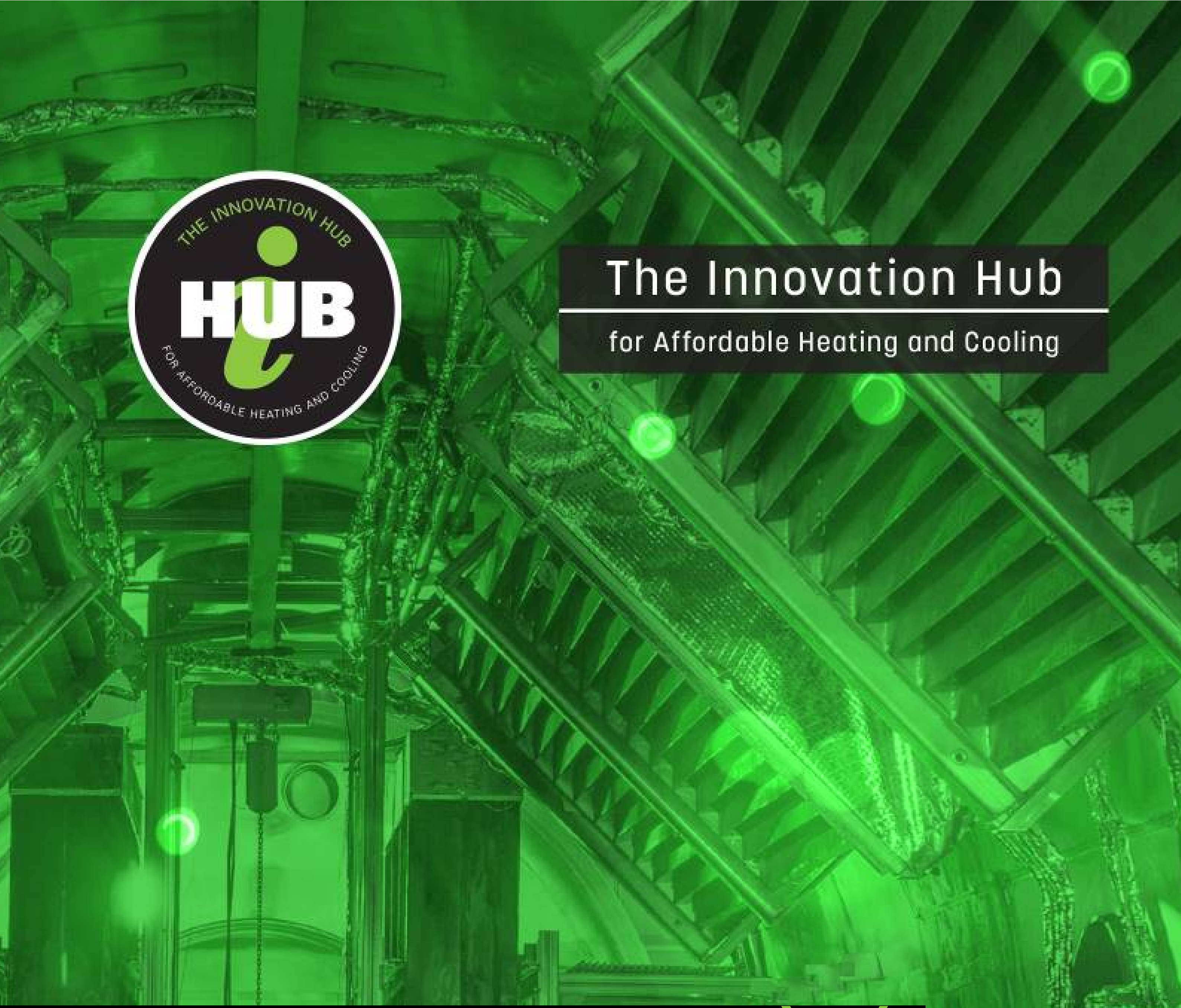

The Innovation Hub

for Affordable Heating and Cooling

Report #LLHC4-1

Healthcare Living Laboratories: Queensland Children's Hospital – Operation Manual and Baseline Data

V3. 16 October 2020 (Additions since V2 highlighted)

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.

This Project received funding from ARENA as part of ARENA's Advancing Renewables Program.
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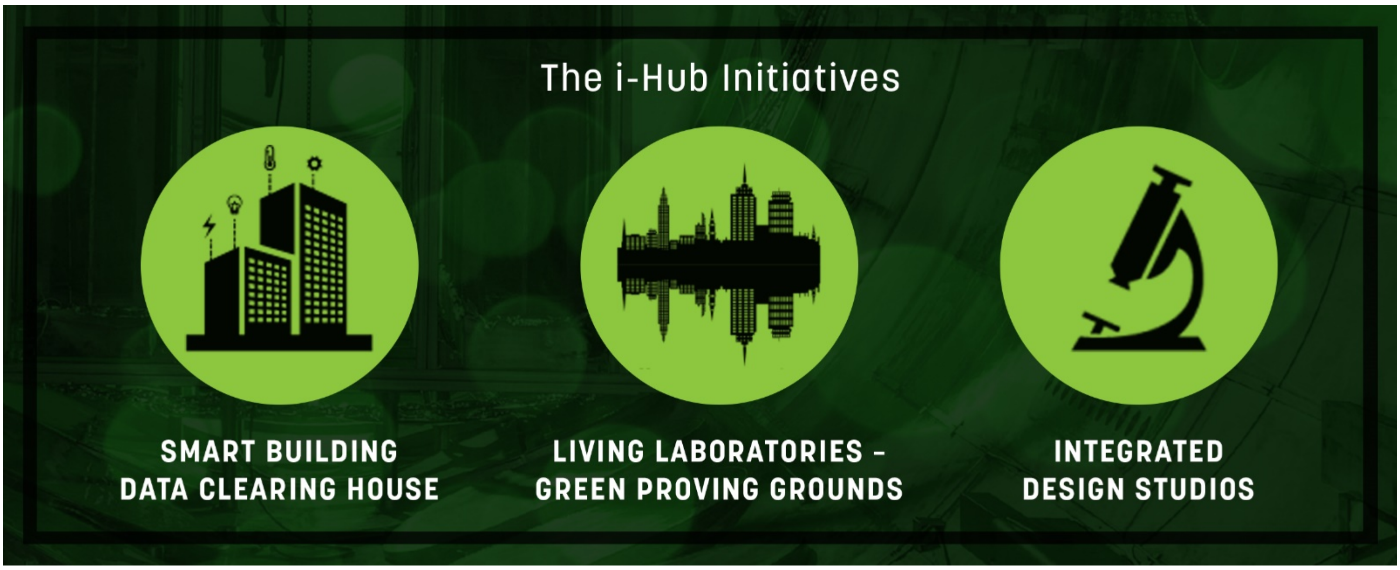

Healthcare Living Laboratories: Queensland Children's Hospital – Operation Manual

The Living Laboratory in Queensland Children's Hospital (QCH) will support the hospital 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 hospital 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.

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QLD CHILDREN'S HOSPITAL LIVING LAB PROSPECTUS

This prospectus provides information about the Queensland Children's Hospital precinct and its energy use.

1 INTRODUCTION

Hospitals are one of the most energy intensive commercial building types in Australia. In 2014-15, hospitals accounted for 44% of Australian of greenhouse gas emissions attributed to the healthcare sector, which in turn accounted for approximately 7% of the total Australian CO_2 emissions. The energy intensity of hospitals is attributed to their 24/7 operation, the use of energy intensive equipment, the need for infection and temperature control, and the frequent inclusion of onsite kitchen and laundry services. Improving energy productivity and developing appropriate sector wide key performance measures are challenging because of differences in clinical services, patient activity and floor space utilisation. With rising health care costs and demand, there is a need to optimise high-cost hospital infrastructure. In particular there is a need for (a) control and optimisation strategies that can provide the essential energy services cost effectively, (b) renewable energy supply options that reduce exposure to rising commodity prices, and (c) demand response capability to reduce exposure to peak demand pricing and extreme weather events.

This project will directly address these challenges by establishing a Living Laboratory in Queensland Children's Hospital (QCH) precinct. It will enable a community of innovators, designers, researchers, practitioners and educators to test and evaluate technologies and practices to deliver greater energy productivity, reduce peak demand and explore innovative options for embedding renewable energy and storage into a hospital campus.

QCH is a specialist state-wide quaternary hospital and health service which provides safe, high-quality and family-centred care for children and young people from across QLD and northern NSW. The Living Lab 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. patient numbers or length of hospitalisation or staffing levels or occupant health). Outputs from this Living Lab will feed into the i-Hub's Healthcare Sector Wide project (LLHC1).

