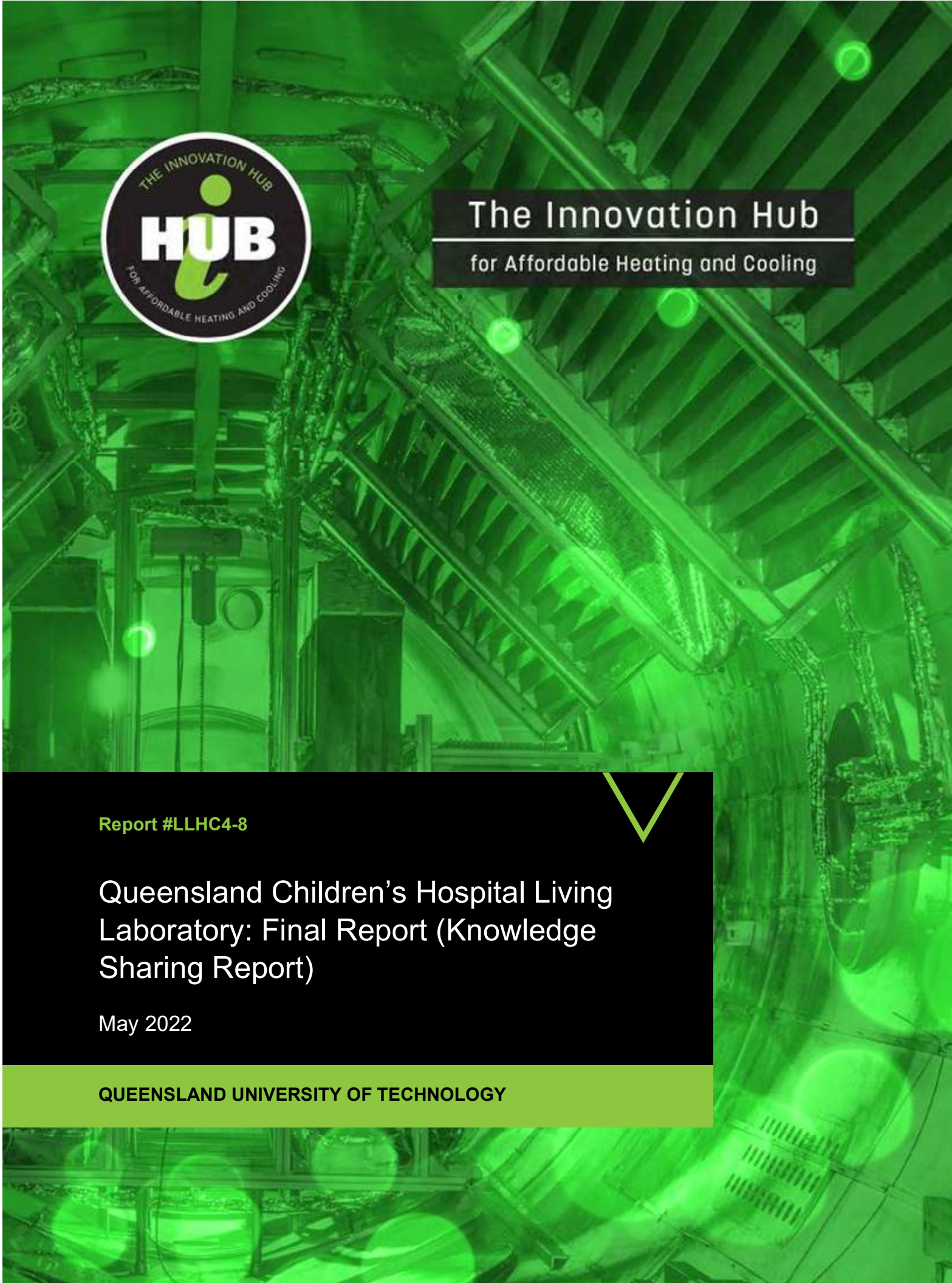

Report #LLHC4-8

Queensland Children's Hospital Living Laboratory: Final Report (Knowledge Sharing Report)

May 2022

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.
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: Queensland Children's Hospital – Final Report

The Living Laboratory in Queensland Children's Hospital (QCH) supports the hospital 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 hospital policies, plans, operating manuals and procurement processes. It tests innovative technologies and processes 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)

