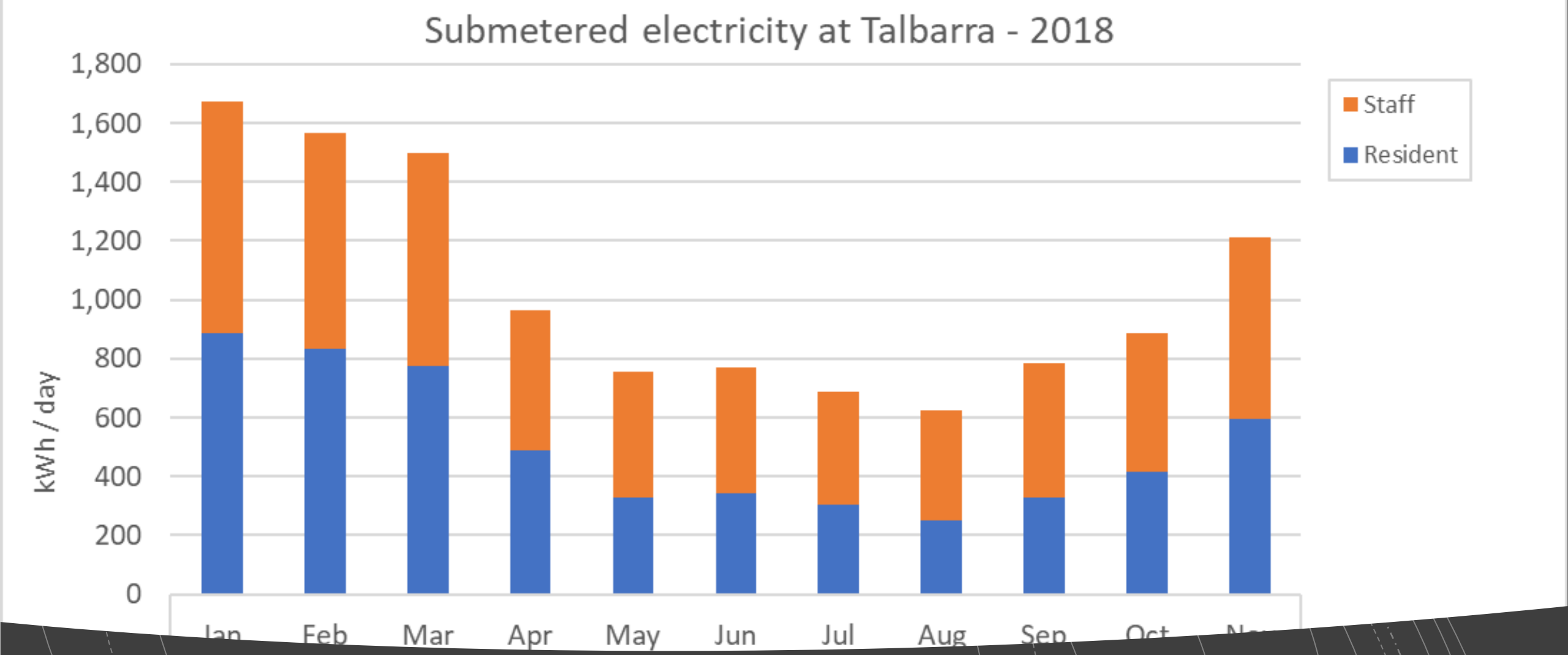


Annually consistent...





... But highly seasonal AC cooling



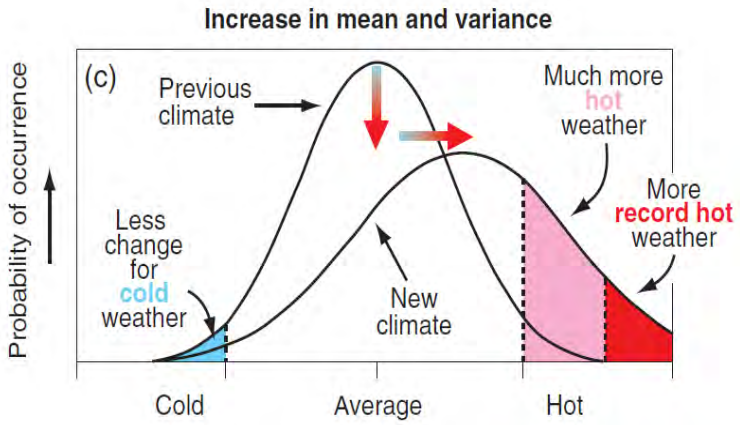
... and attributed to staff and residents

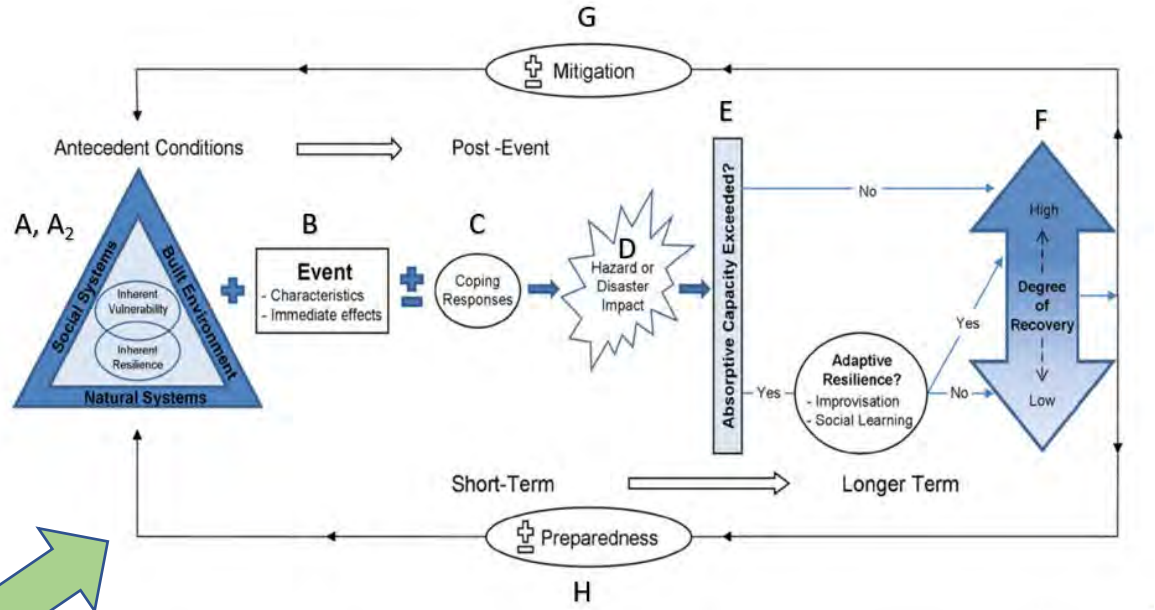
Attribute	Category examples	Most useful for
End use category	Load type, task or appliances	Energy efficiency initiatives
End user	Resident, staff or visitor	Understanding user needs and behaviour
Load characteristics	Deferrable, interruptible, variable	Demand response system design
Building use / characteristics	Accommodation, shared services (kitchen / laundry / auditorium) or office space	Energy association for targeted initiatives in a hybrid building setting