2 SITE DESCRIPTION

The Queensland Children's Hospital precinct is comprised of three buildings:

- the Main Hospital (MH) Building;
- the Centre for Children's Health Research (CCHR); and
- the Central Energy Plant (QCH EP) Building.

Chilled water, heating water, gas, power, communications, security monitoring and a pneumatic tube system are provided on a precinct basis, connecting all three buildings. The HVAC system is essential for not only thermal comfort conditions (controlling temperature, relative humidity and ventilation), but also for control of airborne infection transmission.

2.1 QCH Main Hospital (MH) building description

The Queensland Children's Hospital is a public children's hospital in Brisbane, Queensland. It opened on 29 November 2014. The main hospital building consists of 19 levels (consisting of 12 clinical levels, 3 levels for general health services and 4 levels of basement carpark). The total floor area is 112,000 m^2, including approximately 80,000 m^2 of clinical space to accommodate 359 public hospital beds (overnight and same day). There are seven retail tenancies within the QCH MH building, providing a range of food and other retail services for the patients, families and staff. Other facilities include roof garden areas and garden terraces, a play and performance areas and a school.

The building was designed to be welcoming (not 'hospital-like), safe and environmentally sustainable. It features a well-sealed façade (1-2m^3/hr/m^2 at 50Pa), a curtain wall façade system with external fins to provide shading, use of natural light, and two large full-height atria.

Three main types of HVAC systems condition the various spaces:

(i) Constant-air-volume (CAV) systems are used for critical departments that have even loads, such as the emergency department, medical imaging and the paediatric intensive care unit (PICU);
(ii) Variable-air-volume (VAV) systems are used in load varying spaces such as outpatient areas, consulting rooms and offices where some form of localised control is required;
(iii) Active chilled beam systems are used in areas where 100% fresh air is desirable such as patient wards. The chilled beam systems also offer the additional benefit of being able to provide individual temperature control to rooms.

Carbon dioxide sensors are used in some areas as a proxy for occupancy levels, in order to enable modification of ventilation rates to match occupancy.

In addition to the main HVAC systems, a number of small packaged air conditioning (PAC) systems are utilized in non-clinical areas, such as 9 PAC systems for the kitchen area on Level 3.

The MH building also features more than 60 fire compartments and 80 smoke compartments, with some floors having up to nine compartments each. It has more than 200 air-handling units (AHUs), about 1000 motorised fire dampers, 73 smoke exhaust fans and 13 stair pressurisation fans.

Figure 1 QCH Main Hospital Building

There is an outdoor plant room on Level 3 of the main hospital (Figure 2). The plant room has seven outdoor APAC condensers available for HVAC related technology testing. The seven condensers are for the cooling rooms and freezer in the hospital's kitchen area.

Figure 2 QCH Main Hospital Outdoor Plant Room

2.2 Centre for Children's Health Research (CCHR) description

The Centre for Children's Health Research (CCHR), is a 9-storey building which unites children's health research and services with the hospital. Five levels of the CCHR are dedicated to research spaces and include:

(i) wet and dry laboratories;
(ii) a gait laboratory;
(iii) a nutrition laboratory; and
(iv) the Queensland Children's Tumour Bank, which provides a tissue repository for national and international cancer research.

The remaining levels accommodate the QCH Pathology service, office areas, facilities management staff, reception, car parking and a COVID19 testing area.

The CCHR building, previously also called Academic and Research Facility (ARF) building, has a total floor area of 14,108 m^2. The building has five different types of HVAC systems (including CAV systems, VAV systems and fan coil units (FCUs)), serving 41 different zones. There are 55 air distribution terminal units.

Figure 3 Centre for Children's Health Research (CCHR)

A few meeting room spaces are available for installing or testing building thermal performance related energy efficiency products or technologies (Figure 4). Examples of potential technologies may include lighting technologies, shades, blinds, control technologies for blinds or shades, tinting, indoor environment sensors.

Figure 4 An Office Space in CCHR

2.3 Central Energy Plant (EP) building description

The QCH EP building (Figure 5) consists of five levels with the total floor area of 4,500 m^2. Its function is to house the equipment that provides the entire power, heating, cooling and steam requirements to the QCH MH building and the CCHR building. The energy plant consists of

- (i) a central chilled water plant, supplying chilled water to the QCH precinct;
- (ii) a central natural gas fuelled hot water plant, for HVAC and domestic hot water needs;
- (iii) a central natural gas fuelled steam boiler plant (two boilers rated at 1958 kg/hr) used primarily to supply steam for the central sterilisation process of the MH and for humidification within the HVAC system;
- (iv) a condenser water plant for heat rejection;
- (v) six cooling towers including water treatment plant for the cooling towers;
- (vi) a natural gas fuelled power generation (trigeneration) facility (decommissioned 2019);
- (vii) other items ancillary to the central plant (e.g. ventilation and other air conditioning);
- (viii) a standby power plant (12MW) consisting of four diesel powered continuous-rated generators of 3.0MVA (2,400kWe) each. This provides QCH with full power security;
- (ix) a chlorine dosing plant located within the basement carpark of the MH; and
- (x) three 7MW each, 11kV electrical cables feeding the EP from the local supply authority (Energex). This provides an N+2 redundancy for the electrical supply to the precinct.

Energy efficiency or renewable enabling technologies can be tested on the EP. Examples may include:

- technologies to optimise the operation of HVAC system in terms of reliability, costs and performances, predictive maintenance, threat identification and countermeasures
- technologies to improve HVAC chiller efficiency and water treatment
- heating electrification

Figure 5 QCH Central Energy Plant (QCH EP) Building

2.3.1 Cooling and heating

This central energy plant supplies the hospital and research facility with their chilled water and heating hot-water requirements.

The chilled water plant comprises one 1,100kWr low-load swing variable-speed drive (VSD) low-voltage electric centrifugal chiller, and five VSD low-voltage electric centrifugal chillers of 3,315kWr each, with a full-load minimum coefficient of performance (COP) of 6.7. These are configured in an N+1 redundancy arrangement. Combined, the total chilled water capacity of the central energy plant is up to 20MWr.

The central-heating hot-water plant consists of seven 1,110kW gas-powered hot-water heating boilers that have been sized to meet the total heating load. These are configured in an N+1 redundancy arrangement, and serve air conditioning, heating and dehumidification, as well as domestic hot water.

2.3.2 Steam

The central energy plant also provides the entire hospital site with its steam requirements, typically used for cleaning, disinfection and sterilisation. This is achieved by two natural-gas-fired steam boilers of 1,300kW each, configured in a duty/stand-by arrangement.

2.3.3 Trigeneration

The trigeneration system designed for the building was decommissioned in 2019, due to the high price of gas. The trigeneration system originally featured two gas-powered 2,400kWe turbine generators combined with hot water heat exchangers providing 5,400kW of heating hot water, and two single-stage lithium bromide absorption chillers of 1,100kWr each. Two selective catalytic reduction (SCR) systems were also provided, featuring 15,000L of urea storage providing nitrous oxide (NOx) emission control for each generator. The trigeneration could supply most of the hospital's power, heating, cooling and steam requirements, which also reduced the demand on the local electricity grid by 60 per cent during peak consumption period.

The decommissioning of the trigeneration system came about as the result of a whole of government electricity procurement process with one of the government owned generators that locked in a single electricity supply for all government departments for a 10-year period from January 2019. The low price of energy (network prices remained untouched) has meant that the trigeneration plant is no longer economical to operate when fuel and maintenance costs are factored in.

Previously, the trigeneration plant was used to off-set peak electricity prices when gas prices were low. This is no longer the case with gas prices being higher than the price of electricity taken from the grid. The lithium bromide chillers and SCR systems have also been decommissioned.

2.3.4 Other plant

The central energy plant facility also accommodates the site's stormwater treatment and reuse plant. It features two ultrafiltration modules and an ultraviolet disinfection system with chlorine dosing. This plant is able to treat and supply 65,000L of high-quality recycled water that is then used as make-up water by the site's six 4,951kW crossflow induced-draft cooling towers.

2.3.5 Monitoring

A Trend Building Management System (BMS) is used in the QCH precinct to control and monitor the buildings' climate and other controllable devices and variables, such as air-handling units (AHUs), fan coil units (FCUs), and ancillary items of HVAC plant. The monitored system includes: chilled water plant, condenser water plant, hot water plant, trigeneration system, air conditioning system, ventilation, hydraulic equipment, and fire services.

Monitoring of the electrical energy throughout QCH EP is split into two packages – The BMS monitoring all Mechanical Electrical kWe Meters (54 × ION/6200 EPL), and the EMS monitoring all Distribution Electrical Meters (55 × CET PMC 660).

