The Innovation Hub

for Affordable Heating and Cooling

The Innovation Hub for affordable Heating and Cooling (i-Hub)

Knowledge Sharing Final Report

20 September 2022

AIRAH

Acknowledgement and disclaimer

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 the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Queensland University of Technology (QUT), the University of Melbourne (UoM) and the University of Wollongong (UOW) and supported by the 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.

This Project received funding from the Australian Renewable Energy Agency (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.

Primary Project Partners

Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Queensland University of Technology (QUT)

University of Melbourne (UoM)

University of Wollongong (UOW)

The information or advice contained in this document is intended for use only by persons who have had adequate technical training in the field to which the Report relates. The information or advice should be verified before it is put to use by any person. Reasonable efforts have been taken to ensure that the information or advice is accurate, reliable and accords with current standards as at the date of publication. To maximum extent permitted by law, the Australian Institute of Refrigeration, Air Conditioning and Heating Inc. (AIRAH), its officers, employees and agents:

a) disclaim all responsibility and all liability (including without limitation, liability in negligence) for all expenses, losses, damages and costs, whether direct, indirect, consequential or special you might incur as a result of the information in this publication being inaccurate or incomplete in any way, and for any reason; and
b) exclude any warranty, condition, guarantee, description or representation in relation to this publication, whether express or implied.

In all cases, the user should be able to establish the accuracy, currency and applicability of the information or advice in relation to any specific circumstances and must rely on his or her professional judgment at all times.

The Innovation Hub for Affordable Heating and Cooling (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 the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Queensland University of Technology (QUT), the University of Melbourne (UoM) and the University of Wollongong (UOW) and supported by the 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.

The i-Hub Project has supported a number of sub-projects to demonstrate how renewable energy technology can be optimally integrated with HVAC&R equipment. The Project included three Activity Streams; the Living Laboratories, the Data Clearing House and the Integrated Design Studios. Each of these Activity Streams comprised of a set of Sub-projects, which contributed to the Outcomes of i-Hub. The Project, and its Sub-projects, were coordinated by AIRAH which was responsible for managing and distributing ARENA Funding for the Project and the Sub-projects. AIRAH also established and constituted the i-Hub Steering Committee to oversee the Project.

Lead organisation

The Australian Institute of Refrigeration, Air Conditioning and Heating (Incorporated)

Project commencement date

19 November 2019

Completion date

30 June 2022

Contact name

Tony Gleeson, i-Hub Chair

Report Author

Vince Aherne, i-Hub Project Leader

Project website

https://www.ihub.org.au/

Message From the i-Hub Chair

Over the last three years, i-Hub has brought together a community of industry innovators, designers, researchers, building owners, manufacturers, and educators to access knowledge and research infrastructures to create a connected research and development community to incubate ideas, and reshape the HVAC&R industry practice to the needs of the 21st century.

Three main activity streams covering Living Laboratories, Data Clearing House and the Integrated Design Studios conducted 32 projects across Australia. The i-Hub project demonstrated how renewable energy technology could be optimally integrated with heating ventilation, air conditioning and refrigeration equipment to facilitate the HVAC&R industry transition to a low emissions future.

The i-Hub project was able to provide a variety of opportunities for valuable knowledge and research sharing to provide a positive impact on our environment, open new opportunities for employment and opportunities for industry wide collaboration.

As chair of the i-Hub steering committee I would like to thank our committee members Phil Cowling, Nathan Groenhout, Peter Haenke, Stephen Humphries, Luke Menzel, Kriston Symons and Troy Wilson for their valuable contribution and guidance, particularly through the COVID impacted times.

I would also like to thank the activity stream leaders, Wendy Miller from Queensland University of Technology, Stephen White from CSIRO, Georgios Kokogiannakis from University of Wollongong, Brendon McNiven and Lu Aye from University of Melbourne, for their dedication and collaboration to achieve such outstanding results. Thanks of course also to all of the individuals and organisations involved in the management and delivery of the i-Hub sub-projects.

Mention must also go to our project leader Vince Aherne and finance director Sami Zheng for keeping this complex project on track and to schedule.

Lastly, I would like to thank Lyndon Collier from ARENA for his assistance in working so closely with AIRAH and i-Hub, and of course to ARENA itself for the valuable funding from their Advancing Renewables Program.

Tony Gleeson
i-Hub Chair
21 June 2022

Table of Contents

List of Figures

List of Tables

1 Executive summary

The i-Hub Project was facilitated by an agreement between the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH), the Australian Renewable Energy Agency (ARENA), and 65 different project delivery partners and participant organisations from a range of research, university, government and industry organisations. With a focus on efficiency and renewable energy, i-Hub conducted extensive research on how to reduce emissions and improve performance of HVA&R systems.

i-Hub is the collaboration between a range of innovative organisations to deliver tools and information to help make buildings, and building heating and cooling systems, more affordable, more efficient, more integrated and less energy intensive. More efficient building and HVAC&R system design and operation enables more buildings to be powered by more renewable energy. Understanding how buildings and systems can flex energy and heating and cooling loads is demonstrating how buildings can become thermal and energy storage assets, that can be controlled to promote grid stability and efficiency. In order to achieve cheaper low emission heating and cooling we need to have more efficient systems in more efficient buildings powered by low-emission energy sources.

i-Hub is showing industry how integrated design can help building owners and project teams design buildings that fully integrate their energy assets and engineering with their architecture and design, and provides clear directions and pathways to net zero buildings in a variety of sectors. i-Hub is also demonstrating the power of unlocking building data and making innovative use of that data to address a range of desirable outcomes including optimising operational energy efficiency and renewable energy use as well as opportunities to reduce peak demand and create flexible demand to participate in electricity management markets.

The Data Clearing House activity created an innovative data platform to help owners manage building energy use and address a range of potential use cases including building operation efficiency, optimisation of renewable energy assets, measurement and verification of energy savings, perk demand manipulation/reduction, and participation in demand response schemes. The Data Clearing House platform provides building owners with an easy pathway to turn their building data into useful and useable information. The activity has also provided a range of insights into the barriers and solutions during a building’s journey towards becoming a digitally connected smart building.

The Integrated Design Studio activity has demonstrated and analysed the integrated design process and innovative design output across 9 different building typologies and 14 different building design projects. The work has shown how design teams can better apply integrated design, identifying a range of barriers to the process and suggesting a series of solutions to overcome those barriers. The program has also developed, assessed and documented a range of design responses to show how almost any building can be a low emission renewable energy powered building, if that is what the designers aim to create from the beginning.

The Living Laboratory activity has shown how a living laboratory can be set up and operated to help building owners assess potential technologies and services that can help them reduce energy through rapid, wide-spread deployment. This work has resulted in sector-wide roadmaps that can be used by schools and healthcare facility operators and owners to help plan a pathway to net zero buildings.

This report summarises the overall i-Hub activity and ties together the three activity streams. It provides a high-level overview of the tools and knowledge developed and how these have helped i-Hub achieve its target outcomes.

2 i-Hub Project overview

2.1 About the i-Hub project

2.1.1 Context

Buildings in Australia account for approximately 19% of total energy consumption and 23% of greenhouse gas (GHG) emissions. Heating Ventilation Air Conditioning and Refrigeration (HVAC&R) is the largest end-use of energy in commercial buildings.

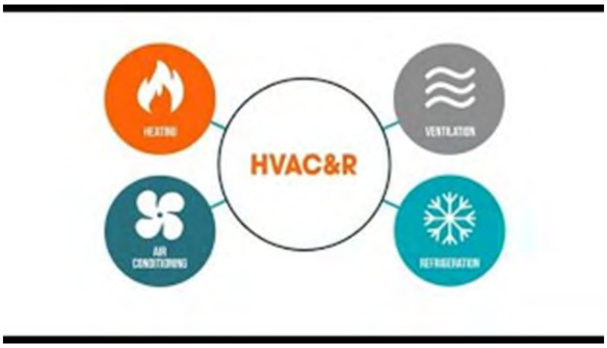


Figure 1: Heating Ventilation Air Conditioning and Refrigeration (HVAC&R)

The Australian HVAC&R sector consumes around 22% of all electricity produced in Australia and is responsible for up to 50% of peak demand on the electricity grid and around 12% of Australia's total national carbon emissions.

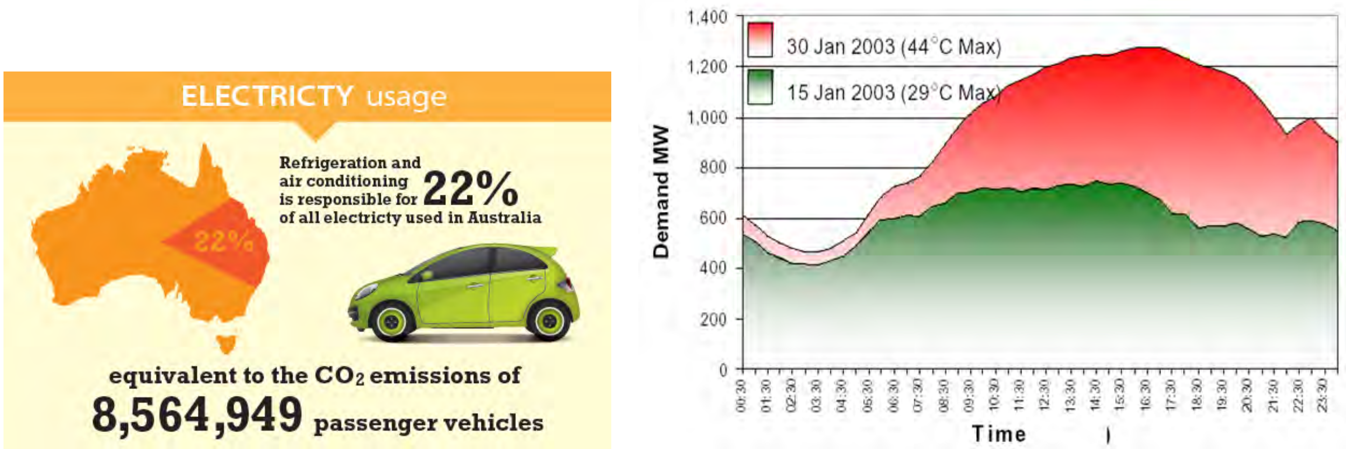


Figure 2: HVAC&R - 22% of all electricity consumed and 50% of Peak Demand

Clearly the HVAC&R sector is a substantial energy-consuming sector that provides a largely untapped opportunity for enhanced grid-interactive control of demand response, load flexibility, renewable energy uptake and integration of various technologies. It is also clear that buildings and HVAC systems can be designed, installed and operated better and the emissions trajectory of a building is directly linked to the emissions produced by its heating and cooling systems.

2.1.2 Genesis - How i-Hub came about

i-Hub was formed from the intersection of several different activities and sources.

AIRAH played a lead role in the development of a whole of industry pathway to a low emissions future called **PRIME,** access here [PRIME (airah.org.au)](https://www.airah.org.au).

PRIME is the HVAC&R industry's blueprint for a successful transition to a low-emissions future through Professionalism, Regulation, Information, Measurement, and Emission abatement. The PRIME initiative revealed significant deficiencies within the delivery of low emission HVAC.

AIRAH has strongly advocated for **low emission HVAC&R** – energy efficient buildings heated and cooled by energy efficient systems, using carbon free or low emission electricity

The **AIRAH Future of HVAC** industry think tank identified, in 2016, that the Information Technology (IT) systems in use in the building/HVAC industry were still in the 'software' phase and had not yet moved into the 'app' phase.

Mission Innovation is a global initiative to accelerate the clean energy revolution which includes the Affordable Heating and Cooling of Buildings Innovation Challenge. The objective is to develop core building heating and cooling systems and services, and measures to improve building envelopes that deliver affordable heating and cooling without the carbon emissions.

ARENA is the government agency tasked with supporting the global transition to net zero emissions by accelerating the pace of pre-commercial innovation, to the benefit of Australian consumers, businesses and workers. The Advancing Renewables Program supports a range of development, demonstration and pre-commercial deployment projects that address opportunities to optimise the transition to renewable electricity and can deliver affordable and reliable renewable energy for Australian families and businesses. Projects supported include low emissions technologies and emerging and enabling technologies that support renewable energy.

Figure 3: The Genesis of i-Hub

Championed by AIRAH and CSIRO, supported by major University partners UoM, UOW, QUT and the Australian Government through the ARENA Advancing Renewables Program, after several years of program design and development, the i-Hub officially commenced on 19th November 2019.

Figure 4: i-Hub 2019 Aims

2.1.3 i-Hub project architecture

AIRAH have long advocated for low emission HVAC&R supported by the three pillars of (1) highly efficient buildings cooled and heated by (2) highly efficient systems powered by (3) low carbon/carbon free energy sources.

The architecture of the i-Hub project was designed to address these three pillars.

> **Highly efficient buildings** – through exploring net zero design and understanding barriers in the **Integrated Design Studios,** exploring building fabric performance in the **Living Laboratories** and creating the **Data Clearing House** digital platform to unlock operational energy saving opportunities in the building sector.
>
> **Highly efficient HVAC systems** – through the **Living Laboratories** evaluating and validating new technologies and services and through the **Data Clearing House** digital platform promoting and creating innovative applications, algorithms and software that connected buildings can access to improve HVAC energy efficiency in operations.
>
> **Low carbon/carbon free energy sources** – reducing emissions and enhancing grid stability and renewable energy use though integrating onsite renewable energy assets with HVAC load control and building energy efficiency and exploring opportunities for participating in Demand Response and flexible demand initiatives across the full range of i-Hub initiatives.

The i-Hub Project included low emission renewable energy technologies as well as emerging and enabling technologies. These are services and processes that support renewable energy, including technologies that reduce heating and cooling loads, technologies that improve building and system efficiency, technologies that can control and move loads, technologies that can store thermal energy, and a range of technologies and services that can improve utilisation of renewable energy within the building and the grid.

Jointly funded by ARENA (34%) and project partners and participants (66%), i-Hub embarked on a series of innovative technology and process development and demonstration projects designed to address the nexus of renewable energy, building heating and cooling, building energy efficiency and flexible demand/demand response opportunities and how these can be integrated to significantly reduce a buildings emissions and grid energy use.

AIRAH was the project manager for i-Hub and responsible for coordinating, managing and monitoring the sub-projects under the advice of the i-Hub steering committee. AIRAH delivered sub-project management, financial management, knowledge sharing and communications functions and reported to ARENA.

2.2 i-Hub Activity Streams

The i-Hub project was delivered within three activity streams:

1. Data Clearing House (DCH)
2. Integrated Design Studio (IDS)
3. Living Laboratories (LL).

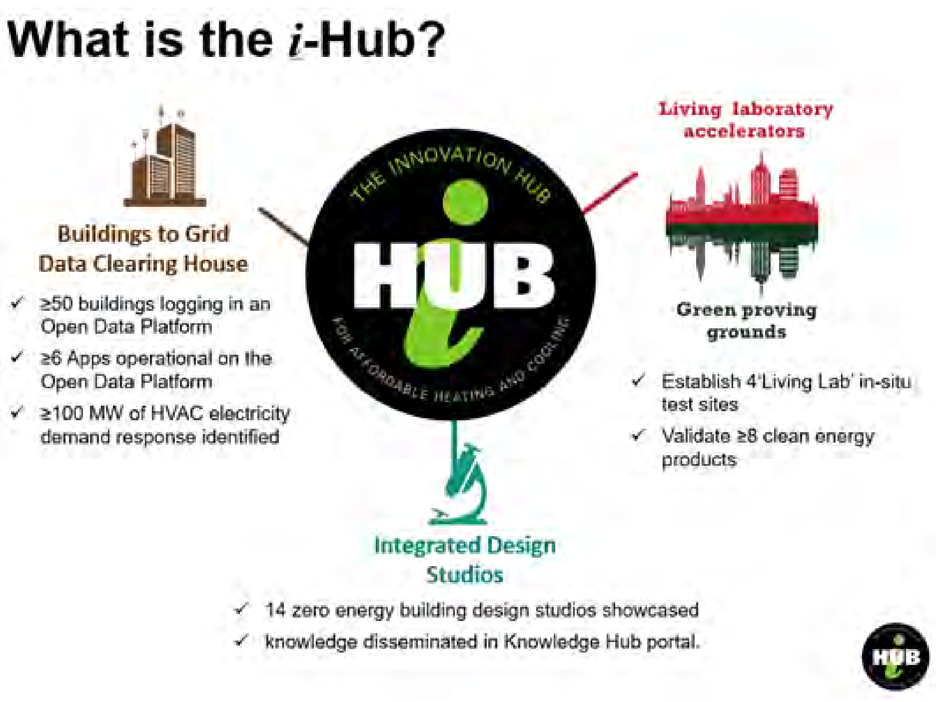


Figure 5: Three Activity Streams

The **Data Clearing House** (DCH) activity focused on developing, testing and refining a new open-access digital 'Data Institute' for buildings, where building owners can connect their smart buildings and use a range of innovative energy-based applications to reduce the cost (and emissions) of building operation and optimise their energy assets. A major focus of the DCH activity is optimising a building's energy and HVAC assets, minimising operational energy use, and exploring opportunities for connected buildings to participate in flexible demand markets.

The **Integrated Design Studio** (IDS) activity focused on running a series of Integrated Design Studios, bringing architectural and engineering design together for a range of building and owner types and putting renewable energy and net zero outcomes at the core of the design process. Each design studio is facilitated by a university, bringing owners and designers together in a 'neutral' design environment and leveraging academics and university students to generate and evaluate innovative design solutions, all the while studying the barriers and enablers of a successful integrated design process.