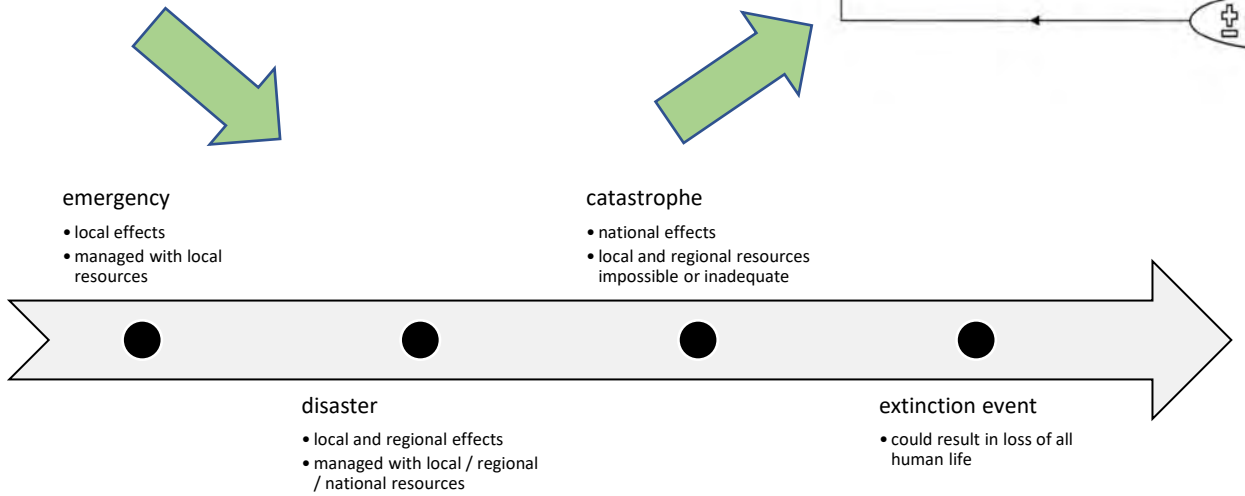
What to analyse?

What KPIs?

IEA Annex 80 – Resilient Cooling in Buildings







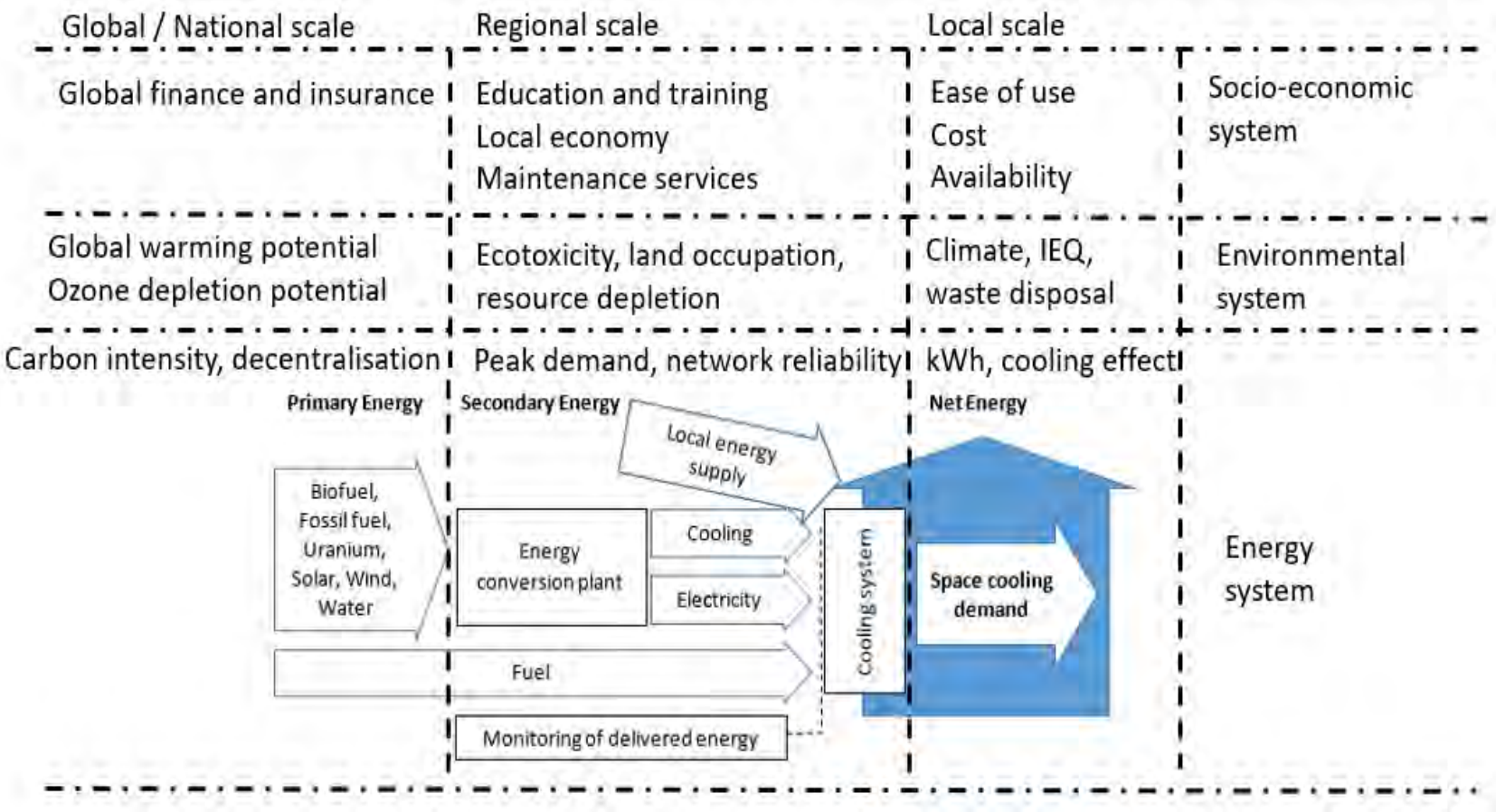
Understand the hazard

Temperature hazard (extended high temperatures and heat waves)