3 SITE BASELINE ENERGY DATA

3.1 Site energy composition and usage

This section provides an overview of the QCH Precinct's 2019 electrical energy use and peak demand.

3.1.1 Site electrical energy use

Table 1 summarises the monthly electrical energy use for the QCH precinct by building type and major energy sources, for 2019. (Note: more historical data will be available in the coming months for analysis). The three buildings are the energy plant building (EP Building), QCH MH Building and the CCHR Building. The three sources of electrical energy were site import (through Energex network, and with a power purchase agreement), and self-consumed onsite electricity generation using gas and diesel. Note that there has been no gas-powered electricity generation since April 2019, when the trigeneration plant was fully decommissioned.

Table 1 Site electricity energy use in 2019

Total (kWh)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Site Energex Import	2602801	2327742	2638798	2267107	2213731	2035173	2112287	2073437	2086117	2279833	2372280	2518246
EP Building	988940	852039	987640	695175	557370	444707	444192	424182	494118	628978	765663	891394
QCH MH Building	1466637	1340606	1480513	1429252	1498001	1443177	1503778	1497927	1439638	1487180	1447744	1462831
CCHR Building	171953	163801	183124	173181	177911	166243	174342	169645	168490	180773	176020	181702
Gas Generation	6482	21157	0	12884	0	0	0	0	0	0	0	0
Diesel Generation	7979	0	4998	8643	10365	8638	1	8639	7977	7973	7976	7976
Total Import + Generation	2617262	2348899	2643796	2288634	2224096	2043811	2112288	2082076	2094094	2287806	2380256	2526222
Total Site Use	2627530	2356446	2651277	2297608	2233282	2054127	2122312	2091754	2102246	2296931	2389427	2535927

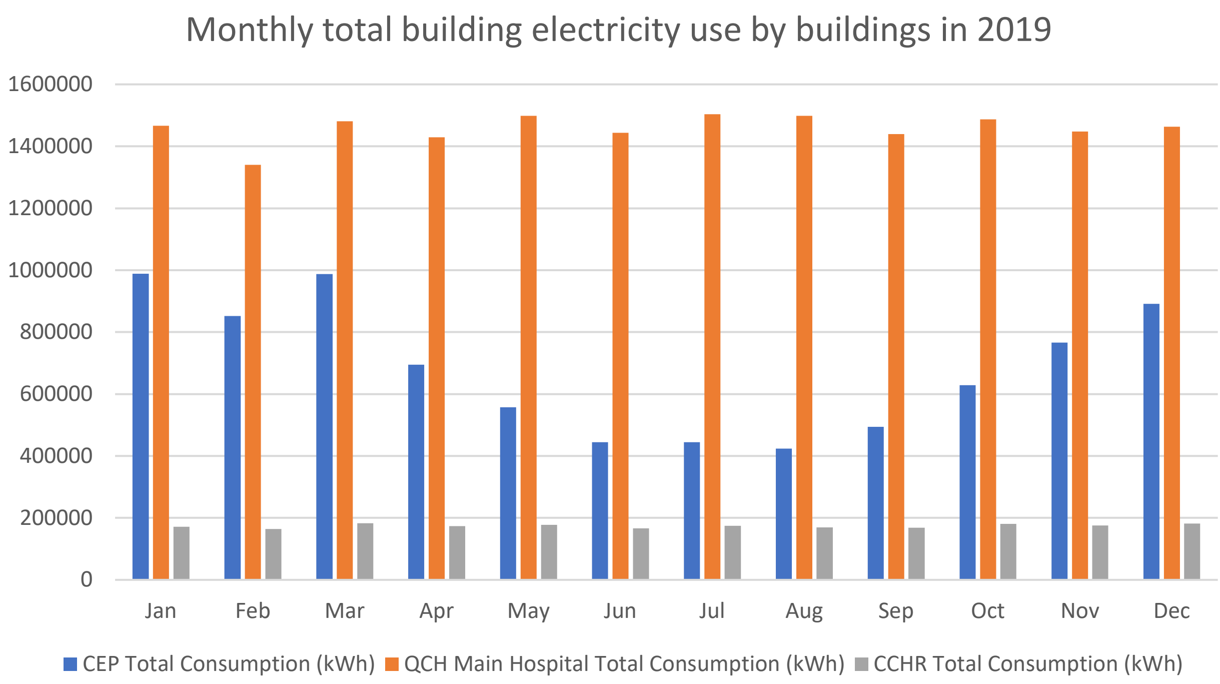

Figure 6 Monthly total building electricity energy consumption by buildings in 2019

Figure 6 demonstrates the monthly total building electricity energy consumption in each building in 2019. The energy use of the EP building varied seasonally: high in the summer months (December to March) and low in winter months (June to August). Jan 2019 to Aug 2019 electricity consumption ratio is 2.3. The likely explanation for this large variation is the variation in heating and cooling demand (assuming no significant change in the number of patients visits to the hospital across winter and summer seasons.) The QCH MH building had the largest total electricity electrical energy use, but it is relatively consistent throughout the year (i.e. no seasonal variation). The CCHR building uses the least energy, and usage is also consistent across all month. The non-seasonality of the MH and CCHR makes sense in that cooling loads are accounted for in the EP.

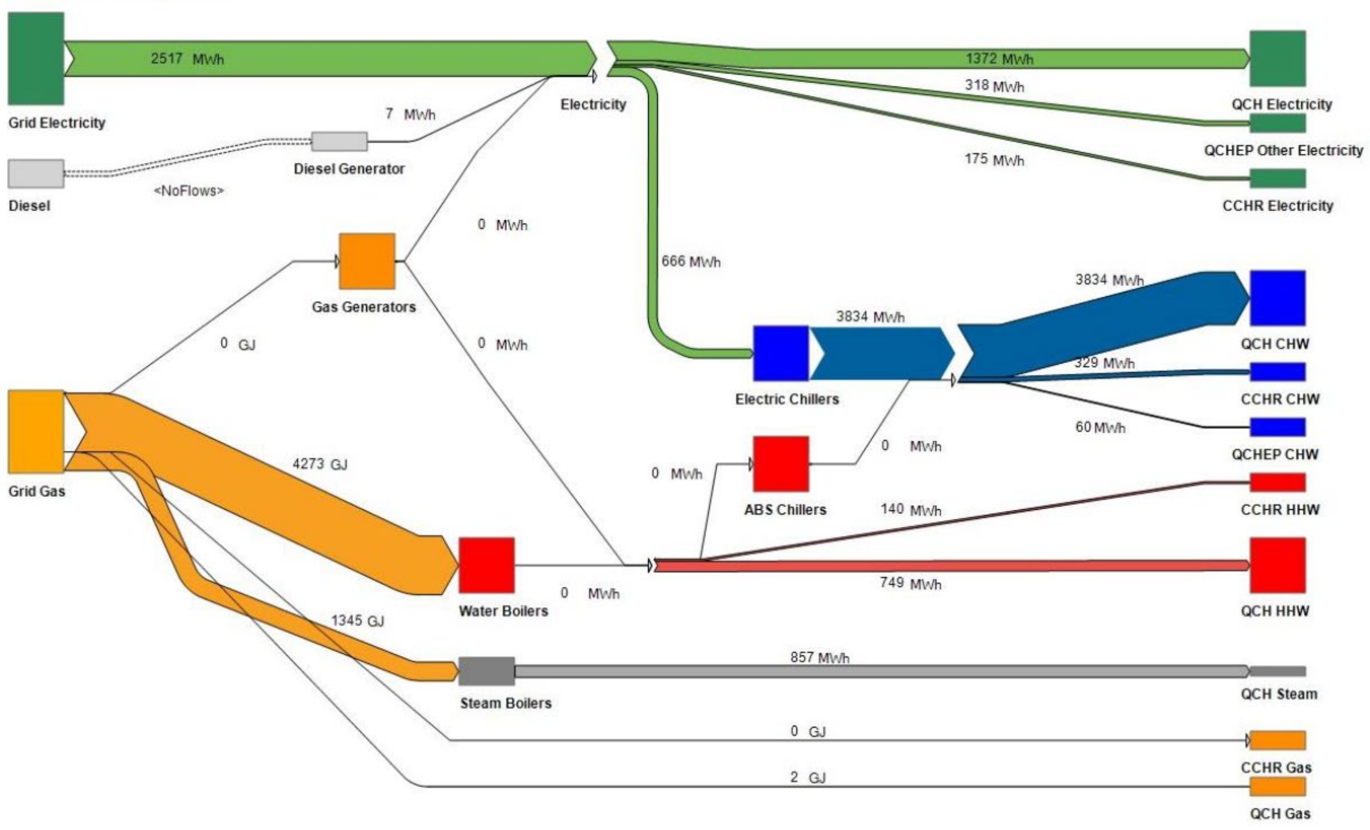

Figure 7 QCH precinct energy flow Sankey Diagram February 2020

Figure 7 shows the precinct's energy flows (grid electricity, diesel and grid gas) for February 2020. It shows the flows of energy for the main energy services – electricity, chilled water, heating hot water, steam and gas.