The **Living Laboratories** (LL) activity included the establishment of 5 living laboratories (one Hospital, two Aged Care facilities and two School sites) and 2 sector-wide analysis projects. Healthcare and Education buildings was a focus for i-Hub due to their intensive energy use profiles and their tendency to be owned in large portfolios. Living Laboratories establish research-quality measurement and verification systems within existing buildings in order to observe and evaluate technology upgrades within the context of the daily operation of these buildings. This is different from 'normal' laboratory testing which is often undertaken under standardised (and most commonly steady-state) conditions and does not address occupant needs and system interactions with the building.

Over the course of the project period AIRAH and i-Hub created and managed 33 individual i-Hub sub-projects that were all designed and targeted to address the i-Hub objectives. i-Hub sub-projects were delivered by independent project delivery teams across the 3 activity streams and overseen by the respective Activity Leader and AIRAH. AIRAH was responsible for the overall management and coordination of i-Hub sub-projects, including knowledge sharing, and constituted an i-Hub Steering Committee to provide advice to AIRAH and ARENA.

A short summary of each project, and the main knowledge sharing materials produced, is provided in the Activity Stream sections 3, 4 and 5 of this report.

2.3 I-Hub Objectives

I-Hub commenced with a range of high-level objectives that were underpinned by targeted outcomes and monitored key performance indicators.

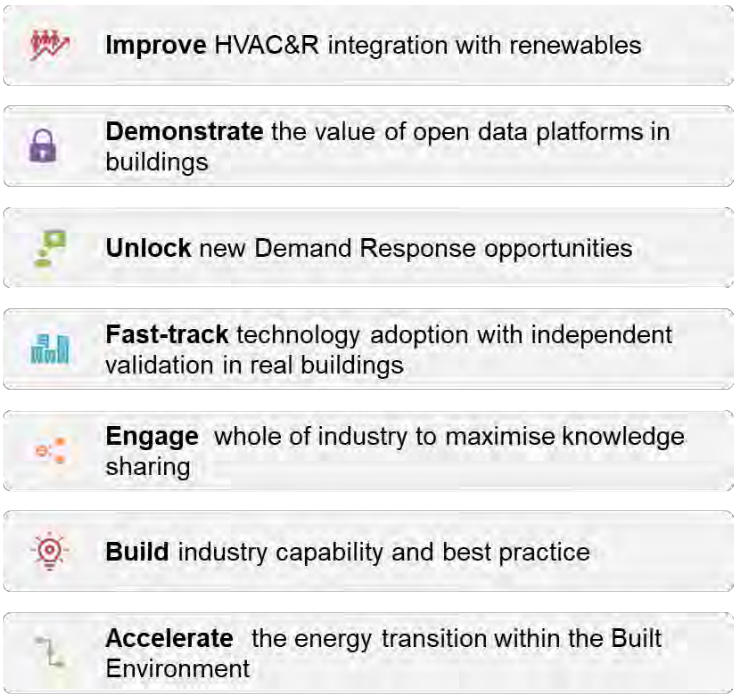


Figure 6: i-Hub objectives

The objectives of the i-Hub project related to both Operation and Design of HVAC. These were:

a. Operation: Test and validate means by which the energy demand of HVAC can be coordinated with onsite and grid level renewable energy production in order to maximise the value of on-site renewable energy production by:

   i. Maximising efficient and productive HVAC operation during renewable generation peaks

   ii. Deferring HVAC loads during short term generation variabilities

   iii. Storing energy within HVAC systems to enable the timing of site energy demand to be modulated in order to:

      1. Minimise on-site generation export,

      2. Optimise revenue via tariff or grid-level mechanisms, e.g., Reliability and Emergency Reserve Trader (RERT) or Frequency Control Ancillary Services (FCAS),

      3. Enhance grid-level stability and robustness thereby reducing the cost of firming supply for grid-level renewable generation contracts.

b. Design: Increase implementation of renewable energy generation with HVAC by:

   i. Developing design processes that consider on-site renewable solar as an integral component of high efficiency/net zero building design, with consideration of revenue maximisation, rather than an add-on

   ii. Developing equipment selection processes that build efficient and practical HVAC demand response into design, in order to maximise the ability of buildings to support stable and robust grid operation in the presence of a high renewable grid energy content

   iii. Fast-tracking knowledge sharing across the supply chain in the built environment

The importance to industry is underscored by the range of reports that have been published identifying the high level of carbon emissions associated with Australian buildings and HVAC&R. The HVAC&R industry needs to understand how it can become part of the low emissions solution, and i-Hub project has demonstrated a range of pathways to low emission HVAC/Buildings.

2.4 i-Hub Outcomes

The main outcomes that the i-Hub Project targeted to help achieve the objectives were:

1. **Establishment of an industry-run Data Clearing House platform**, offering new data sharing and control strategies that will enable automated participation in demand response markets, efficient and productive HVAC operation, optimised renewable generation and energy storage assets, and improved cyber security data control, building/system connectivity and digital interoperability.
2. Increased availability of demand response with specific **identification of 100 MW of DR potential** within the broader i-Hub portfolio.
3. **Increased understanding** of methods to reduce **peak demand and demand charges** as well as increase the hosting capacity of solar through **HVAC load control** combined with onsite **renewable energy control**.
4. **New Integrated Design Studio approach** showcasing the benefits of co-design delivering lower cost and higher performance buildings.
5. Establishment and legacy of **5 Living Laboratories** where industry and property owners can test innovative decarbonisation technologies and services in a fully instrumented real world occupied building.

6. Development of a **Renewable Energy and Enabling Technology and Services Roadmap for Healthcare/Education**, showing the benefits and impacts of the potential widespread application of technologies assessed in the Living Laboratories.
7. Identification of **design, digital and technological solutions to reduce onsite energy use by at least 25%** compared to business as usual.

2.5 Knowledge Sharing

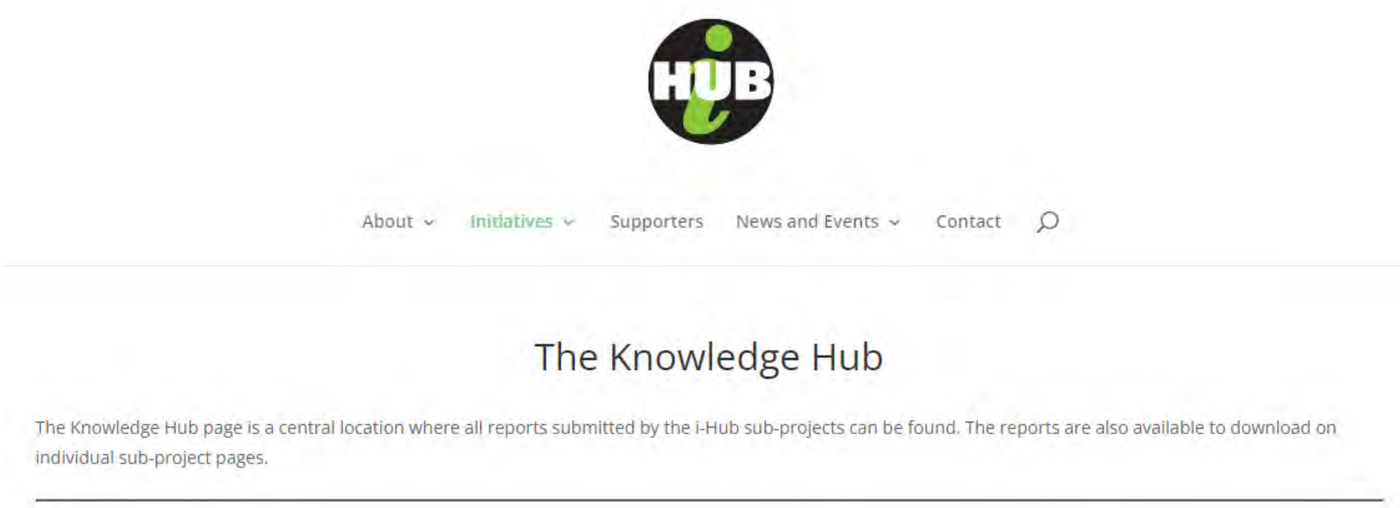
A fundamental key purpose of the i-Hub project was to generate and share knowledge, in order to promote innovation and to enable transition of the industry. Key elements of knowledge to be shared include:

- Living Laboratories: **Knowledge on the performance and efficacy of emerging products and services in real world applications**. As independent, highly visual summary collateral, Technology Evaluation Reports provide support to company marketing efforts and accelerate adoption into a sector or portfolio. Sector wide work was developed and delivered in partnership with an industry Knowledge Sharing Task Group, to produce sector wide roadmaps for building owners and operators.
- **Data Clearing House**: **Knowledge on performance benchmarks and the performance of individual buildings and building equipment.** Data sharing through the DCH will empower innovators to develop new software services that will empower building owners to optimise their energy assets. It will also facilitate the benchmarking and performance assessment of buildings. This will enable much more sophisticated understanding and control of buildings, their energy assets and their heating and cooling systems.
- Integrated Design Studios: **Knowledge on the most appropriate design solutions for net zero building, different building typologies and climates**. Knowledge on the barriers to integrated design and how to overcome them.

This information is all available as publicly accessible knowledge sharing technical reports and videos of a range of i-Hub knowledge sharing presentations and forums, all disseminated through the online i-Hub knowledge portal.

Access here -

[The Knowledge Hub - i-Hub (ihub.org.au)]



3 The Data Clearing House (DCH) Activity Stream

3.1 The i-Hub Data Clearing House (DCH)

The PRIME initiative outlined the emission reduction opportunities that building heating and cooling, energy use and building data would provide if the right information could be provided to the right people at the right time. The Future of HVAC 2016 visioning workshop noted that building efficiency was still in the 'mainframe' age of computing as opposed to the 'application' age of mobile devices.

CSIRO and AIRAH had a vision to build an open access data sharing platform for buildings that could assist in overcoming the barriers to the provision of energy services within Australian buildings, with a focus on building heating and cooling.

The i-Hub *Data Clearing House* open data platform is a visionary initiative that fits perfectly into the future vision of smart and connected buildings. By exposing building data to service providers, entrepreneurs, software developers, research scientists, students, and organisations owning and operating buildings, the DCH will open the door to a never-seen-before ecosystem of smart building digital innovation rooted in connectivity.

This initiative could create and support an entire eco-system of world-class Australian-born smart building technologies, creating thousands of new jobs and upskilling many existing jobs such as trades involved in building services and maintenance. This industry growth can create skills and grow revenue and at the same time transition Australian buildings to smart, sustainable low-emission buildings, reducing their carbon footprint and leaving a measurable, positive impact on Australian emissions.

3.2 DCH Objectives

The Data Clearing House activity aimed to achieve the following outcomes:

- Overcome key barriers (data ownership ambiguity, data acquisition cost, and trust) to building participation in electricity markets by providing a legacy open data platform for accessing and securely sharing HVAC operational data.
- Enable electricity system planners and policy makers to deliver a more reliable and affordable national electricity system by quantifying (and proving up) the amount of demand response available nationally from building HVAC systems.
- Identify >100 megawatts of electricity demand response from building HVAC systems, that can be used by i-Hub building owner participants to:
    - Increase the value of their on-site renewable energy (through increased self-consumption of onsite renewable electricity generation)
    - Reduce their peak electricity import/export (through discretionary load control of HVAC during peak demand events)
    - Increase hosting capacity for on-site solar generation (through reduced need to export low value renewable electricity generation).

3.3 DCH Outcomes and KPIs

The DCH activity long term outcomes and the KPIs that were monitored to determine progress toward achieving those outcomes are shown in Table 1.

Table 1: DCH Long-term outcomes and evidence

Long term outcome	Long term KPI - Evidence
Data Clearing House established and key barriers to data ownership, data acquisition cost, and data security, (restricting building participation in electricity markets) are overcome for DCH participants	The Data Clearing House digital platform has been established, with up to 60 buildings connected and using data services. Reports on DCH platform operation, including (i) hosted DCH buildings and (ii) hosted DCH Applications. Knowledge sharing collateral produced for the DCH final public release.
Evidence established to enable electricity system planners and policy makers to deliver a more affordable national electricity system through enhanced Demand Response derived from building HVAC systems and opportunities to reduce building HVAC energy consumption	9 x Software as a Service "Applications" hosted on DCH Marketplace. Provided a Public Report that demonstrates the potential to provide up to 100MW of Demand Response from HVAC systems.
DR demonstrated, with scale-up potential representative of up to 100MW of DR in the National Electricity Market (NEM)	Assessment of Demand Response Potentials in Australian Non-Residential Buildings - The potential for HVAC related demand response has been quantified, nationally. Public Report that demonstrates the potential to provide up to 100MW of Demand Response from HVAC. Demand response use cases have been demonstrated, with scale-up potential in the NEM
A wide range of building types are streaming HVAC data through the Data Clearing House	Over 50 Buildings connected to Data Clearing House. A range of knowledge sharing and technical collateral to support the Data Clearing House and the various technology and innovative data use case demonstrations, documenting the Data Clearing House project journey.
A wide range of applications are hosted on the Data Clearing House which are registered by members and active participants	9 x Software as a Service "Applications" hosted on DCH Marketplace

3.4 DCH Methodology

The DCH Activity has established an open data platform for receiving and securely sharing data relating to building HVAC, on-site renewable energy equipment and other energy assets. The Data Clearing House platform has been built with the capability to provide supervisory control of building HVAC equipment in order to deliver demand response capacity.

The Data Clearing House Activity has used the DCH software platform to create an ecosystem of data providers and data users, all innovating to develop new demand response and energy-related software “Applications”. Separate DCH sub-projects have been delivered to enable digital innovators to cost-effectively develop various energy-based software-as-a-service (SaaS) “Applications” for a range of building owners, that are all hosted on the DCH platform.

The value of the DCH is not limited to energy services, with a wide variety of other productivity benefits possible, through greater access to building data. It will be important in future development to encourage a rich exploration of applications, and areas of impact, in order to bundle value streams.

Additionally, access to data will enable broader and more sophisticated analysis of building performance in different building typologies, climate zones and HVAC system configurations. This can be used to inform policy, roadmaps and best-practice guidelines.

3.5 The DCH Platform

The i-Hub Data Clearing House (DCH) is a middleware software platform that connects data providers (e.g., Building Management Systems and 3rd party data sources) with data users (e.g., data analytics companies, facilities managers) to provide a match-making platform/marketplace that connects building owners with building services SaaS companies.

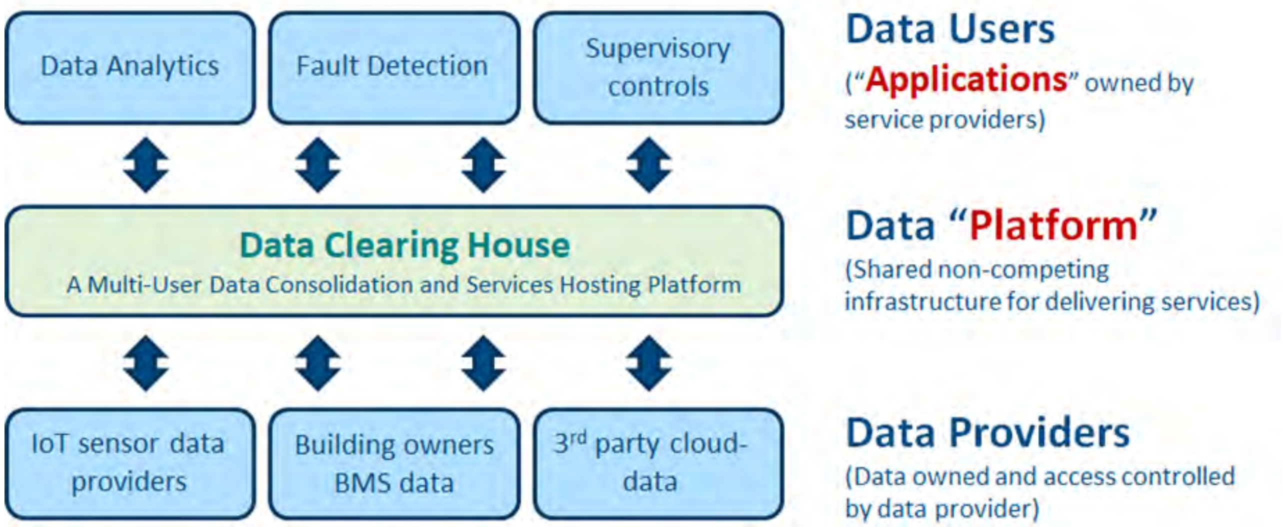


Figure 7: The DCH Platform data ecosystem

The Data Clearing House is a critical step in the digitalisation of building operations across Australia, and in the fostering of all data-driven services. It is intended to overcome the following key barriers:

- **Data ownership ambiguity**. Data held within existing proprietary platforms often vests with the technology provider rather than with the building - discouraging platform mobility and industry innovation.
- **Data acquisition cost**. Currently the establishment and management of reliable data acquisition in a building may account for more than 50% of the cost of providing data-driven services. Each proprietary application has its own processes in this respect, meaning that buildings are faced with duplicating set-up costs when changing technology provider. This discourages innovation and the adoption of any data driven application for the optimisation of renewable energy value.
- **Trust**. Innovators have expressed unwillingness to collaborate on data platforms provided by vertically integrated vendors. Building owners have demonstrated preference to be able to build bespoke renewable energy analytics rather than commit to proprietary black-box solutions. The proposed collaborative, horizontal open-data platform fills this gap.
- **Data/System Integration Barriers.** There is poor hardware/software interoperability and a lack of standards for managing data. Integrators have significant Cyber security, privacy and data-leakage fears while engagement with IT department can be difficult due to a conservative industry structure.
- **Skills Barriers.** There is a significant lack of system-integration skills and a diverse range of implementation practices.
- **Commercial Barriers.** There are significant building owner commercial lock-in/ purchasing fears. Current offerings are often siloed product offerings exhibiting a lack of innovation/ narrow range of services.