Criteria	Sub-criteria
Predictability	Regular; Irregular; Outside of collective experience
Origin of the threat	Internal; External
Spatial distribution	Household, community, city, region, nation
Temporal distribution	Timing of the hazard (e.g. spring or early summer; during holidays; at night)
Speed of onset	Slow; Rapid; Prolonged
Scope and magnitude of impact	Scale of population impacted / displaced Emergency; crisis; disaster; catastrophe
Number of threats	Single or multiple stressors

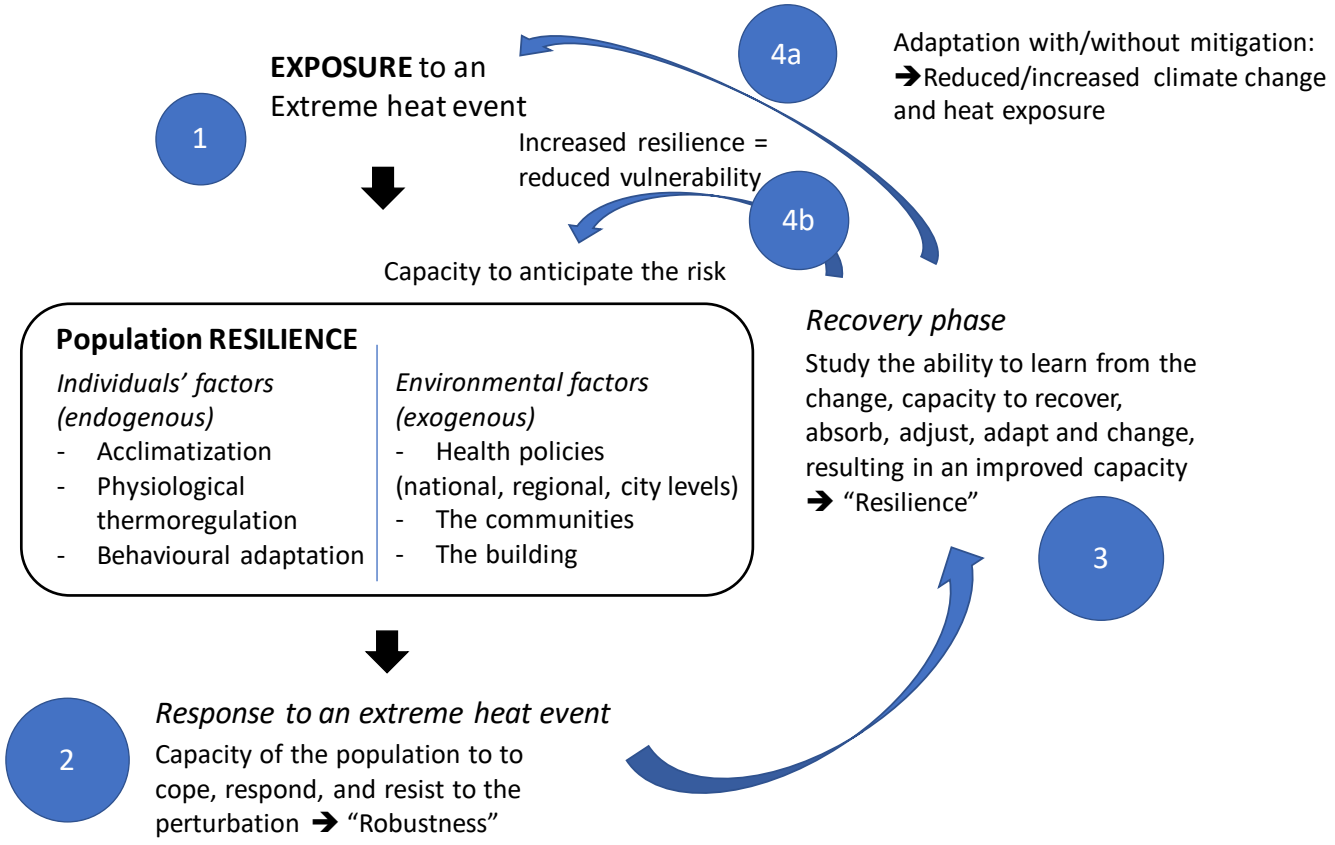
Resilient cooling requires...

- Resilient cooling strategies must start with individuals / communities as active agents enabled to cope with, adapt to, and manage cooling needs
- The building protects individuals from heat exposure, therefore buildings' resilience to temperature hazard needs to be defined
- Resilience (and limitations) of cooling technologies and energy systems needs to quantified and communicated
- Cooling strategies should satisfy sustainability, energy efficiency and greenhouse gas reduction goals
- Both qualitative and quantitative indicators are required, encompassing all parts of the 'system'



Multiscale Resilient Cooling Framework

Population resilience to temperature hazard



USA Green Proving Grounds

- Building envelope
- Energy management
- HVAC
- Lighting
- On-site power and renewables
- Water