Project commencement date
1 July 2019

Completion date
30 June 2022

Date published
June 2022

Contact name
Dr Aaron Liu

Authors
Dr Aaron Liu, l50.liu@qut.edu.au
Associate Professor Wendy Miller, w2.miller@qut.edu.au

Project website
www.ihub.org.au

Project partners
Living lab host: Children's Health Queensland Hospital and Hospital Services (Queensland Children's Hospital's parent body)
DeltaFM – site principal contractor for QCH precinct
Stantec consulting
Technology providers: Exergenics, Buildings Alive, GMG graphene coating

1 EXECUTIVE SUMMARY

A Living Laboratory was established in Queensland Children's' Hospital (QCH) in Brisbane, Queensland, Australia.

Four technology evaluations and one technical evaluation (hospital future energy use) were undertaken, as summarised in Table 1-1. Three two technologies highlighted reductions in energy demand of QCH HVAC system. The graphene coating technology reduced energy demand for refrigeration condensers. The last item on hospital's future energy research forecast QCH precinct's electricity use in 2030, 2050, 2070 and 2090 scenarios, evaluated the impact of HVAC heating electrification for QCH's CCHR building, effectiveness of pandemic model ventilation strategies and AS4187 sterilisation standard's impact on hospital's energy use.

Table 1-1 Technology evaluation results

Technology type	Technology supplier & Goals	Performance highlights
Technology Evaluation Report – Exergenics: Stage 1 digital twin for QCH chiller primary system optimisation	**Exergenics** Model the QCH chiller primary system and optimisation of operation	Annual energy saving: 432MWh Peak demand reduction: 99kVA (assuming 0.98 pf) Annual emission reduction: 350tonnes Annual bill saving: $62,581 (assuming $0.15/kWh)
Technology Evaluation Report – Exergenics: Stage 2 optimised chiller staging)	**Exergenics** Identify the impact of optimised chiller system staging logic	Annual energy saving: 188MWh Annual emission reduction: 150tonnes (QLD's grid emission intensity at 0.8 kg CO_2e/kWh) Annual bill saving: $3600 (assuming $0.15/kWh)
Technology Evaluation Report- Graphene coating for refrigeration outdoor condenser units	**Graphene Manufacturing Group** Measure impact of graphene coating on cool room condenser units	Annual energy saving: 474kWh for each unit Annual emission reduction: 379kg for each unit Annual bill saving: $71 for each unit (assuming $0.15/kWh)
Technology Evaluation Report – Buildings Alive Rapid Efficiency Feedback technology	**Buildings Alive** Identify CCHR building energy performance and operational improvement opportunities	Annual energy saving potential: 34MWh Annual emission reduction: 27tonnes Annual bill saving $5119 (assuming $0.15/kWh)
Technology Report on Hospital's future energy use	**QUT & Stantec Aus.** Model the impact of future climate on QCH energy use Evaluate space heating electrification impact for CCHR building Model the effectiveness of pandemic mode ventilation Assess energy plant impact of AS4187	QCH precinct future electricity use forecast: • At least 13% more renewables (3.57GWh) need to be enabled to match with electricity increase in the 2080-2100 period. CCHR HVAC heating electrification • Annual energy saving: 819 GJ • Annual emission reduction: 43tonnes Pandemic mode ventilation • Outdoor air % ineffective • Need local exhaust/filtration AS4187 • Can support electrification (no gas) • Large impacts on peak demand and annual electrical consumption

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 availability) could include long term analysis of building energy performance, hospitals' heating electrification, 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 QCH Living Lab.	The agreement between QCH and QUT was fully executed, and a management committee was formed. A new automatic weather station has been installed on QCH CCHR building.
Enable the Australian HVAC and building services industries to have their innovative technologies independently validated at QCH LL.	Four sets of HVAC and building service technologies were tested with reports prepared. One additional report explores hospitals' future energy use. Evaluation of the technologies at QCH Living Lab 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.	QCH Living Lab has identified a 2.4MW (3MVA) demand response capability which can be used to achieve nearly 50% reduction in energy demand. QCH is a participant of LLHC5 and participates regularly in healthcare sector workshops. In terms of HVAC & R , the technologies tested in QCH Living Lab are collectively capable of reducing annual energy by 468MWh, which is equivalent to 71 households' annual electricity use in total.
Information is promulgated to the wider industry.	9 main reports, 2 scientific publications, 3 industry publications and 15 industry presentations, + Healthcare Knowledge Sharing Taskgroup.