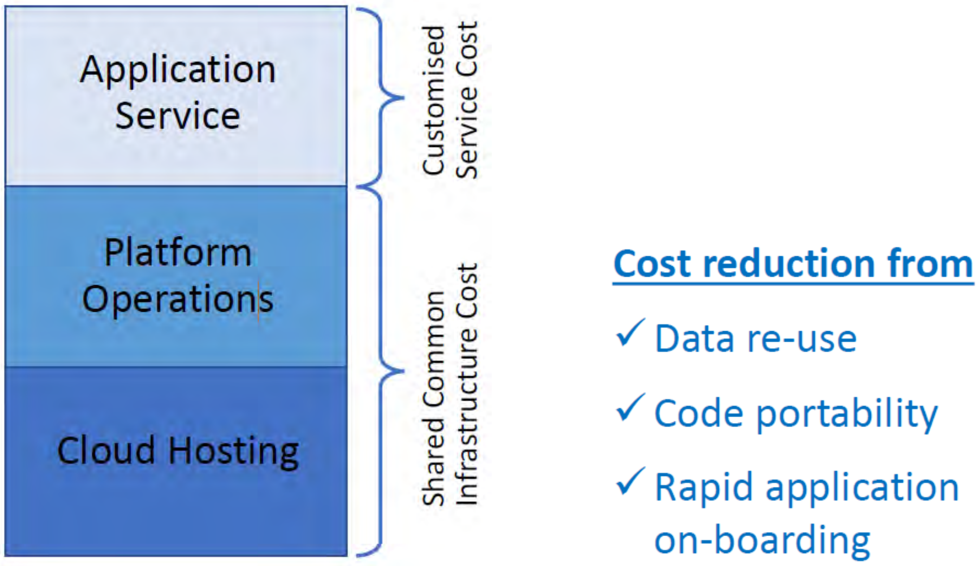


Figure 8: DCH Reducing costs, removing duplication, reusing data

To overcome these barriers DCH has delivered a platform with the following features:

Facilitate self-service onboarding and offboarding processes – building owners and managers control connection and disconnection of their buildings, which will minimise their costs.

Support data collection and data sharing without vendor lock ins– data owners retain control of their data and how/where/why it is used.

Facilitate easy deployment of application-based services to connected buildings – there is a data Applications marketplace where data users offer a range of services to connected buildings and data owners can choose which services to use.

Facilitate access to data, measurement and verification, and building model-based capabilities – providing self-service connection/disconnection, self-service software selection, an in-built Plug and Play IPMVP Application (International Performance Measurement and Verification Protocol) which normalises energy savings, and providing data/building visualisation and building model analysis capabilities, all built into the DCH platform.

Serve as a secure platform that can be used by various partners – Data ownership stays with the building owner who can choose which services to share their data with. Buildings owners can also choose to securely share their data with external 3rd party service providers through DCH.

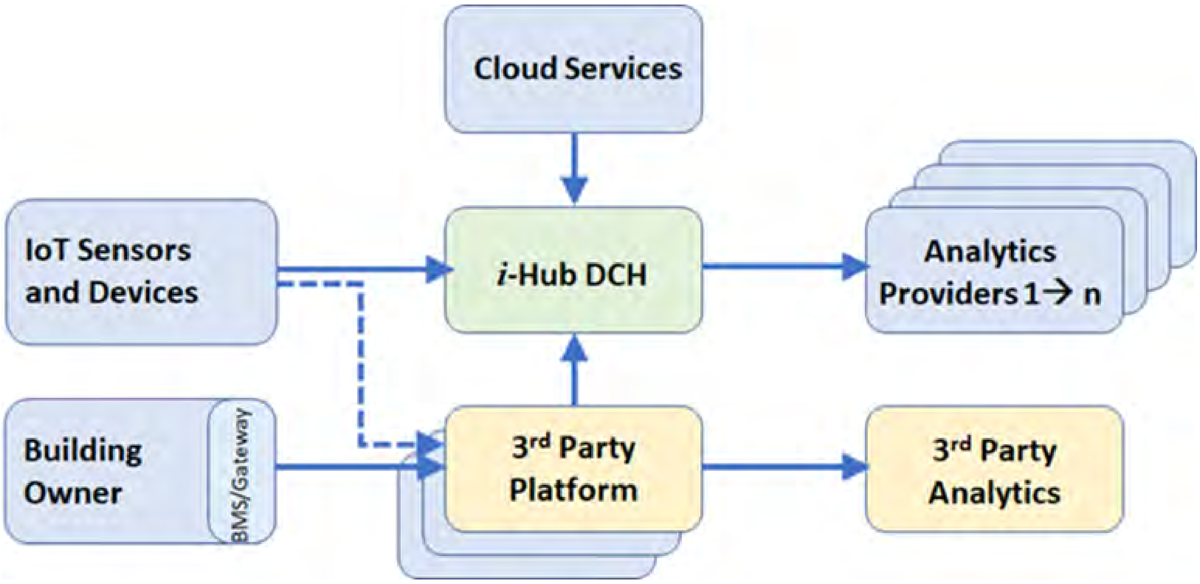


Figure 9: DCH platform facilitates access to data

The Data Clearing House philosophy is that the first step on the journey to energy savings, to participation in flexible demand markets and to many other emerging digital building services is to get the building "digital ready" with the necessary basic IT infrastructure and connectivity. From there, the cost of onboarding additional services can be a fraction of the cost compared with treating every service as a bespoke siloed offering.

For its part of the solution, the Data Clearing House is aiming to solve the challenge of enabling software to understand the workings of a building, without human intervention. It provides the cloud-computing services (storage, database management, software and algorithms) necessary to consolidate diverse data sources in one place, run real-time data-driven analytics and automate processes through machine-to-machine connectivity. It provides the underpinning infrastructure for building owners (and authorised agents) to easily access information on the operation of their buildings through their web-browser.

3.6 Projects

The were 10 sub-projects delivered in the DCH activity stream.

10 x Data Clearing House Activity Stream projects – DCH1 to DCH10

- DCH1: CSIRO Senaps data platform demonstration and development of the Data Clearing House
- DCH2: Switch Data Clearing House (DCH) - Early Data Clearing House Development
- DCH3: Precinct Energy Integration for Accessing the Wholesale Demand Response Mechanism
- DCH4: Sustainability monitoring and energy innovation in 5 NSW Govt Buildings
- DCH5: Development and experimental implementation of Transactive Demand Response Management System through Open ADR-approach for institutional buildings
- DCH6.1: Peak demand management and renewable energy integration in NSW Schools – Stage 1
- DCH7: Improving the accuracy of PV analytics and energy analytics in buildings using open asset standards and data platform integration
- DCH8: Exergenics Chiller Staging Application
- DCH9: DCH at Scale: On-boarding Proof-of-Concept at a Queensland Hospital Site
- DCH10: Increasing the value of onsite renewables in Darwin through data driven analytics

The following is a description and summary of each project.

#:DCH1	Title: CSIRO Senaps data platform demonstration and development of the Data Clearing House	DCH1 Link
Partners and participants: AIRAH, CSIRO		
Summary: This project developed and delivered a cloud-based building data management and application enablement platform known as the Data Clearing House (DCH) digital platform. The Data Clearing House digital platform overcomes the main barriers for adoption of data driven solutions for reducing building energy use, improving renewable energy integration in buildings, and unlocking opportunities for delivering buildings-to-grid services. This project is also responsible for assessing the Demand Response potential in the Australian air-conditioning sector, integrating other DCH sub-projects, buildings and applications, onto the DCH digital platform, as well as developing a business case and governance structure to inform future development and application of the Data Clearing House platform.		
Reports: The **DCH Product Feature Report** outlines the current capabilities of the Data Clearing House (DCH) digital platform. The report **Air conditioning demand response resource assessment for Australia** and the **Tableau DR visualisation tool** both help to identify the potential for air-conditioning related demand response potential. The project developed a number of **reports and protocols** including user manuals, cyber security and data governance protocols and a business case and governance structure to help build the capacity and application base of the platform into the future. A detailed project summary is provided in the **Knowledge Sharing Report** and selected lessons in the **Lessons Learned report**. All the reports are accessible through the DCH1 webpage: https://www.ihub.org.au/dch1-csiro-senaps-data-platform-demonstration-and-development-of-the-data-clearing-house/		

#:DCH2	Title: Switch Data Clearing House (DCH) - Early Data Clearing House Development	DCH2 Link
Partners and participants: AIRAH, CSIRO, Switch Automation		
Summary: This project developed and delivered a proof-of-concept minimum viable platform that demonstrates how technology infrastructure can underpin an open data clearing house for all Australian buildings. The solution was based on Switch Automation software and tested on three CSIRO campuses by integrating their building data, and showcasing how that data can be collected in a consistent format, normalized, then used to benchmark buildings and ultimately hasten the transition to more renewable power sources and a net zero future. The project informed the technical development of stage 2 of the Data Clearing House Platform.		
Reports: A detailed project summary is provided in the **Knowledge Sharing Report**. The learnings from the use of fault detection, analytics and demand response Applications in the 3 trial buildings was outlined in the Technical Report **Learnings from the use of FDD, Analytics and Demand Response Applications in the 3 trial buildings (hosted on the Digital Layer software platform DCH 1.2).** All the reports are accessible through the DCH2 webpage: https://www.ihub.org.au/dch2-switch-data-clearing-house-early-data-clearing-house-development/		

#:DCH3	Title: Precinct Energy Integration for Accessing the Wholesale Demand Response Mechanism	DCH3 Link
Partners and participants: AIRAH, CSIRO, DeltaQ, Walker Asset Services, CopperTree Analytics Australia		
Summary: This project has focussed on the enablement of a potentially significant resource of existing, underutilised gas-fired generation, including managing the impacts of the variability of renewable generation. This project sought to understand how existing gas fired generation assets can operate in sync with on-site energy consumption and renewable energy generation to maximise life-cycle-and environmental benefits while also providing useful support services to the grid. The project is deployed through the Data Clearing House digital platform.		
Reports: The **Technical Report** outlines the scope and boundaries of the analysis and the external factors and limitations as well as a clear utilisation pathway for other asset owners. A detailed project summary is provided in the **Knowledge Sharing Report** and selected lessons in the **Lessons Learned report.** All the reports are accessible through the DCH3 webpage: https://www.ihub.org.au/dch3-precinct-energy-integration-for-accessing-the-wholesale-demand-response-mechanism/		

#:DCH4	Title: Sustainability monitoring and energy innovation in 5 NSW Govt Buildings	DCH4 Link
Partners and participants: AIRAH, CSIRO, Property NSW - Dept. Planning, Industry and Environment, AM Building Efficiency		
Summary: This project ingested data from 11 Property NSW buildings into the Data Clearing House digital platform, and evaluated the ability of the DCH to store, organise and structure the data in a standardised framework, such that anyone can query the information with high level of confidence, in order to generate business insights and actions that help optimise building performance, manage energy consumption and solar Photovoltaic (PV) generation, and reduce Operation and Maintenance (O&M) costs. Flexible demand applications are being trialled in two buildings.		
Reports: The **Demand response trial technical report** outlines the trials carried out and the **Stakeholder consultation and (Internet of Things) IoT forward plan report** draw together experiences of all stakeholders, from suppliers, CSIRO, IOT system users and third-party integrators. A detailed project summary is provided in the **Knowledge Sharing Report** and selected lessons in the **Lessons Learned report.** All the reports are accessible through the DCH4 webpage: https://www.ihub.org.au/dch4-sustainability-monitoring-and-energy-innovation-in-five-nsw-government-buildings/		

#:DCH5	Title: Development and experimental implementation of Transactive Demand Response Management System through Open ADR-approach for institutional buildings	DCH5 Link
Partners and participants: AIRAH, Swinburne University of Technology, KIG Energy, Braemac, CSIRO		
Summary: In this project, Swinburne University of Technology collaborated with industry partners to install photovoltaic and battery storage systems and HVAC control systems in two commercial buildings located on the Hawthorn campus of Swinburne University. The system is designed to be able to participate in DR events through a novel Open Transactive Demand Response (openTDR) framework. The OpenTDR framework incorporates a multiagent model to help simulate microgrid energy management in communities. The objectives of this framework include to enhance the efficiency of HVAC operation within each building/microgrid and the utilization of on-site renewables. The primary component of the model is a game-theory-based optimization of energy consumption across diverse DER assets, based on activity type, weather conditions, and occupancy rate.		
Reports: The project developed a number of supporting **documents, manuals and configuration protocols** to help build the capacity and application base of the open TDR framework. A detailed project summary is provided in the **Knowledge Sharing Report** and selected lessons in the **Lessons Learned report**. All the reports are accessible through the DCH5 webpage: https://www.ihub.org.au/dch5-development-and-experimental-implementation-of-transactive-demand-response-management-system-through-open-adr-approach-for-institutional-buildings/		

#:DCH6.1	Title: Energy Control and Integration Program in NSW Schools – Stage	DCH6.1 Link
Partners and participants: AIRAH, Department of Education - School Infrastructure NSW, Buildings Evolved, CSIRO		
Summary: The project developed a proof of concept on how to integrate and control solar PV, battery storage and air-conditioning in schools to reduce energy costs and provide a better understanding of the requirements and impacts of demand response initiatives. The objectives were to install battery storage and control equipment in three schools, to complement the demand response enabled air-conditioning and solar already installed as part of the Department of Education's Cooler Classrooms program, and create a control application to integrate the installations at each site.		
Reports: The **Report on installation and commissioning of the PV, batteries and control systems in 3 schools** details the solar/batteries/HVAC load management systems used in the pilot schools. The **Report on operational testing and evaluation of control systems in each of the 3 schools** demonstrates the performance of the system and, by economic feasibility analysis, the potential for positive economic returns from widespread rollout across a		

portfolio of buildings. A detailed project summary is provided in the **Knowledge Sharing Report** and selected lessons in the **Lessons Learned report.** All the reports are accessible through the DCH6.1 webpage: https://www.ihub.org.au/dch6-1-data-clearing-house/

#:DCH7	Title: Improving the accuracy of PV analytics and energy analytics in buildings using open asset standards and data platform integration	DCH7 Link
Partners and participants: AIRAH, Virtual Buildings Information System (VBIS), PrediQ, CSIRO, City of Melbourne A.G. Coombs		
Summary: This project utilised the VBIS open standard and linked them with DCH based semantic models on the Data Clearing House digital platform to demonstrate the benefits of integrated asset and building tagging systems. Application development partner PrediQ incorporated the tagging and semantic modelling approaches to support delivery of their PV analytics and energy analytics applications. These 2 applications were implemented on 5 City of Melbourne buildings and their assets, through the DCH platform. This project resulted in the deployment of two applications in DCH that focus on better utilisation of (i) onsite energy generation and (ii) HVAC equipment maintenance, resulting in operational performance improvements leading to reduction in site energy use through better management of supply (renewable energy generation) and demand (reduction in HVAC energy use) in buildings.		
Reports: The **PV analytics and energy analytics applications development** report details the development and implementation of the two 'Applications' and the Building data models report outlines the creation of the first two semantic building models for the DCH7 project by the CSIRO. **The Application Development in Trial Buildings** report covers semantic model creation, data onboarding, and application development as well as details on how the deployed applications improved the reliability of onsite PV generation through deployed PV system analytics and HVAC system analytics applications. The **Application Use Case Report** details the use cases of the various applications that can be delivered using the Data Clearing House platform, VBIS standard and PrediQ applications. Eight (8) applications have been developed that can be mass deployable through DCH for repeatable results. A detailed project summary is provided in the **Knowledge Sharing Report** and selected lessons in the **Lessons Learned report.** All the reports are accessible through the DCH7 webpage: https://www.ihub.org.au/dch7-improving-the-accuracy-of-pv-analytics-and-energy-analytics-in-buildings-using-open-asset-standards-and-data-platform-integration/		

#:DCH8	Title: Exergenics Chiller Staging Application	DCH8 Link
Partners and participants: AIRAH, Exergenics, CSIRO		
Summary: This project integrated the Exergenics PlantScore™ central HVAC plant optimisation solution with the Data Clearing House digital platform and used it to demonstrate energy savings and renewable energy demand profile matching, in at least one CSIRO building. This helped validate the efficacy of the Data Clearing House as a tool for Energetics to rapidly onboard buildings. It also provided a rigorous case-study of the PlantScore™ software that has been used to develop the market for Exergenics services.		
Reports: A detailed project summary is provided in the **Knowledge Sharing Report** and selected lessons detailed in the **Lessons Learned report.** A case study of the project **CSIRO Synergy building Case Study** was developed and measurement and verification of Exergenics Chilled Water Plant Optimisation is detailed in the **CSIRO Synergy Building Preliminary Measurement and Verification (M&V) Report** which details savings of 4.3% of the energy consumed during the reporting period, representing an annual cost saving of approximately $3907. All the reports are accessible through the DCH8 webpage: https://www.ihub.org.au/dch8-exergenics-chiller-staging-app/		

#:DCH9	Title: DCH at Scale: On-boarding Proof-of-Concept at a Queensland Hospital Site	DCH9 Link
Partners and participants: AIRAH, Buildings Evolved, Metro North Health, Bar-tech Automation Pty Ltd, CSIRO,		
Summary: This project on-boarded HVAC systems at a large complex of buildings at a QLD hospital site into the iHub Data Clearing House digital platform. This allowed scalability testing of the DCH and improved the development of the Brick building data model (schema and ontology) to support a wider range of use cases. The project will use an M&V application hosted in the DCH to begin to develop a baseline, and reports will be developed in a BI tool against the Renewable Energy and Enabling Technology and Services Evaluation Framework (REETSEF) KPIs for Metro North Health. The rich data set collated will allow development of advanced applications and services.		
Reports: The **Final Project Report** covers the overall project delivery including the Building Data Model, the process of DCH on-boarding workflow automation and the REETSEF reporting requirements and other user stories. A detailed project summary is provided in the **Knowledge Sharing Report** and selected lessons in the **Lessons Learned report**. All the reports are accessible through the DCH9 webpage: https://www.ihub.org.au/dhc9-dch-at-scale-on-boarding-proof-of-concept-at-a-qld-hospital-site/		

#:DCH10	Title: Increasing the value of onsite renewables in Darwin through data driven analytics	DCH10 Link
Partners and participants: AIRAH, Charles Darwin University, City of Darwin, CSIRO		
Summary: This project identified opportunities for improving the value of onsite renewables in three Darwin buildings. These buildings were connected to the Data Clearing House to provide real time data about consumption and generation. Existing tools in DCH were utilised to carry out data driven analysis for improving self-consumption. Learnings associated with onboarding three buildings in Darwin region were documented and opportunities for incorporation of digital technologies in buildings identified. A knowledge sharing workshop was organised to support upgrading of existing buildings in Darwin to smart buildings. The project is supported by ongoing dissemination through the Darwin Living Lab.		
Reports: The **Report on Onboarding process** documents the process for onboarding old and new buildings in the Darwin region onto the Data Clearing House digital platform. The **Energy use reduction, improving value of onsite generation** report documents the energy use analysis of the pilot buildings to inform a net zero pathway for these buildings and provides insights on parameters such as HVAC energy use and PV generation. A detailed project summary is provided in the **Knowledge Sharing Report** and selected lessons in the **Lessons Learned report.** All the reports are accessible through the DCH10 webpage: https://www.ihub.org.au/dch10-increasing-the-value-of-onsite-renewables-in-darwin-through-data-driven-analytics/		

3.7 Buildings

The DCH platform is connected to over 50 different buildings as of May 2022 release. These comprise:

- DCH pilot project buildings – **46** buildings connected
- Private partner buildings – **5** buildings connected
- Buildings in process of or in pipeline for onboarding – **8** buildings

The connected buildings cover a rage of building typologies, sizes and complexities and includes:

- Hospital buildings/campus
- Office buildings
- Public buildings
- Laboratory and industrial buildings
- Schools

- University campus.

