Report #LLHC3-Final

LLHC3 Fernhill Residential Aged Care: Final Report (Knowledge Sharing Report)

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QUEENSLAND UNIVERSITY OF TECHNOLOGY

About i-Hub

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

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

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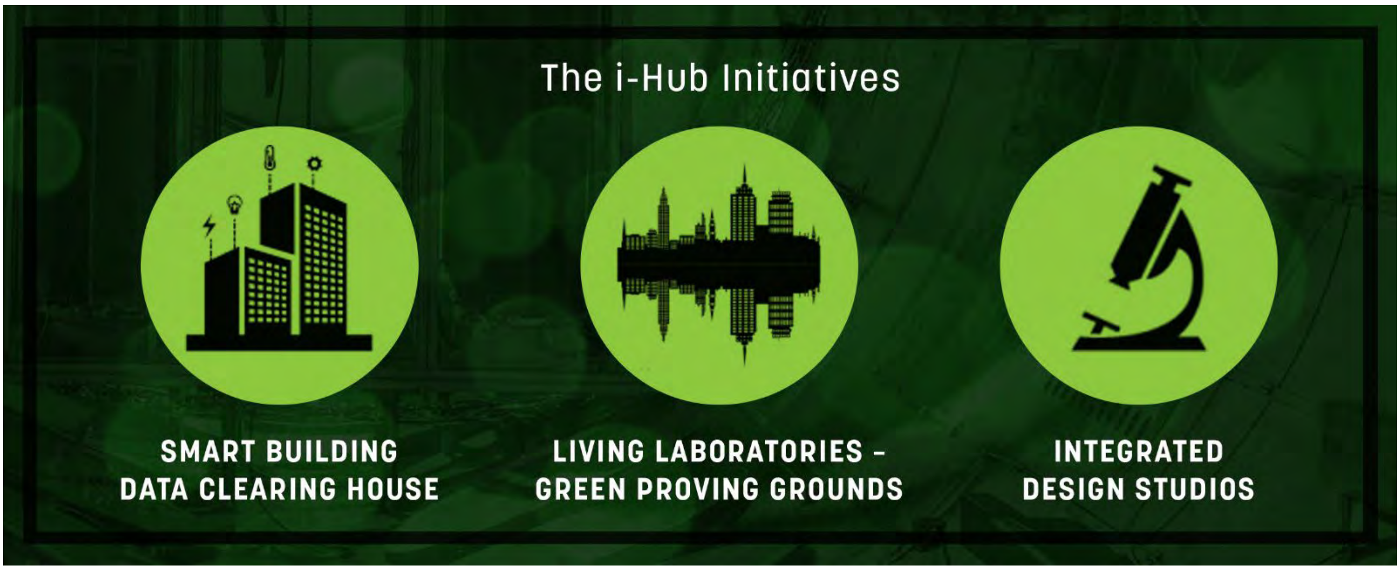
The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.



Healthcare Living Laboratories: Fernhill Residential Aged Care – Final Report

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

Lead organisation
Queensland University of Technology (QUT)

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1 EXECUTIVE SUMMARY

A Living Laboratory was established in a new residential aged care facility in sub-tropical Caboolture, Queensland. Despite being design with energy efficiency and sustainability in mind, opportunities for demand reduction were identified.

Two technology evaluations were undertaken, as summarised in Table 1-1. Both technologies highlighted reductions in energy demand of HVAC equipment. A further seven technologies were proposed for testing, but did not / could not meet the criteria for testing in accordance with the Living Lab Prospectus and Operation Manual (refer to Table 2-2 for further information).

Table 1-1 Technology evaluation results

Technology type	Manufacturer / supplier	Goals	Performance
Technology Evaluation Report – Synengco HVAC Plant Digital Twin (stage 1)	Synengco	Model the HVAC plant to quantify the actual accumulated electricity and cost deviations from design performance	Chiller 1 is operating close to its design performance, while **chillers 2 and 3 are operating below their design performance by 25%.** Overall, the systems used 13.6 MWh more than they are designed to, which is equivalent to 10,940 kg CO2e
Technology Evaluation Report – Synengco HVAC Plant Digital Twin (stage 2)	Synengco	Monitor and predict how the plant will perform under certain circumstances and produce alerts at an early stage.	Actual cooling load to the building and COP of most systems are lower than predicted. **Performance can be enhanced 25%** through several recommendations such as reaching the maximum capacity of chillers, maintaining constant mass flow rate, sharing the cooling fan, and allowing for precooling on hot days.
Technology Evaluation Report – HoneyComb Blinds	Norman Australia	1-In-situ identification of the impact of different honeycomb blind types on thermal transmission through windows, and 2-The impact of different closing/opening scenarios of the honeycomb blinds on the heating and cooling energy consumption.	Blinds can achieve: - 50 to 62% reduction in U-value of windows - **4.6% Total energy reduction** - **12.5% Cooling energy reduction** - $10k Yearly savings - 4% Additional savings when compared to normal drapes - 6% reduction in energy if blinds are operated in an informed manner **Blinds can be easily retrofitted to existing buildings to provide energy efficiency and thermal comfort benefits**

The living lab delivered all of the required project outcomes (Table 1-2) and met all of the project key performance indicators (Table 1-3).