Figure 8 is a visual presentation of the total site Energex import shown in Table 1. It shows four months of high electricity use in summer (December to March), low use in winter and early spring (June to September), and two shoulder seasons of two months each. The total electricity import for 2019 was almost 25,636 MWh.

Figure 9 shows three years of monthly total energy use for the QCH precinct. The three years of monthly data show a similar trend: higher energy use in summer months and lower energy use in winter months. Februaries seemed to use less electricity, which was because February had 3 days less than January and March. The per day energy uses in February were similar to other summer months.

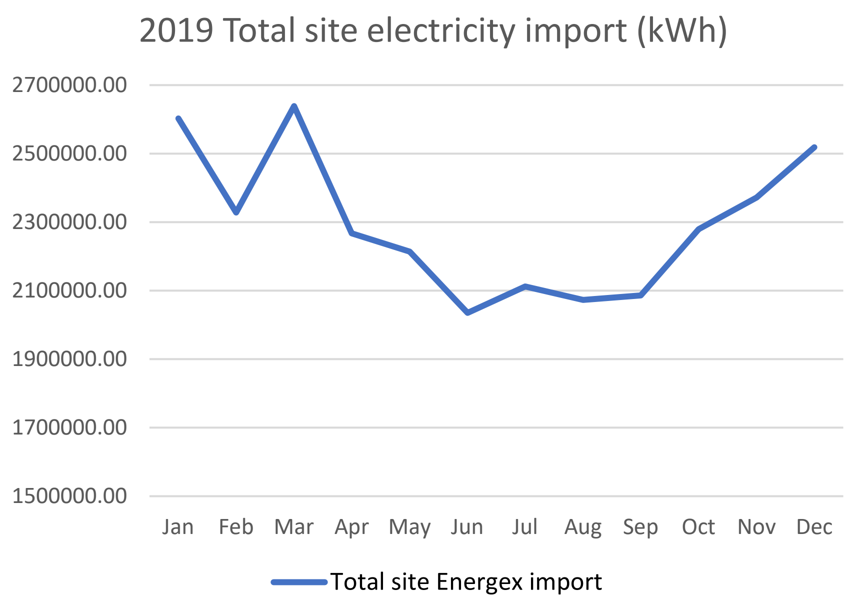

Figure 8 QCH Precinct Energex electricity import by month

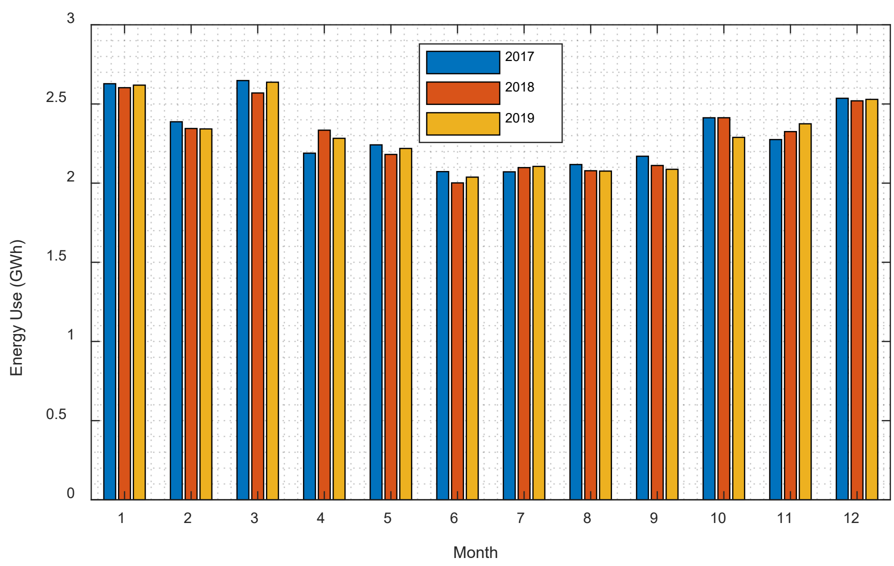

Figure 9 QCH Precinct total electricity consumption by month

3.1.2 Demand profile

Demand (or power demand) is a rate and shows how fast energy is used. Demand tariffs are often applied to businesses and large organisations. Demand tariffs often have a demand charge component and an energy use component. In Australia, demand charges are calculated based on the highest 30-min demand in a month (e.g. in kilowatts kW). The QCH precinct's highest demands of each month for 2017, 2018 and 2019 are listed in Table 2 and visually presented in Figure 10. February always had the highest monthly peak demand and the Feb 2018 peak demand is 38% higher than the lowest monthly peak demand in Jun 2018.

Table 2 Site building peak demand profile in 2019

30min peak kW	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
QCH Precinct 2017	4670	4711	4663	3957	4051	3860	3810	3716	4153	4412	4557	4647
QCH Precinct 2018	4756	5045	4628	4236	4056	3666	3846	3691	4134	4187	4638	4795
QCH Precinct 2019	4721	4915	4672	4208	4000	3840	3667	3733	4005	4491	4541	4578

Figure 10 QCH Precinct peak power demand by month

Figure 11, Figure 12 and Figure 13 show the boxplots of four month's demand profile in 2017, 2018 and 2019. The four months were February, April July and September in each year and they were selected out of each season. The demand is the total demand (kW) in 30min interval, including electricity imported from three Energex feeders and onsite generation from diesel generators and gas generators.

The red horizontal dashes inside each blue box are median values. The top edge of each blue box is the 75th percentile and the bottom edge of each blue box is the 25th percentile. When there are no outliers, the top end of the whisker above each blue box is the maximum value; the bottom end of the whisker below each blue box is the minimum value. The red crosses are outliers for each 30min interval.

The boxplots show three different seasonal demand profiles: a high demand profile in summer, a low demand profile in winter, and medium demand profiles in the shoulder seasons. The likely reasons for this relate to Brisbane's climate which has a mild winter (and therefore minimum energy required for HVAC loads), and a hot and humid summer (and therefore more energy and power demand required to keep buildings cool). This data analysis strongly suggests that the variation of electrical demands is largely related to HVAC loads for cooling.

