The Innovation Hub

for Affordable Heating and Cooling

Report #LLHC1-1

Healthcare Sector: Renewable Energy and Enabling Technology and Services Framework (REETSEF)

17 April 2020

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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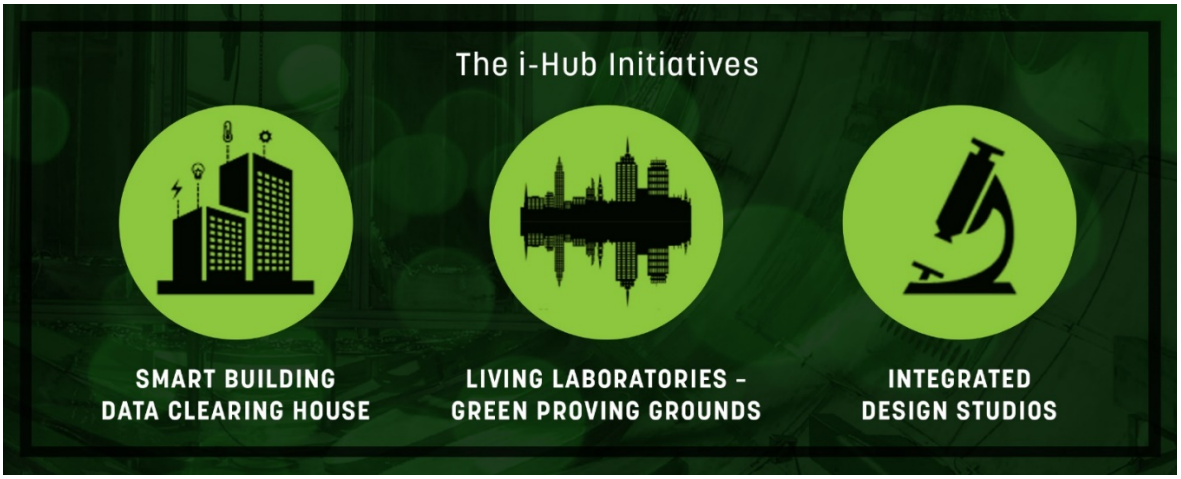

REETSEF: Healthcare Sector

Healthcare Living Laboratories Sector-wide engagement and impact

The Healthcare Living Laboratories Sector Engagement project will quantify healthcare sector energy consumption, identify the potential for renewable energy technologies to reduce sector energy consumption and cost for HVAC in particular, and propose requirements for optimal integration of renewable energy technologies.

This REETSEF describes the general conditions that will be considered for the establishment and operation of three Healthcare Living Laboratories in order to meet the i-Hub objectives:

- Warrigal Aged Care, Shell Cove, NSW
- Fernhill Residential Aged Care, Caboolture, QLD
- Queensland Children's Hospital, Brisbane, QLD

Lead organisation
Queensland University of Technology (QUT)

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1 INTRODUCTION

1.1 Background

The i-Hub Living Laboratories activity stream has the objective to quantify (i.e. analyse measurable data) and qualify (i.e. develop insights into reasons, motivations and opinions) the potential for innovative technologies and the integration of technologies in healthcare settings to add value to renewable energy, enabling hospitals and residential aged care centres to transition to a net-zero energy/demand future while simultaneously contributing to occupant wellbeing, comfort and health. A nominal target of a 25% increase in the value of renewable energy for healthcare, relative to business-as-usual (BAU), was hypothesised. In order to quantify this, key performance indicators (KPIs) will need to be calculated.

At a high level, the indicators of interest are:

1. The exploitable value of renewables installed in one of the healthcare living laboratories (actual and extrapolated potential)
2. The impact of the technology intervention on
    - o building occupants (residents, patients, staff) – indoor environment quality
    - o building managers (maintenance and operations impact)
    - o asset owners (total cost of ownership)
3. The energy use (kWh), energy demand (kW), CO_2 and utility cost in the respective living laboratory.

The main objective of any technology tested in the Living Labs activity stream is to quantify the improvement (or not) in the value of renewables. Several different indicators can be used individually or collectively to do this. At the same time, other indicators are needed to quantify and qualify service quality, to ensure that services, are a minimum, are not worse post implementation of the intervention. Ideally, technologies that enhance the value of renewable energy AND improve service quality, will provide broad societal benefits.

1.2 The Value of Renewable Energy

The value of renewable energy accrues to a variety of stakeholders, and is considered to comprise, in the first instance, of value to society, to the electricity network, and to the facility owner:

- Social value: The social value of renewable energy generation includes net job creation, public health and social inclusiveness[1], however monetary value can be attributed to avoided carbon emission ($/tCO2-e) and avoided air pollution ($/MWh). Societal benefits

[1] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Nov/IRENA_Understanding_Socio_Economics_2017.pdf?la=en&hash=C430B7EF772BA0E631190A75F7243B992211F102

may primarily be influenced by additional renewable generation, or fuel switching from gas to electricity.

- Electricity Network value: Network benefits from healthcare facility upgrades could include reduced peak demand and/or load shifting (i.e. a permanent change to the energy use profile), and demand response capacity (i.e. a temporary pre-arranged adjustment in energy consumption). Both benefits have a power (kW) and energy (kWh) component[2]. Potential additional benefits include exploring the aggregation of demand response capacity across multiple sites in order to participate in electricity market mechanisms that enhance grid stability and robustness, such as frequency control ancillary services (FCAS) and Reliability and Emergency Reserve Trader (RERT). The ability to offer these ancillary services is a function of demand response capacity.
- Facility owner / manager value: The benefit to the facility may be reflected in the utility costs for all energy. This includes supply charges, consumption charges, peak demand charges and export benefits. Additional benefits may include reduced maintenance, reduced total-cost-of-ownership (TCO) and maintained or improved indoor environment quality (IEQ).

The potential value of energy flexible buildings will vary depending on the building and system characterisation, the method of participation or aggregation in the electricity network, and the billing or reward incentives on offer. For instance, Demand Response (DR) value can be realised in a number of ways, i.e. the customer can be paid by the retailer for the potential DR capacity available for use or the DR capacity actually used; the customer can be incentivised to control DR based on time of use pricing or peak demand charging, the customer (if of a sufficient size) can directly participate in the wholesale electricity market, or a third party aggregator can offer an incentive to provide DR capacity (a diverse range of incentives have been trialled).