Future work (subject to funding) could include completion of post occupancy evaluation, long term analysis of building energy performance, and further technology evaluations particularly in demand response, energy storage or generation decarbonisation.

Table 1-2 Evidence of project outcomes

Project outcomes	Evidence
The establishment of the Fernhill Residential Aged Care iHUB Living Laboratory.	The newly built building enabled the incorporation of testing equipment during construction phase. The occupied living lab enabled monitoring and analysis of actual data gathered from the BMS, and actual behaviours and responses to the implemented technologies.
Enable the Australian HVAC and building services industries to have their innovative technologies independently validated at Fernhill LL.	The Fernhill RAC facilitated access to install sensors, technologies, and do testing on the building. Access was granted to the BMS to monitor and download data that enabled technologies' evaluation based on real live data. Evaluation of the technologies at Fernhill LL were performed by parties that had no conflict of interests with the suppliers or manufacturers of technologies.
Practical and cost-effective ways to aged care facilities will be able to achieve a 30%+ reduction in energy demand/consumption and greenhouse gas emissions, through the use of new technologies relating to HVAC control, demand management, grid interoperability and renewable energy are demonstrated.	The tested technologies show that they have the potential to collectively reduce 31% of energy consumption. 25% energy savings can be reached if the digital twin is utilised to optimise the HVAC plant operation so that it can perform as designed, and 6% energy savings if the honeycomb blinds were installed and operated in an informed manner.
Information is promulgated to the wider industry.	6 main reports, 4 scientific publications, 2 industry publications and 11 industry presentations, + Healthcare Knowledge Sharing Taskgroup.

Table 1-3 Achievement of project key performance indicators

Key Performance Indicators (KPIs)	Evidence
Fernhill Residential Aged Care Living Lab facility established and operational	Construction completed; building is operational. Evaluated technologies were successfully installed on site. Sensors were installed and incorporated to the BMS. Additional sensors and reed switches were installed and data were collected on a cloud platform. BMS and EMS were operational and accessible, and they were used in technology evaluation.
Information (Prospectus and Manual) provided for prospective technology/service providers	Fernhill Residential Aged Care – Prospectus and Manual was completed and submitted to AIRAH/ARENA. It is available to prospective technology/service providers directly and through the i-Hub website (Refer to Table 2-4)
Quarterly Progress report that includes progress against KPIs, including baseline metrics for energy consumption, demand and renewable energy specific to this facility	Fernhill Operations Manual and Baseline Data Analysis_V04 (Oct 2020) was completed and submitted to AIRAH/ARENA. It is available to prospective technology/service providers directly and through the i-Hub website (Refer to Table 2-4)
At least 2 technology assessment completed and published	Technology Evaluation Reports were delivered at M6. They are available to prospective technology/service providers directly and through the i-Hub website (Refer to Table 2-4)
A waiting list for product validation / testing	A list of products proposed for testing was formed, and all technologies on that list were subject to the initial vetting as outlined in the living lab operation manual. A number of products did not / could not proceed for testing (refer to Table 2-2) and were hence removed from the list. There is currently no waiting list.

Outputs disseminated through Renewable Energy Knowledge Sharing Task Group for Healthcare and other pathways	Knowledge shared with professionals, AIRAH members, and the public, through multiple webinars, and the iHUB healthcare knowledge sharing task group (Refer to Tables 2-2, 2-3, and 2-4).

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2 FERNHILL LIVING LAB OPERATION

2.1 Fernhill Living Lab Overview

Fernhill is a residential aged care facility (RAC) and retirement village (RV) on freehold property located at Caboolture, approximately 42 kilometres north of Brisbane's CBD. The spread-out nature of the hostel accommodation did not permit efficient staffing or facilitate the best possible level of care, and the shared bed wards and bathrooms of the nursing home did not meet the company's standards or community expectations. Therefore, the first stage of a multi-staged site development plan inconcluded the construction of a new 144 bed over 4-level RAC with communal facilities, allied health spaces, landscaped outdoor activity spaces and basement care parking.