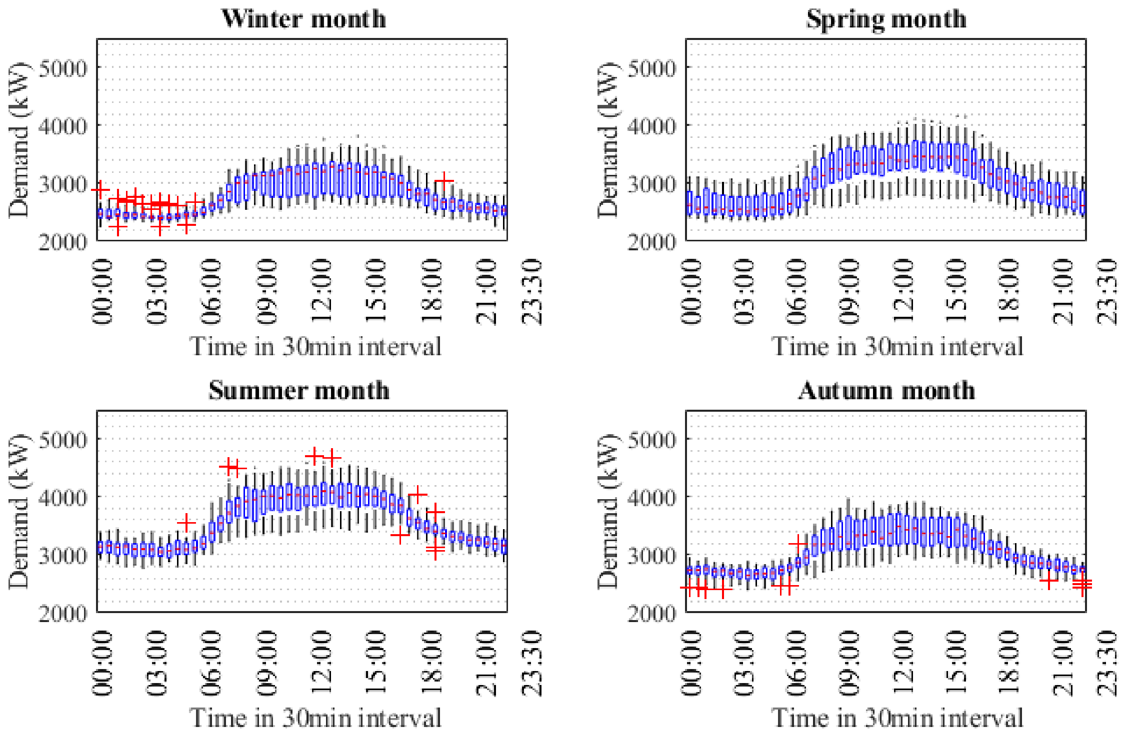

Figure 11 QCH Precinct 30min power demand profile in four months in 2017

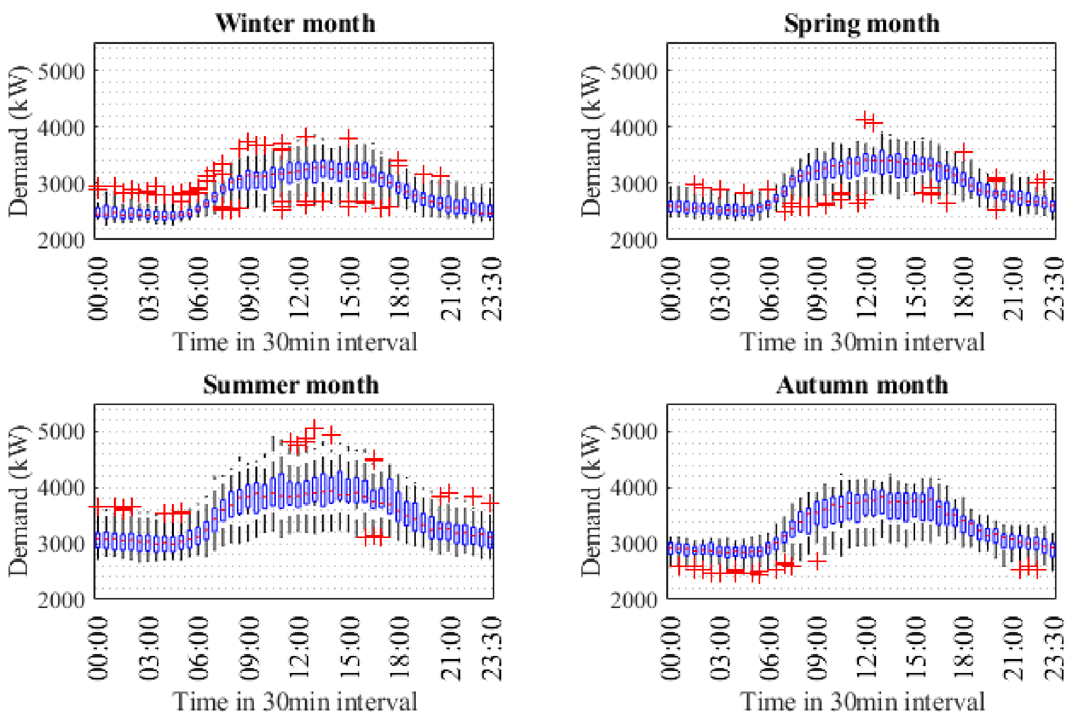

Figure 12 QCH Precinct 30min power demand profile in four months in 2018

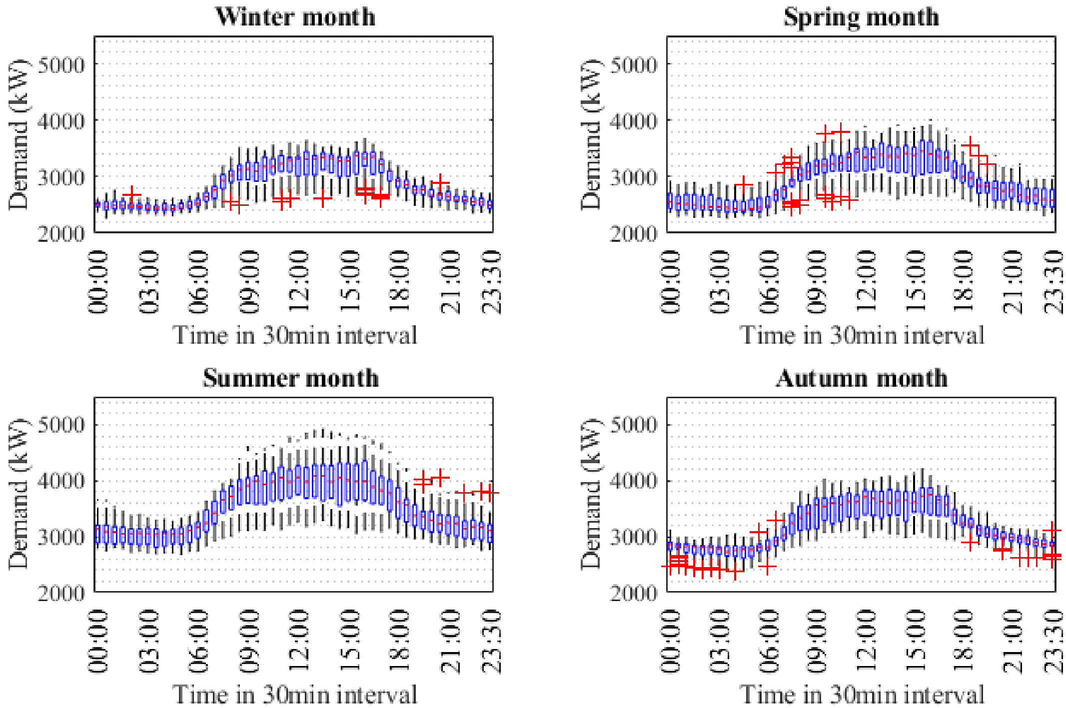

Figure 13 QCH Precinct 30min power demand profile in four months in 2019

3.1.3 Current key performance indicators (KPIs)

Three commonly used KPIs for energy use intensity in hospitals are energy use per floor area per annum (kWh/m^2/yr), energy use per bed day per annum (kWh/bed day/yr) and energy use per separation (kWh/c). Each of these has its own benefits and limitations, as outlined in the Healthcare Baseline Energy Report. NABERS Energy and Water Use for Hospitals adjusts annual energy use figures by hospital characteristics including annual occupied bed days, annual separations, hospital peer group (types of services offered) and climates.

QCH precinct data analysis to date includes the last full calendar year (2019). Further data analysis will be undertaken when more historical data becomes available. Table 3 shows the monthly and annual (2019) energy use intensity (EUI) in kWh/m^2 of each of the QCH precinct buildings. The total QCH precinct EUI ranges from 125 kWh/m^2 in August to 252 kWh/m^2 in March. The CCHR building has the lowest annual EUI of 148 kWh/m^2/yr. followed by the MH building of 219 kWh/m^2/yr and the EP building of 1817 kWh/m^2/yr. The total QCH precinct energy intensity is 2183 kWh/m^2/yr. These results seem to indicate that the MH's EUI is well under the mean EUI of Australian hospitals[1] (426.7 kWh/m^2/yr), however it should be remembered that the cooling load of the MH building is not included in this figure: it is accounted for in the EP building. The total QCH precinct EUI is approximately five times the mean EUI of Australian hospitals, however the

[1] Council of Australian Governments (COAG), Baseline Energy Consumption and Greenhouse Gas Emissions in Commercial Buildings in Australia. Department of Climate change and Energy Efficiency, Canberra, 2012.

precinct has a research building that is not typical in all hospitals, and as a quaternary hospital potentially has more energy intensive medical diagnostic equipment than is typical in other hospitals. The wide range of EUIs reported by hospitals nationally and internationally highlights one of the problems with this metric. Floor area alone cannot explain differences in energy use intensity. Variations in EUI could conceivably be due to differences in climate, types of clinical services provided, and the presence of various high-power medical diagnostic equipment. This is one reason why the NABERS for Hospitals data adjusts data as explained previously. QCH's energy data will be compared to NABERS Energy and Water Use for Hospitals data when it becomes available.

Table 3 Energy use intensity in QCH precinct by month in 2019

Total (kWh/m2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
EP Building	219.8	189.3	219.5	154.5	123.9	98.8	98.7	94.3	109.8	139.8	170.1	198.1	1817
QCH MH Building	18.3	16.8	18.5	17.9	18.7	18.0	18.8	18.7	18.0	18.6	18.1	18.3	219
CCHR Building	12.2	11.6	13.0	12.3	12.6	11.8	12.4	12.0	11.9	12.8	12.5	12.9	148
Total precinct	250	220	252	184	156	129	130	125	140	172	200	229	2183

Table 4 Energy use figure of the QCH MH building in 2019

Total (kWh/bed)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
QCH MH Building	4085	3734	4124	3981	4173	4020	4189	4172	4010	4143	4033	4075	48739

Table 4 demonstrates the monthly energy use in kWh/bed for the QCH MH building in 2019 and the annual energy use intensity of 48,739 kWh/bed/yr. Note that the monthly energy use intensity for this building is relatively stable, at around 4,000 kWh/bed. This is another indicator that the cooling load of the MH is not accounted for in these figures.