The progressive growth in buildings being onboarded to the platform is illustrated in Figure 10.

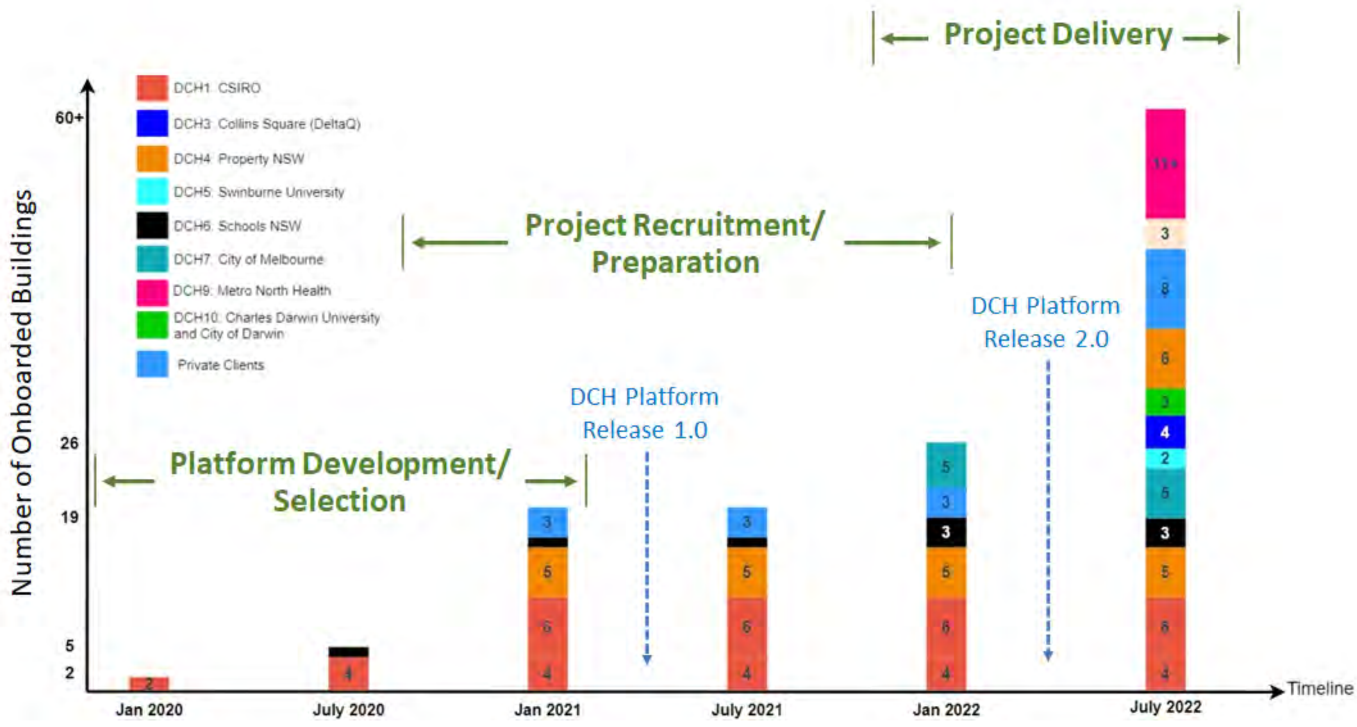


Figure 10: Development of Data Clearing House (DCH) digital platform – Jan 2020 to June 2022

3.8 Application marketplace

9 Applications (Apps) have been developed and are connected to the DCH, either directly hosted on the site or accessing data via API. These applications include:

- Measurement & Verification (M&V): This M&V App uses machine learning to predict the energy consumption of a building in real-time, based on historic patterns of energy consumption. It can provide low-cost trusted independent energy baselines for IPMVP Option C measurement and verification. The App is one of the best performing M&V algorithms on the EVO algorithm testing portal.
- Water-side flexible demand: This flexible demand App provides supervisory control of chilled water setpoints to reduce chiller electricity demand for short duration flexible demand events. The App utilises available thermal storage in existing chilled water tanks and pipes to maintain occupant thermal conditions while reducing chiller electricity demand during flexible demand events.
- Air-side flexible demand: This flexible demand App provides supervisory control of thermostat set points in the occupied space to reduce cooling load for longer duration events. The App utilises available thermal storage in the building fabric to reduce demand in response to predicted high electricity price events, load or shortage of renewables.
- Battery flexible demand: This flexible demand App manages the charging and discharging of electrical batteries to take advantage of fluctuations in the price of electricity, predicted renewables generation and predicted building HVAC load.
- Precinct flexible demand orchestration: This aggregation App uses an agent-based approach to balance supply and demand from a suite of distributed energy resources (loads, generation and storage assets) to optimise energy savings and renewable energy utilisation.

- Chiller staging: This energy efficiency and chiller maintenance App uses the Building Management System (BMS) and other data to create a digital twin of the operation of a chilled water HVAC system. The digital twin is then used to produce a chiller staging strategy that reduces energy consumption and peak demand, while maximising chiller life through reduced starts and chiller run time.
- Energy Analytics: This energy efficiency App analyses time-series data from the host-site BMS, to identify anomalies in equipment operation and identify energy savings opportunities. The App includes over 20 rules to help identify these energy savings opportunities.
- Solar PV maintenance analytics: This maintenance App analyses time-series data from solar PV assets, to identify anomalies in equipment operation and identify maintenance opportunities for maximising solar PV production.
- Comfort monitoring: This measurement App monitors comfort in the occupied space to determine if it fits within the acceptable thermal comfort bands, specified in the ASHRAE 55 thermal comfort standard.

3.9 Value propositions

Significant stakeholder consultation has been conducted throughout the project delivery and platform development. The chief value propositions, to building owners, are considered to be:

1. **Data consolidation**: Get 'portfolio-level insights' and avoid having to respond to changing requirements on a building-by-building basis.
2. **Service provider mobility**: The ability to consolidate data in a secure cloud environment outside of the enterprise firewall and then be able to easily re-route data to alternative service providers minimises difficult interactions with IT departments when onboarding new services. This, in turn reduces the friction of running competitive tendering processes.
3. **Data sovereignty**: Prevent leakage of data to third parties and ensure that data stays with the owner of the building.
4. **Cost and resources**: Reduce 'on-premises' labour, particularly in regional centres where charges can be high.
5. **Core business uses:** In some cases, there will be a core business use-case where IoT (prop-tech) creates significant value (e.g., retailers gathering shopper movement data). Use cases involving occupant engagement (e.g., COVID-19 return to work occupant monitoring, productivity apps, etc.) could potentially create interest in the property industry.
6. **Smart building certification:** As the importance and value of digitalization becomes more widely accepted in the industry, there is potential for some form of 'smart building' certification that could positively impact on asset value (i.e., a smart building could be judged to be worth more). This could create significant industry motivation. At very least, authoritative guidance on suitable IT and connectivity infrastructure (for hosting digital energy productivity solutions) will reduce confusion and complexity, helping to de-risk investment in building digitalisation and energy optimisation.

Key requirements and aspirations for the DCH platform include:

- **Cyber security and data access controls**. A number of stakeholders note that the industry is coming off a low base from a cyber security perspective. Some building owners view data protection as critical, but many others feel more sanguine. In general owners don't object to having data in the cloud and what should occur at 'the-edge' vs what should occur in 'the cloud' needs to be explored.
- **Interoperability** Everyone agrees that interoperability was important and access to an array of software drivers, to rapidly onboard buildings, will be required. Most of the software developers had developed some form of data schema and data management approach but were still mildly supportive of better standardisation in this area.

- **'Application portability'** is good. Some form of machine learning wizard for onboarding buildings is an area that would add value. Standardisation on a machine-readable data schema would help with the expensive process of onboarding buildings.
- **Data validation/provenance** is an important attribute. If the wrong data or poor data comes in, then no good analysis can be performed, leading to potential reputational issues. Technical and governance-based assurances on data validity would be good
- **Independent M&V**. Building owners are used to benchmarking (e.g., National Australian Built Environment Rating System, NABERS), and system integrators feel that trust is an important ingredient for success that can be enhanced through independent M&V.

The Data Clearing House digital platform has been constructed and developed to address all of these value propositions and key requirements.

3.10 DCH use cases

There are a wide range of use cases that the DCH platform has been designed to achieve and a wide range of other use cases that are being explored and developed.

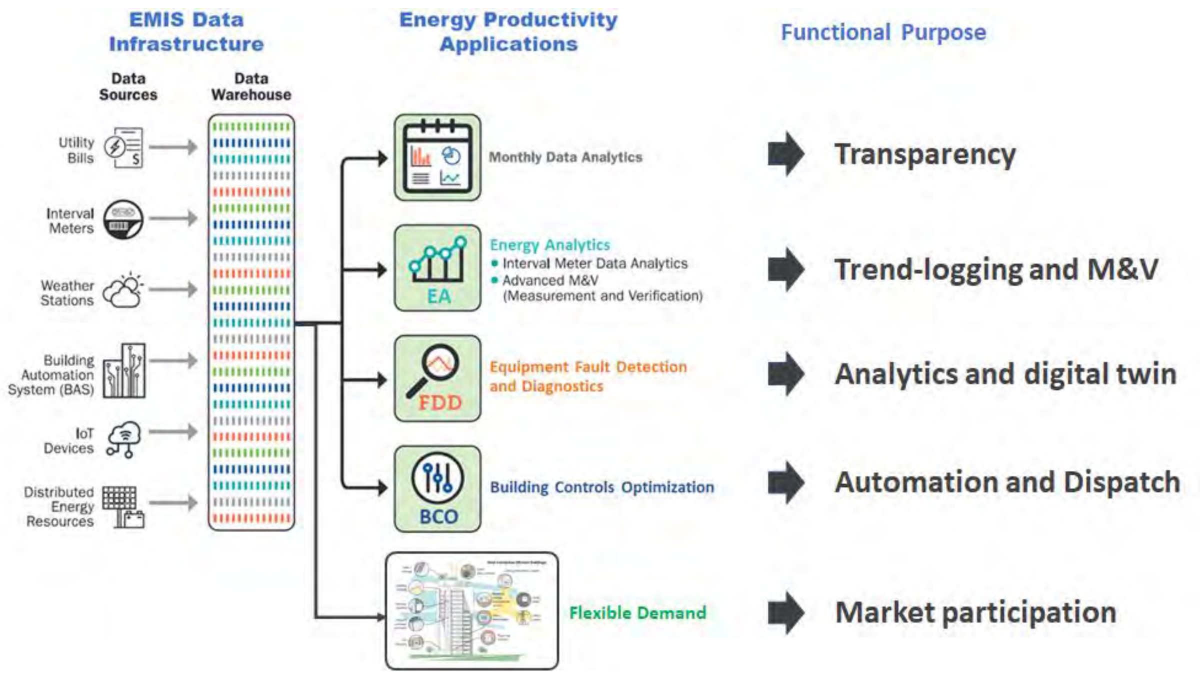


Figure 11: DCH use cases – Functional purpose

As shown in Figure 11, the following use cases have been addressed or are being investigated:

1. **Management and monitoring** – transparency on building and HVAC performance
2. **Energy Analytics** – benchmarking and M&V
3. **Automated Fault Detection and Diagnosis (AFDD)** – performance-based maintenance
4. **Dynamic optimisation of building and HVAC** – integrating building energy Assets and HVAC systems
5. **White certificate schemes** - trend logging and M&V for greenhouse gas abatement, energy efficiency, energy upgrades

6. **Flexible demand marketplace** – range of options being discovered and demonstrated
7. **Smart Building Index** – Exploring opportunities and barriers

The potential for additional end uses for the digital data and the DCH platform is just being discovered.

3.11 International work

The Data Clearing House has been selected as a platform for hosting data-driven building-services competitions for a consortium of European industry and research partners. The ADREANALIN consortium is funded under the ERAnet "Digital Transformation for Green Energy Transition" program.

Knowledge exchange is also occurring with the International Energy Agency Annex 81 'Data-Driven Smart Buildings' initiative, including participation on Brick data schema working groups.

3.12 Overall DCH Activity Stream Outcomes

The following is a summary of the overall Data Clearing House activity stream outcomes:

The Data Clearing House (DCH) created a digital platform that enables building energy efficiency and renewable energy optimisation. The current release of the platform has 60 connected buildings and is hosting 9 different applications/software as a service offerings.

The Data Clearing House digital platform is hosting Applications (Apps) that enable:

- Photovoltaic system optimisation
- Measurement and verification for connected buildings
- Software solutions for managing peak demand and creating flexible demand.
- Asset identification, monitoring and energy optimisation for buildings
- Energy analytics for building HVAC
- Chiller staging and optimisation
- Comfort monitoring

Two resource assessment models have been created, to determine the demand response potential that could be achieved from HVAC equipment in the built environment. The DCH Activity has demonstrated the potential for at least 250MW of demand response in the national electricity market, through both modelling and demonstration trials.

Refer to Section 6 for a detailed discussion on how the Data Clearing House activity stream contributed to the achievement of the i-Hub target outcomes.

4 The Integrated Design Studios (IDS) Activity Stream

4.1 Facilitating Integrated Design (IDS)

The Integrated Design Studios (IDS) Activity Stream consisted of on running a series of 14 Integrated Design Studios, bringing architectural and engineering design together for a range of building and owner types and putting renewable energy and net zero outcomes at the core of the design process. Each design studio was facilitated by a university, bringing owners and designers together in a 'neutral' design environment and leveraging industry consultants, academics and university students to generate and evaluate innovative design solutions, all the while studying the barriers and enablers of a successful integrated design process.

The delivery of the activity was an iterative process with the learnings and outcomes from preceding studios feeding into subsequent studios. The learnings from successive studios refine the process in an iterative manner.

The design industry is conservative and unlikely to be swayed by a single example of new practices. More generally (the design industry being a human labour hire industry) human behaviour is known to follow groups rather than lone wolf examples. So, the desired industry transformation outcomes required a sense of 'a movement' just as much as providing a "guiding light" or a 'beacon-on-a-hill'. Hence the activity was designed to deliver a program of 14 separate design studio projects.

The following 9 building typologies were addressed in IDS projects, across 14 separate integrated design studios:

1. Data Centre x 1
2. Schools x 2
3. Health care x 2 (Aged care)
4. Arts and Culture x 1 (Community centre)
5. Industrial x 1 (Ambulance Victoria)
6. Aquatic centre x 1
7. Laboratories x 1
8. Mixed use x 4
9. Transport buildings x 1

Certain building typologies were found to have similar challenges and solutions and so were further rationalised into Simple, Complex and Specialist type project groupings (see Figure 12).

Figure 12: Building Typology – Scale and complexity

The sub-project outputs have shown and demonstrated how an integrated design process, with renewable energy and energy efficiency at its core, can optimize renewable energy and energy efficiency opportunities at the earliest stages of design and significantly improve the building energy performance. The design target was maximised renewable energy use and net zero buildings, and this was found to be possible in many of the typologies using current technologies and practices.