Determining the change in value of renewable energy at a site due to an energy retrofit or technology intervention requires consideration of changes in value to each stakeholder separately, as well as careful monitoring of the service quality constraints (e.g. IEQ). This Renewable Energy and Enabling Technology and Services Evaluation Framework (REETSEF) for the Healthcare Sector summarises the methods by which a living laboratory can be established in the healthcare sector, and the measurement and verification method most appropriate to determine a change to the value of renewables as a result of an intervention. It defines the context, approaches, key performance indicators (KPIs) and methods of evaluation to be used to assess the impact of a technology upgrade[3]. This report should be read in conjunction with the complementary report: Living Labs Healthcare Sector Baselines and Key Performance Indicators.

[2] https://www.energyrating.gov.au/sites/default/files/2020-01/smart_appliance_decision_ris.pdf

[3] A technology upgrade can include the installation of an energy conservation measure that impacts peak demand, or the installation of a distributed energy resource that can generate, store, or actively manage energy demand.

1.3 Green Proving Grounds program (US)

The i-Hub's Living Laboratories activity stream is, to some extent, modelled on the USA's Green Proving Ground program. This program, established in 2011, tests emerging building technologies in government building settings, to evaluate the potential for their deployment in the government building portfolio of assets and the broader commercial property sector. The two overarching objectives are to enable the US General Services Administration (the property portfolio owner) to demonstrate its leadership in promoting technology innovation, and to provide a robust investment decision process for procurement of emerging technologies for their own portfolio.

Innovative and emerging technologies in six main categories are tested:

- Building envelope
- Energy Management
- HVAC
- Lighting
- On-site power and renewables
- water

Technology assessment reports are published on the GSA website:
https://www.gsa.gov/governmentwide-initiatives/sustainability/emerging-building-technologies/about-gsas-proving-ground-gpg

The measurement and verification (M&V) timeframe adopted by the US program ranges from four to twelve months, to enable calculation of the following impacts, depending on specific sites:

- Deferring HVAC load during short-term generation variabilities, thereby enhancing the peak demand benefits of on-site renewable generation
- Enhancing productive HVAC load during periods of local or grid level generation excess to reduce demand and thus import at other periods, including
    - Evening peaks (for sites with large scale on-site generation and longer HVAC hours)
    - Weekends (for sites with five-day operation)
    - Seasonal load differences (for sites with strong seasonality in HVAC load)
- Enabling the combination of HVAC control and on-site renewable generation to provide the potential to respond to mechanisms that enhance grid stability and robustness, currently characterised by mechanisms such as the RERT and FCAS.

In all cases, these need to be achieved (i) without causing loss of comfort for occupants; and (ii) ensuring efficient use of energy at the site level. These objectives may be achieved, for example, via a combination of load management, efficiency, renewable generation and short-term and long-term storage, as shown in Figure 1.

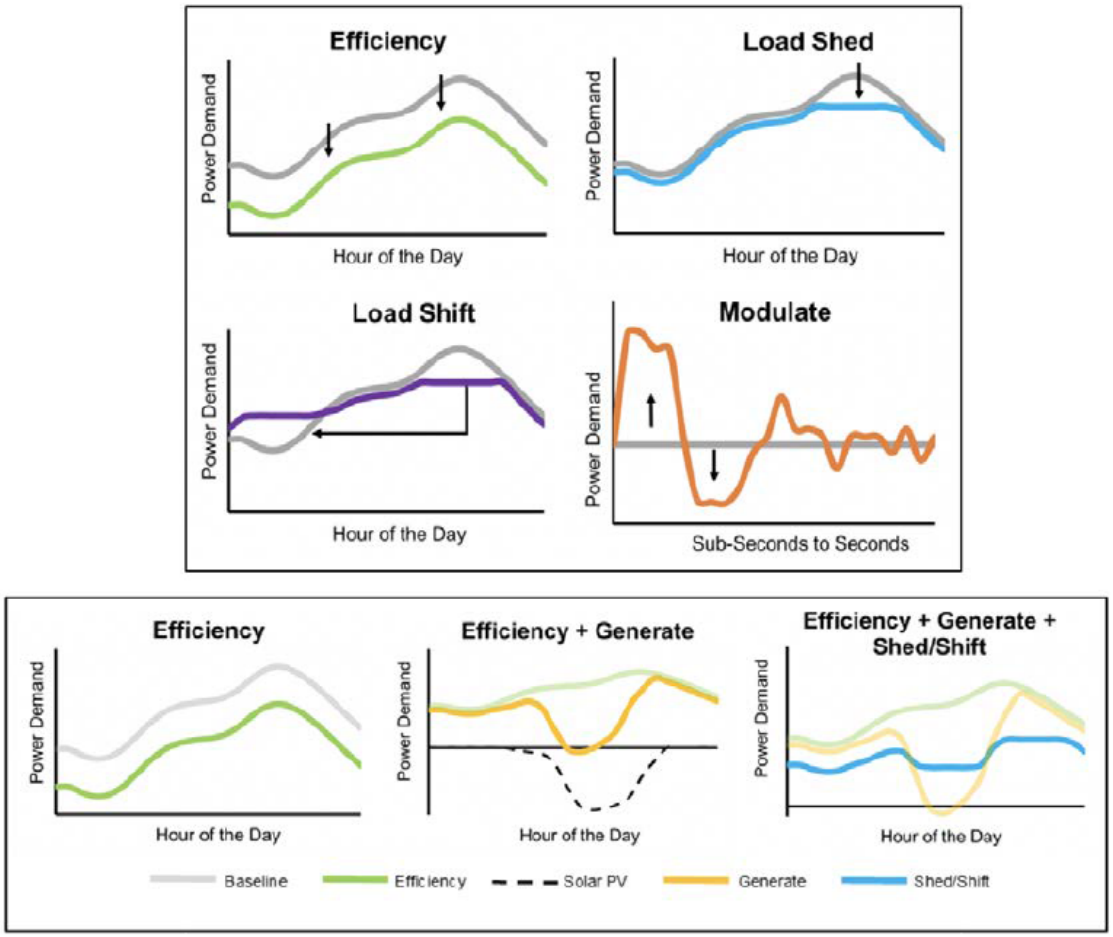

Figure 1. Illustration of the effects of load flexibility strategies on building energy, individually and combined.