Table 1-3 Achievement of project key performance indicators

Key Performance Indicators (KPIs)	Evidence
QCH Living Lab facility established and operational	The living lab had been fully functional and tested a few low-risk innovative technologies. A detailed EnergyPlus model has been completed for CCHR building and used for heating electrification research.
Information (Prospectus and Manual) provided for prospective technology/service providers	QCH Living Lab 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.
Quarterly Progress report that includes progress against KPIs, including baseline metrics for energy consumption, demand and renewable energy specific to this facility	QCH Living Lab Operations Manual and Baseline Data report was completed and submitted to AIRAH/ARENA. It is available to prospective technology/service providers directly and through the i-Hub website.
At least 5 technology assessments completed and published	One technology evaluation report was delivered at M5. Three technology evaluation reports and one technical report are delivered at M7. They are available to prospective technology/service providers directly and through the i-Hub website.
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. Suitable technologies on the waiting list of were incorporated into a project variation, enabling additional testing to be carried out. There is currently no waiting list.
Outputs disseminated through Renewable Energy Knowledge Sharing Task Group for Healthcare and other pathways	Knowledge shared with industry professionals, AIRAH members, academics and the public, through multiple webinars, and the i-Hub healthcare knowledge sharing task group.

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2 QUEENSLAND CHILDREN'S HOSPITAL LIVING LAB OPERATION

2.1 QCH Living Lab Overview

QCH is a specialist state-wide quaternary hospital and health service which provides safe, high-quality and family-centred care for children and young people from across QLD and northern NSW. The Living Lab enables the testing of innovative technologies and processes, and it also examines the potential usefulness of new key performance indicators (KPIs) and metrics that link energy performance and core health services. Outputs from this Living Lab feed into the i-Hub's Healthcare Sector Wide project (LLHC1). Also, QCH is a project participant for the i-Hub Healthcare Living Lab 5 (LLHC5) : Net-zero Energy and Resilient Hospitals – considerations of future climate, pandemics and demand management.

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

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

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

2.2 Operation

In terms of site data collection, monthly QCH precinct electricity and gas use data have been collected to establish the energy baseline and electricity forecast into 2030, 2050, 2070 and 2090 scenarios. The energy baseline is published in QCH Living Lab Operational Manual and Baseline Report on i-Hub website. QCH's chiller system energy data have been obtained and utilised for digital twin technologies and optimisation of the chiller plant.

A new automatic weather station has been procured and installed on CCHR building to collect weather and solar data at 1min interval. This data fills in the gap in Australian Bureau of Meteorology's observation database, as there is no fine resolution solar data available for southeast Queensland.

CCHR building has been modelled in details on EnergyPlus (an internationally recognised building modelling software for energy simulation and assessment). The CCHR building model has been used to analyse the impact of heating electrification, as the current CCHR building's heating in HVAC system is supplied from the central energy plant by gas boilers.

An Operation Manual for this living lab was developed and uploaded to the i-Hub 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.

A range of different innovative technologies expressed interests in participating QCH Living Lab. After evaluation of the technologies, such as suitability for the site and risk management, four technologies were implemented at QCH Living Lab, including digital twin technologies and graphene coating. Technology evaluation outcomes are discussed in the following sections.

2.3 Technology Evaluations

The table below summarised the four technologies evaluated and one technology report for hospital's future energy use at the QCH Living Lab.