Another common way of communicating energy use intensity is correlation with heating and/or cooling loads. The annual Cooling Degree Days (CDD18) in Brisbane is 1129 (45 years data 1967-2012) based on RMY2012 weather data. The kWh/CDD18 were calculated for each of the buildings and the precinct, as shown in Table 5. It shows that the CCHR building has the lowest kWh/CDD18, and the main hospital has the highest. It is not clear, at this stage, whether this metric by itself provides useful information for managing energy demand and consumption. For example, 2019 weather data would need to be analysed to calculate actual CDD to compare with actual electricity use for that year. Actual CDDs would also need to be compared with historical CDDs to determine trends due to a warming climate, and then determine the impact of such trends on cooling loads.

Table 5 Energy use data in kWh/CDD18 of the QCH precinct in 2019

Energy intensity (kWh/CDD18)	Annual
EP Building	7240
QCH MH Building	15498
CCHR Building	1849
Total precinct	24,587

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 Potential key performance indicators

Current hospital sector KPIs are often based on energy use per annum, as demonstrated in the previous section. To assist with energy management decisions, more detailed or purpose oriented KPIs may be needed. As indicated previously, the hospital precinct's energy use and power demand are seasonal and 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 6. Additional KPIs may be identified and tested over time, including KPIs that relate to health outcomes.

Table 6 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

This manual outlines the processes that will be followed in operating the Living Laboratory at Queensland Children's Hospital. Technology providers are advised to read this manual carefully to understand whether this facility is a suitable avenue for testing of their technology.

5 MEASUREMENT AND VERIFICATION (M&V)

5.1 M&V techniques

All Measurement and Verification (M&V) techniques employed will be consistent with the International Performance Measurement and Verification Protocol (IPMVP), which outlines minimum requirements for calculating savings from energy efficiency improvement projects.

However, this Living Lab will differ from typical M&V in several key points:

- The measured output of the i-Hub project is the increase in the value of renewable generation, rather than simply increasing energy efficiency. This means that M&V will have increased complexity that includes considering energy use of HVAC-related equipment, energy generation of renewables and the potential energy demand management strategies to improve grid stability and reduce site costs.
- Some of the renewable energy and enabling technology benefits, for instance peak demand reduction and demand response (DR) capacity, may not be able to be metered or directly observed. Benefits could be calculated based on a comparison between the observed load, and a theoretical estimate of what the load would have been in the absence of the renewable energy or enabling technology.
- The specific technologies that will be (could be) tested in the Living Lab are unknown, and as such, the monitoring systems will need to be flexible, detailed and comprehensive.
- This project is a research-grade living laboratory, designed to delve deeper than the typical M&V project requirement to comply with the minimum standards of an accepted protocol in order to report the energy savings of an energy conservation measure.

As a result of these considerations, the M&V processes implemented in this Living Lab will go beyond those outlined in the IPMVP.

The key calculation principle to determine 'savings' from an intervention will be calculated as:

Savings = (Baseline Period Use or Demand – Reporting Period Use or Demand) ± Adjustments

where adjustments refer to calculations completed to account for differences in independent variables between the baseline and reporting periods.

This principle is illustrated in Figure 14, where 'retrofit' is equivalent to a technology intervention.

For this hospital, the major calculated adjustment is expected to be changes to external weather conditions. Further explanations of expected adjustments are discussed in Section 5.3.

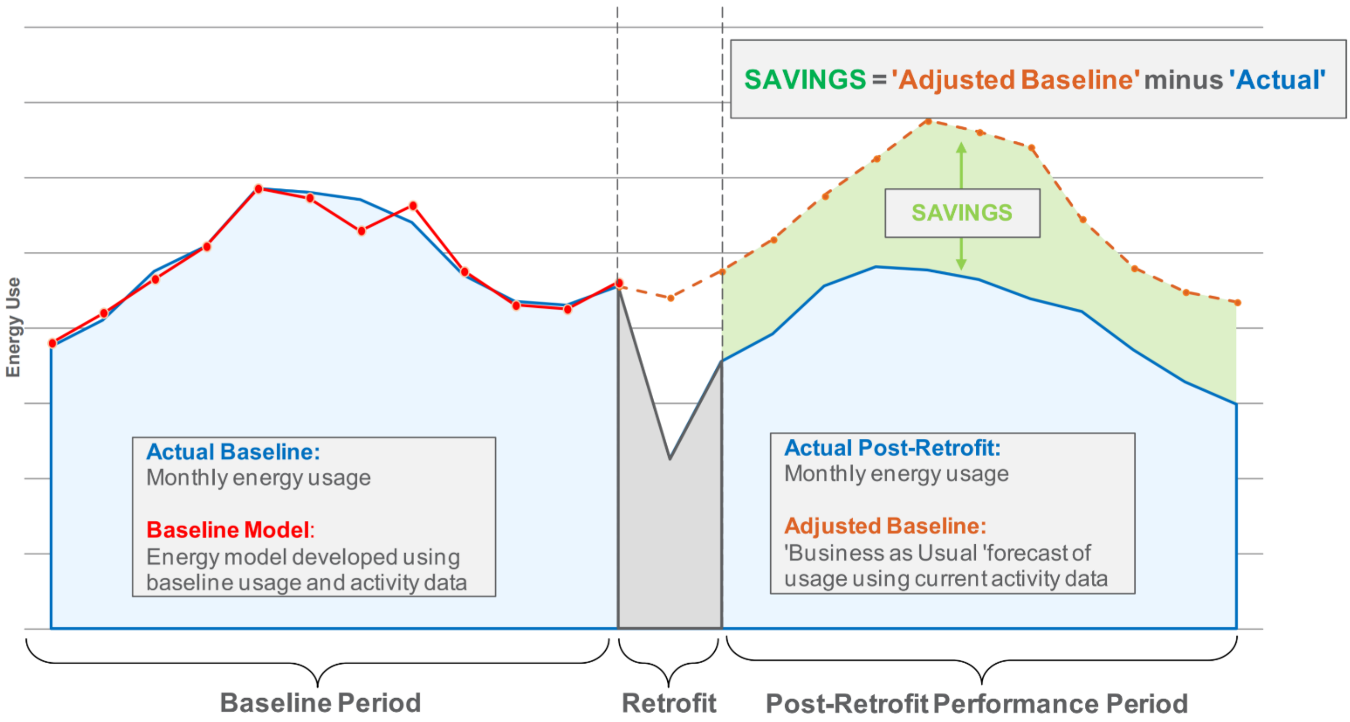

Figure 14 Savings calculation principle[2]

The IPMVP outlines four M&V options:

(i) Option A: Partially Measured Retrofit Isolation;
(ii) Option B: Retrofit Isolation;
(iii) Option C: Whole Facility (Building); and
(iv) Option D: Calibrated Simulation.

The option utilised for any technology test regime will depend on the technology and where it connects to QCH's energy system. Key conditions for selecting the most appropriate option include:

- whether the measurement boundary can be isolated for technology testing/intervention and all associated conditioned room(s);
- key parameters that may significantly influence the energy savings calculation (e.g. outdoor weather, occupancy patterns, changes to key energy equipment);
- baseline data availability;
- building data to enable a simulation to be constructed and calibrated.

It is envisaged that technology testing / intervention will likely use Options B, C and D individually and/or in combination, as determined case by case. A summary of how these three options will be applied is shown in Table 7.

[2] https://www.environment.nsw.gov.au/resources/energyefficiencyindustry/120990bestpractice.pdf

Table 7 IPMVP Options B, C and D

Excerpt from IPMVP (2012): Overview of IPMVP Options	
IPMVP Option	**How Savings Are Calculated**
Option B. Retrofit Isolation: All Parameter Measurement Savings are determined by field measurement of the energy use of the ECM-affected system. Measurement frequency ranges from short-term to continuous, depending on the expected variations in the savings and the length of the reporting period.	Short-term or continuous measurements of baseline and reporting period energy, and/or engineering computations using measurements of proxies of energy use. Routine and nonroutine adjustments as required.
Option C. Whole Facility Savings are determined by measuring energy use at the whole facility or sub-facility level. Continuous measurements of the entire facility's energy use are taken throughout the reporting period.	Analysis of whole facility baseline and reporting period (utility) meter data. Routine adjustments as required, using techniques such as simple comparison or regression analysis. Non-routine adjustments as required.
D. Calibrated Simulation Savings are determined through simulation of the energy use of the whole facility, or of a sub-facility. Simulation routines are demonstrated to adequately model actual energy performance measured in the facility. This Option usually requires considerable skill in calibrated simulation.	Energy use simulation, calibrated with hourly or monthly utility billing data. (Energy end use metering may be used to help refine input data.)