4.2 IDS Objectives

The objectives of the integrated design studio activity stream sub-projects were to:

- Establish a standardised Integrated Design Studios facilitation service used to co-create new ideas for better integration of HVAC and renewable energy generation and storage resources into architectural design.
- Conduct integrated design studio processes in relation to 14 buildings across a range of non-residential building types covering 7 sectors (or building typologies), with a focus on developing innovative whole-of-building approaches for reducing the cost of deploying renewable energy technologies and increasing the value of renewable energy produced.
- Demonstrate technical and commercial value of the integrated design studio process such that it becomes adopted by industry and practitioners.

The IDS studio facilitation service that continues to be offered by the delivering Universities includes bringing design teams and students together to facilitate innovative approaches. The service includes:

1. match making to bring building owners together with a diverse mix of i-Hub member consultants, academics, and graduate/undergraduate students
2. facilitation of design charrettes
3. modelling exploration of alternative design strategies

The end objective of the IDS activity is to drive change in the design industry around renewables, net zero energy buildings, and their supporting technologies.

The purpose of the IDS activity is to implement integrated design into industry. It has:

1. road tested, refined and demonstrated what we currently know about integrated design in a controlled environment, and
2. developed a suite of evidence-based demonstration ideas in integrated design (focusing on renewable energy), across a number of building typologies, for use by industry.

4.3 IDS Methodology

The Integrated Design Studios Activity Stream consisted of the facilitation of 14 integrated design studios for 9 different building typologies.

Each individual building, or sub-project has similar processes, deliverables, knowledge sharing activities and budget. For each case, different owners and design professionals work through the process with different universities and cohorts of design students.

Once a suitable client and project has been identified, other parties (University, Architectural and Engineering Consultants, academics, and students) were enlisted to create the IDS. It was a dynamic activity and Studios were delivered sequentially across the university semester timetable. Each studio was facilitated and monitored by academic staff in a commercially neutral university studio environment.

Owners, designers and academic staff collaborated in the integrated design studios to develop potential engineering and architectural design solutions to renewable energy usage and net zero building design for that particular typology. Lessons learned and other insights were compiled throughout the process and described and detailed for the following studios. Individual design solutions were workshopped and documented as part of each studio and the expected performance and benefits rated against a business as usual (BAU) baseline.

The 2.5-year IDS delivery program allowed 5 iterations of evaluation and refinement of the IDS process across 14 studios (9 building typologies). This was considered to be close to the minimum number required to fully road test and establish confidence in the final process – i.e., that the process has the necessary flexibility and resilience to maintain applicability in wider industry and building typologies.

The universities set up a controlled assessable integrated studio design environment that was able to produce new knowledge collateral at an achievable cost. The client, the architects, and the engineers are the three most effective parties in design teams able to influence implementation of integrated design solutions. As well as the thinking, communication and mindset barriers that exist between these parties (which the studios are designed to explore and overcome), barriers may also come from other sources (legal, regulatory, contractual etc.). One of the tasks of the IDS's was to identify these other barriers and formulate ways of overcoming them.

The other important party to project outcomes in many procurement models is the contractor. Several of the later design studios included construction stakeholders into the integrated design program which brought additional benefits and learnings to the process.

Each typology studied in the IDS program has been vetted for net zero potential. The pathway to net zero is typically:

1. Establishment of business as usual (BAU) operational energy consumption as energy use intensity (EUI) for a typical building of the studio typology and location
2. Identification of integrated interventions including passive design strategies, active services technologies and on-site renewable energy generation and storage technologies
3. Estimate of EUI reduction from passive design strategies and active services technologies
4. Estimate of EUI offset from on-site renewable energy generation and storage technologies to determine residual grid energy consumption

4.4 IDS Outcomes and KPIs

The individual studio project outcomes were

- Overcome discipline prioritisation and risk-management barriers that prevent design consultants from providing innovative designs for their clients.
- Contribute to the knowledge and development of the IDS process being developed and facilitated by i-Hub.
- The potential contribution of innovations to increasing the fraction of building energy that can be economically provided by on-site renewable energy (target 25% increase relative to BAU) is assessed.
- Maximise the local use of on-site renewable energy.

The individual studio project KPIs were

- The IDS studio process produces 4-6 innovative design concepts.
- Technical vetting by consultant team presenting quantifiable comparisons showing performance relative to BAU, in order to identify solutions worthy of further follow up by client/industry.

- Presenting solutions that consider on-site renewable solar as an integral component of high efficiency/net zero building design, with consideration of revenue maximisation, rather than an add-on (demonstrated by documentation of minimum one solar integrated design concept).
- Information from the IDS studio process is shared with the wider industry.

The IDS activity long term outcomes and the KPIs that were monitored to determine progress toward achieving those outcomes are shown in Table 2.

Table 2: IDS Long-term outcomes and evidence

Long term outcome	Long term KPI - Evidence
Establish a standardised IDS facilitation process used to co-create new ideas for better integration of HVAC and renewable energy generation in building designs.	The integrated design process was developed (tested and refined), through 14 successive buildings/projects across a range of non-residential building types and sectors. Integrated design process studied and documented. Results from 14 integrated design studios analysed and shared with industry. Final Integrated design process documented to demonstrate the technical and commercial value of the IDS process. Carbon catalogue – documenting approaches to net zero design for a range of building typologies. Catalyst for integrated design – industry guidance on the best practice approach to integrating design.
Evidence to support the removal of risk-management barriers that prevent design consultants from providing innovative designs for their clients	Complete IDS processes in relation to 14 integrated design studios delivered for more than 9 building typologies and across a range of sectors. The IDSs generated design ideas for clients that were able to able to move towards net zero that in many cases had proven problematic beforehand. Ambulance Victoria is a good example, where demonstrated net zero feasibility led to the organisation's first net zero prototype facility, currently planned for construction in Mallacoota. Integrated Design Studio facilitation process has been established in three universities.
Industry professionals, building owners and university students actively participating in IDS subprojects.	Barriers to and enablers of good Integrated design process documented. The technical and commercial value of the IDS process demonstrated to be effective to stakeholders. Results from 14 integrated design studios analysed and shared with industry. Integrated Design Symposium to bring industry together and share knowledge. A range of knowledge sharing and technical collateral, documenting the integrated design journey and learnings.

4.5 Projects

There were 15 individual IDS sub-projects delivered under i-Hub, the IDSKS knowledge curation project and 14 individual Integrated design studios facilitated by three universities over the project period (see Table 3).

Table 3: 14 individual integrated design studios facilitated by three universities

Studio	Client/ Developer	Host University	Engineering	Architecture / Specialist Consultant
01 – Data Centres:	Next DC	University of Melbourne	Aurecon	Greenbox Architects
02 – Schools I	ACT Govt	University of Melbourne	Arup	Grimshaw Architects
03 – Schools II	ACT Govt	University of Melbourne	Jacobs	Jacobs

04 - Emergency Response Centres	Ambulance Victoria	University of Melbourne	Atelier Ten	Ewers Architects
05 – Aquatic Centres	Banyule City Council, Yarra City Council, Brimbank Council	University of Melbourne	WSP	Alan Pears (Heat Pump specialist)
06 – Transportation Buildings (Stations)	LXRP, Fiona McLean Architecture, Cox Architects	University of Melbourne	WSP	Cox Architects
07 – Aged Care I (Small)	Active Community Group	University of Melbourne	Atelier Ten	Place Design
08 – Laboratories	CSIRO	University of Melbourne	Atelier Ten	Designinc
09 – Multi-Purpose Buildings I – Indigenous Multi-purpose facility.	Lightning Ridge Local Aboriginal Land Council	University of Wollongong	Stantec Australia, MIE Engineers	Edmiston Jones (AEJ)
10 – Aged Care II (Large)	LendLease	University of Wollongong	Stantec Australia, MIE Engineers, Arup	Cox Architects
11 – Community Centres	Wollongong City Council	University of Wollongong	Stantec Australia, MIE Engineers, Arup	Cox Architects
12 – Multi-Purpose Buildings II – Indigenous Multi-purpose facility.	Illawarra Local Aboriginal Land Council	University of Wollongong	Stantec Australia, MIE Engineers	Edmiston Jones (AEJ)
13 & 14 – Mixed Use Buildings (Sub-Tropical & Tropical)	Bolton Clarke	QUT	Stantec Australia, JHA Engineers, Norman Disney Young/Tetra Tech, Hansen Yunken, The Built Environment Collective (BEC)	Fulton Trotter Architects

15 x i-Hub Integrated Design Studios sub-projects – IDSKS and IDS01 to IDS14

- IDSKS: Integrated Design Studio KS – Cross Programme Knowledge Sharing Activity
- IDS01: Integrated Design Studio 01 – NextDC Data Centre
- IDS02: Integrated Design Studio 02 – ACT Schools
- IDS03: Integrated Design Studio 03 – ACT Schools II

- IDS04: Integrated Design Studio 04 – Ambulance Victoria
- IDS05: Integrated Design Studio 05 – Aquatic Centres
- IDS06: Integrated Design Studio 06 – LXRP Transport buildings
- IDS07: Integrated Design Studio 07 – Aged Care
- IDS08: Integrated Design Studio 08 – CSIRO Laboratories
- IDS09: Integrated Design Studio 09 – Lightning Ridge LALC Multi-Purpose Building
- IDS10: Integrated Design Studio 10 – Lendlease Residential Aged Care
- IDS11: Integrated Design Studio 11 – WCC Ribbonwood Community Centre
- IDS12: Integrated Design Studio 12 – Illawarra LALC - Mixed Use Development
- IDS14: Integrated Design Studio 13 & 14 – Subtropical and Tropical Mixed-use Buildings

The following is a description and summary of each IDS project.

#:IDSKS	**Title: Integrated Design Studio – Cross Programme Knowledge Sharing Activity**	IDSKS Link
Partners and participants: AIRAH, The University of Melbourne (UoM), University of Wollongong (UOW), Queensland University of Technology (QUT)		
Summary: The IDS Knowledge Sharing Activity operated in tandem with the Individual Design Studio activities. The objective was to collate the findings of each of the individual Integrated Design Studios (IDS01 to IDS14) in relation to the IDS design methodology (barriers and enablers), extract learnings and publish findings. The second objective was to extract, collate/compare where applicable, and publish the technical exploration of the successful design solutions with regard to the individual building typologies in each studio.		
Reports: The **Catalyst for Integrated Design** has been iteratively updated throughout the program and provides the best practice guidelines for applying integrated design to a design team/project. The **Report on Combined Outcomes** summarises findings from each of the fourteen integrated design studios and incorporates the **'Carbon Catalogue'** which provides an array of net zero technical design learnings that were amassed across nine building typologies, and were then distilled to practical best practice guidance across three typology groupings (simple buildings, complex buildings, and specialist buildings). The **IDSKS Lessons Learnt Report** consolidates lessons learnt (technical and logistical) from across all studios in one report. All the reports are accessible through the IDSKS webpage: https://www.ihub.org.au/ids-ks-integrated-design-studio-knowledge-sharing/		

#:IDS01	**Title: Integrated Design Studio – NEXTDC Data Centre**	IDS01 Link
Partners and participants: AIRAH, Next DC, The University of Melbourne (UoM), Greenbox Architecture, Aurecon Australasia		
Summary: Integrated Design Studio for Data Centres building typology. The case study building typology used for IDS01 is a NextDC Data Centre. The rapid and continuing growth of the ICT industry means that data centres will be one of the worlds large energy users in the future. Significant opportunities exist for building strategies involving energy capture, generation (through renewables), and waste heat recovery.		
Reports: The **Design Studio Outcomes** report summarises all findings taken from studio and the **Lessons Learnt Report** documents the lessons specific to that IDS. The **Sub-project Knowledge Sharing Report** shares the technical innovations, the lessons learned and the final results and findings of the studio. All the reports are accessible through the IDS01 webpage: https://www.ihub.org.au/ids-01-nextdc-data-centres-i/		

#:IDS02	Title: Integrated Design Studio – ACT Schools Refurbishment Programme	IDS02 Link
Partners and participants: AIRAH, ACT Government Infrastructure and Capital Works – Education, The University of Melbourne (UoM), Grimshaw Architects, Arup Australia		
Summary: Integrated Design Studio for Schools. Schools and the education sector represent almost 30% of all non-residential floor area in the built environment. The i-Hub integrated design studios (IDS) activity brings together architects, engineers and clients to explore new ways of designing schools that will integrate technical performance with the many other design aspects of the building. Applicable equally to refurbishment or new build projects, the 'ACT Schools IDS will produce innovative design concepts that will be a crucial part of the ACT government achieving its ambitious target of net zero emissions by 2045.		
Reports: The **Design Studio Outcomes** report summarises all findings taken from studio and the **Lessons Learnt Report** documents the lessons specific to that IDS. The **Sub-project Knowledge Sharing Report** shares the technical innovations, the lessons learned and the final results and findings of the studio. All the reports are accessible through the IDS02 webpage: https://www.ihub.org.au/ids-02-act-schools/		

#:IDS03	Title: Integrated Design Studio – ACT Schools II	IDS03 Link
Partners and participants: AIRAH, ACT Government Infrastructure and Capital Works – Education, The University of Melbourne (UoM), Jacobs Group (Australia)		
Summary: Integrated Design Studio for Schools building typology. This is the second IDS for Schools. Running a second IDS was deemed necessary to enable exploration to an adequate depth. The first time a typology is run a steep learning curve exists both in terms of the studio mechanics and the depth of design explored. The aim of the integrated design studios is to explore, develop and test ways of achieving better integrated building design outcomes for schools - new builds and refurbishments.		
Reports: The **Design Studio Outcomes** report summarises all findings taken from studio and the **Lessons Learnt Report** documents the lessons specific to that IDS. The **Sub-project Knowledge Sharing Report** shares the technical innovations, the lessons learned and the final results and findings of the studio. All the reports are accessible through the IDS03 webpage: https://www.ihub.org.au/ids-03-act-schools-ii/		

#:IDS04	Title: Integrated Design Studio – Ambulance Victoria Emergency Response Stations I	IDS04 Link
Partners and participants: AIRAH, Ambulance Victoria, The University of Melbourne (UoM), Ed Ewers Architecture, Atelier Ten Australia		
Summary: Integrated Design Studio for Ambulance Station building typology. Ambulance Victoria maintains over 300 facilities across Victoria. As a part of this it is perpetually replacing old stock with new, improved buildings. In line with the Victorian Climate Change Act (2017), Ambulance Victoria (AV) is required to reach zero-net carbon by 2050. Ambulance Victoria see a bright future powered by renewable energy, whilst maintaining baseload and energy security. Solutions developed in this IDS will be innovative and adaptable to each of Victoria's climatic zones and the future electrification of fleet. They will also be socially responsible, so it tends for the wellbeing of the paramedics it sends out onto the road and can also be a refuge for its surrounding community in times of need.		
Reports: The **Design Studio Outcomes** report summarises all findings taken from studio and the **Lessons Learnt Report** documents the lessons specific to that IDS. The **Sub-project Knowledge Sharing Report** shares the technical innovations, the lessons learned and the final results and findings of the studio. All the reports are accessible through the IDS04 webpage: https://www.ihub.org.au/ids-04-ambulance-victoria/		

#:IDS05	Title Integrated Design Studio – Aquatic Centres I	[IDS05 Link](https://www.ihub.org.au/ids-05-aquatic-centres-i/)
Partners and participants: AIRAH, Banyule City Council, Yarra City Council, Brimbank Council, The University of Melbourne (UoM), WSP Australia, Büro North		
Summary: Integrated Design Studio for Aquatic centres building typology, working with a group of councils, who are owners and managers of aquatic centres. Aquatic centres are notoriously heavy users of energy. Their extended operating hours, large heating loads and subsequent large energy costs represent a significant drain on council finances. As public buildings with a recreation agenda there is also considerable pressure to provide open architecture with areas of glass façade etc. This makes them ideal candidates for the Integrated Design Studio.		
Reports: The **Design Studio Outcomes** report summarises all findings taken from studio and the **Lessons Learnt Report** documents the lessons specific to that IDS. The **Sub-project Knowledge Sharing Report** shares the technical innovations, the lessons learned and the final results and findings of the studio. All the reports are accessible through the IDS05 webpage: https://www.ihub.org.au/ids-05-aquatic-centres-i/		

#:IDS06	Title: Integrated Design Studio – LXRP Transport buildings	[IDS06 Link](https://www.ihub.org.au/ids-06-lxrp-transport-buildings/)
Partners and participants: AIRAH, Level Crossing Removal Project, The University of Melbourne (UoM), WSP Australia, Cox Architecture, Fiona McLean Architecture		
Summary: Integrated Design Studio for Transport building typology. The LXRP (Level Crossing Removal Project) was established by the Victorian Government and is a part of the Major Transport Infrastructure Authority. The design of transport dominated buildings differs from most buildings in that the lead design role is more usually filled by the engineer than the architect. As such they offer a unique insight into relations between the two professions. This studio will use two new station buildings planned for Edithvale and Chelsea as a case study in the application of integrated design to develop sustainable transport buildings. Exploring integrated design and innovative approaches around renewables and zero carbon has the potential to benefit future projects incorporating station buildings.		
Reports: The **Design Studio Outcomes** report summarises all findings taken from studio and the **Lessons Learnt Report** documents the lessons specific to that IDS. The **Sub-project Knowledge Sharing Report** shares the technical innovations, the lessons learned and the final results and findings of the studio. All the reports are accessible through the IDS06 webpage: https://www.ihub.org.au/ids-06-lxrp-transport-buildings/		