Table 2-1 Technologies evaluated at QCH Living Lab

Technology type	Technology supplier & Goals	Performance highlights
Technology Evaluation Report – Exergenics: Stage 1 digital twin for QCH chiller primary system optimisation	**Exergenics** Model the QCH chiller primary system and optimisation of operation	Annual energy saving: 432MWh Peak demand reduction: 99kVA (assuming 0.98 pf) Annual emission reduction: 350tonnes Annual bill saving: $62,581 (assuming $0.15/kWh)
Technology Evaluation Report – Exergenics: Stage 2 optimised chiller staging)	**Exergenics** Identify the impact of optimised chiller system staging logic	Annual energy saving: 188MWh Annual emission reduction: 150tonnes (QLD's grid emission intensity at 0.8 kg CO_2e/kWh) Annual bill saving: $3600 (assuming $0.15/kWh)
Technology Evaluation Report- Graphene coating for refrigeration outdoor condenser units	**Graphene Manufacturing Group** Measure impact of graphene coating on cool room condenser units	Annual energy saving: 474kWh for each unit Annual emission reduction: 379kg for each unit Annual bill saving: $71 for each unit (assuming $0.15/kWh)
Technology Evaluation Report – Buildings Alive Rapid Efficiency Feedback technology	**Buildings Alive** Identify CCHR building energy performance and operational improvement opportunities	Annual energy saving potential: 34MWh Annual emission reduction: 27tonnes Annual bill saving $5119 (assuming $0.15/kWh)

Technology Report on Hospital's future energy use	**QUT & Stantec Aus.** Model the impact of future climate on QCH energy use Evaluate space heating electrification impact for CCHR building Model the effectiveness of pandemic mode ventilation Assess energy plant impact of AS4187	QCH precinct future electricity use forecast: • At least 13% more renewables (3.57GWh) need to be enabled to match with electricity increase in the 2080-2100 period. CCHR HVAC heating electrification • Annual energy saving: 819 GJ • Annual emission reduction: 43tonnes Pandemic mode ventilation • Outdoor air % ineffective • Need local exhaust/filtration AS4187 • Can support electrification (no gas) • Large impacts on peak demand and annual electrical consumption

There are other technologies of potential interests to building energy optimisation and operation improvement, which can be considered for future projects, for example

- Compliance Water Services technologies to improve water cycle scale issue with pulse-based technologies
- Graphene additive into chiller coolant to improve HVAC system efficiency
- Synengco's digital twin technology for predictive maintenance and thermal risk management

2.4 Project Outputs

Aside from the Technology Evaluation Reports mentioned previously, publicly available project outputs include project reports (Table 2-2), peer-reviewed scientific publications (Table 2-3) and industry publications (Table 2-4) and industry presentations (Table 2-5).

Table 2-2 Project main reports

Report title	Brief synopsis
QCH Living Lab Prospectus and Manual	Purpose: To provide a detailed description of the site; the types of technologies that can be evaluated; the energy management system onsite; 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.
QCH Energy Baseline Data Report	*Purpose:* To report historical energy use from the QCH precinct, current and potential energy KPIs, trends of energy use, *Method:* Exploratory data analysis, data visualisation and quantification of energy KPIs *Key findings:* There is a significant correlation between external temperature and energy use, with the highest consumption in the summer period between December and February next year. HVAC system is the site's highest energy user.
QCH Operation Manual and Baseline Data	*Purpose*: Build on the Prospectus, and present more detailed baseline data analysis of the demand profile of the QCH precinct and HVAC plant. *Method*: Exploratory data analysis, data visualisation and quantification of energy KPIs *Key Findings*: summer months used the highest energy and caused the highest peak demand. 5MW is the highest demand the whole QCH precinct ever experienced in the history dataset. There are standby diesel generators onsite which can potentially be used for demand response.

LLHC4 M7 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*: Three key lessons relate to (1) hospital design and data access; (2) preparing private sector companies to work within healthcare facilities; and (3) the need for establishing rapport through regular catch-ups.
LLHC4 Technology Evaluation Report on Exergenics QCH Chiller System Digital Twin and Optimisation	QCH's chiller system primary plant was modelled with Exergenics' digital twin technology. This digital twin allowed optimisation of the chiller operation settings, predicting the plant performance via machine learning, and identifying control improvement opportunities that can reduce energy consumption.
LLHC4 Technology Evaluation Report on Exergenics Optimised Chiller Staging	QCH chillers' staging logic is optimised following Exergenics' recommendation. Onsite measurements and data analysis have shown energy savings. The energy and environment impact of the chiller staging logic optimisation is presented in the report.
LLHC4 Technology Evaluation Report on Graphene coating for refrigeration outdoor condenser units	Graphene coating technology is applied to QCH cool rooms' outdoor condenser units. This technology may improve heat transfer coefficient for condensers' heat exchangers. This report presents the energy savings for the graphene coating applied to those QCH condensers.
LLHC4 Technology Evaluation Report on - Buildings Alive Rapid Efficiency Feedback Technology	Buildings Alive's Rapid Efficiency Feedback Technology is tested at CCHR building. This report presents the energy and emission saving potentials for the building are identified through a machine learning enabled digital twin model and data analytic program.
LLHC4 Technology Report on Hospital Future Energy	To understand hospitals' future energy use and renewable impact, this report presents four areas of findings: - Forecasting QCH precinct electricity use into 2030, 2050, 2070 and 2090 scenarios using a regression model - Analysis of HVAC heating electrification for CCHR building - Understanding the effectiveness of pandemic model ventilation strategies - Estimating AS4187 (a sterilisation standard) impact on hospital's energy use