The new building provided value to the market/industry as a prototype of a facility that incorporates a range of energy efficiency and ecologically sustainable design features; and enhances the health and wellbeing of its residents. These features include:

- Hybrid building design: Enables both natural ventilation (NV) and mechanical heating, ventilation, and air-conditioning (HVAC). NV is through installing ceiling fans and operable windows (louvres) in all occupant rooms.
- Three air cooled chillers (electrical dual screw type): Two at 475kWr and one at 950kWr to provide a wide range of flexibility in meeting the seasonal loads in a more efficient manner.
- Building Management System (BMS): a tool that helps maintenance staff control, monitor, and identify alarms in building services. The system also provides various data about the building's operations that include HVAC, lighting , and electrical submetering using WebCTRL software and Automated Logic sensors.
- Solar PV: 100 kWp system, 250 modules, with 144MWh estimated annual production
- LED lighting: with motion sensors in common areas, time clocks, and PE cell.
- Onsite backup generator: Provides back-up power to essential services in the building in case of power outage.

2.2 Operation

A set of 18 rooms over levels 2, 3, and 4 of the NW wing of the building has been selected as the living lab resident rooms. These rooms were specifically selected to encompass west, north and east orientations (the orientations most affected by solar radiation). In order to achieve this 'laboratory' testing, additional monitoring has been installed in the selected rooms:

- Automated Logic sensors to measure temperature, relative humidity, CO_2 and motion, connected to the BMS;
- Wiring to enable for the installation of reed switches on openable windows (louvre type) and possible future connection to the BMS for FCU control;
- Steinel True Presence sensors (six rooms, one level only) to measure presence/movement, brightness, temperature, relative humidity, air pressure, VOC and CO_2;
- Nube reed switches and temperature, relative humidity, and lux sensors connected to a cloud based platform.

- Roof-mounted weather station connected to BMS that provides data on temperature, relative humidity, barometric pressure, solar radiation, rainfall, rain rate, wind speed and direction.

Baseline analysis evaluation included:

- Airtightness blower door test operated by ATTMA accredited professionals to compare the designed performance to the as built performance and identify the locations of air leakage.
- Volatile Organic Compounds (VOC) to quantify the indoor air quality and identify the location with highest VOC concentration and emission rates.

In addition to the quantitative data collection, qualitative data were collected from post occupancy evaluation interviews with the residents to identify how they use their rooms (e.g. operate the windows, blinds, air conditioner, etc.). The interviews provided a number of insights about how design assumptions might not always match real operations.

Staff surveys were also developed and deployed but, because of long-term COVID lockdowns and restrictions, these have not yet been filled out by staff.

The Living Lab was operated in accordance with the developed documentation. A Prospectus and Manual for this living lab was developed and uploaded to the iHUB website, providing industry with the information they would need in order to apply for their technology to be tested at this facility. This Manual includes:

- a full site description
- site energy composition and usage
- current and potential future key performance indicators
- Measurement and verification techniques to be used in technology testing
- Monitoring and metering requirements
- Data analysis methodologies
- Contractual arrangements, and ethics and IP protocols
- Technology selection process
- baseline energy consumption

The Living Lab's Baseline Energy Report, also on the iHUB website, further explained:

- energy use in aged care settings internationally, nationally, and for Bolton Clark
- the site's daily energy use per month (prior to the construction of the new RAC)
- the potential technologies that could be in-situ tested

2.3 Technology Evaluations

Two technologies were tested at Fernhill:

(1) Honeycomb Blinds which were installed in 6 rooms, and

(2) a Digital Twin of the HVAC plant was developed.

The Data collection and evaluation were done by either QUT or an external independent contractor. The technology Evaluation Reports are summarised in Table 2-1. For the full report please refer to iHUB LLHC3 website.

Table 2-1 Summary of tested technologies and outcomes

Technology type	Manufacturer / supplier	Goals	Performance
Technology Evaluation Report – Synengco HVAC Plant Digital Twin (stage 1)	Synengco	Model the HVAC plant to quantify the actual accumulated electricity and cost deviations from design performance	Chiller 1 is operating close to its design performance, while chillers 2 and 3 are operating below their design performance by 25%. Overall, the systems used 13.6 MWh more than they are designed to, which is equivalent to 10,940 kg CO2e.
Technology Evaluation Report – Synengco HVAC Plant Digital Twin (stage 2)	Synengco	Monitor and predict how the plant will perform under certain circumstances and produce alerts at an early stage.	Actual cooling load to the building and COP of most systems are lower than predicted. Performance can be enhanced through several recommendations such as reaching the maximum capacity of chillers, maintaining constant mass flow rate, sharing the cooling fan, and allowing for precooling on hot days.
Technology Evaluation Report – HoneyComb Blinds	Norman Australia	1-In-situ identification of the impact of different honeycomb blind types on thermal transmission through windows, and 2-The impact of different closing/opening scenarios of the honeycomb blinds on the heating and cooling energy consumption.	Blinds can achieve: - 50 to 62% reduction in U-value of windows - 4.6% Total energy reduction - 12.5% Cooling energy reduction - $10k Yearly savings - 4% Additional savings when compared to normal drapes - 6% reduction in energy if blinds are operated in an informed manner Blinds can be easily retrofitted to existing buildings to provide energy efficiency and thermal comfort benefits.