All methods require detailed and long-term monitoring of key parameters and independent variables. Option B and C uses this data directly to create a regression model for normalisation. Option D uses the data to calibrate a building performance simulation model of the facility, which can then be simulated under consistent conditions for the baseline and reporting periods. Option D can use the baseline period data to calibrate and verify a building performance simulation model of the facility, which can then be used to simulate energy use under consistent conditions for both the pre-retrofit and post-retrofit configurations during the post-retrofit reporting period. The use of a validated and calibrated simulation will be better able to normalise for external conditions using representations of typical weather conditions than regression methods. Further information about building simulation can be found in Section 7.1.

5.2 Defining the measurement boundary

The measurement boundaries for measurement and verification of HVAC-related technology upgrades are normally defined in reference to:

- A piece of HVAC equipment or energy system, including all the spaces it serves; or
- A separately zoned conditioned space, such as a room, or a group of rooms, which may contain multiple HVAC systems.

The measurement boundaries for the QCH Living Lab will depend on the type of technology being tested, and may include, for example:

- A specific room or floor (e.g. for measuring the impact of a building element on reducing external heat gains, and hence the impact on HVAC load and energy consumption)
- A specific HVAC component (e.g. a PAC serving a specific area, such as the kitchen; or the cooling towers; or the chilled water system; or roof-mounted equipment)
- A part of a building (e.g. the car park; or a specific operational area)
- A whole building (e.g. the CCHR)
- The whole precinct (e.g. energy system optimisation through software connecting to the building management system)

It is not envisaged at this stage that the QCH Living Lab will test technologies in clinically functional areas of the main hospital building.

As one of the main goals of the i-Hub is to assess the change to the value of renewable energy, each technology assessment will include an evaluation of the impact of the technology on QCH's ability to increase the percentage of renewable energy purchased through the current Power Purchase Agreement (PPA) and/or enable onsite precinct level or neighbourhood level renewable energy generation.

In general, all technology assessments will use before and after comparison. Control and intervention comparison may be used in addition in the case that two comparable test units are able to be effectively isolated. The preferred analysis method is to monitor multiple functional spaces and use a combination of pre- and post- comparison and control- intervention pairs. In this case one functional space would not receive an intervention and would be used to validate the multi-variate regression model that is then used to adjust the baseline and reporting data for the intervention space.

5.3 Adjustments and constraints

IPMVP classifies adjustments as routine and non-routine adjustments. Routine adjustments are adjustments to the monitored data that were anticipated as part of the M&V plan, for instance adjusting for different weather conditions. Non-routine adjustments are unexpected events that require adjustments, for instance failure of a piece of equipment during the monitoring period.

Some constraints will be held constant between the reporting and baseline period. These constraints will be used to define the multi-variate regression model for adjustment of observed differences.

5.3.1 External conditions

In order to calculate weather corrected indices, the following external conditions will be monitored via the onsite weather station:

- Global horizontal irradiance (GHI)
- External temperature (T_a)
- External relative humidity (RH_a)
- Air velocity and direction
- Rainfall (duration, intensity)

The existing weather station records, in 15-minute increments, temperature, relative humidity, wind speed and direction, light levels in Lux and rainfall events (not quantity). An additional weather station will be installed to collect GHI and rainfall data. The two weather stations provide a redundancy and sensor calibration functionality. Weather station data will be used for performance evaluation and building simulation. Onsite weather data may be compared to the nearest Bureau of Meteorology site data, to determine any potential microclimate conditions.

5.3.2 Indoor environment quality

Internal conditions (e.g. temperature, relative humidity, CO_2 levels) will be monitored as per QCH's building management system (relative to the area under test). This is to ensure that comfort conditions are consistent between the baseline and reporting periods.

5.3.3 Energy plant performance

Energy plant performance (e.g. chilled water, air handling units, fan coil units) will be monitored as per QCH's building management system (relative to the area under test). This is to ensure that plant operation conditions are consistent between the baseline and reporting periods (other than those parameters that may be changed deliberately as part of the test regime being undertaken).

5.3.4 Hospital operational changes

Major impacts on 'standard' QCH precinct operation will be taken into consideration (e.g. if there is a major disease or illness that increases or decreases typical patient numbers or profiles; or if there is a change in a major tenancy in the CCHR).

6 MONITORING AND METERING REQUIREMENTS

QCH has energy meters for all three Energex feeders, as well as meters for energy supply to the three buildings. There are submeters for each floor for the CCHR building. Major equipment in the energy plant is also metered. Monitoring of the electrical energy throughout the QCH EP is split into two packages – the BMS monitoring all Mechanical Electrical kWe Meters (54 × ION/6200 EPL), and the EMS monitoring all Distribution Electrical Meters (55 × CET PMC 660). There are separate specialist contractors for the two data management systems.

There is an onsite weather station on the main hospital building. It monitors temperature, humidity, wind speed, wind direction, light level and rainfall. To help evaluate the performance of building related technologies, a new weather station (Vantage Pro2) will be installed alongside the existing weather station for additional measurements of UV and solar radiation. This weather station will enable remote access to data, reducing the need to impact on general hospital activities.

The need for additional meters will be considered on a case-by-case basis to enable appropriate measurement and verification of technologies being tested. Either QUT or an external independent contractor will be engaged to provide / manage any such monitoring and metering as is required, and as approved by QCH. Any additional devices added need to meet the following criteria:

- Be suited for the M&V purpose
- Be approved by QCH (and their installation / use managed by QCH)
- Meet relevant Australian Standards (or equivalent)
- Be calibrated
- Enable remote access to the data

- Have fault alarms

7 DATA ANALYSIS METHODOLOGIES

Depending on the purpose of technologies under test, three types of data analysis methodologies will be used: quantitative, qualitative, or simulation (or a mix of all three).

7.1 Quantitative analysis

Quantitative analysis will be used to analyse the impact of innovative technologies to improve HVAC efficiency, reduce peak demand, control energy loads, enhance energy productivity and add value to renewable energy options. Methods may include regression analysis, ANOVA analysis, distribution and modelling, simulation and forecasting, unsupervised machine learning etc. Quantitative analysis will also include financial analysis incorporating, for example, cost benefit analysis, cash flow, internal rate of return, etc.

7.2 Qualitative analysis

Qualitative analysis will be used to analyse the impact of innovative technologies on building users and building managers. Instruments such as surveys, questionnaires, interviews and focus groups can be used to obtain qualitative data. Such data could include, but is not limited to:

- The impact (positive, negative, none) on occupant comfort (thermal, visual, acoustic, air quality)
- The impact on clinical and administration staff (if the equipment relates to their work or working environment)
- The impact on facilities management (e.g. operational complexity, maintenance regime, staff training)
- The impact on asset management (e.g. total cost of ownership)

7.3 Modelling / simulation

Building simulation is Option 4 under the IPMVP process as discussed previously. An EnergyPlus building model is being created for the CCHR building in the first instance (future work may involve creating a model of the main hospital). The CCHR building has five different types of HVAC systems, serving 41 HVAC zones with 55 air distribution terminal units. The CCHR EnergyPlus model is being developed to model all the zones and terminal units.

EnergyPlus, open platform software, is a whole-building energy analysis tool that can simulate the actual energy performance of the building and its HVAC systems to predict annual building system operation cost and energy consumption. EnergyPlus is widely considered to be industry-standard software that is tested against both the International Energy Agency (IEA) BESTEST (Building Energy Simulation Test and Diagnostic Method) and ASHRAE Standard 140, making it as bug-free as possible. It also meets with the requirements of Protocol for Building Energy Analysis Software by the Australian Building Codes Board (ABCB).

Building simulation can then be used to extrapolate findings to the broader hospital sector (e.g. simulating the model in different climate zones). This will assist in calculating potential sector wide benefits of the tested technologies.

A model of the HVAC system will also be created in TRNSYS or similar software. The model will be verified against actual performance data. It can then be used to test 'what if' scenarios in terms of changes to plant operation. The use of modelling provides certainty to building operators of the likely impacts of changes to building operations, and dramatically reduces the risks associated with making changes to facilities management.

8 CONTRACTUAL ARRANGEMENTS AND ETHICS PROTOCOLS

8.1 Contractual arrangement

Queensland University of Technology (QUT) has an agreement with Children Health Queensland (Queensland Children Hospital's management body) regarding how QCH Living laboratory operates.