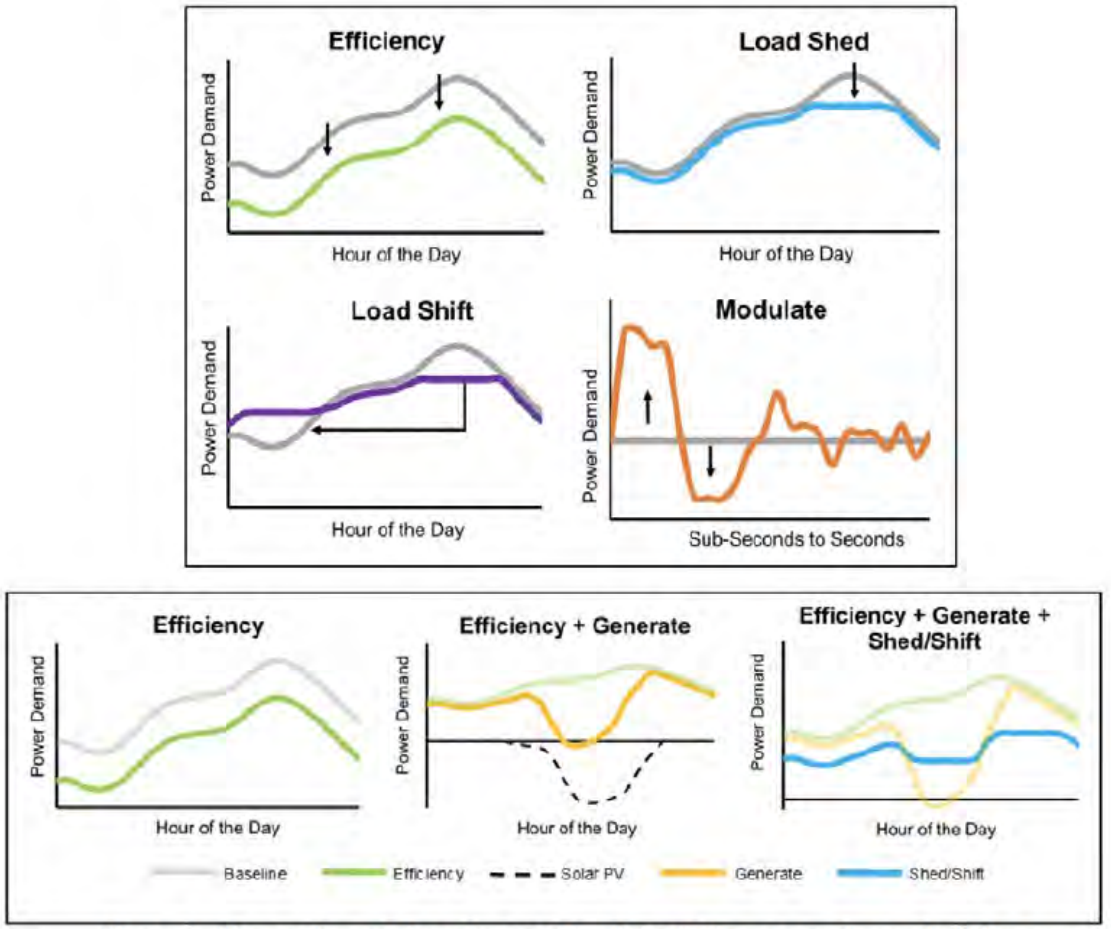


Figure 1. Illustration of the effects of load flexibility strategies on building energy, individually and combined.

Beyond traditional KPIs...

- EUI (kWh/m^2 or bed)
- Avoided GHGE (tCO_2-e and $); Avoided air pollution
- Peak 30min electricity demand; Wholesale $ peak 30min demand
- Total self-consumption; HVAC self-consumption
- Net facility load factor
- Demand response capacity
- Healthcare sector benefits
- Energy cost
- Building Heat Performance Index
- Gain utilisation factor
- Passive survivability; thermal autonomy
- Overheating escalation factor
- Mean time to failure
- System interruption frequency / duration
- Energy index of unreliability
- Restorative / recovery capability

QCH Precinct - main hospital

- 19 levels (12 clinical, 3 general services, 4 basement carpark)
- 112,000 m^2 (80,000 clinical)
- Three main types of HVAC
  - Constant-air-volume for critical departments with even loads
  - Variable-air-volume for load varying spaces
  - Active chilled beam for wards (100% fresh air)
  - + PAC systems in non-clinical areas e.g. kitchen

QCH Precinct - Centre for Children's Health Research

- 9 storeys, 14,108 m^2
  - Five dedicated to research labs (wet and dry; gait; nutrition; Tumour Bank)
  - Pathology service, offices, FM, reception, car parking, COVID19 testing area
- Main HVAC systems
  - CAV + VAV + FCUs

QCH Precinct – Central Energy Plant

Cooling towers: 6 x 4,951kW crossflow induced-draft

Chilled water plant: Total capacity 20MWr: 1,100kWr low-load VSD low-voltage electric centrifugal chiller + 5 x VSD 3,315kWr VSD low-voltage electric centrifugal chillers; N+1 redundancy

Central heating hot water plant: 7 x 1,110kW gas-powered hot water boilers (AC, heating, dehumidification, domestic hot water)

Steam: 2 x 1,300kW natural gas steam boilers

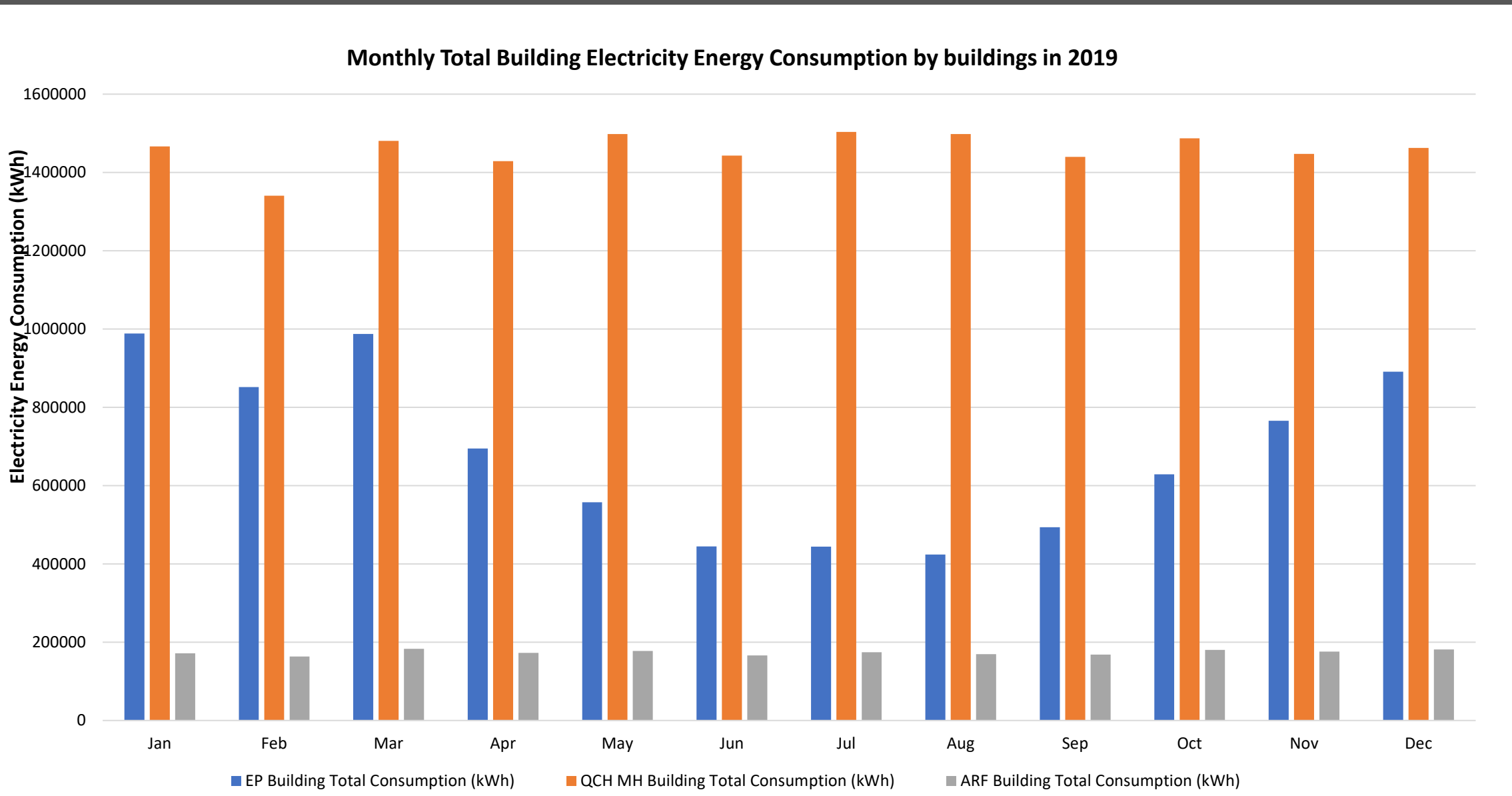
Trigen (decommissioned 2019)