A number of other technology providers were involved in discussions about potential testing in this living lab, but these test opportunities did not eventuate for a number of reasons, as shown in Table 2-2.

Table 2-2 Technologies discussed but not implemented for testing

Technology type	Technology	Reasons for not being tested
Building envelope	Electro-chromic / thermos-chromic glazing	Provider required financial support to cover the cost of the glazing and installation. This was not available through the iHUB
Building envelope	Double-glazed louvres	Manufacturer could not provide the product in sufficient time for inclusion at time of construction, nor for retrofit within the living lab timeframes
Heat recovery	Kitchen/laundry exhaust heat recovery	Kitchen at Fernhill is not heavily used (meals are reheated here, not fully prepared), and will not provide sufficient heat to make it feasible
HVAC efficiency	Graphene coating to condensers / graphene dosing to chilled water	Difficulty in evaluating the effect of the coating since the plant utilised three chillers simultaneously. The graphene coating was tested at the QLD Children's Hospital Living Lab instead. Graphene dosing has not been tested.
Energy storage	Hot and cold thermal energy storage technologies	Technologies difficult to justify and implement in a newly constructed building
Electric boiler	Electric boiler	Technologies difficult to justify and implement in a newly constructed building
HVAC innovation	Thermosphere / QCool	Technology not of sufficient Technology Readiness Level for implementation to meet the living lab host requirements

2.4 Additional evaluations

Just as it is important to quantify and performance of technologies such as HVAC and renewable energy systems, it is important to quantify and qualify the performance of a building in other ways, and its impact on building occupants. Post-construction and post-occupancy evaluations (POE) are a critical means to understand the success (or otherwise) of design and construction, and to drive, refine and embrace more efficient design solutions.

Three types of evaluations were planned for Fernhill, to add richness to the Living Lab technology evaluations:

1) *Occupant thermal comfort evaluations* (for staff and residents): these were devised to gain an understanding of the extent to which the hybrid building (natural ventilation and mechanical ventilation) was meeting the occupants needs (or not)
2) *Occupant perceptions of building design*: these were devised to understand whether the building, designed through an inclusive design process, meets the expectations of residents and staff
3) *Post-construction evaluations* were performed to measure construction and fitout quality (i.e. airtightness and indoor air quality), as these impact on building energy use and occupant health and wellbeing.

The specific evaluation methods and implications are summarised in Table 2-3.

Table 2-3 Additional post-construction, post-occupancy evaluations and implications

Type of evaluation	Purpose	Key finding / implication
Post occupancy evaluation – resident interviews	Understand occupant thermal perceptions and preferences, occupation patterns, activities and operation (curtains, windows, ceiling fans, AC)	Residents clothing levels varied greatly (0.3 – 1). No residents used the ceiling fan; few operated the HVAC (leaving it to others), most operated the curtains / windows.
Post occupancy evaluation – resident focus groups	To understand how the design and layout of the building affects resident health and satisfaction	Unable to be implemented because of COVID lockdowns and access restrictions
Post occupancy evaluation – staff surveys	(a) To understand staff thermal comfort (b) To understand how the design and layout of the building affects staff productivity and satisfaction	Survey links provided to administrator and staff, but unable to be implemented yet due to COVID workload issues
Post-construction evaluation - airtightness	To quantify the leakiness of the construction	Only top floor could be tested. ACH 9.85m3/h/m3 @50pa. JV3 report (reference building) uses 1ACH.
Post-construction evaluation – indoor air quality	To quantify the indoor air quality (VOC) post construction but prior to occupancy	No significant VOCs detected.
Post-construction evaluation – sensor type and placement	Reed switches and temperature, relative humidity, and LUX sensors were installed in all 18 living lab rooms, and the data were automatically uploaded on a cloud based platform to evaluate the patterns of opening/closing the openings and their impact on internal temperature/RH and lighting.	Reed switch data was used to help explain the differences in temperature and HVAC operation in each room. The data show that windows are sometimes left open for days while airconditioning is running.
	Three sensor types were installed in each of 6 living lab rooms: at the entry (typical location), on the ceiling in the centre of the room, and on an external wall	The intent was to determine if/ to what extent the location of the HVAC control sensor impacts on the thermal conditions and thermal perceptions within a resident room. This has not yet happened, due to trechnical and shipping delays.
	Trial a multi-sensor (human presence, lux, temperature, relative humidity, air quality, VOC and CO2) to determine effectiveness and usefulness	Sensors installed in 6 rooms, but in addition to typical BMS sensors, lighting controls, etc). Missed opportunity for potential cost savings by having 1 sensor performance multiple functions. Design and construction process, often in relatively discrete silos, does not easily allow for such innovation, without perception of added risk and complexity.