#:IDS07	Title: Integrated Design Studio – Aged Care I	[IDS07 Link](https://www.ihub.org.au/ids-07-aged-care-active-community-group/)
Partners and participants: AIRAH, Active Community Group, The University of Melbourne (UoM), Place Design Studio, Atelier Ten Australia		
Summary: Integrated Design Studio for Aged care building typology. Aged care continues to be an important growing sector in construction. The sector is also undergoing constant and rapid change. Increased public scrutiny is being applied to the health and quality of life outcomes, as well financial ethics related concerns. COVID-19, the aged care commission, and the growing number of financing models around residential housing are providing impetus and opportunity for change and reinvention of traditional care models. Design integration between client, architect and engineer has never been more important. IDS07 explores the design of residential focused aged care.		
Reports: The **Design Studio Outcomes** report summarises all findings taken from studio and the **Lessons Learnt Report** documents the lessons specific to that IDS. The **Sub-project Knowledge Sharing Report** shares the technical innovations, the lessons learned and the final results and findings of the studio. All the reports are accessible through the IDS07 webpage: https://www.ihub.org.au/ids-07-aged-care-active-community-group/		

#:IDS08	Title: Integrated Design Studio – Laboratories CSIRO	IDS08 Link
Partners and participants: AIRAH, CSIRO, The University of Melbourne (UoM), DesignInc Melbourne, Atelier Ten Australia		
Summary: Integrated Design Studio for Laboratory building typology. Viewed as industrial and highly function driven buildings, laboratories often give design aspects such as energy performance and sustainability a lower priority. In many cases this is deserved given the strict performance requirements around the spaces being provided, in many instances however it is not, and this studio aims to challenge the preconceptions in this regard. It will use contemporary mixed use facilities containing laboratory and office spaces while assessing their place in society and community. CSIRO will act in the client role, the lessons learned will be able to be leveraged across the wider laboratory and health buildings sectors.		
Reports: The **Design Studio Outcomes** report summarises all findings taken from studio and the **Lessons Learnt Report** documents the lessons specific to that IDS. The **Sub-project Knowledge Sharing Report** shares the technical innovations, the lessons learned and the final results and findings of the studio. All the reports are accessible through the IDS08 webpage: https://www.ihub.org.au/ids-08-csiro-laboratories/		

#:IDS09	Title: Integrated Design Studio – Lightning Ridge LALC Multi-Purpose Building	IDS09 Link
Partners and participants: AIRAH, Lightning Ridge Local Aboriginal Land Council, The University of Wollongong (UOW), Stantec Australia, MIEngineers, Edmiston Jones, E-LAB, Northrop		
Summary: Integrated Design Studio for mixed use/multi-purpose building typology. The Lightning Ridge (LR) Local Aboriginal Land Council owns the land where they are exploring building a multi-use and multi-functional facility. The Local Aboriginal Land Council is looking to use the building for hosting their staff and their operations as well as develop retail and community spaces (e.g., function rooms). This IDS program will inform the development process by bringing together architects, civil, structural, environmental and mechanical engineers to test an integrated design process for exploring the most optimum designs of a multi-purpose (mixed-use) building in order to maximise its utilisation and ensure high quality environmental design.		
Reports: The **Design Studio Outcomes** report summarises all findings taken from studio and the **Lessons Learnt Report** documents the lessons specific to that IDS. The **Sub-project Knowledge Sharing Report** shares the technical innovations, the lessons learned and the final results and findings of the studio. All the reports are accessible through the IDS09 webpage: https://www.ihub.org.au/ids-09-lightning-ridge-lalc-multi-purpose-building/		

#:IDS10	Title: Integrated Design Studio – Lendlease Residential Aged Care	IDS10 Link
Partners and participants: AIRAH, Lendlease, The University of Wollongong (UOW), ARUP, Stantec Australia, MIEngineers, Cox Architecture		
Summary: Integrated Design Studio for Aged care building typology. The Health and Wellbeing Precinct project on the UOW Innovation Campus is one of the first to be designed with a 2040 zero carbon emissions target in mind. The Precinct will include a Residential Aged Care Facility which will be the main focus of the proposed Integrated Design Studio. The residential aged-care sector faces a number of specific challenges in the move to absolute zero carbon. Not least of these is the current reliance on natural gas and the need for increased levels of thermal comfort whilst reducing energy consumption. Furthermore, the sector has been at the focus of concerns regarding infection control in the light of the covid-19 pandemic. The residential aged care IDS will produce innovative design concepts that will be a crucial part of Lendlease achieving its ambitious target of absolute zero emissions by 2040.		
Reports: The **Design Studio Outcomes** report summarises all findings taken from studio and the **Lessons Learnt Report** documents the lessons specific to that IDS. The **Sub-project Knowledge Sharing Report** shares the technical innovations, the lessons learned and the final results and findings of the studio. All the reports are accessible through the IDS10 webpage: https://www.ihub.org.au/ids-10-lendlease-residential-aged-care/		

#:IDS11	Title: Integrated Design Studio – WCC Ribbonwood Community Centre	[IDS11 Link]
Partners and participants: AIRAH, Wollongong City Council, The University of Wollongong (UOW), ARUP, Stantec Australia, MIEngineers, Cox Architecture		
Summary: Integrated Design Studio for Community Centre building typology. Wollongong City Council (WCC) has adopted a target of net zero emissions for its own operations by 2030. The Council owns and manages a range of infrastructure and community facilities. The focus of this integrated design studio is Ribbonwood Community Centre in Dapto. Built in 2000, the facility provides much needed spaces and services to the community and is scheduled for upgrade in 2022/23. The community centre IDS produced innovative retrofit design concepts that have the potential to inspire and support WCC in achieving its ambitious target of net zero emissions by 2030.		
Reports: The **Design Studio Outcomes** report summarises all findings taken from studio and the **Lessons Learnt Report** documents the lessons specific to that IDS. The **Sub-project Knowledge Sharing Report** shares the technical innovations, the lessons learned and the final results and findings of the studio. All the reports are accessible through the IDS11 webpage: https://www.ihub.org.au/ids-11-wcc-ribbonwood-community-centre/		

#:IDS12	Title: Integrated Design Studio – Illawarra Local Aboriginal Land Council - Mixed Use Development	[IDS12 Link]
Partners and participants: AIRAH, Illawarra Local Aboriginal Land Council, The University of Wollongong (UOW), Stantec Australia, MIEngineers, Edmiston Jones, E-LAB, Northrop		
Summary: Integrated Design Studio for mixed use/multi-purpose building typology. The Illawarra Local Aboriginal Land Council (ILALC) owns the land and the building where the former police station in Unanderra, NSW is located. ILALC is looking to redevelop the site in order to relocate their staff and their operations as well as develop retail and office spaces to lease out to local businesses. This IDS program will inform the redevelopment process by bringing together architects, civil, structural, environmental and mechanical engineers to test an integrated design process for exploring the most optimum designs of a mixed-use building in order to maximise its utilisation and ensure high quality environmental design.		
Reports: The **Design Studio Outcomes** report summarises all findings taken from studio and the **Lessons Learnt Report** documents the lessons specific to that IDS. The **Sub-project Knowledge Sharing Report** shares the technical innovations, the lessons learned and the final results and findings of the studio. All the reports are accessible through the IDS13 webpage: https://www.ihub.org.au/ids-12-illawarra-lalc-mixed-use-development/		

#:IDS14	Title: Integrated Design Studio – Subtropical and Tropical Mixed-use Buildings	[IDS13] [IDS14] [Link]
Partners and participants: AIRAH, Bolton Clarke, Queensland University of Technology, Norman Disney & Young (NDY), Built Environment Collective , Stantec Australia, JHA Consulting Engineers, Fulton Trotter Architects		
Summary: A two-studio project, IDS14 incorporates IDS13. Integrated Design Studios for mixed use/multi-purpose building typology in a tropical/sub-tropical environment.		
Reports: The **Design Studio Outcomes** report for each design studio summarises all findings taken from studio and the **Lessons Learnt Report** documents the lessons specific to that IDS. The **Sub-project Knowledge Sharing Report** shares the technical innovations, the lessons learned and the final results and findings of the overall project. All the reports are accessible through the IDS14 webpage: https://www.ihub.org.au/ids-14-subtropical-and-tropical-mixed-use-buildings/		

4.6 IDS Activity Stream outputs

The IDS Activity Stream had two levels of focus and outputs:

1. **Integrated Design Process** itself (a planning and delivery guideline) that was refined to address best practices and new learnings as the stream progressed, and
2. **Innovations and design outputs** from the individual studios that cumulatively offer at least a 25% reduction on business-as-usual BAU energy use. These are referred to as 'Net Zero' design learnings in the documentation.

Being able to examine the variation in solutions developed across typologies is important in providing an understanding of how the process crosses building typologies and complexities as well as understanding the potential cross fertilisation aspects. It also widens the audience to which information disseminations on the IDS's appeal in industry, giving wider reach and impact to the knowledge learned and the tools developed.

4.6.1 Integrated Design Outputs

The first area of focus was on how to better facilitate Integrated Design, particularly relationships and interactions between architects and engineers, unfortunately there are a number of reasons this is often not achieved in current practice, despite best intentions to do so. It is imperative, given the large energy consumption attributable to our built environment, that our designs deliver better technically performing buildings and infrastructure. Good theoretical knowledge exists in this respect, the IDS activity has been testing this practically in real design environments and we have learned a lot in the process.

Integrated Design Process		Conventional Design Process
Inclusive from the outset	vs	Involves team members only when essential
Front-loaded — time and energy invested early	vs	Less time, energy, and collaboration exhibited in early stages
Decisions influenced by broad team	vs	More decisions made by fewer people
Iterative process	vs	Linear process
Whole-systems thinking	vs	Systems often considered in isolation
Allows for full optimization	vs	Limited to constrained optimization
Seeks synergies	vs	Diminished opportunity for synergies
Life-cycle costing	vs	Emphasis on up-front costs
Process continues through post-occupancy	vs	Typically finished when construction is complete

Figure 13: Integrated design process (Source: Roadmap for the Integrated Design Process)

4.6.1 Net Zero Design Learnings

The second area is on zero carbon design. Given the i-Hub focus on renewable energy, designing net zero carbon buildings is a natural case study to use in examining how architects and engineers work together. Through the various design studios run with consultants from industry the IDS activity has created a pool of knowledge and appropriate ‘design moves’ that can be made in different building typologies to try and get to zero carbon outcomes. Building types range from schools through laboratories and aquatic centres to transportation buildings. The wider context of the IDS activity is visualised in Figure 13.

At the end of the 14 studios a compendium of solutions, applicable across various building typologies, was assembled and forms a valuable documented resource for industry reference. Many of the building typologies examined were found to have similar challenges and possible solutions in moving to zero carbon outcomes enabling the learnings to be rationalised into building typology groupings.

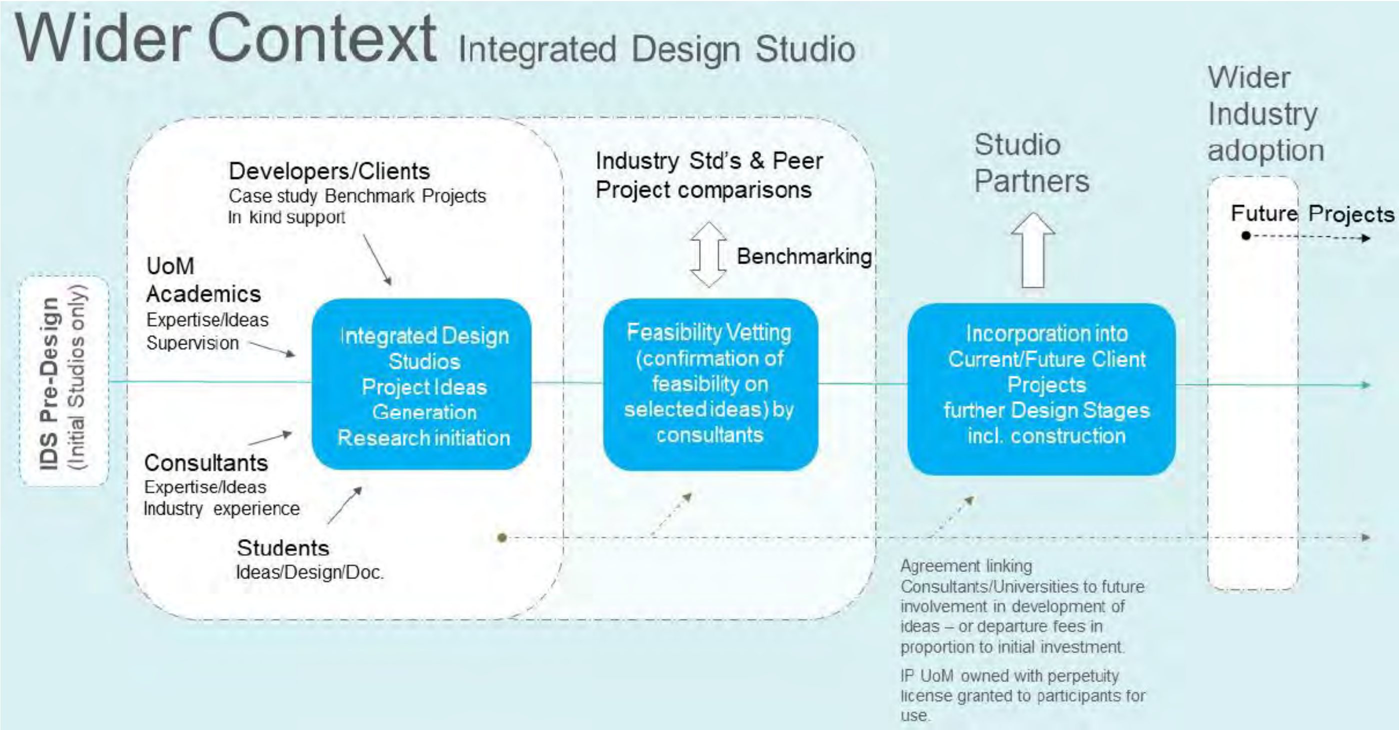


Figure 14: Wider context of the IDS activity

4.7 Overall IDS Activity stream Outcomes

The following is a summary of the overall Integrated Design Studio activity stream outcomes:

- A standardised Integrated Design Studios facilitation service developed, tested and demonstrated
- 14 individual design studios have been delivered and documented, detailing a range of net zero design approaches across 9 different building typologies
- Developed and documented a detailed understanding of the processes and relationships required for successful design integration to happen
- Standardised Integrated Design Guidelines have been developed, to help industry better understand and use the process
- Developed a wide range of innovate integrated design ideas and evaluated their feasibility
- Produced a Carbon Catalogue detailing a range of design pathways to net zero buildings
- Demonstrated the ease of achieving significant operational energy reduction through early stage Integrated Design

Refer to Section 6 for a detailed discussion on how the IDS stream activities contributed to the achievement of the i-Hub target outcomes.

5 The Living Laboratories (LL) Activity Stream

5.1 Living Laboratories (LL) for targeted sectors

Living Laboratories establish research-quality measurement and verification systems within existing buildings in order to observe and evaluate technology upgrades within the context of the daily operation of these buildings. This is different from 'normal' laboratory testing which is often undertaken under standardised (and most commonly steady state) conditions and does not address occupant needs and system interactions with the building.

A 'Living laboratory' is a user-centred open-innovation ecosystem within collaborative partnerships. Living Laboratories benefit both technology providers and technology users, addressing barriers to the uptake of innovation, such as lack of familiarity, risk aversion and distrust in supplier claims. The i-Hub Living Laboratories are flexible spaces where product suppliers can bring their technology for validation. Many technologies can be tested over time.

The i-Hub living laboratories activity stream has the objective to investigate the potential for the integration of innovative technologies in the healthcare and education sectors to add value to renewable energy, enabling these sectors 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, relative to business-as-usual (BAU), was hypothesised.

HVAC is the electricity end-use application with by far the greatest potential for increasing the value of renewables in this way. HVAC&R accounts for ~22% of all electricity consumed in Australia and around 50% of peak electricity demand. HVAC is already reasonably well correlated with solar generation in large commercial and institutional buildings, thus creating the opportunity for relatively minor adjustments of HVAC load timing to significantly increase the value of on-site generation by:

1. Deferring HVAC load during short-term solar generation variabilities, thereby enhancing the peak demand benefits of the on-site renewable generation
2. Utilising HVAC as a 'productive source of demand' during periods of local or grid level solar generation excess (and subsequently reducing demand and electricity import at other periods)
3. 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 without causing loss of comfort for occupants, and have to be based on 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.

The i-Hub Living Laboratories activity included the establishment of 5 living laboratories (one Hospital, two Aged Care facilities, two School sites, with the fifth living laboratory established in two transportable school buildings) and 2 sector-wide analysis projects. Healthcare and Education buildings and sectors were a focus for i-Hub due to their intensive energy use profiles and their tendency to be owned in large portfolios.