Note: All i-Hub reports can be found on www.ihub.org.au.

Table 2-3 Scientific publications (journals and conference papers)

Title	Reference
Principles to Define Energy Key Performance Indicators for the Healthcare Sector	Liu, A., Crompton, G., & Miller, W. (2021). Principles to Define Energy Key Performance Indicators for the Healthcare Sector. In F. Wen & F. Shahnia (Eds.), Smart Grid and Energy System Conference. IEEE Xplore. https://doi.org/10.1109/SGES51519.2020.00165
Heating Electrification Impacts on Commercial HVAC Performance Today and Future: A Case Study	Ma, Y., Liu, A., Zedan, S., Miller, W., Bonney, B., Sanders, J., & Campbell, M. (2022). Heating Electrification Impacts on Commercial HVAC Performance Today and Future: A Case Study. Australasian Building Simulation 2022 Conference, 1–12. https://eprints.qut.edu.au/

Table 2-4 Industry publications

Title / link	Type
Healthcare Living Laboratories: Queensland Children's Hospital (LLHC4) https://research.qut.edu.au/ccetp/projects/healthcare-living-laboratories-queensland-childrens-hospital-llhc4/	Media release
Healthy alternatives (feature article) https://www.airah.org.au/Content_Files/EcoLibrium/2021/05-21-Eco-003.pdf	Ecolibrium article (AIRAH's official journal)
RACE for 2030 CRC Research Theme B3 Electrification & Renewables to Displace Fossil Fuel Process Heating Opportunity Assessment Final Report https://issuu.com/racefor2030/docs/b3_oa_project_final_report_july_2021_-_20210721a	Industry research outcome

Table 2-5 Industry Presentations

Title	Type	Purpose
Artificial Intelligence in the Built Environment (8/8/2019) Industry Forum	Presentation and discussion (invited panelist)	Engage QLD industry on AI in the built environment. Include i-Hub activities.
Building Designers Association conference 6-7/8/2019	Presentation / engagement with product providers	Engage building designers in discussions on i-Hub / Living Labs
Future of HVAC conference 11-12/8/2019	Presentation / engagement with product and service providers	Announce i-Hub / Living Labs to HVAC industry
Power, Energy and Clean Technology Seminar (QUT), 01/05/2020	Webinar presentation on i-Hub Living Laboratories	Engage professionals, government employees, NGOs and academics in power and energy areas Webinar recording will be available on QUT site and i-Hub site
i-Hub Summit – Living Laboratories 08/07/2020	Webinar presentation on i-Hub Living Laboratories	Engage professionals, industry participants, students and academics in HVAC&R areas Sharing knowledge of healthcare energy baseline and planned activities at QCH living lab Webinar is available on ihub.org.au
i-Hub webinar for Australian industry (Noja Power) 28/08/2020	Webinar presentation on i-Hub Living Laboratories and Healthcare Sector Activities	Engage professionals, inform our iHub living lab learnings in energy and peak demand management.
International Conference on Smart grid and Energy Systems 26/11/2020	Conference presentation	A conference paper on "Principles to define energy KPIs for the healthcare sector" has been accepted by International Conference on Smart Grid and Energy Systems, which was virtually presented in Nov 2020 and published on IEEE Xplore database.
i-Hub Summit II – Living Laboratories 02/12/2020	Webinar presentation on i-Hub Living Laboratories	Engage professionals, industry participants, students and academics in HVAC&R areas Sharing knowledge of healthcare energy baseline and planned activities at QCH living lab Webinar is available on ihub.org.au