2.5 Project Outputs

Aside from the Technology Evaluation Reports mentioned previously, publicly available project outputs include project reports (Table 2-4), peer-reviewed scientific publications (Table 2-5), industry publications (Table 2-6) and industry presentations (Table 2-7).

Table 2-4 Project main reports[1]

Report title (& link)	Brief synopsis
Fernhill Residential Aged Care – Prospectus and Manual	*Purpose*: To provide a detailed description of the site; the types of technologies that can be evaluated; the sensing/metering infrastructure installed; the protocols for conducting product evaluations; and the data acquisition, processing and storage systems *Method*: Exploring technology verification techniques, constraints, and monitoring requirements. Presenting the protocols for POE, IP, Technology selection, and reporting processes.
Fernhill Baseline Energy Report_V04	*Purpose:* To report historical energy use from the existing buildings (hostels and nursing home) and analyse the effect of the building envelope on the stability of indoor temperature of the new building and compare the "designed" with the "as built" air tightness. *Method:* Analysis of the energy consumption profiles and its correlation with temperature. Performing a blower door test by ATTMA accredited professionals *Key findings:* There is a significant correlation between external temperature and energy use, with the highest consumption in January and December, and the daily peak load is at 11am in summer and 6am in winter. Air leakage test results shows a 9.85 ACH compared to a targeted design of 1 ACH. Observed leakage paths were mostly located in the top and bottom of louver windows and between the sliding door panels.
Fernhill Operations Manual and Baseline Data Analysis_V04 (Oct 2020)	*Purpose*: Build on the Prospectus, and present more detailed baseline data analysis of the building envelope performance, HVAC plant, and air tightness. *Method*: Using temperature sensors to monitor unconditioned zones temperature patterns. Exploring technology verification techniques, constraints, and monitoring requirements. Presenting the protocols for POE, IP, Technology selection, and reporting processes. *Key Findings*: Rooms on the west have the highest peak in temperature, with 10°C difference between the coldest internal and external temperature, and about 15°C between the hottest internal and external temperature. The western rooms spent 9 hours a day above 25°C.
LLHC3 M6 Lessons Learnt Report	*Purpose*: To share with the public the lessons learnt from managing the living lab, and things to be avoided or encouraged in future living labs. *Key Findings*: Lessons learnt: 1- Managing a living lab is a complicated process that requires a lot of allocated time and resources. 2- Integrating technologies in the construction phase of the living lab is a good way to ensure the establishment and ease of evaluation of technologies. 3 – POE is very important, but not always easy to implement. Some level of management buy-in may assist. 4 – supply chain issues to delay equipment installation and operation, impacting on data availability.
LLHC3 Technology Evaluation Report – Synengco HVAC Plant Digital Twin	Fernhill's HVAC plant and building information was modelled with SentientSystem to build a precise digital twin of the plant. This digital twin allowed monitoring the chiller performance compared to its design, predicting the plant performance via machine learning, and identifying control improvement opportunities that can reduce energy consumption.
LLHC3 Technology Evaluation Report – Application of Honeycomb Blinds	Honeycomb blinds are a type of window dressing that have a cellular structure that can trap air and make it act as an additional layer of insulation. The unique honeycomb shape increases thermal resistance, and reduce the thermal transmittance and solar heat gain through windows. This report demonstrates the results of testing the U-value of different honeycomb blind types and simulating their impact on reducing energy consumption and carbon emissions in current and future climate conditions.

[1] All iHUB reports can be found at www.ihub.org.au.