Figure 1 Load flexibility strategies for buildings (US DOE, 2019)[4]

The i-Hub Healthcare Living Laboratories will implement similar strategies, as outlined in this REETSEF.

[4] https://www.energy.gov/sites/prod/files/2019/04/f61/bto-geb_overview-4.15.19.pdf

1.4 Nomenclature

Table 1 contains the nomenclature used throughout this report.

Table 1 Nomenclature used in this report

	Explanation	Measure
REETSEF	Renewable Energy and Enabling Technology and Services Evaluation Framework	
REET	Renewable Energy and Enabling Technology	
DM	Demand Management	
DR	Demand Response	
EC	Energy content factor	
EF	Emissions factor	
FCAS	Frequency control ancillary services	
FIT	Feed-in Tariff (the $ earned per kWh of exported PV)	
HVAC&R	Heating, Ventilation, Air-Conditioning and Refrigeration	
IEQ	Indoor environment quality	
L*f*	Load factor	
PPM	Parts per million	
RERT	Reliability and Emergency Reserve Trader	
SC	Self-consumption (electricity generated and used onsite)	
Tp	Tariff - Peak	
Top	Tariff – Off-peak	
Ts	Tariff - Shoulder	
DHVAC i	Energy consumed by HVAC equipment at hour i	(kWh)
Di	Electricity demand for hour i	(kWh)
Dnet i	Grid Electricity consumption for hour i	(kWh)
EUI	Energy Use Intensity	kWh per unit
PVi	PV generation at hour i	(kWh)
PVSC i	Onsite self-consumption of PV generation at hour i	(kWh)
PVe i	Onsite PV exported from site at hour i	(kWh)
GHI	Global Horizontal Irradiance	W/m^2
GFA	Gross Floor Area	m^2
RH_{in}	Relative Humidity (inside ambient)	%RH
RH_{out}	Relative Humidity (outside ambient)	%RH
T_{in}	Temperature (inside ambient)	*°C*
T_{out}	Temperature (outside ambient)	*°C*
V_{wind}	Wind speed	m/s
DIR_{wind}	Wind direction	Degrees (0 – 360º)
CO_2-e	Greenhouse gas emissions in carbon equivalent	tCO_2-e

2 KEY PERFORMANCE INDICATORS

This section discusses the range of key performance indicators that may be used to report on the impact of a technology tested in a healthcare living laboratory. It is not an exhaustive list, but an indicative list of ten KPIs that may be useful in helping to understand, manage, and improve the energy productivity of healthcare facilities and the value of renewable energy utilisation in these facilities.

2.1 Energy Use Intensity / Productivity

The three commonly used KPIs for energy use intensity in hospitals (and to a lesser extent aged care facilities) 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 climate.

KPI 1. **Energy intensity** (kWh/m^2) (kWh/bed day/yr) (kWh/bed/yr)

2.2 Societal Benefits

Several societal benefits could accrue to renewable energy and enabling technologies. Two KPIs that could be used to quantify these benefits are provided here. Additional social benefit KPIs may be developed over the duration of the Living Lab program of activities.

KPI 2. **Avoided GHG emission** (tCO_2-e and $)

Avoided GHG emission = (Baseline CO_2-e – Reporting CO_2-e) ± Adjustments

CO_2-e is the sum of GHG emission for all fuel sources in use at a site, to be calculated as per the National Greenhouse Accounts Factor[5] method for fuel combustion (gas) or scope 2 emissions electricity, i.e. as per the following method:

[5] https://www.environment.gov.au/system/files/resources/5a169bfb-f417-4b00-9b70-6ba328ea8671/files/national-greenhouse-accounts-factors-july-2017.pdf

Gas	*Electricity*
$GHG\ emission_{gas} = \frac{E_{gas,gross}\ x\ EC\ x\ EF}{1000}$ *Where:* *Q = quantity of fuel consumed (m^3);* *EF = the emission factor (kg CO2-e/kWh);* *EC = the energy content factor (kWh/m^3);*	$GHG\ emission_{\ elec} = \frac{E_{elec,net}\ x\ EF}{1000}$ *Where:* *Q = the quantity of electricity purchased (kilowatt hours);* *EF = the scope 2 emission factor (kg CO_2-e/kWh)*

Conversion from emission (tCO_2-e) to societal benefit ($) will use an estimated social cost of carbon from the literature (e.g. US$35/$tCO_2$[6]) as a conversion factor.

KPI 3. Avoided air pollution

The social benefit due to avoided air pollution puts a cost value to air pollution (PM_{10}, NO_x, and SO_2) impacting populations close to power stations.

The calculation applies a damage benefit to each MWh[7] of energy saved, i.e.

Value of avoided air pollution = Damage Benefit Factor x ((Baseline Energy Use – Reporting Energy Use) ± Adjustments)

2.3 Network Benefits

Six KPIs that could be used to quantify electricity network benefits are presented here. Additional or alternative KPIs may be added throughout the duration of the Living Lab activities.

KPI 4. Peak 30 minute electricity demand.

Peak demand, $E^*_{elec,net}$ will be calculated as the highest 30 min electricity demand. Peak demand will be reported monthly, seasonally and annually (i.e. highest 30 min consumption per month, seasons, year). This KPI will be normalised for floor area, number of beds or bed days, and adjusted for weather. Shorter period peak demand (e.g. 5 min) may also be reported.

[6] http://www.climateinstitute.org.au/verve/_resources/TCI_SocialCostOfCarbon_PolicyBrief_September2014.pdf
[7] https://apo.org.au/sites/default/files/resource-files/2009/03/apo-nid4196-1189331.pdf

KPI 5. Wholesale cost of peak 30 minute electricity demand

To determine whether the healthcare facility peak demand is co-incident with periods of network peak demand, the wholesale cost of peak demand at the time of occurrence will be calculated using actual co-incidental wholesale spot prices.