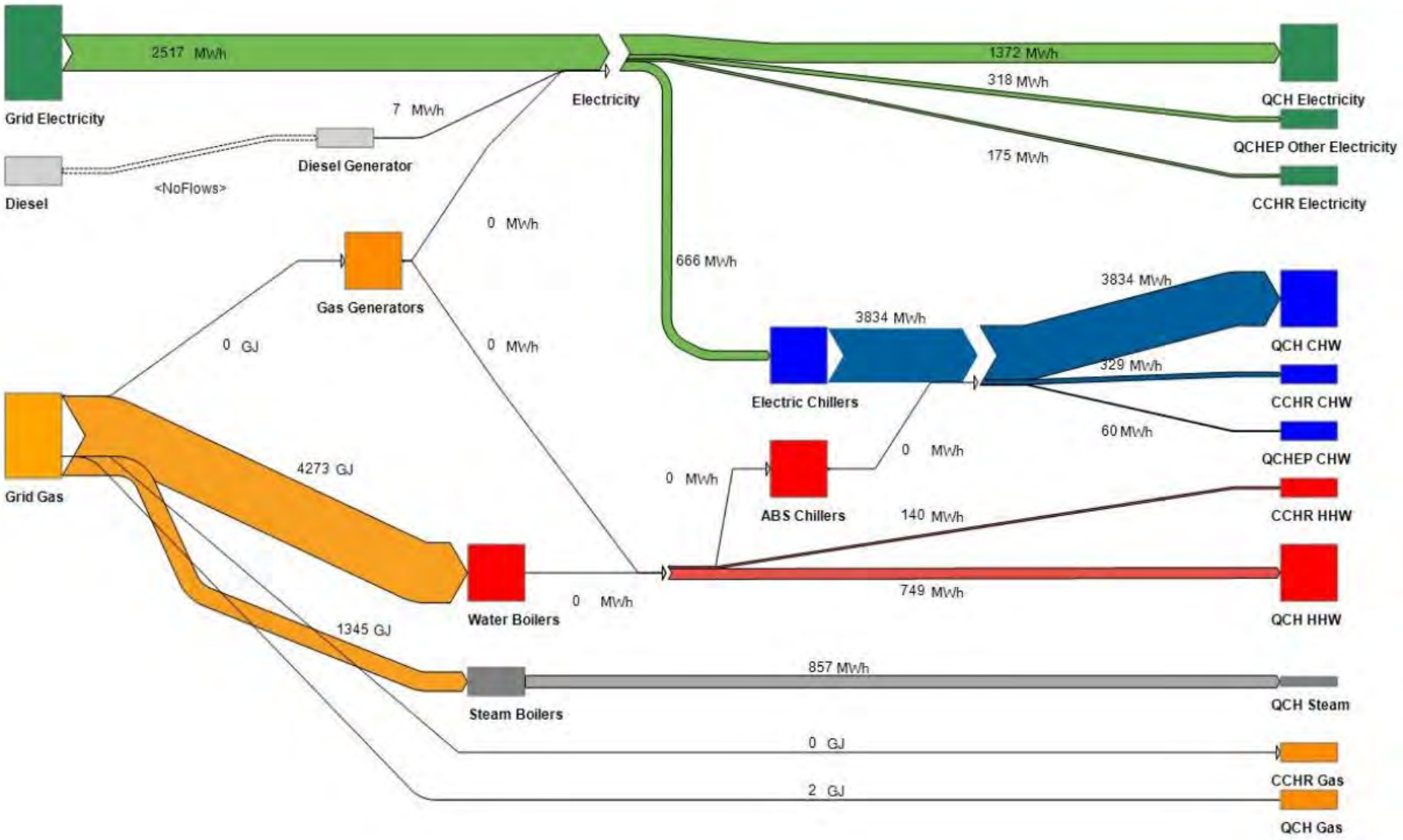
Stormwater treatment and reuse

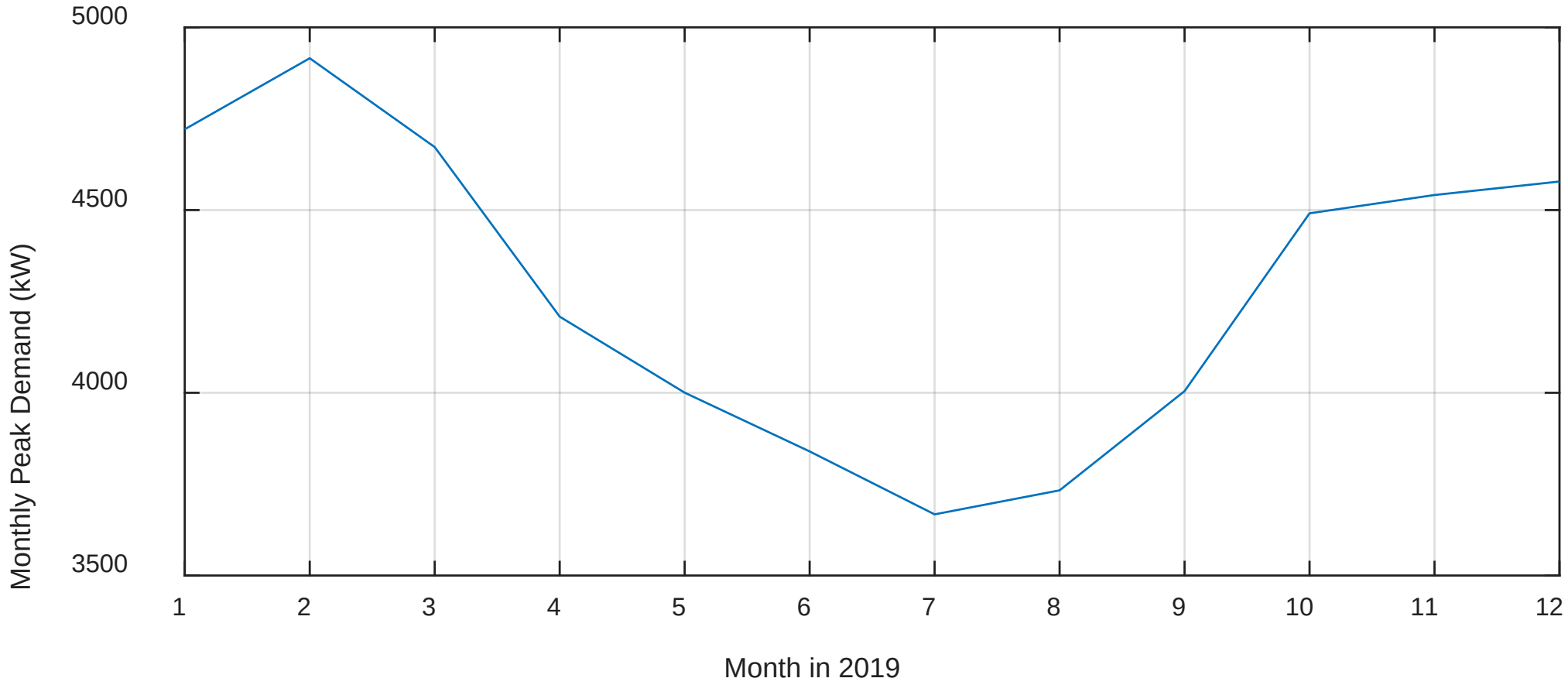
Chlorine dosing plant

Standby power plant: 4 x 2,4000kWe diesel generators

Grid connection: 3 x 7MW 11kV electrical cables (N+2 redundancy)


Monthly Total Building Electricity Energy Consumption by buildings in 2019
Electricity Energy Consumption (kWh)
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
EP Building Total Consumption (kWh)
QCH MH Building Total Consumption (kWh)
ARF Building Total Consumption (kWh)


Grid Electricity
2517 MWh
Electricity
7 MWh
Diesel Generator
Diesel
<NoFlows>
1372 MWh
318 MWh
175 MWh
QCH Electricity
QCHEP Other Electricity
CCHR Electricity
0 MWh
666 MWh
Gas Generators
0 GJ
0 MWh
3834 MWh
3834 MWh
329 MWh
60 MWh
QCH CHW
CCHR CHW
QCHEP CHW
Electric Chillers
0 MWh
0 MWh
ABS Chillers
Grid Gas
4273 GJ
140 MWh
CCHR HHW
749 MWh
0 MWh
Water Boilers
QCH HHW
1345 GJ
857 MWh
Steam Boilers
QCH Steam
0 GJ
CCHR Gas
2 GJ
QCH Gas


5000
4500
4000
3500
Monthly Peak Demand (kW)
1
2
3
4
5
6
7
8
9
10
11
12
Month in 2019

FERNHILL Residential Aged Care - Caboolture

144 Bed RAC across 4 levels (36 beds per floor; 26m^2 and 35m^2 with ensuites)

18 bed dementia wing

Resident facility (café, day spa, library, hobby workshop room, reflection room)