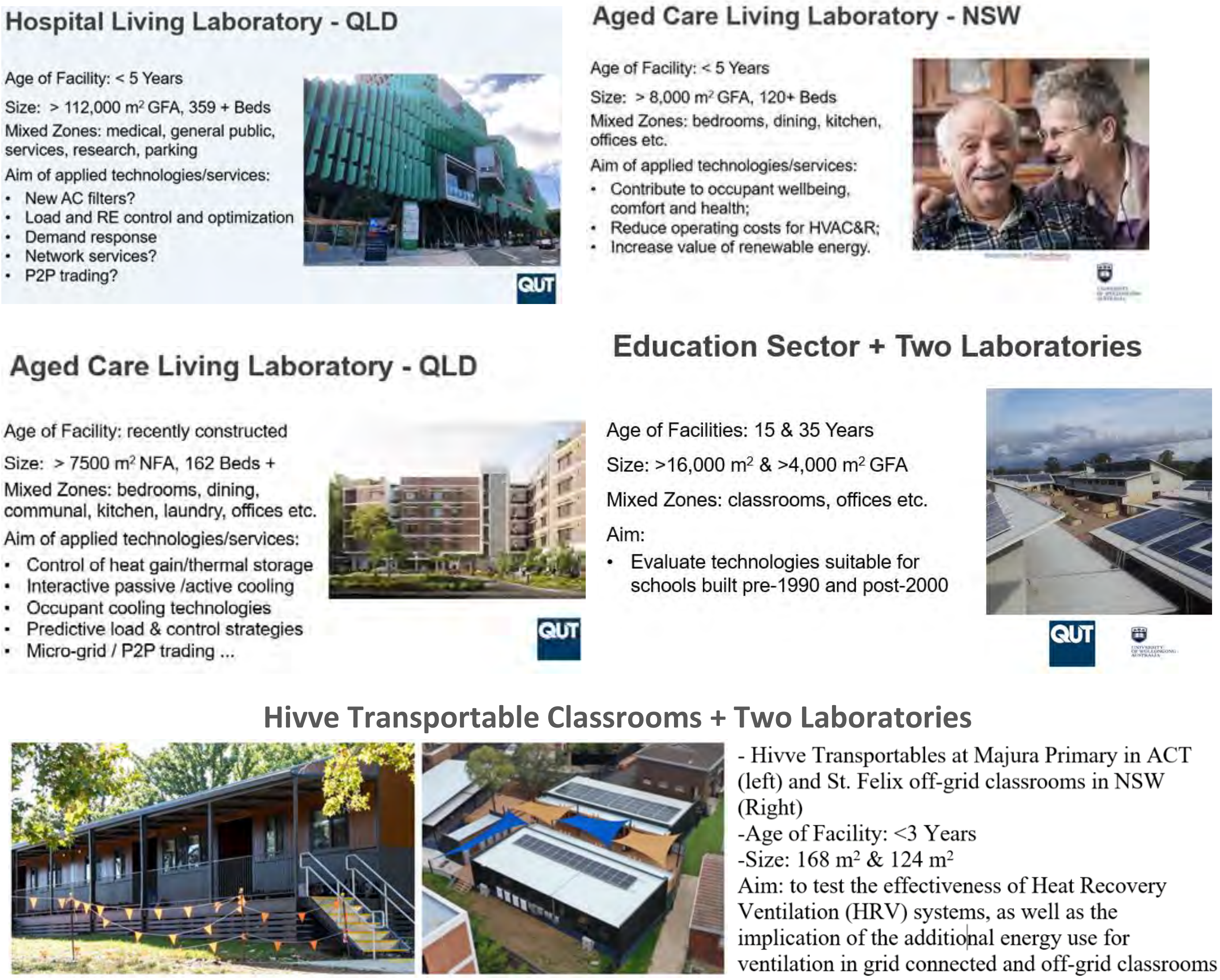


Figure 15: The five i-Hub Living Laboratories

The i-Hub living laboratory program was based on the General Service Administrations (GSA) Green Proving Grounds model from the USA. This program has partnered with research groups to convert many buildings in the GSA real estate portfolio into living laboratories and completed measurement and verification of new and emerging sustainable building technologies.

5.2 Sector wide analysis

The Living Laboratories activity also includes 2 sector-wide analysis projects for the healthcare and education sectors. Healthcare and Education buildings have been a focus for i-Hub due to their intensive energy use profiles and their tendency to be owned in large portfolios.

The Living Laboratory Sector Wide projects aimed to enable Healthcare and Education Facilities to address multiple energy challenges - high energy use, peak demand, renewable energy utilisation, energy costs and the environmental impact of energy sources. They created energy-use baselines for the sectors and explored sector-wide solutions including any technologies identified through the living lab testing processes.

The sector-wide analysis projects developed 'Roadmaps' for each sector. The roadmaps have drawn on all of the activities undertaken in the living lab projects (technology evaluations as well as sector-wide activities), in order to present a guidance document and checklist to assist organisations to develop a bespoke renewable energy and enabling technologies plan for individual buildings or sets of assets in their portfolios. The main avenue for broad utilisation and uptake of the Framework, Roadmap and emerging technologies will be the Renewable Energy Knowledge Sharing Task-Groups for Healthcare and Education, established for this purpose.

Focus on schools and health care

School buildings in Australia are experiencing a period transformation in community expectations, HVAC equipment and energy supply in the context of increasing global temperatures. Schools offer significant opportunities for matching their energy demand daily patterns with renewable energy supply. Historically, Australian schools have typically relied on gas heating during the winter, and ceiling fans combined with natural ventilation to maintain comfort. Increasing normalisation of mechanical cooling in Australian homes is translating into increased community expectations for active control of both thermal comfort and ventilation in schools. This is supported by emerging research into the relationship between Indoor Environment Quality (IEQ) and learning performance, which highlights the importance of comfortable learning environments. A lack of performance data presents a challenge to the development of appropriate energy policies to improve the sector's energy performance and pathway towards electrification. A confluence of transformational trends has also increased the importance of understanding the energy performance of schools, to ensure improvements to internal learning environment and risk management responses to COVID-19 and air pollution events do not undermine progress to decarbonisation.

In 2014-15 Australia spent $161.6 billion on healthcare in 15 health care sectors (not including Aged Care) which contributed 7% of national CO_2 *emissions in 2014-15. Hospitals accounted for 44% of these emissions. Energy use in this sector is also rising, as shown in the 46% increase in electricity use in the Victorian public health services in the decade to 2016 and in that state's health services accounting for over a quarter of public sector energy consumption. The energy intensity of hospitals and aged care facilities is attributed to their 24/7 operation, the use of energy intensive equipment, the need for infection and temperature control, and the frequent inclusion of onsite kitchen and laundry services. Improving energy productivity and developing appropriate sector wide key performance measures is challenging because of differences in clinical services, patient activity and floor space utilisation.*

The i-Hub Living Laboratories activity directly addresses the above challenges by engaging the HVAC and building services sectors and Education/Healthcare sectors in collaboratively developing the processes for testing and verifying potential solutions, on-site under real operation conditions.

The healthcare sector wide work examined a range of existing energy KPIs and data for the healthcare sector domestically and internationally. The activity produced an Interim Report: *The link between energy and health* which has enhanced the healthcare industry understanding of links between energy and health, improving the value proposition for energy efficiency / renewable energy.

The education sector wide activity also produced an energy baseline database and analysis for Australian Schools and a whole of life assessment guide to HVAC procurement.

5.3 LL Objectives

The major objectives for the Living Labs activity stream sub-projects were:

1. Establish a legacy of 4 Living Laboratories across the Healthcare and Education sectors for ongoing product validation in front of major building portfolio owners. Provide in-situ testing infrastructure that delivers independent validation of supplier claims and sharing of application specific implementation knowledge in order to reduce risks for developers and owners.
2. Support validation and consequent commercial adoption of emerging products and services (at least 8) that can help to decarbonise buildings. Using that information to identify opportunities for demand management and renewables integration in each sector.
3. Establishing a national "Renewable Energy Knowledge Sharing Task-Group" for each of the two Sectors, and empowering them with a sector specific "Renewable Energy and Enabling Technology and Services Roadmap", to drive implementation of renewables through the National Energy Productivity Plan Measure#12.

5.4 LL Outcomes and KPIs

The long-term outcomes and the KPIs that were monitored to determine progress toward achieving those outcomes are outlined in Table 4.

Table 4: LL Long-term outcomes and evidence

Long term outcome	Long term KPI - Evidence
Provide a legacy of 4 Living Laboratories across the Healthcare and Education Sectors.	5 Living Laboratories are operating and providing independent testing facilities to industry – 2 x Aged Care Buildings, 1 x Hospital Building, 2 x School Buildings, 1 x Transportable Buildings. Prospectus, Manual and risk management protocols established. Process of creating a Living Laboratory documented and demonstrated. REETSEF being applied to 4 Living Laboratory sites. Ongoing analysis of progress of each Living Laboratory site against KPIs, including baseline metrics for energy consumption, demand and renewable energy specific to each facility
8 x emerging HVAC products/services validated in Technology Report	11 emerging technologies that are able to contribute to decarbonization of buildings have been tested and performance evaluated in I-Hub Living Labs, all documented in Technology Evaluation Reports.
Sector is provided with tools and information to be applied to own sites to improve RE integration and productivity	Two Knowledge Sharing Task groups operating to engage with the sector stakeholders. Living Laboratory results and analysis have been fed into the sector wide evaluation. Renewable Energy and Enabling Technology and Services Roadmap for Healthcare and Education sector has been developed in collaboration with sector stakeholders. Sector has been provided with additional information on integrating energy and health, procurement guidelines for HVAC, sector baselines and KPIs and an analysis of potential future impacts on building energy use. Tools and information provided include: • Healthcare Sector: Examination of the potential to align health and energy co-benefits • Education sector: Life Cycle/Whole of Life Assessment KPIs - HVAC Life cycle report • Education sector: Analysis of energy consumption in Australian Schools • Healthcare sector Roadmap - Renewable Energy and Enabling Technologies and Services • Education sector Roadmap - Renewable Energy and Enabling Technologies and Services • A range of knowledge sharing and technical collateral to support the Living laboratories and document the project journey.

5.5 Projects

The Living Laboratory activity comprised 8 individual sub-projects.

8 x i-Hub Living Laboratories sub-projects – LLHC1 to LLHC5 and LLS1 to LLS3

- LLHC1: Healthcare Living Laboratories: Sector-wide engagement and impact
- LLHC2: Healthcare Living Laboratories: Warrigal Aged Care
- LLHC3: Healthcare Living Laboratories: Fernhill Residential Aged Care

- LLHC4: Healthcare Living Laboratories: Queensland Children's Hospital
- LLHC5: Net-zero Energy and Resilient Hospitals – considerations of future climate, pandemics and demand management
- LLS1: Education (Schools) Living Laboratories: Sector-wide engagement and impact
- LLS2: Education (Schools) Living Laboratories: ACT Schools
- LLS3: Hivve transportable classrooms: evaluating the effectiveness of the PV-battery-HVAC control-ERV nexus system

The following is a description and summary of each project.

#:LLHC1	**Title: i-Hub Healthcare Living Laboratories Sector-wide engagement and impact**	LLHC1 Link
Partners and participants: AIRAH, Warrigal, Bolton Clarke, Children's Health Queensland, Queensland University of Technology and University of Wollongong		
Summary: The Healthcare Living Laboratories Sector Engagement project quantified healthcare sector energy consumption, identified the potential for renewable energy technologies to reduce sector energy consumption and cost for HVAC in particular, and proposed requirements for optimal integration of renewable energy technologies. The HVAC, building services and healthcare sectors worked collaboratively to develop new key performance indicators and metrics that link energy performance to core health services. A Healthcare Knowledge Sharing Taskgroup was established to disseminate the knowledge from the project		
Reports: The **Renewable Energy and Enabling Technologies Roadmap for Healthcare** is presented in the form of a practical guide to assist organisations to develop a bespoke renewable energy and enabling technologies and services implementation plan for individual healthcare buildings (that may also be part of a portfolio of assets). The **Healthcare Sector Energy Baseline** report was developed to help the sector better understand current energy use, emissions and key performance indicators (KPIs). The **Renewable Energy and Enabling Technology and Services Evaluation Framework (REETSEF)** describe the general conditions that were considered for the establishment and operation of the three healthcare living laboratories. The Report on **Healthcare Sector: Examination of the potential to align health and energy co-benefits** examine key performance indicators and metrics for indoor environment quality from the perspectives of health, building services, resilience and smart technologies. A detailed project summary is provided in the **Knowledge sharing Report** and selected lessons in the **Lessons Learned report**. All the reports are accessible through the LLHC1 webpage: https://www.ihub.org.au/llhc1-sector-wide-engagement-and-impact/		

#:LLHC2	**Title: Healthcare Living Laboratories: Warrigal Aged Care**	LLHC2 Link
Partners and participants: AIRAH, Warrigal, and University of Wollongong		
Summary: The Warrigal Shell Cove living laboratory established research-quality measurement and verification systems within an existing aged care facility, to monitor HVAC services and occupant behavioural impact on indoor environmental quality (IEQ) in order to observe and evaluate technology upgrades within the context of the daily life of these aged care ecosystems. The technologies trialled in this living laboratory were selected from promising electric heating and cooling strategies and passive design features that increase the energy flexibility of aged care facilities, and deliver increased value for renewable energy, at the site and grid level.		
Reports: The **Renewable Energy and Enabling Technology and Services Evaluation Framework** (REETSEF) was applied to the living laboratory. The **Warrigal Residential Care Home Monitoring and Baseline Data Analysis** and the **Living Laboratory Operations Manual: Warrigal Residential Care Home** were produced to support the lab. Two Technical Evaluation reports have been completed to date, **Flow Power Electricity Spot Price Trading Evaluation** and **DNA Energy – HVAC Demand Response.** A detailed project summary is provided in the **Knowledge sharing Report** and selected lessons in the **Lessons Learned report**.		

All the reports are accessible through the LLHC2 webpage: https://www.ihub.org.au/llhc2-warrigal-aged-care-establishment-and-operation/

#:LLHC3	Title: Healthcare Living Laboratories: Fernhill Residential Aged Care	LLHC3 Link
Partners and participants: AIRAH, Bolton Clarke, Steinel Australia, Synengco, Queensland University of Technology		
Summary: The Fernhill 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. 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.		
Reports: The **Fernhill Residential Aged Care – Prospectus and Manual** provides 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. The **Fernhill Baseline Energy Report** provides historical energy use from the existing buildings (hostels and nursing home) and analysis the effect of the building envelope on the stability of indoor temperature of the new building and compares the "designed" with the "as built" air tightness. The **Fernhill Operations Manual and Baseline Data Analysis** provides more information on the Prospectus, and presents more detailed baseline data analysis of the building envelope performance, HVAC plant, and air tightness. Two Technical Evaluation reports have been completed to date, **Synengco HVAC Plant Digital Twin** and **Application of Honeycomb Blinds.** A detailed project summary is provided in the **Knowledge sharing Report** and selected lessons in the **Lessons Learned report**. All the reports are accessible through the LLHC3 webpage: https://www.ihub.org.au/llhc3-fernhill-residential-aged-care/		

#:LLHC4	Title: Healthcare Living Laboratories: Queensland Children's Hospital	LLHC4 Link
Partners and participants: AIRAH, Children's Health Queensland, Synengco, Queensland University of Technology		
Summary: The Queensland Children's Hospital Living Laboratory was established in an existing hospital in Brisbane, Queensland. The Laboratory 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.		
Reports: Four technologies were tested and evaluated in Technology Evaluation Reports – (1) **Exergenics: Stage 1 digital twin for Queensland Children's Hospital (QCH) chiller primary system optimisation**, (2) **Exergenics: Stage 2 optimised chiller staging, (3) Graphene coating for refrigeration outdoor condenser units**, (4) **Buildings Alive Rapid Efficiency Feedback technology** and an additional technical report on **Hospital's future energy use** was produced (assessing 4 future impacts on QCH hospital energy use). A detailed project summary is provided in the **Knowledge sharing Report** and selected lessons in the **Lessons Learned report**. All the reports are accessible through the LLHC4 webpage: https://www.ihub.org.au/llhc4-queensland-childrens-hospital/		

#:LLHC5	Title: Healthcare Living Laboratories: Net-zero Energy and Resilient Hospitals – considerations of future climate, pandemics and demand management	LLHC5 Link
Partners and participants: AIRAH, Australasian Health Infrastructure Alliance (AHIA), Queensland Children's Hospital, South Australian Department of Health & Wellbeing, Uniting Care, Mater Group, Queensland University of Technology, Stantec		

Summary: The purpose of this project was to assist healthcare facility asset managers in operating and managing their building and energy infrastructure assets. The project focused on future proofing facilities through (i) simulating the impact of future climates on thermal demand, HVAC performance and renewable energy potential; (ii) evaluating the impact of HVAC operation in response to COVID-19 management; (iii) assessing the feasibility of hospital participation in demand response markets. Two hospital models, based on real hospitals, were developed to enable simulation of the impact of future climates on the energy use of hospitals around Australia. Project outputs included a set of guidelines or processes to supplement the Australasian Health Facilities Guidelines for the benefit of both public and private health facilities.
Reports: The **Healthcare Living Laboratories: Net Zero Energy and Resilient Hospitals – considerations of future climate, pandemics, and demand management** report answers the four key questions: 1. How will hospitals perform in future climates, 2. What are the energy implications of changes to HVAC operation strategies as advised in response to COVID-19? 3. What are the impacts of the energy changes on net zero energy goals, in particular the role of renewable energy? and 4. What opportunities are available to hospitals (and aged care facilities) to participate in Demand Response markets utilising their generator assets? A detailed project summary is provided in the **Knowledge sharing Report** and selected lessons in the **Lessons Learned report**. All the reports are accessible through the LLHC5 webpage: https://www.ihub.org.au/llhc5-net-zero-energy-and-resilient-hospitals-considerations-of-future-climate-pandemics-and-demand-management/