Peak demand wholesale price ($) = $E^*_{elec,net}$ *x co-incident wholesale spot price*

KPI 6. Total self-consumption rate (0-1)

For locations with renewable generation, the self-consumption rate of renewable generation, that is the proportion of energy use for a facility that is generated by on-site renewable generation (Figure 2), will be reported. As for KPI 3, self-consumption rate will be reported monthly, seasonally and annually, and calculated as:

$$For\ time\ periods\ with\ E_{PV,gross,i} > 0:$$

$$SC_t = \frac{1}{N}\sum_{i}^{N} \frac{E_{elec,gross,i}}{E_{PV,gross,i}}:$$

$$if\ D_i > PV_i, \qquad \frac{E_{elec,gross,i}}{E_{PV,gross,i}} = 1.$$

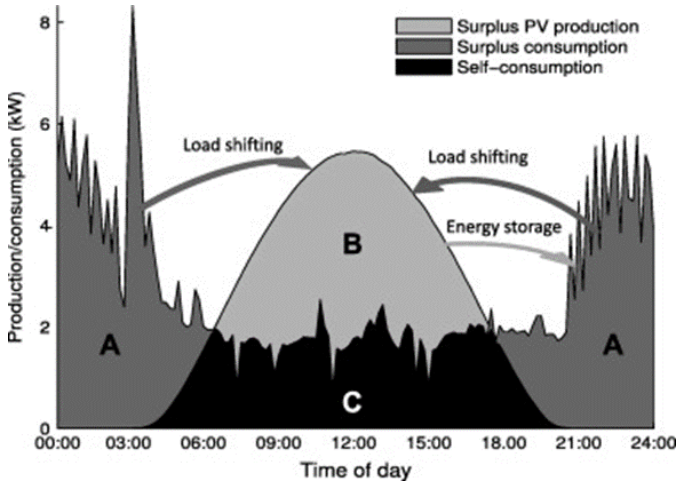

Figure 2 Visual outline of self-consumption rate (C), and opportunities for improving self-consumption rate[8].

[8] Luthander, Widén, Nilsson, Palm, (2015), *Photovoltaic self-consumption in buildings: A review,* Applied Energy, Vol. 142.

KPI 7. HVAC self consumption rate (0-1)

Similar to KPI 5, for locations with renewable generation, the HVAC self-consumption rate of renewable generation is the proportion of energy use for HVAC in a facility that is generated by on-site renewable generation. As for KPI 5, self-consumption rate will be reported monthly, seasonally and annually, and calculated as:

$$For\ time\ periods\ with\ E_{PV,gross,i} > 0:$$

$$SC_{HVAC,t} = \frac{1}{N}\sum_{i}^{N}\frac{E_{HVAC,i}}{E_{PV,gross,i}}:$$

$$if\ E_{HVAC,i} > E_{PV,gross,i}, \frac{E_{HVAC,i}}{E_{PV,gross,i}} = 1.$$

KPI 8. Net Facility Load Factor

Net Facility Load Factor is the average load divided by the peak load during a specified time period and is a measure of how 'peaky' an energy use profile is. It will be reported monthly, seasonally and annually, and is calculated as (note: Peak demand, $E^{*}_{elec,net}$):

$$Lf = \frac{\frac{1}{n}(sum\ (E_{elec,net})}{E^{*}_{elec,net}}$$

KPI 9. Demand response capacity

Determining the network benefit of demand response capacity if difficult, as the value is highly time variant. Any upgrade that introduces demand response capacity to the education facility should have the demand response capacity characterised as available demand response (kW) for different time scales (e.g 6 sec, 1 minute, 10 minutes, 1 hour, 4 hour). This can be determined from monitored component power consumption during grid peak periods (summer and winter) or calculated based on capacity of loads made available for demand response. However, capacity available for participation in longer DR events (e.g. 1 hour, 4 hour) is contingent on maintaining appropriate service quality (i.e. Indoor Environmental Quality, IEQ).

2.4 Healthcare Sector Benefits

There may be some KPIs that can show benefit to the healthcare sector broadly, such as:

- in terms of maintenance, operational budgets (and hence releasing limited funds for investment in further assets or in making funds available for health services)

- in terms of indoor environment quality. International research relating to hospitals[9] indicates that indoor environment parameters may have quantifiable benefits such as:
    - Reduction in patient length of stay
    - Reduction in medication costs
    - Reduction in noise levels that have positive effects on heart-rate, pulse, respiration and sleep
    - Reduction in mortality rate
    - Reduction in employee turnover

It is not yet known how such benefits could be quantified and qualified in the Australian context. This will be the subject of further research as one of the Living Lab activities.

In the first instance, a bespoke tariff model could be constructed for each healthcare facility, based on actual billing data for all energy sources, and including demand, time of use and supply charges. This can be combined with any renewable generation income (if any) and be used to quantify the value to the healthcare facility for any changes. This can be normalised for floor area and bed days. For some facilities, instead of onsite renewable generation, such a KPI might include the value of power purchase agreements from off-site or neighbourhood renewable energy generation.

KPI 10. Energy cost

The total energy cost will need to include electricity and gas usage costs and other charges (e.g. supply and demand charges) less any financial payment for exported renewable energy.

Energy cost = electricity supply charge + peak demand charges + usage charges + gas supply charge + gas usage charge – renewable generation feed-in-value

A bespoke tariff model will be constructed for each facility, based on actual billing data for all energy sources, and including demand, time of use and supply charges. This will be combined with any renewable generation income (if any) and be used to quantify the value to the healthcare facility for any changes. This will be normalised.

[9]Building 4 People: Quantifying the benefits of energy renovation investments in schools, offices and hospitals. Buildings 2030 project. Buildings Performance Institute Europe. 2018.