Communal dining and sitting areas on each level

Reception area + staff, management, training and consultation rooms

Commercial kitchen and laundry for this RAC and future SLAs

Workshop, loading dock, ambulance bay

Basement facilities – 57 bikes, 46 cars

Future day therapy centre and day care area

General public – Café / retail space

EE and ESD features

- Hybrid building design (NV and Mech HVAC)
- Airtight building envelope (1ACH.hr @ 50Pa)
- Ceiling fans and operable windows in all occupant rooms
- Infrared sensors in all bathroom exhaust fans
- Dual hot water reticulation system
- LED lighting, with motion sensors in common areas, amenities, circulation spaces
- BMS – HVAC, lighting, sub-metering (electrical and chilled water loads), weather station
- Provision for future RE and power factor correction

HVAC Plant

- Cooling: peak design load 1860kWr
- Chiller water system:3 x air cooled dual screw type electric chillers (2 @ 475kWr +1 @ 950kWr)
- 3 x variable speed chilled water pumps
- 3 x variable speed heating water pumps
- 10,0000 l chilled water storage
- 5,000 l heating hot water buffer tank
- Variable speed secondary chilled water pumps

Occupant rooms

6 ‘lab’ rooms plus control rooms above / below

Encompass N, W, E orientations

Automated logic sensors (T, RH, CO_2, motion)