Table 2-5 Scientific publications (journals and conference papers)

Details (as per academic referencing style)
Liu, A., Miller, W., Crompton, G., & Zedan, S. (2021). Has COVID-19 lockdown impacted on aged care energy use and demand?. *Energy and Buildings*, 235, 110759. https://doi.org/10.1016/j.enbuild.2021.110759
Zedan, S., Miller, W., Liu, A., & Ma, Y. (2022). Cellular blinds' effect on aged care now and in the future. *Australasian Building Simulation Conference, Brisbane, July 2022*. (Accepted)
Liu, A., Miller, W., Chiou, J., Zedan, S., Yigitcanlar, T., & Ding, Y. (2021). Aged Care Energy Use and Peak Demand Change in the COVID-19 Year: Empirical Evidence from Australia. *Buildings*, 11(12), 570. https://doi.org/10.3390/buildings11120570
Liu, A., Miller, W., Chiou, J., Zedan, S., Chen, X., & Susilawati, C. (2021, December). How is occupancy related to energy use in healthcare buildings?. In *2021 IEEE PES Innovative Smart Grid Technologies-Asia* (ISGT Asia) (pp. 1-5). IEEE. https://ieeexplore.ieee.org/abstract/document/9715638

Table 2-6 Industry publications

Title / link	Type
Innovative heating & cooling products tested in living labs[2]	Media Release
QUT Living Lab to trial new technologies at Fernhill community[3]	News Article

Table 2-7 Industry Presentations

Title	Type	Purpose
Artificial Intelligence in the Built Environment	Industry Forum	Engage QLD industry on AI in the built environment. Include iHUB activities.
Building Designers Association conference	Conference	Engage building designers in discussions on iHUB / Living Labs
Future of HVAC conference	Conference	Announce iHUB / Living Labs to HVAC industry
Power, Energy and Clean Technology Seminar (QUT)	Webinar presentation	Engage professionals, government employees, NGOs and academics in power and energy areas
i-Hub Summit – Living Laboratories	Webinar presentation	Sharing knowledge of healthcare energy baseline and planned activities at Fernhill Living Lab
i-HUB webinar - NOJA Power	Webinar presentation	Engaging leading energy products manufacturer. QUT iHub team shared knowledges about healthcare energy baseline, building energy technologies and planned iHub living lab activities.
i-Hub Summit II	Webinar presentation	Engaging leading energy products manufacturer. QUT iHub team shared knowledges about Indoor air quality and air infiltration testing
i-Hub Summit III	Webinar presentation	Engaging leading energy products manufacturer. QUT iHub team shared knowledges about stage one of the technology evaluation of two technologies
i-Hub Summit IV	Webinar presentation	Engaging leading energy products manufacturer. QUT iHub team shared knowledges about findings from evaluating the honeycomb blinds
Webinar with Energy Queensland Demand Management Team	Webinar presentation and discussion	Knowledge sharing on iHub project and explore potential areas for collaboration
Presentation for Uniting Care	Webinar presentation and discussion	Knowledge sharing on iHub project and explore potential areas for collaboration

[2] https://research.qut.edu.au/ccetp/projectshealthcare-living-laboratories-fernhill-residential-aged-care-llhc-3/

[3] https://www.newfernhill.com.au/qut-living-lab-to-trial-new-technologies-at-fernhill-community/

3 PROJECT ANALYSIS AND EVALUATION

This section evaluates the project against its core deliverables, outcomes and KPIs (section 3.1), and analyses challenges (section 3.2), lessons learned (section 3.3), and impact (section 3.4). It concludes with a short discussion on 'what next' (section 3.5).

3.1 Deliverables, outcomes and KPIs

The six specific project knowledge deliverables, and how they have been met, are shown in Table 3-1. Achievement of project outcomes is shown in Table 3-2, and project KPIs in Table 3-3.

Table 3-1 Achievement of knowledge deliverables

Project Knowledge Deliverables	Evidence
Fernhill Living Lab – Prospectus and Manual	Refer to the output table 2-1
Technical Report: Caboolture Site LL Monitoring and Initial Baseline Data Analysis	Refer to the output table 2-1
Technical Report: Fernhill Living Lab Operations Manual (REETSEF) and Baseline Data Analysis	Refer to the output table 2-1
Technology Evaluation Report #1	Refer to the technology evaluation output table
Technology Evaluation Report #2	Refer to the technology evaluation output table
Fernhill Living Lab Final Report	This report