3 MEASUREMENT AND VERIFICATION (M&V)

3.1 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, the REETSEF differs from a typical measurement and verification in several key points:

- The measured output of this project is the increase in the value of renewable generation, rather than simply increasing energy efficiency. This increased complexity includes considering energy consumption of HVAC-related equipment, energy generation of renewables and the potential energy demand management strategies to improve grid stability and reduce site costs.
- Many of the REET benefits, for instance peak demand reduction and DR capacity, are not possible to meter or directly observe. The calculation of the benefit is based on a comparison between the observed load, and a theoretical estimate of what the load would have been in the absence of the REET.
- The technology upgrade(s) to be assessed are unknown, and as such the monitoring systems will need to be more flexible, detailed and comprehensive.
- The Healthcare Living Laboratories will be research-grade living laboratories, 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, the requirements of this REETSEF will go beyond those outlined in the IPMVP.

The underlying calculation principle in the REETSEF to determine change in a KPI remains the same as that from the IPMVP, namely:

Change in KPI = (Baseline Use or Demand – Reporting Use or Demand) ± Adjustments

Where adjustments refer to calculations completed to account for differences in independent variables between the baseline and reporting parameter. In education facilities the major calculated adjustments are expected to be to account for changes in external weather conditions, internal environmental conditions, and changes to occupancy.

This principle is illustrated in Figure 3, where ‘retrofit’ is equivalent to a technology intervention.

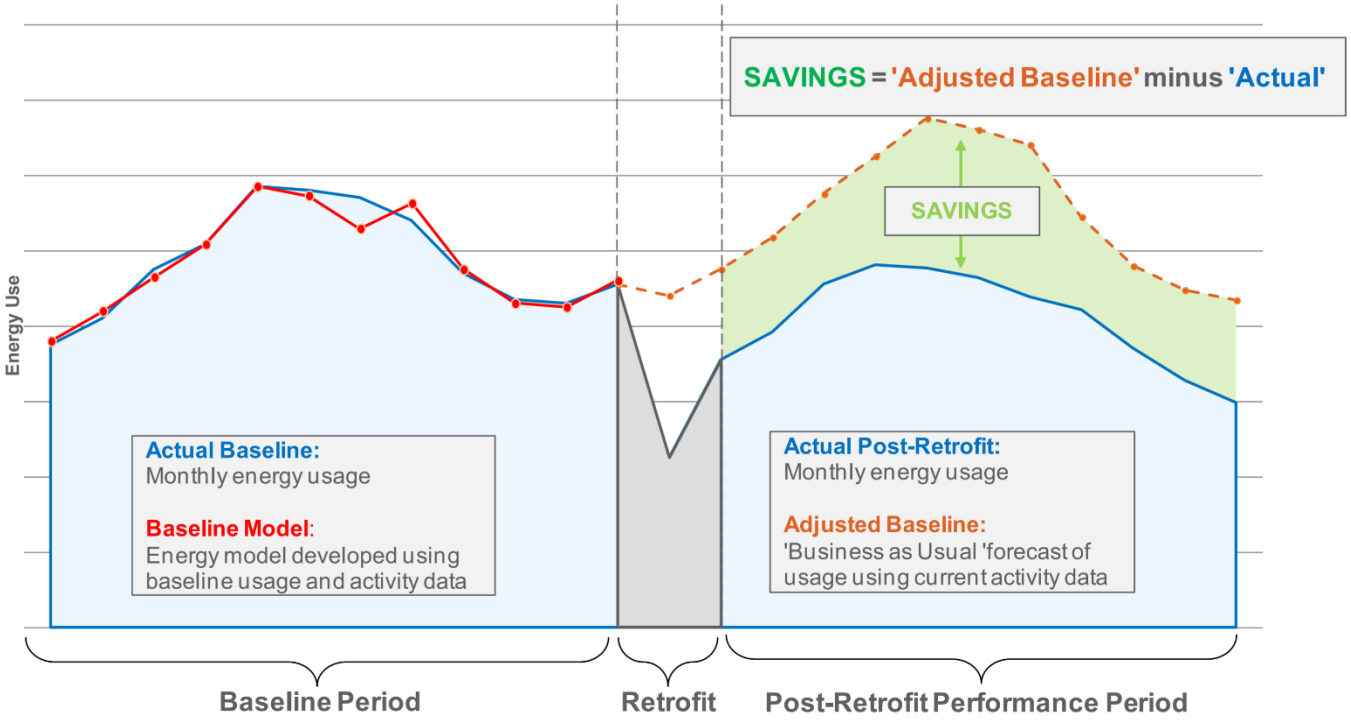

Figure 3 The savings calculation principle, where differences are estimated between recorded values and theoretical values[10].

Adjustments refer to calculations completed to account for differences in independent variables between the baseline and reporting periods. In hospital facilities the major calculated adjustments are expected to be to account for changes in external weather conditions. For Aged Care facilities, there may also need to be a need to account for changes to internal environmental conditions (if all internal spaces are not conditioned), and changes in occupancy (i.e. vacancy rates).

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)
(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 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)

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

- 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. Refer to Table 2 for more information about each of these options.

Table 2 IPMVP options

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 use 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 is typically recommended in the case that baseline data is not available. Calibrated models can demonstrate to building operators how a particular system can operate under different weather conditions: calibrated models are better than regression methods for normalising for external conditions. In the case of the i-Hub Healthcare Living Labs, calibrated models may also be used to explore 'what if' energy management strategies in a low risk manner.

3.2 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.
- A separately zoned conditioned space, such as a room, group of rooms, which may contain multiple HVAC systems.

A challenge for establishing an effective and functional living laboratory is establishing a robust measurement framework, whilst maintaining flexibility to assess unknown upgrade measures. The wider the measurement boundary the more flexible the living laboratory can be to test proposed technologies. The selection of the measurement boundary for the Healthcare Living Labs is not likely to be the whole facility; it is more likely to be a portion of the facility where the energy consumption and impacts of a retrofit can be effectively isolated. The measurement boundary will also depend, to a certain extent, on the technology being tested. As such, measurement boundaries for the Healthcare Living Labs may be:

- 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 a kitchen; or the cooling towers; or the chilled water system; or roof-mounted equipment)
- A part of a building (e.g. a floor or wing or a specific operational area)
- A whole building
- The whole precinct (all of the Healthcare living lab sites have multiple buildings)

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.

3.3 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.