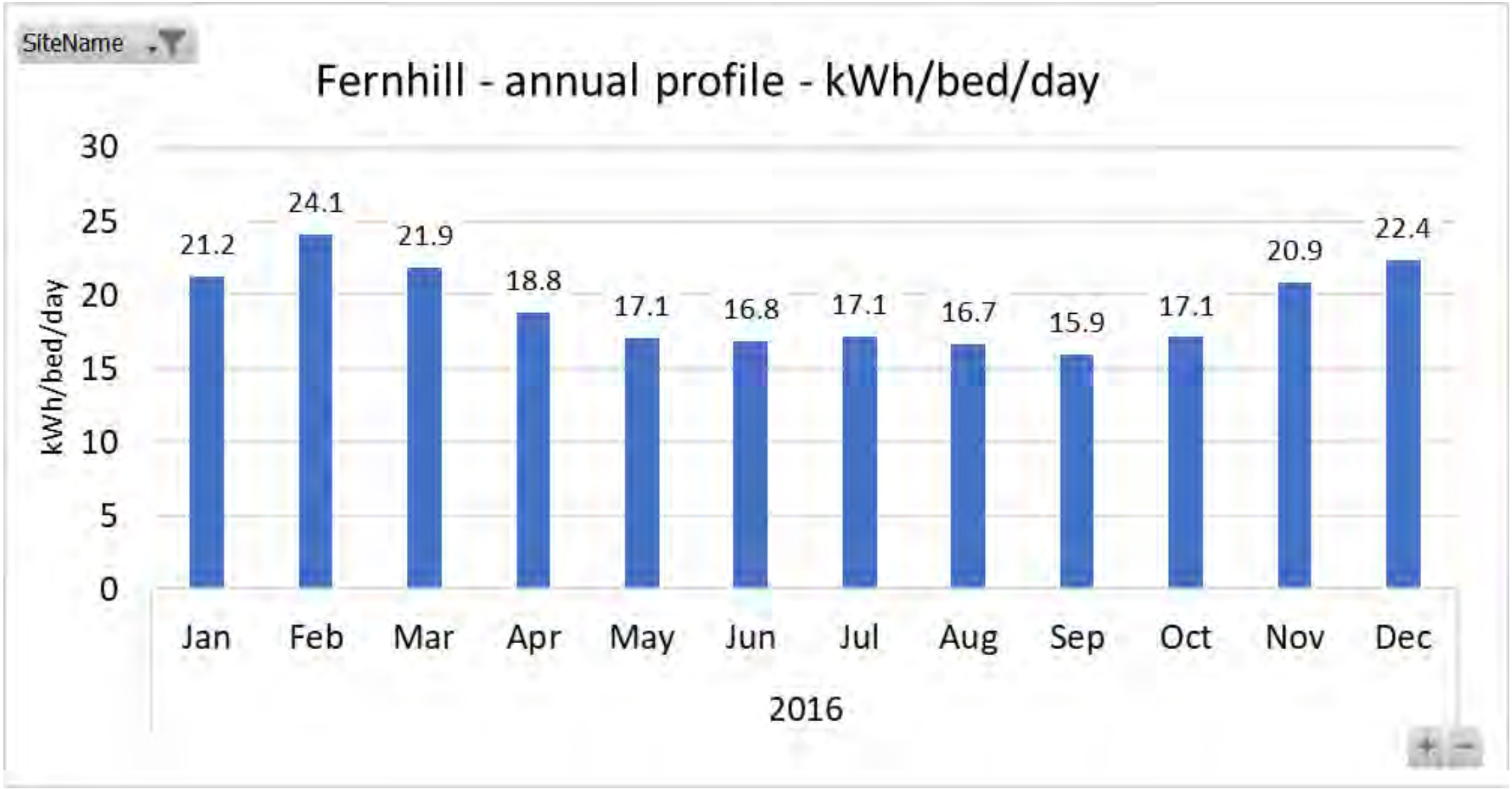
Steinel True Presence Sensors (T, RH, air pressure, VOC, CO2, Presence/movement, lux)

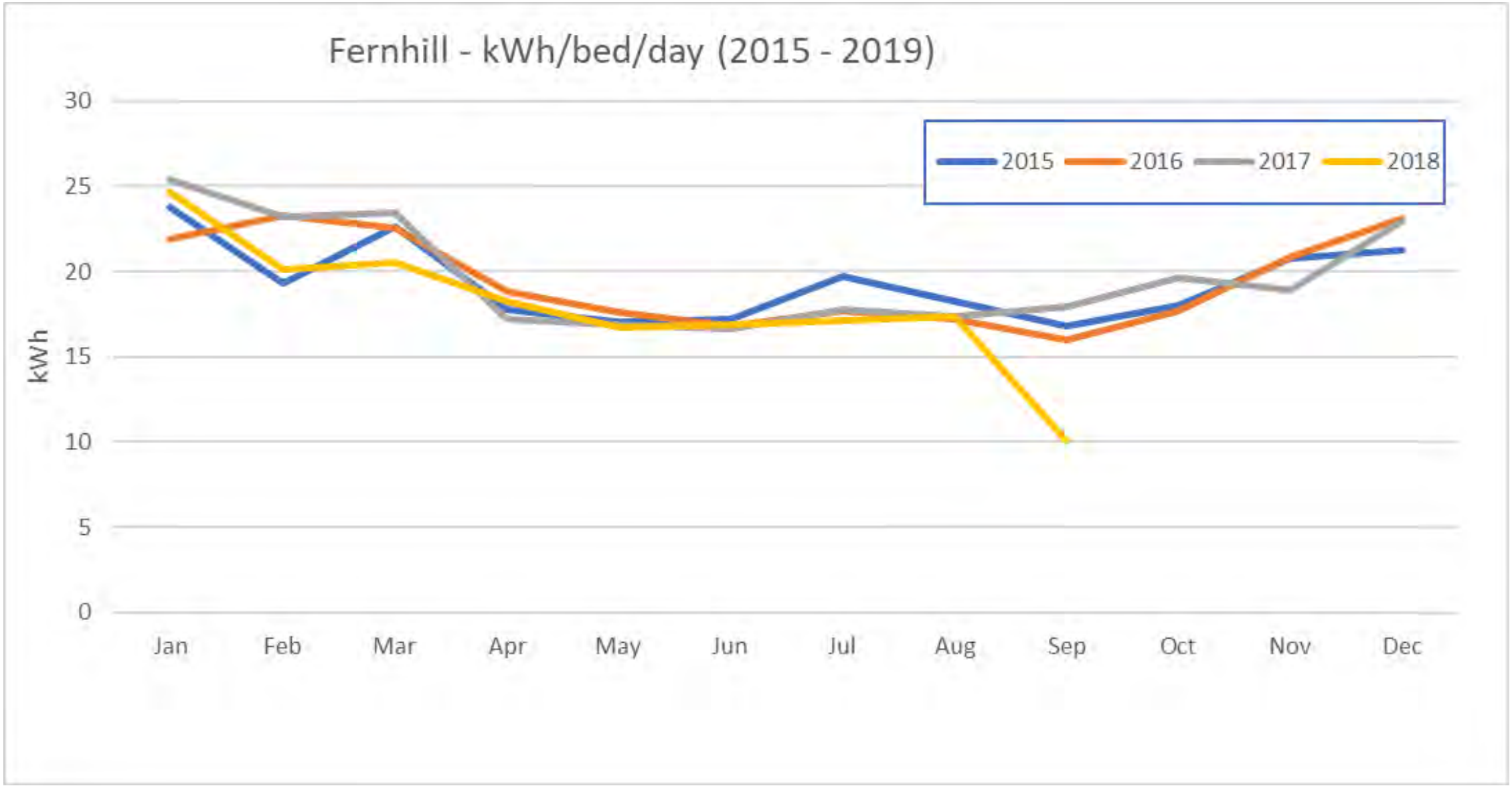
Netatmo IAQ sensors (T, RH, CO_2, Sound)