Table 3-2 Achievement of project outcomes

Project outcomes	Evidence
The establishment of the Fernhill Residential Aged Care iHUB Living Laboratory.	The newly built building enabled the incorporation of testing equipment during construction phase. The occupied living lab enabled monitoring and analysis of actual data gathered from the BMS, and actual behaviours and responses to the implemented technologies.
Enable the Australian HVAC and building services industries to have their innovative technologies independently validated at Fernhill LL.	The Fernhill RAC facilitated access to install sensors, technologies, and do testing on the building. Access was granted to the BMS to monitor and download data that enabled technologies' evaluation based on real live data. Evaluation of the technologies at Fernhill LL were performed by parties that had no conflict of interests with the suppliers or manufacturers of technologies.
Practical and cost-effective ways to aged care facilities will be able to achieve a 30%+ reduction in energy demand/consumption and greenhouse gas emissions, through the use of new technologies relating to HVAC control, demand management, grid interoperability and renewable energy are demonstrated.	The tested technologies show that they have the potential to collectively reduce 31% of energy consumption. 25% energy savings can be reached if the digital twin is utilised to optimise the HVAC plant operation so that it can perform as designed, and 6% savings if the honeycomb blinds were installed and operated in an informed manner.
Information is promulgated to the wider industry.	Refer to knowledge sharing tables 2-1, 2-2, 2-3, 2-4.

Table 3-3 Achievement of key performance indicators

Key Performance Indicators (KPIs)	Evidence
Fernhill Residential Aged Care Living Lab facility established and operational	Construction completed; building is operational. Evaluated technologies were successfully installed on site. Sensors were installed and incorporated to the BMS. Additional sensors and reed switches were installed and data were collected on a cloud platform. BMS and EMS were operational and accessible, and they were used in technology evaluation.
Information (Prospectus and Manual) provided for prospective technology/service providers	Fernhill Residential Aged Care – Prospectus and Manual was completed and submitted to AIRAH/ARENA. It is available to prospective technology/service providers directly and through the i-Hub website (Refer to Table 2-4)
Quarterly Progress report that includes progress against KPIs, including baseline metrics for energy consumption, demand and renewable energy specific to this facility	Fernhill Operations Manual and Baseline Data Analysis_V04 (Oct 2020) was completed and submitted to AIRAH/ARENA. It is available to prospective technology/service providers directly and through the i-Hub website (Refer to Table 2-4)
At least 2 technology assessment completed and published	Technology Evaluation Reports were delivered at M6. They are available to prospective technology/service providers directly and through the i-Hub website (Refer to Table 2-4)
A waiting list for product validation / testing	A list of products proposed for testing was formed, and all technologies on that list were subject to the initial vetting as outlined in the living lab operation manual. A number of products did not / could not proceed for testing (refer to Table 2-2) and were hence removed from the list. There is currently no waiting list.
Outputs disseminated through Renewable Energy Knowledge Sharing Task Group for Healthcare and other pathways	Knowledge shared with professionals, AIRAH members, and the public, through multiple webinars, and the iHUB healthcare knowledge sharing task group (Refer to Tables 2-2, 2-3, and 2-4).

3.2 Challenges

The research team would like to sincerely thank the Living Lab host – Bolton Clark – and their staff and contractors and residents for allowing this lab to be established. Overall the operation of the living lab has been very successful, and it is intended that research in this facility will continue (subject of course to available funding). Despite this, three main challenges were identified, as discussed below.

3.2.1 Nature of an occupied health care facility

The main challenge at Fernhill Living Lab was that it is an occupied healthcare building. Due to the high-quality care that Bolton Clarke aims to provide to its residents, QUT had to be extra careful on how to handle the living lab activities without being intrusive or causing disruption to the residents and staff.

To minimise disruption to residents, QUT staff arranged to have most testing/installations finalised before the residents moved into the new building. After the building became operational, QUT staff coordinated with Bolton Clarke's staff to gather the baseline data from unoccupied rooms. Notes were printed and hung on walls to prevent staff from opening the windows and/or the air conditioners in the tested rooms.

3.2.2 Complicated coordination process

The organisational model/structure of the Living lab host comprises of multiple departments with different responsibilities. These department are located in two different sites: the head office in Brisbane (which houses upper management, the ethics committee and the legal department), and the actual living lab site (where building manager/administration, maintenance, and lifestyle managers are located). In addition to the multiple departments of the LL host, there were external parties/subcontractors such as the construction contractor, technology suppliers, and BMS provider.

QUT's living lab manager had to coordinate with all of these parties and get approvals from the multiple departments (e.g. non disclosure agreement or ethics approval) to implement and the test the innovative technologies/ sensors. The distribution of responsibilities across various departments, made the coordination process lengthy and time consuming, which was not accounted for in the initial planning.

3.2.3 Impact of COVID 19

Most of the living lab duration coincided with the outbreak of COVID 19. Due to its high risk on the RAC residents, the living lab went through a series of lockdowns that prohibited access of QUT staff and technology suppliers to the premises. To overcome this challenge QUT followed two strategies. The first was to access the data remotely via a wireless router and through a cloud based platform or via the BMS. The second strategy was to test the technology performance outside of the RAC then use the performance parameters to simulate the technology's effect on the living lab using an energy model.