3.3.1 External Conditions

In order to calculate weather corrected indices, the following external conditions are expected to be monitored at each Living Lab site via onsite weather station:

- Global horizontal irradiance (GHI)
- External temperature (T_{out})
- External relative humidity (RH_{out})
- Air velocity and direction
- Rainfall (duration, intensity)

Onsite weather data may be compared to the nearest Bureau of Meteorology site data, to determine any potential microclimate conditions.

3.3.2 Indoor Environment Quality

Internal conditions (e.g. temperature, relative humidity, CO2 levels) will be monitored in appropriate areas of each site (relative to the area under test). This is to ensure that comfort conditions are consistent between the baseline and reporting periods.

3.3.3 Building and occupancy adjustments

It may be necessary to account for variations in occupancy. This is expected to be less of an issue for the hospital living lab but may be an issue for the aged care living labs.

Further adjustments may need to be made for non-project-related changes to buildings and equipment, that may introduce step changes to energy consumption models. Instances of these static factors in the healthcare sector may include, for example, the failure or replacement of HVAC equipment; maintenance work that impacts the air permeability or insulation of the building envelope; fenestration modifications, repairs or faults; lighting upgrades; shading structure modifications; landscaping changes; and extreme weather events. An appropriate method for recording these static factors is to keep as logbook with the site facility manager.

3.4 Constraints for adjustment

As the goal of the i-Hub living laboratories is to demonstrate increased value of renewable energy, only those KPIs listed above will be considered as indicators of increased value of renewable. However, the values will be adjusted to ensure a number of constraints are held constant between the reporting and baseline period. These constraints will be used to define the multi-variate regression model for adjustment of and observed differences.

3.4.1 External Conditions

In order to calculate weather corrected indices, the following external conditions should be monitored.

- Global Horizontal Irradiance (GHI)

- External Temperature
- External Relative Humidity
- Air velocity and direction
- Rainfall

Adjustment for external conditions will typically be completed using heating degree days and cooling degree days, unless otherwise specified. Monitoring of GHI is necessary to assess PV efficiency, to ensure panel performance has not degraded between control and reporting period.

3.4.2 IEQ monitoring

To ensure the internal comfort conditions are consistent between the baseline and reporting period, the following internal parameters will be monitored.

- Dry Bulb Temperature (T_{in})
- Relative Humidity (RH_{in})
- CO_2 Levels
- Air velocity
- Mean radiant temperature

Adjustment for internal conditions will typically be completed based on degree days outside of comfort conditions (based on simple dry bulb temperature thresholds).

Degree hours. $C_e = \frac{1}{n}\sum_i^n (t_{in,i} - t_{ub,i})\ if\ t_{in,i} > t_{(ub,i)}$

Time outside of the comfort band will be determined depending on the specific comfort model (adaptive or steady state) utilised by the Living Lab in question. For example, many areas within the hospital will have fixed temperature and humidity setpoints, depending on the specific department. The Aged Care living lab, on the other hand, is a hybrid-ventilation building, so more in line with the adaptive comfort model. Each will require different monitoring approaches which will be described in each specific Living Lab Prospectus and Manual.

3.4.3 Occupancy

Occupancy and occupant behaviour will be monitored from time to time, as appropriate to each technology test. Occupant data will be supplied for administration records (for patients / residents). Staffing levels will also be supplied from administration and visual records. In the case where a facility has an operational BMS with logging capability, occupancy can be validated against BMS data (including occupancy, noise, CO_2, or other proxy measures). In this case, a record of temperature set points may also be used as a direct indication of changes in occupant behaviour. In the case that BMS data also collects window opening behaviour (in the aged care living lab), this should also be used for adjustment.

4 MONITORING AND METERING REQUIREMENTS

The prior stated key performance indicators, constraints and adjustments impose minimum monitoring requirements for the effective operation of a living laboratory. The typical minimum requirements, encompassing electricity supply and network connection, HVAC and other building loads, and indoor and external conditions, are illustrated visually in Figure 4.