Prior to site work relating to any technology to be tested, a written agreement needs to be signed between QUT and the approved technology supplier. This agreement will stipulate the roles and responsibilities of all parties with regard to testing technologies within the QCH Living Lab. The agreement will include, as a schedule, the approved product testing plan that is developed by QUT in conjunction with QCH Facilities Management and the technology provider.

8.2 Ethics protocols

In general, this project focuses on technical studies of innovative technologies in improving HVAC efficiency, reducing energy consumption/demand and enabling renewable energy. However, one of the purposes of Living Laboratories is to deliberately include 'users' in the evaluation of technologies. Different categories of 'users' and how they could be involved, were presented in Section 7.2 (qualitative analysis). All such activities will require approval by both QUT's Research Ethics Committee and QCH's Research Ethics Committee. It is the responsibility of QUT's Project Manager and QCH's lead participant to ensure that the relevant processes are followed, and approvals are received before collecting data from any building occupant or user (other than those directly involved in the Living Lab).

9 INTELLECTUAL PROPERTY (IP) PROTOCOLS

9.1 Intellectual property

QCH and QUT jointly own this QCH Living Lab Operation Manual, with rights assigned to AIRAH/i-Hub to utilise the document for the purposes of operating the Living Lab and all associated activities. No commercialisation of this Operation Manual is permitted.

All background IP (i.e. intellectual property that exists prior to any product testing) will remain vested with the relevant party. Pre-existing material (such as that outlined in Section 10.3.1) provided by a technology provider to QUT and QCH will only be used for the purposes of product testing.

The Technical Report (for a specific technology) will include the technology test plan (how the test was conducted) and the results. It will be owned by QUT and published under Creative Commons (with attribution). **It is a requirement of i-Hub funding that all test results be made public** (without the disclosure of pre-existing commercial-in-confidence material).

The test report will be published, as a minimum, on the i-Hub website.

Test results may also be communicated by QUT in other ways, such as through academic publications, industry seminars, sector wide publications etc.

Test results can also be used by the technology provider for product development and commercialisation purposes. In all instances, the full Technical Report should be referenced, and test results should be fairly and accurately communicated by ensuring there is appropriate acknowledgement of the context, boundary conditions, test parameters and limitations of the test results.

9.2 Confidentiality

All parties are bound by confidentiality requirements. The provision of commercial-in-confidence information by technology providers for the purposes of product testing does not permit QUT or QCH to disclose that information to any other persons or for any other purposes. Conversely, technology providers are not to disclose any information about QUT or QCH that they may gain access to during the product testing processes. This includes patient or employee personal information, clinical data, and building and operations data. protocols.

10 TECHNOLOGY SELECTION PROCESS

10.1 Application process

10.1.1 Expression of interest / selection criteria

Potential technology providers are to, in the first instance, contact the i-Hub (www.ihub.org.au) or the QCH Living Lab project manager (refer to inside cover of this report). The technology provider will be encouraged to complete an Expression of Interest (EOI) form, in which they will communicate how they envisage their technology can meet the overall objectives of the i-Hub as well as be applicable for this Living Lab.

To be eligible for testing with i-Hub QCH LL, the potential technology suppliers need to:

- Be an Australian registered company
- Demonstrate that the application of the innovative technology may meet one or more of the i-Hub project goals:
    - control and optimisation strategies that can provide the essential energy services cost effectively,
    - renewable energy supply options that reduce exposure to rising commodity prices,
    - demand response capability to reduce exposure to peak demand pricing and extreme weather events.

10.1.2 Initial meetings

QUT will organise an initial meeting with the technology provider to discuss the technology and its current stage of development. If considered potentially suitable for the QCH Living Lab, a follow up meeting will be conducted between the technology provider, QUT and QCH representatives. This will include onsite visits so all parties are fully aware of the Living Lab conditions and limitations.

10.1.3 Project planning

On verbal agreement by QCH to potentially test the proposed technology, QUT will facilitate further meetings between all parties to plan the technology testing regime and scope. Technology providers will be expected to

- Sign a collaborative agreement with QUT relating to the test regime (refer to Section 8.1);
- Satisfy the business considerations, engineering, risk management and legal requirements (outlined in the following sections); and
- Be responsible for the installation, commissioning, maintenance and decommissioning of their equipment, for the duration of the test regime, and in accordance with any and all requirements of QUT and QCH.

10.2 Business considerations

This section outlines the core business aspects that technology providers need to comply with, in order to be considered for this Living Lab test regime.

10.2.1 Business registration and taxation status

In addition to provide register company name, address and contact details, companies will be asked to provide details of their business, such as Australian Business Number (ABN), Australian Company Number (ACN) and Tax File Number (TFN).

10.2.2 Insurances

Companies will be asked to provide details of relevant insurances, such as

- Public liability
- Professional Indemnity
- Product warranties

10.2.3 Living Lab bond

In some instances, technology providers may be required to pay a Living Lab bond – an amount that covers the potential cost of removal of the technology at the end of the testing period. The amount of this bond is to reflect the level of risk and cost associated with removal of the technology at the end of the test period, should the technology provider become insolvent or otherwise unable to decommission and remove the technology.

10.3 Engineering and risk management considerations

As part of the QCH's Living Lab due diligence, technology providers will need to meet a range of engineering, risk management and legal requirements as discussed below. This list is indicative, not exhaustive. Additional requirements may need to apply to specific technologies: these will be raised with companies in the discussion phase.

10.3.1 Engineering requirements

The technology proposed to be tested must meet Australian legislation and standards when there are relevant Australian legislation or standards. In case there is no relevant Australian legislation or standard for the technology, relevant European/US standards (e.g. BS, EU, ISO, IEC, ASHRAE, ASME, IEEE) would need to be referred to.

Technology providers will be required to submit the following information relative to the specific technology to be tested:

- certified copies of any previous test results
- all technical specifications and performance information (including, for example, Material Safety Data Sheets)
- all instructions (including installation, commissioning and operation information)
  Such information will be treated in confidence by QUT and QCH and will only be used for the purposes of determining an appropriate test plan.
- reference of previous case studies, contact person names, position, phone numbers and emails.

10.3.2 On-site work requirements

All onsite technology test work needs to comply with QUT, CHQ, and QCH workplace HSE requirements, as well as site specific requirements, such as site induction, building or area specific induction, safe work method etc.

A section of the written agreement between QUT and technology providers will include specific requirements from CHQ, and/or QCH, relative to the technology being tested.

10.3.3 Risk management

Risk management is a key part for selecting technologies and available test areas. Preferences may be given to areas and technologies

- with least to none exposure to QCH patients and clinicians
- with no connection needed to onsite communication network, IT infrastructure
- with a potential to be applied, tested and validated offsite, such as data driven technologies

The QCH Living Lab has a comprehensive Risk Management Plan (RMP) and Health, Safety and Environment (HSE) Plan. Technology providers and associated contractors will be required to work collaboratively with QUT and QCH staff to assess possible risks associated with the proposed technology, and to develop appropriate risk management strategies. These risks are to be added to the QCH Living Lab RMP and HSE Plan and signed off by QUT and QCH.

All work done onsite will require the approval of QCH Facilities Management. This will be given through the signing of an agreed Work Method Plan.

11 TECHNOLOGY TEST REPORTS AND DISSEMINATION

The test report will be in the form of a Test Plan and Technology Evaluation Report (TER). The first part of the report – the Test Plan- will include, as relevant, the following sections:

- Introduction (Problem statement, technology background, objectives)
- Test item (description of test item, approach, pass/fail criteria, expected results)
- Risk Management considerations, management
- Test environment and infrastructure
- Roles and responsibilities
- Methodology
- M&V plan
- Test plan (milestones, schedule)

The Results section will include, as relevant, the following sections:

- Test results (quantitative, qualitative, cost effectiveness)
- Overall technology assessment (extrapolation to other buildings / sector etc)
- Barriers and enablers to adoption
- Recommendations

The report will be disseminated according to ARENA's Knowledge Sharing requirements for i-Hub projects. This may include, but is not limited to:

- Publication of the report on the i-Hub website
- Utilisation of results in other publications by QUT (e.g. academic articles)
- Dissemination through the Renewable Energy Knowledge Sharing Task-Group for Healthcare
- Incorporation into other Living Lab outputs, such as the “Renewable Energy and Enabling Technology and Services Roadmap for Healthcare”
- Integration of the results into other i-Hub outputs, such as AIRAH webinars, industry publications, conferences, seminars etc.
- Publications by the technology provider, as long as reference to the full report is provided, and the context of the test conditions and limitations are clear and unambiguous.