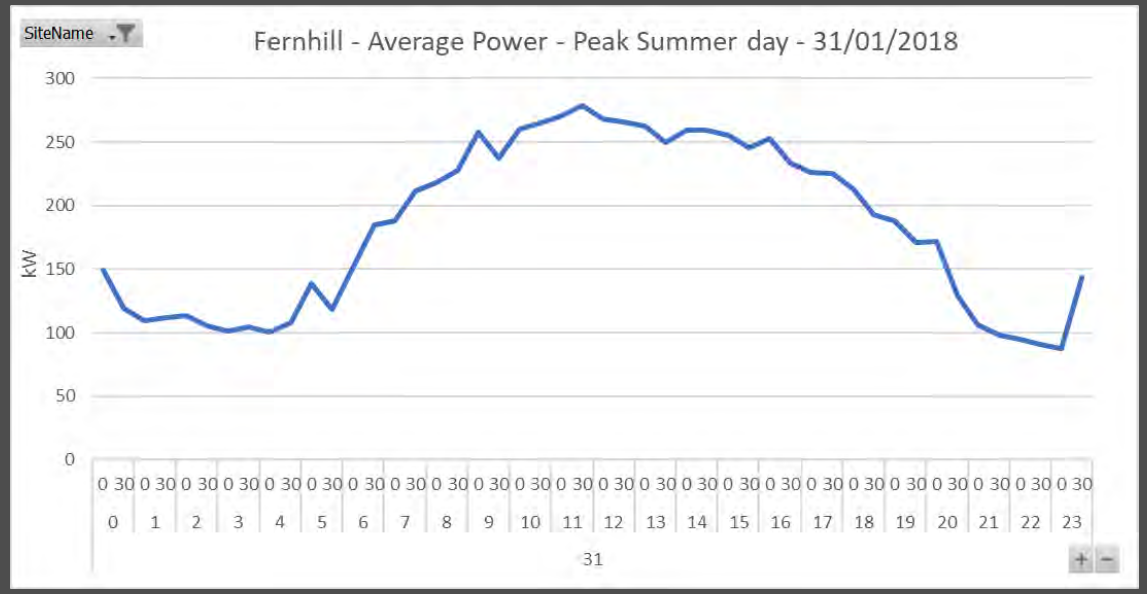
Portable IEQ cart

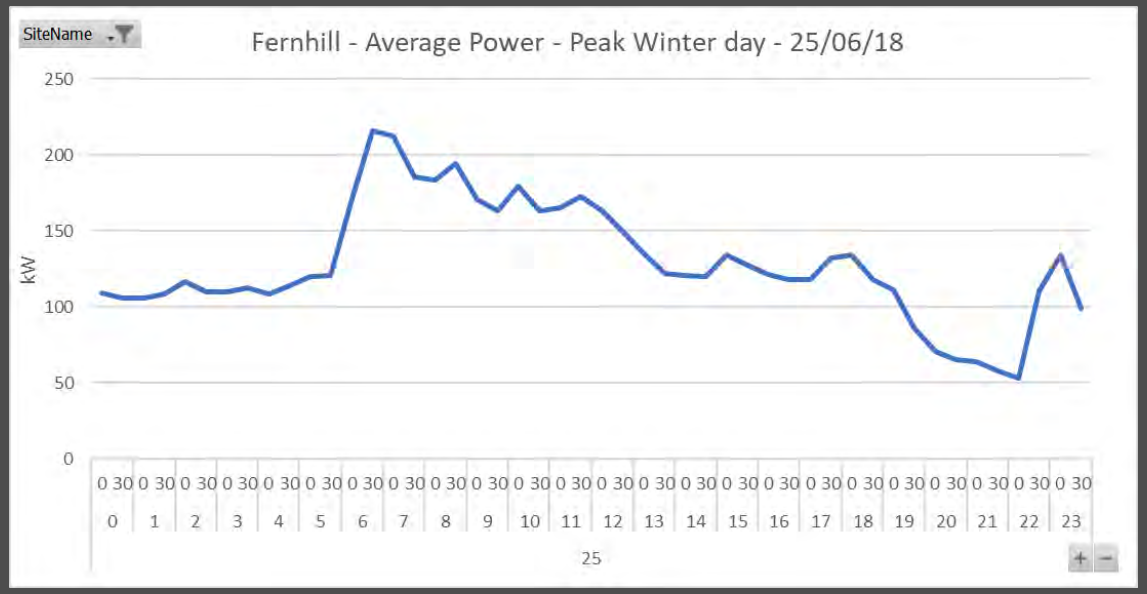
Wiring for reed switches /control of openable windows and AHUs

Additional meters and sensors when required


SiteName
Fernhill - annual profile - kWh/bed/day
kWh/bed/day
30
25
20
15
10
5
0
21.2
24.1
21.9
18.8
17.1
16.8
17.1
16.7
15.9
17.1
20.9
22.4
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2016


Fernhill - kWh/bed/day (2015 - 2019)
30
25
20
15
10
5
0
kWh
2015
2016
2017
2018
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


SiteName
Fernhill - Average Power - Peak Summer day - 31/01/2018
kW
300
250
200
150
100
50
0
0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
31


SiteName
Fernhill - Average Power - Peak Winter day - 25/06/18
kW
250
200
150
100
50
0
0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30 0 30
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
25

QCH

- Reducing building heat loads
- HVAC efficiency improvements
- Control / optimisation / MPC
- Precinct renewables / trading
- Contact Aaron Liu (l50.liu@qut.edu.au)

Living Lab testing options?

Fernhill

- NV / adaptive comfort
- Sensors / controls
- HVAC predictive control
- Precinct renewables/storage/trading
- Contact Wendy Miller (w2.miller@qut.edu.au)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