QCH chiller system digital twin and optimization 7/05/2021	AIRAH/QUT industry webinar	Disseminate learning and potential benefits for optimising chiller system operation.
i-Hub Summit III – Living Laboratories 17/06/2021	Webinar presentation on iHub Living Laboratories	Engage professionals, industry participants, students and academics in HVAC&R areas Sharing the 1st technology testing progress
Webinar with Energy Queensland Demand Management Team 08/09/2021	Webinar presentation and discussion	Knowledge sharing on i-Hub project and explore potential areas for collaboration
Presentation for Uniting Care 10/09/2021	Webinar presentation and discussion	Knowledge sharing on i-Hub project and explore potential areas for collaboration
Presentation at Griffith University Annual Energy Symposium 03/12/2021	Mixed mode presentation and discussion	Knowledge sharing on i-Hub project
Presentation at IEEE Innovative Smart Grid Technology Asia conference, Brisbane Convention Centre, 07/12/2021	Presentation, webinar and Q&A	Knowledge sharing on i-Hub project
AIRAH i-Hub Outcomes Summit 17/05/2022	In person presentation and webinar; co-operating with AIRAH Refrigeration Conference	Knowledge sharing on i-Hub project

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
QCH Living Lab - Prospectus and Manual	Refer to the output table in Section 2.4.
Technical Report: QCH Living Lab Monitoring and Initial Baseline Data Analysis	Refer to the output table in Section 2.4. Healthcare Living Laboratories: Queensland Children's Hospital – Energy Baseline Data
Technical Report: QCH Living Lab Prospectus Operations Manual (REETSEF) and Baseline Data Analysis	Refer to the output table in Section 2.4. Healthcare Living Laboratories: Queensland Children's Hospital – Operation Manual and Baseline Data
Technology Evaluation Report on Exergenics QCH Chiller System Digital Twin and Optimisation	Refer to the output table in Section 2.4. Healthcare Living Laboratories : Queensland Children's Hospital – Exergenics QCH Chiller System Digital Twin and Optimisation
Technology Evaluation Report on Exergenics Optimised Chiller Staging	Refer to the output table in Section 2.4. Healthcare Living Laboratories : Queensland Children ' s Hospital : Technology Evaluation Report for Exergenics ' Optimised Chiller Staging
Technology Evaluation Report on Graphene coating for refrigeration outdoor condenser units	Refer to the output table in Section 2.4. Healthcare Living Laboratories: Queensland Children's Hospital – GMG Thermal-XR Coating System Technology Evaluation Report
Technology Evaluation Report on - Buildings Alive Rapid Efficiency Feedback Technology	Refer to the output table in Section 2.4. Healthcare Living Laboratories: Queensland Children's Hospital – Technology Evaluation Report: Buildings Alive (Centre for Children's Health Research)
Technology Report on Hospital Future Energy	Refer to the output table in Section 2.4. Healthcare Living Laboratories: Queensland Children's Hospital – Technical Report on Hospital's Future energy
QCH Living Lab Final Report	This report.

Table 3-2 Achievement of project outcomes

Project outcomes	Evidence
The establishment of the QCH Living Lab.	The agreement between QCH and QUT was fully executed, and a management committee was formed. A new automatic weather station has been installed on QCH CCHR building.
Enable the Australian HVAC and building services industries to have their innovative technologies independently validated at QCH LL.	Four sets of HVAC and building service technologies were tested with reports prepared. One additional report explores hospitals' future energy use. Evaluation of the technologies at QCH Living Lab 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.	QCH Living Lab has identified a 2.4MW (3MVA) demand response capability which can be used to achieve nearly 50% reduction in energy demand. QCH is a participant of LLHC5 and participates regularly in healthcare sector workshops. In terms of HVAC & R , the technologies tested in QCH Living Lab are collectively capable of reducing annual energy by 468MWh, which is equivalent to 71 households annual electricity use in total.
Information is promulgated to the wider industry.	Refer to knowledge sharing tables in the previous section.