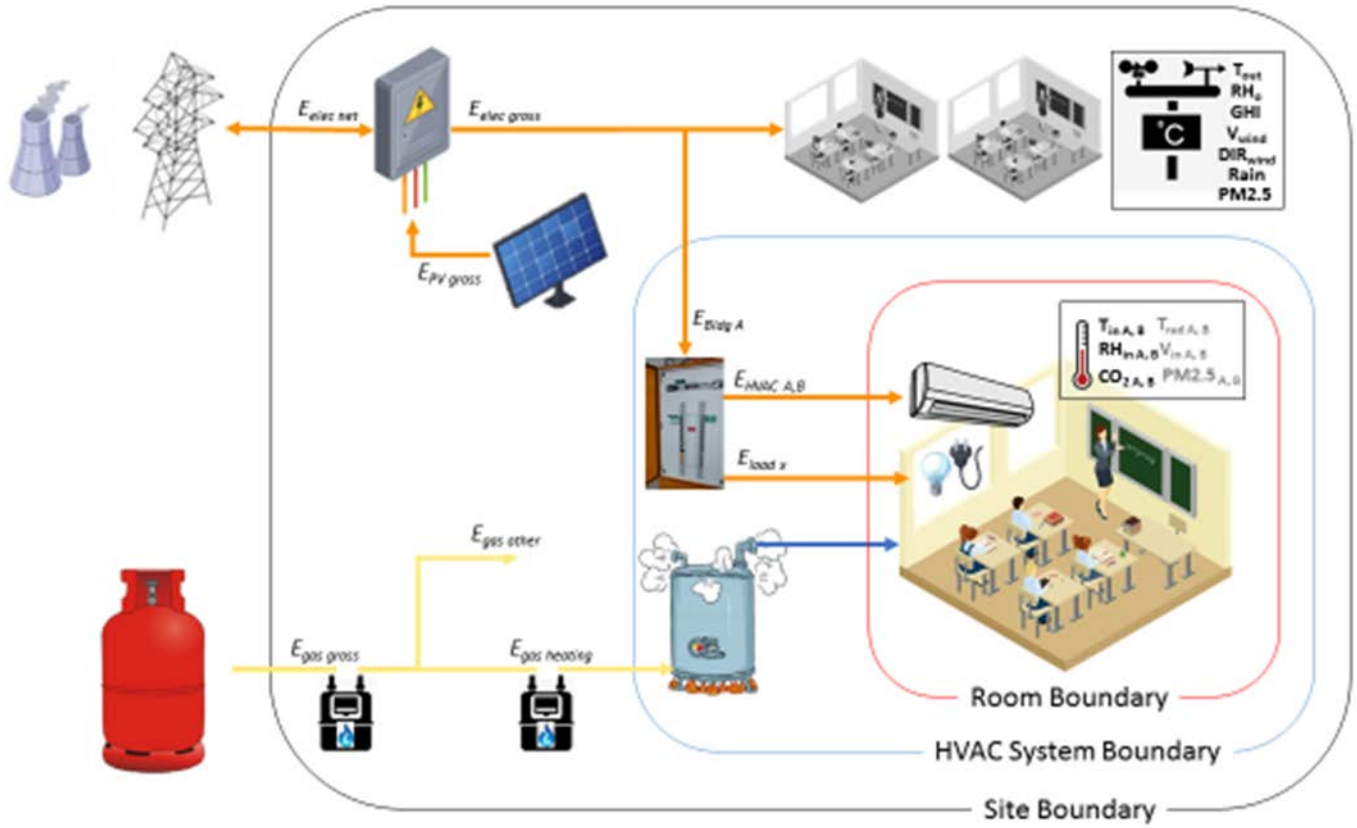

Figure 4 Generic monitoring approach for establishment of living laboratory

Further information about data requirements and generic collection methods are summarised in Table 3.

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Table 3 Data requirements and collection methods

General description	Detail	Source
Simple normalisation data	Gross floor area	Building plans, measurement
	Conditioned floor area	Building plans, measurement, site visit
	Occupant numbers	Operation data, site visit
Weather data	Global Horizontal Irradiance	Onsite weather station and nearest Bureau of Meteorology (BOM) weather station
	External Temperature	
	External Relative Humidity	
	Air velocity and direction	
	Rainfall	
IEQ data	Dry bulb temperature	In-room measurement devices (fixed, stand-alone and incidental testing)
	Relative humidity	
	CO2 levels	
	Air velocity	
	Mean radiant temperature	
Occupancy data	Facility-specific	Facility administrative documents, occupancy sensors (or proxies), visual observations
	Number of occupants	
	Demographic (age group, gender)	
	Metabolic rate (met) (estimate, for aged care)	
	clothing insulation level (clo)	
	Activity level	
Energy data	Gross facility energy consumption and generation	Facilities Management data
	Total gross electricity consumption	Need total and sub-metering of all major components to be impacts by an intervention. Minimum 30min intervals (5 minutes preferred)
	Total gross electricity generation, by source (<30min)	Sub-metering on all sources
	Total gas consumption	Pulse meters or volumetric meters
Sector-wide energy data	Energy and water consumption (monthly or quarterly utility bills and/or metering data); GreenPower purchases	NABERS Energy and Water for Hospitals database

5 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).

5.1 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.

5.2 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)

5.3 Modelling / Simulation

Building simulation is Option 4 under the IPMVP process as discussed previously. It is envisaged that, where possible, a building model will be created of the respective living labs. This may utilise EnergyPlus, open platform software that 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. Commercial software such as REVIT might also be used.

It is also possible that, for some living labs, models of the HVAC system can be created using TRNSYS or similar software. Such models will be calibrated against actual performance data. They 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.

6 POST OCCUPANCY EVALUATION PROTOCOLS

Post Occupancy Evaluations (POE) are designed to obtain feedback on the operational performance of a building, and to assess the extent to which the building satisfies the needs of its occupants. POE use interviews or questionnaires with the building occupants to explore perceptions of thermal comfort, ideally with concurrent 'right here, right now' IEQ physical parameter measurement. POEs are designed to complement the physical measurement of thermal environmental parameters and provide deeper insights into occupant and context specific thermal comfort issues.

POE is a well-established building assessment tool, and there are numerous approaches that can be employed. For example, Brambilla and Capolongo (2019)[11] have reviewed POE tools for hospital environments, and the US Federal Facilities Council (2001)[12] explored the evolution of POE and state-of-the-art POE practices for building improvement.

There are several well-established standardised methods for conducting POE, which were originally designed for use in office buildings. These methods use standardised questionaries, and the results for a facility can be compared against the performance of other similar facilities in the database. A concise summary of the most relevant and frequently used standardised approaches for a POE are shown in Table 4.

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For the purpose of the current REETSEF, it is acceptable to employ any of the standardised POE methods outlined in Table 3 or develop alternative tailored surveys that cover areas relevant to the impacts of the technology being tested on occupants. Bespoke POE designed for hospitals and aged care facilities are also acceptable, however the survey instruments must be reviewed and approved by both an approved HREC committee, and the i-Hub education steering committee.

[11] Brambilla, A, Capolongo, S (2019). Health and Sustainable Hospital Evaluation – A Review of POE tools for hospital assessment in an evidence-based design framework. *Buildings*, 9(76). DOI:10.3390/buildings9040076

[12] Federal Facilities Council (2001). *Learning from our buildings: a State-of-the-Practice Summary of Post-Occupancy Evaluation.* Federal Facilities Council Technical Report No. 145. National Academy Press, Washington DC.

Table 4 Summary of standardised Post Occupancy Evaluation methods

Tool	Developed and main usage	Benchmarks	Method	More information
Building Use Studies (BUS)	UK	UK, NZ, Canada, Australia and International non-domestic; UK housing; UK schools benchmark	5 – 15 min questionnaires	busmethodology.org.uk/
CBE Occupant Survey Toolkit	USA	Office buildings; Laboratories; K-12 schools; Higher education; Residence halls;	10 min web-based survey	cbe.berkeley.edu/resources/occupant-survey/
BOSSA	AUS	Office Buildings;	10 min survey	www.bossasystem.com/

7 CONTRACTUAL ARRANGEMENTS AND ETHICS PROTOCOLS

7.1 Contractual arrangement

The relevant research partner (Queensland University of Technology (QUT) or University of Wollongong) will have an agreement with the specific Healthcare Living Lab (Warrigal Aged Care, Fernhill Residential Aged Care and Queensland Children's Hospital) regarding how the respective Living Laboratories will operate.