3.3 Lessons Learned

The following is a very brief summary of the lessons learned. Refer to the Lessons Learned report for more details.

1. A fully constructed living lab can add limitations on the type of technologies that can be implemented to them.
2. Some potential technologies were supposed to be implemented into the living lab while it is being constructed. However, due to delay in the decision making from the technology provider compared to construction timeline, it became difficult to add these technologies to the fully constructed living lab.
3. For a living lab to accommodate a wider range of technologies, agreements about implementing those technologies should be reached prior to finalising construction agreements. To do so, an integrated design studio (IDS) process or early engagement of technology provider with the host and construction manager would be required.
4. The initial allocation of funds underestimated the time and effort required by the living lab project manager to coordinate with the various parties. Responsibilities need to be clearly identified, and more time/manpower for coordination needs to be allocated during the planning phase. Another possible solution is to give the coordination responsibility

to one person within the LL organisation. This however might require an extensive amount of time and effort from that person. Therefore, if not compensated for that time, coordination activities might not be treated as a priority, which could risk or delay the goals of the iHUB.

3.4 Project Impact

This project helped set up a Living Laboratory to provide independent real-world product and technology testing/proving facilities. Knowledge was generated in the operation of the living laboratory sites and from the performance results of the technologies and systems. The outcomes were provided to the Knowledge Sharing Task Group for the sector to assist with knowledge development and dissemination, as well as being integrated into the comprehensive knowledge sharing activities. This Healthcare Knowledge Sharing Task Group was a key strategy for actively involving the broad healthcare sector during and beyond this project. The results and their integration with outputs from other i-Hub projects will inform the development of the "Renewable Energy and Enabling Technology and Services Roadmap for Healthcare".

The project investigated the barriers that limit integrating solutions that can reduce energy/demand.

The establishment of a Living Lab in a new residential aged care facility provided an opportunity to evaluate the impact of contemporary design, materials and technologies (e.g. staged chilled water HVAC plant, and BMS) on reducing energy demand. It enabled in-situ testing of emerging technologies, particularly in building envelope performance and predictive building management control systems.

The living lab evaluated easy to implement methods that can be incorporated to Bolton Clarke's existing facilities to reduce future energy demand. The evaluated technologies could provide an estimate of 30% energy/demand reduction from what is currently being used at Fernhill. The findings are applicable not only to new aged care and retirement living facilities, but also to similar building typologies (e.g. hotels and student accommodation).

The living lab activities provided Bolton Clarke with insights about how the building management can contribute to reducing energy demand. Research interviews with the staff and residents about the operational patterns and maintenance issues, helped understand increased HVAC load profiles. The interviews highlighted that design assumptions about how the building is operated were inaccurate and strategies to maintain energy efficient operations are required to optimise the building's energy use.

The project presented opportunities that can provide better utilisation of the BMS through integration with the digital twin to create an intelligent self-learning system that can predict changes in loads and respond to changing building usage, equipment performance, environmental conditions and electricity network requirements. The digital twin also helped highlighting the inefficiencies of the HVAC plant and explain the potential reasons behind them.

The technology evaluation reports can be used by the respective technology providers, to further develop and/or market their product to other clients.

3.5 What comes next

In a general sense, this living lab's outputs and outcomes are expected to contribute to the sector wide activities, including the development of new KPIs that incorporate considerations of weather sensitivity, peak demand and grid impacts.

The results will also be used across the sector for improved health and wellbeing outcomes, as health and energy challenges have significant overlap particularly in terms of rising costs and rising implications from extreme weather.

It is expected that the impact of the combined healthcare living laboratory projects will be the incorporation an integrated systems approach to energy and health into healthcare policies, plans, processes and protocols.

Subject to available funding, a number of future endeavours are possible. The Living Lab is firmly established now with its instrumentation and processes, so some further technology testing is possible. This may best be suited to digital technologies, but may also now include energy trading or demand response technologies, energy storage technologies, and options for reducing the carbon intensity of the backup generators. Longer term building performance data evaluation would also assist in gaining deeper insights into seasonal and annual energy fluctuations and inform continuous commissioning of the building's HVAC system. Completion of the post-occupancy evaluation activities would add further insights and benefits to the host, the sector, and the broader design and construction industry.

Bolton Clark will also evaluate the Living Lab experience and outcomes, as well as that of the Integrated Studios 13 and 14, to help inform future developments in their asset portfolio.