Table 3-3 Achievement of key performance indicators

Key Performance Indicators (KPIs)	Evidence
QCH Living Lab facility established and operational	The living lab had been fully functional and tested a few low risk innovative technologies. A detailed EnergyPlus model has been completed for CCHR building and used for heating electrification research.
Information (Prospectus and Manual) provided for prospective technology/service providers	QCH Living Lab 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 the outcome tables in the previous section) .
Quarterly Progress report that includes progress against KPIs, including baseline metrics for energy consumption, demand and renewable energy specific to this facility	QCH Living Lab Operations Manual and Baseline Data report was completed and submitted to AIRAH/ARENA. It is available to prospective technology/service providers directly and through the i-Hub website (Refer to the outcome tables in the previous section) .
At least 5 technology assessments completed and published	One technology evaluation report was delivered at M5. Three technology evaluation reports and one technology report are delivered at M7. They are available to prospective technology/service providers directly and through the i-Hub website (Refer to the outcome tables in the previous section) .
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. Suitable technologies on the waiting list of were incorporated into a project variation, enabling additional testing to be carried out. There is currently no waiting list.
Outputs disseminated through Renewable Energy Knowledge Sharing Task Group for Healthcare and other pathways	Knowledge shared with industry professionals, AIRAH members, academics and the public, through multiple webinars, and the iHUB healthcare knowledge sharing task group (Refer to the outcome tables in the previous section).

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 a major hospital in operation

QCH is one of the major hospitals in Queensland and the only children hospital in Queensland, providing high quality children related clinical and healthcare services to the whole state of Queensland and Northern New South Wales. QCH engineering staff are usually busy with quite a lot of operational and maintenance tasks. Staff members may not always be able to contribute as much as they would like to.

3.2.2 Access to data

Thermal energy related operational data at QCH are managed and accessible by site principal contractor, for example, HVAC system's chilled water temperature and flow data. Every time, when there is a need of those datasets, QCH Living Lab host issues a new purchase order to acquire such data from the site principal contractor. This accounts for more inkind contribution from QCH and is greatly appreciated. However, this poses new challenges in terms of costs and operational procedures. Potentially, this is also an opportunity to look at whether there is a new way to access operational data.

3.2.3 Impact of COVID

QCH is a COVID hospital with both testing facilities, clinical and ward services to children in needs. Most of the living lab duration coincided with the outbreak of COVID 19. There had been quite a few lockdowns in 2020 and 2021 which restricted physical access to the living lab. Also, there have been resource limitations in terms of timing of technology implementation and technician's availabilities, due to Queensland border closure and COVID lockdowns. However, this challenge has been successfully managed by carefully evaluating technologies, such as technologies without contact with clinicians nor patients and data driven low risk technologies.

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. Healthcare facilities are health and medical services oriented. It may take some time for new companies to learn the contracting process, risk evaluation and management system, documents and induction required.
2. Major hospital sites often have multiple buildings onsite with complex building management systems and engineering services teams.
3. It is crucial to get design and construction right at the beginning to allow data access for later energy optimisation or continuous improvement to happen. One lesson learnt is, we attempted to implement chilled water temperature setting optimisation, however, there is no sufficient secondary or tertiary energy data available for the optimisation, for example, no sufficient metering points available for buildings' air handling units.

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".

It can be very challenging for major urban hospital to manage energy use and peak demand due to health services' high energy use intensity and very limited space available in urban built environment. QCH Living Lab has pioneered in this space, by independently testing innovative low risk technologies to significantly reduce energy use, reduction of 468MWh a year, equivalent to 71 households' yearly energy use.

The onsite standby generators are also capable of participating demand response in Australian national electricity market. In terms of peak demand reduction, one of the site standby generators is capable of reducing about 50% of QCH's peak demand. Facility management of QCH are active contributors to LLHC1 healthcare sector-wide knowledge sharing task group and widely share knowledge in the space.

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, several future endeavours are possible. There are a few corporate research centres (CRC) which may support the continuation of the initiatives generated from the project to futureproof hospitals' resilience and support our low carbon transition.

For example, heating electrification, energy efficiency and renewable enablement aspects of the QCH Living Lab can be further envisioned in the business theme of Renewable Affordable Clean Energy for 2030 (RACE for 2030 CRC): https://www.racefor2030.com.au/. While the building simulation and future energy resilience aspects of the living lab can be extended in Building 4.0 CRC: https://building4pointzero.org/.