Prior to site work relating to any technology to be tested, a written agreement will need to be signed between the relevant research partners and the approved technology provider. This agreement will stipulate the roles and responsibilities of all parties with regard to testing technologies within the respective Healthcare Living Lab. The agreement will include, as a schedule, the approved product testing plan that is developed by the research partner in conjunction with the Living Lab host and the technology provider.

7.2 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, was presented in Section 5.2 (qualitative analysis).

All research conducted in public institutions that involves human participants must be approved by an accredited Human Research Ethics Committee (HREC). The purpose of HRECs is to protect

the welfare and rights of the participants in the research. A secondary aim is to facilitate research of benefit to the wider community. In addition, healthcare providers (public and private) are likely to require additional ethical approvals or consultation prior to undertaking research in their facilities.

HRECs review research proposals to ensure that they meet ethical standards and guidelines, most notably the National Statement on Ethical Conduct in Human Research and the Privacy Act 1988. Any healthcare facility to be established as a living laboratory under the current REETSEF must ensure that all data collection and research processes are properly reviewed. Each living laboratory and monitoring solution will have slightly different ethical considerations according to specific requirements at State and Territory levels, however some common issues that should be addressed include:

- Are appropriate Working with Children or Vulnerable People checks required for research staff and contractor?
- Have all research participants been appropriately informed about the potential risk, harm, discomfort or inconvenience that may occur through participation in the research? In particular, consideration should be given to any potentially identifiable information.
- Has written consent been asked from all participants?
- Have all attempts been made to limit impact on patients / residents and staff, including for instance installing all monitoring equipment during unoccupied periods, or in parts of the facility that will not interrupt usual operations?
- Is there potential for monitoring data to be used to identify individual participants?

All living laboratory manuals should include details to show that appropriate ethical approvals have been obtained prior to the installation of monitoring equipment, site visits, or technology installations. All such activities will require approval by the Research Ethics committees of the research partner and the living lab host. It is the responsibility of the Living Lab project Manager (from the research partner) and the Host's lead participant to ensure that the relevant processes are followed and approvals received before collecting data from any building occupant or user (other than those directly involved in the Living Lab).

8 INTELLECTUAL PROPERTY (IP) PROTOCOLS

8.1 Intellectual property

It is central to achieving the objectives of this REETSEF that the outcomes of the living laboratories be made publicly available in a form that supports relevant stakeholders to take decisions on the appropriate upgrade strategies for their facilities. **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). To this end, the i-Hub project will establish a Renewable Energy Knowledge Sharing Task-Group for Healthcare to guide the dissemination of project findings.

It is anticipated the technology evaluation report will consist of:

- A plain language summary and/or infographic of the results, and
- A Technical Report (for a specific technology) that includes the technology test plan (how the test was conducted) and the results.

Reports produced by the Living Labs will be owned by the relevant research partner and published under Creative Commons (with attribution). Rights are assigned to AIRAH/i-Hub to utilise the documents for the purposes of operating the Living Labs and all associated activities. No commercialisation of these documents 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 9) provided by a technology provider to the research partners or living lab hosts will only be used for the purposes of product testing.

The test report will be disseminated through the Knowledge Sharing Hub, and published, as a minimum, on the i-HUB website. Test results may also be communicated by the relevant research partner 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.

8.2 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, UOW or Living Lab hosts to disclose that information to any other persons or for any other purposes. Conversely, technology providers are not to disclose any information about QUT, UOW

or Living Lab hosts 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.

9 TECHNOLOGY SELECTION PROCESS

9.1 Application process

9.1.1 Expression of Interest

Potential technology providers are to, in the first instance, contact the i-Hub (www.ihub.org.au) or the project manager of the respective Living Lab. 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 the specific Living Lab.

To be eligible for testing within an i-Hub Healthcare Living Lab, 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.

9.1.2 Initial meeting

The research organisation (QUT or UOW) 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 specified Living Lab, a follow up meeting will be conducted between the technology provider, the research provider and the Living Lab host organisation. This will include onsite visits so all parties are fully aware of the Living Lab conditions and limitations.

9.1.3 Consequent meetings

On verbal agreement by the Living Lab host to potentially test the proposed technology, the relevant research provider (QUT or UOW) 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 the research provider relating to the test regime (refer to Section 7.1);
- 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 the relevant research provider and living lab host.

9.2 Business considerations

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

9.2.1 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).

9.2.2 Insurances

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

- Public liability
- Professional Indemnity
- Product warranties

9.2.3 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.

9.3 Engineering and Risk Management Considerations

As part of the due diligence process for each of the Healthcare Living Labs, 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.

9.3.1 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 the research provider and the Living Lab host, and will only be used for the purposes of determining an appropriate test plan.

9.3.2 On-site Work Requirements

All onsite technology test work needs to comply with QUT/UOW and Living Lab host organisation HSE requirements, as well as site specific requirements, such as site induction, building or area specific induction, work method etc.

A section of the written agreement between the research provider and technology providers will include specific requirements relating to the specific Living Lab, and relative to the technology being tested.

9.3.3 Risk Management

Each of the Healthcare Living Labs 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 the research provider and the Living Lab host to assess possible risks associated with the proposed technology, and to develop appropriate risk management strategies. These risks are to be added to the relevant RMP and HSE Plan and signed off by both the research partner and the Living Lab host. All work done onsite will require the approval of the relevant Living Lab host (e.g. facilities management). This will be given through the signing of an agreed Work Method Plan.

9.3.4 Technology Readiness Level

All technologies being proposed for testing will be assessed with regard to their technology readiness level (TRL) or level of technology maturity. Only technologies at deployment stage (levels 7-9) are eligible for testing in the i-Hub Living Labs. Refer to Figure 5.

Figure 5 Technology Readiness Levels[13]

10 TECHNOLOGY TEST REPORTS AND DISSEMINATION

The Technical Report (test report) will be in the form of a Test Plan and Technology Evaluation Report (TER). The first section – 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:

[13] https://www.twi-global.com/technical-knowledge/faqs/technology-readiness-levels

- 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, provided that reference to the full report is provided, and the context of the test conditions and limitations are clear and unambiguous.