#:LLS1	**Title: Education (Schools) Living Laboratories: Sector-wide engagement and impact**	LLS1 Link
Partners and participants: AIRAH, Queensland University of Technology and University of Wollongong		
Summary: The Education (Schools) Laboratories Sector Engagement project quantified school sector energy consumption, identified the potential for renewable energy and other technologies to reduce sector energy consumption and cost for HVAC in particular, and proposed requirements for optimal integration of renewable energy technologies. The HVAC, building services and schools sectors worked collaboratively to develop a whole of life assessment guide for HVAC technologies and an Enabling Technologies Roadmap for schools. A Schools Sector Knowledge Sharing Taskgroup was established to disseminate the knowledge from the project		
Reports: The **Renewable Energy and Enabling Technologies Roadmap for Schools** provides a high-level strategic overview for the school sector, to assist with policy and planning decisions associated with decarbonisation, energy reduction, and improved IEQ within the Australian education sector. The **Renewable Energy and Enabling Technology and Services Evaluation Framework (REETSEF)** was produced to support the schools living labs. The **Education Sector Wide – Baseline data analysis** report and **Baseline addendum** report outlines an in-depth analysis of the Australia-wide schools sector energy data. The **Whole of life assessment guide for HVAC technology replacement decisions: Sector Wide** report provides an easy-to-use guide for sector stakeholders to implement a whole of life design and assessment approach to compare costs and benefits of alternative HVAC technologies. A detailed project summary is provided in the **Knowledge sharing Report** and selected lessons in the **Lessons Learned report**. All the reports are accessible through the LLS1 webpage: https://www.ihub.org.au/lls1-sector-wide-engagement-and-impact/		

#:LLS2	**Title: Education (Schools) Living Laboratories: ACT Schools**	LLS2 Link
Partners and participants: AIRAH, ACT Schools, Environment, Planning and Sustainable Development, ACT Government, University of Wollongong (UOW).		
Summary: The i-Hub ACT Schools living laboratory established research-quality measurement and verification systems within existing school buildings, to monitor HVAC services and occupant behavioural impact on indoor environmental quality (IEQ) in order to observe and evaluate technology upgrades within the context of the daily life of these school ecosystems. The technologies trialled in this living laboratory were selected from promising electric heating and cooling strategies and passive design features that increase the energy flexibility of ACT schools' facilities, and deliver increased value for renewable energy, at the site and grid level.		
Reports: The **Living Lab Operations Manual: ACT Education** report defines the boundaries of the living laboratories, and the **Renewable Energy and Enabling Technology and Services Evaluation Framework (REETSEF)** for the Education Sector defines the KPIs and methods of evaluation to be used to assess the impact of technology upgrades. The **ACT Education Living Laboratory Monitoring and Baseline Data Analysis** report was produced to support the lab. Two Technical		

Evaluation reports have been completed to date, **Hivve Envelope - HVAC Transportable Evaluation** and Air Conditioner (**AC) split system versus gas hydronic system evaluation**. A detailed project summary is provided in the **Knowledge sharing Report** and selected lessons in the **Lessons Learned** report. All the reports are accessible through the LLS2 webpage: https://www.ihub.org.au/lls2-act-schools-establishment-and-operation/		

#:LLS3	**Title: Hivve transportable classrooms: evaluating the effectiveness of the PV-battery-HVAC control-ERV nexus system**	LLS3 Link
Partners and participants: AIRAH, Hivve, and University of Wollongong		
Summary: This project evaluated the overall energy, thermal, and indoor air quality performance of the Hivve transportable classroom package, equipped with Heat Recovery Ventilators (HRVs). HRVs utilise the energy in conditioned exhaust air to precondition incoming fresh air, allowing increased ventilation while mitigating the increased heating or cooling demand. The project consisted of three major phases: establishment of the living lab, baseline data analysis, and technology trial. The technology evaluation explored the impacts of the HRV on energy and ventilation for a period of one month and produced a number of useful findings.		
Reports: The **Hivve Transportable Classrooms: Impact of Heat Recovery Ventilation on Energy Use and Indoor Air Quality** report provides an evaluation of two Hivve classrooms that had HRV retrofitted, in Sydney and Canberra. The report evaluates the overall energy, thermal, and indoor air quality performance of the Hivve transportable classroom package, and specifically looks at whether the installation of a HRV unit provides: 1. Equivalent or improved ventilation to classroom occupants when compared to existing COVID-19 ventilation policies in schools (i.e. windows open, AC operational), and 2. A measurable saving in energy consumption while maintaining comfort conditions and improved ventilation in comparison to current COVID-19 ventilation policies in schools. A detailed project summary is provided in the **Knowledge sharing Report** and selected lessons in the **Lessons Learned report**. All the reports are accessible through the LLS3 webpage: https://www.ihub.org.au/lls3-hivve-transportable-classrooms-evaluating-the-effectiveness-of-the-pv-battery-hvac-control-erv-nexus-system/		

5.6 Overall Living Laboratory activity stream outcomes

The following is a summary of the overall Living Laboratory activity stream outcomes:

- 5 Living laboratories established across 2 sectors.
- 11 technologies tested and documented in Technology Evaluation Reports
- 2 sector wide roadmaps
- A range of technical reports and knowledge sharing materials
- A demonstrated model for Living Laboratory establishment and operation.
- Widespread knowledge dissemination not the industry

Refer to Section 6 for a detailed discussion on how the Living Laboratory stream activities contributed to the achievement of the i-Hub target outcomes.

6 Achieving the i-Hub Outcomes

This section of the report outlines the outcomes that were targeted by the i-Hub project and outlines how the outcomes from individual sub-projects and activity streams combined to help i-Hub achieve these high-level outcomes. This section of the report details the extent to which the Project achieved the target Outcomes 1 - 7

6.1 The targeted i-Hub Outcomes

It is intended that the knowledge developed from the i-Hub project will be shared across the industry to achieve the following targeted outcomes:

1. Improve the control of HVAC&R compared to business as usual by demonstrating the capability within a selection of building types to reduce onsite energy use by at least 25%, (see section 6.2).
2. Reduce peak demand and demand charges as well as increase the hosting capacity of solar through load control combined with onsite renewable energy (see section 6.3).
3. Increase the value of open data platforms and deliver innovation in the built environment to deliver energy savings (see section 6.4).
4. Improve developer and building owner decision making capabilities by demonstrating the value of non-monetary benefits of energy productivity measures (see section 6.5).
5. Identify new technologies that are able to contribute to the decarbonisation of commercial buildings over the next decade (see section 6.6).
6. Increase available demand response by identifying 100 MW of potential within the broader i-Hub portfolio (see section 6.7).
7. Change the industry paradigm to make co-design a mainstream approach to deliver lower cost and higher performance buildings (see section 6.8).

How i-Hub and its sub-project have delivered on those outcomes is outlined in this Section.

6.2 Outcomes that improve the control of HVAC&R

Outcome 1 *is to improve the control of HVAC&R compared to business as usual by demonstrating the capability within a selection of building types to reduce onsite energy use by at least 25%.* The following activity stream sub-projects contributed to achieving this outcome.

6.2.1 Data Clearing House

DCH1 has developed a measurement and verification (M&V) application and DCH7 and DCH8 both include deploying an energy efficiency application in the subject buildings. DCH7 also includes the deployment of a PV optimisation application. These projects and the energy savings achieved are listed in Table 5.

Table 5: DCH projects deploying energy saving software

Project	Software Solution	Host Site	Outcome
DCH7	PrediQ developed energy analytics algorithms to identify energy savings opportunities. The algorithms use the DCH to access and analyse time-series data from the host-site, to identify anomalies in equipment operation.	City of Melbourne (5 buildings)	Potential savings of between 5% and 20% were identified across the five buildings. Savings relate to (i) unnecessary run time of equipment and lighting (ii) failure of solar PV inverters. Rectification works to implement the recommendations are outside the scope of the project.

DCH8	Exergenics provide machine learning algorithms for chiller run-time optimisation. The algorithms use the DCH to access and analyse time-series data from the host-site to minimize energy consumption and peak demand. They also reduce chiller run hours and 'starts' for improved service life.	CSIRO (1 building)	Modelling results identified 1.7% energy savings (note energy savings are relatively low in this scenario because the chillers are air cooled, and the chillers are all the same size). One month of actual trial operation in summer yielded 4.3% energy savings.

Industry providers of energy analytics, such as CopperTree and Buildings Alive, have established APIs with the DCH platform which would enable them to connect their existing energy analytics services. The fault detection and diagnosis (FDD) services that these companies provide, will typically achieve around 9% site energy savings.

Almost all DCH sub-projects address reducing onsite energy use. Covid has significantly impacted building occupancy and normalised energy consumption over the i-Hub project period in some of the subject buildings. DCH energy efficiency and peak demand proof of concept applications have not yet included comprehensive/automated Energy Efficiency control solutions.

The Data Clearing House (DCH) platform provides various data management functionalities (data consolidation, data governance, data interoperability standardization) that enable real time data capture and utilisation in HVAC control applications. It also provides the ability to dispatch supervisory control signals in near real time. Latency in the communications technology, inherent to any cloud-based platform, means that the intended control functionality is to adjust set points of local controllers rather than direct fast-acting PI&D loop control.

The DCH has also developed real-time measurement and verification functionally that enables the benefits of control actions to be measured against weather normalized baseline energy consumption predictions.

The DCH has been developed to a level where it is capable of enabling dynamic HVAC control strategies, such as those described in the NSW OEH/AIRAH HVAC optimisation guidelines, and advanced model predictive control strategies. It has been shown that energy savings from advanced dynamic control strategies can vary anywhere from 0% to 40%.

Almost all DCH sub-projects address reducing onsite energy use. However, at this point, control actions using the DCH have been targeted at flexible demand services rather than energy efficiency services.

6.2.2 Integrated Design Studios

The IDS studios explore design outcomes developed through the integration of architecture and engineering to reduce energy use in the buildings considered. Participants used a business-as-usual baseline from which they implement different passive and active strategies to reduce energy consumption within the building envelope. Feasibility vetting reports provide comparisons between BAU design identifying net savings (reductions in energy usage). With the exception of Data Centres, the opportunities for savings have proven to be well in excess of 25%.

While percentage reductions possible in grid demand vary by building typology, all of the integrated design studios (IDS01 to 14) have contributed to this outcome, energy demand reductions being achieved through:

1. Demand reduction through incorporating measures such as passive design and improved building envelope etc., and
2. On-Site generation through incorporation of renewables.

Significant reductions were generally shown to be feasible on both fronts. The largest reductions (equal to over 300% of BAU) was in schools where the large roof area available for generation provided significant generation capacity. At the other end of the spectrum was the Data Centres typology where the very large BAU energy demands in operation dwarfed the reduction and generation available.

Reductions in excess of 25% BAU were applicable to the majority of building typologies examined see Figure 16.

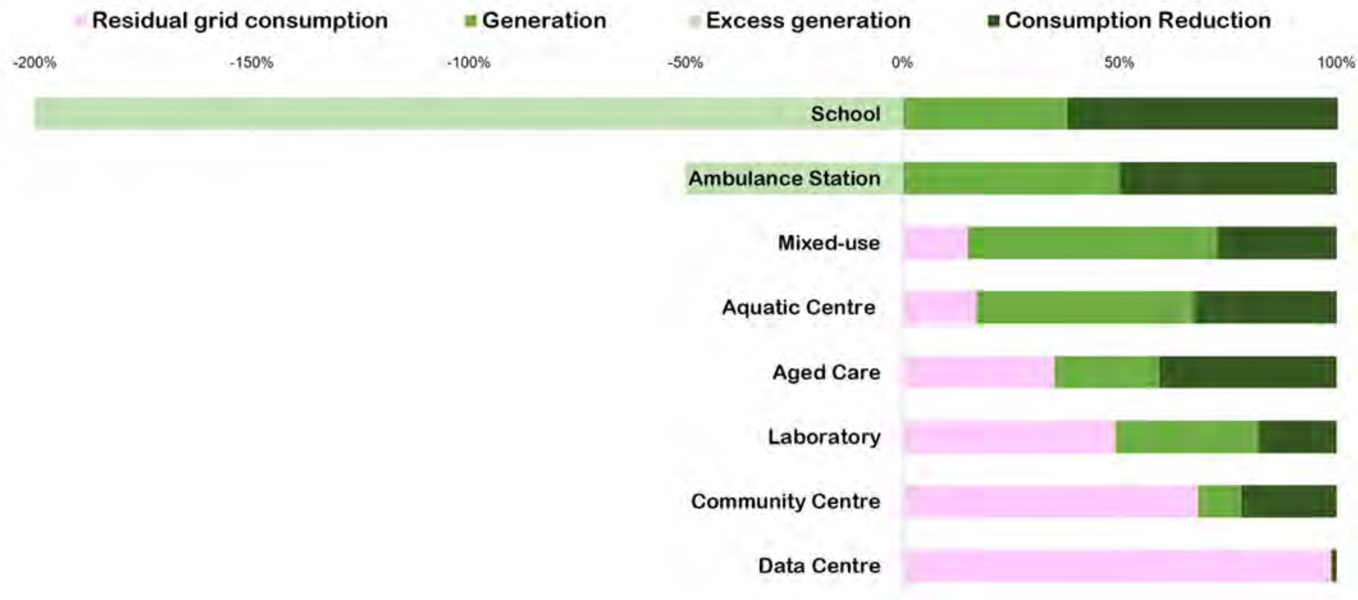


Figure 16: The Reductions in energy use for IDS typologies

The IDSs demonstrated significant grid demand reductions through combinations of consumption reduction as well as the provision of generation on-site, through renewables. Reductions ranged from approximately 30% to 320% for the majority of typologies considered. The exception was the data centres typology which rated lowly (1-2%) on the basis of the extremely high BAU energy base loads required for core IT operations.

Data Centres– Community co-benefits

While the extremely high BAU energy consumption associated with Data Centre core IT operations made it difficult to show reductions approaching 25% through integrated design, the integrated design process yielded other benefits. Possible new ways of doing business through early partnering with councils or communities were identified. Operators could gain early access to potential sites usually subject to competitive bids, by partnering and providing energy to adjacent synergistic facilities such as community greenhouses or aquatic centres.

Due to the high overall energy intensity involved in running data centres the potential to reclaim and reuse energy is significant, if adjacent uses can be included. Significantly reducing the operating energy bills of an aquatic centre or community greenhouse would be seen to solve what is often a major burden for local councils and therefore presents opportunities for the Data Centre industry to better engage with councils and local community. Importantly, by adopting such an approach, data centre providers may find themselves able to better position themselves as preferred partners with councils in competing for sites, while at the same time providing real, tangible community benefits.

6.2.3 Living laboratories

LLHC1 and LLS1 have used the knowledge developed in the living laboratory activity stream to provide a roadmap to show how the schools, hospitals and aged care sectors can reduce their energy footprint well in excess of a 25% reduction on BAU.

The Renewable Energy and Enabling Technologies Roadmaps that have been produced for the Healthcare and Schools sectors are presented in the form of a practical guide to assist organisations to develop a bespoke renewable energy and enabling technologies and services implementation plan for individual buildings or facilities, that may also be part of a portfolio of assets. The roadmaps were developed to enable hospitals, residential aged care, and schools facilities to transition to a net-zero carbon emissions (NZCE) future.

Technology Evaluation Reports (LLHC2, 3 and 4) and the Technical Report (LLHC4) indicate energy consumption savings over 30% (through better HVAC management and/or heat load management) and peak demand savings greater than 10%. The options and feasibility for demand response participation have been evaluated (LLHC2 and LLHC5) and included in the Roadmap (LLHC1).

The LLHC2 technology evaluations have demonstrated that automated temperature set point adjustments are a promising method to implement HVAC load flexing control with the wholesale spot price forecasts, with response times appropriate to existing forecasting of spot prices, and minimal impact on thermal comfort within the duration of typical high price events. The thermal mass of the Warrigal facility was shown to provide adequate thermal stability to allow HVAC demand response control actions, even when an unrealistically large number of DRM1 events were artificially introduced in a short period.

Evaluation of the potential value of delivering FCAS market services using DNA Energy DRM systems found that the annual FCAS market value of the Warrigal site was $69,000 for concurrent Fast Raise and Slow Raise markets. Between 75% and 95% of the time the condenser units were able to respond within the required 6 seconds for the Fast Raise market. The risk of slow response time from an individual condenser can largely be mitigated through aggregation of a large portfolio of devices, and appropriate risk margins, so there remains substantial potential for DRM 1 calls to deliver significant value on FCAS Raise markets. Income from this value stream would be shared by Warrigal with the aggregator depending upon the risk. Even a minor portion of this value stream may be attractive for a site that has an annual electricity bill of approximately $100,000.

LLHC 3 and 4 addressed this through testing of different parts of HVAC systems.

LLHC3: To date the performance outcomes demonstrate 29% reduction in energy for the digital twin technology. A second technology (cellular blinds) has been demonstrated to reduce cooling energy b 12.5%; annual reduction in energy of 6%. 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.

LLHC4: Exergenics: Stage 1 digital twin showed - Annual energy saving: 432MWh, Peak demand reduction: 99kVA (assuming 0.98 pf), Annual emission reduction: 350tonnes Annual bill saving: $62,581. Exergenics: Stage 2 optimised chiller staging showed - Annual energy saving: 188MWh, Annual emission reduction: 150tonnes, Annual bill saving: $3600, Graphene coating for refrigeration outdoor condenser units showed - Annual energy saving: 474kWh for each unit, Annual emission reduction: 379kg for each unit, Annual bill saving: $71 for each unit. Buildings Alive Rapid Efficiency Feedback technology showed - Annual energy saving potential: 34MWh, Annual emission reduction: 27tonnes, Annual bill saving $5119 (assuming $0.15/kWh). All of these represent significant savings.

LLHC5 has modelled 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. The Centre for Children's Health Research (CCHR) building HVAC heating electrification provides an annual energy saving of 819 GJ and an annual emission reduction of 43 tonnes. Pandemic mode ventilation modelling showed that the Outdoor air percentage is ineffective and there is a need for local exhaust/filtration. The AS4187 impact analysis showed that there will be large impacts on peak demand and annual electrical consumption The LLHC5 project has identified a 2.4MW (3MVA) demand response capability within the QCH facility, which can be used to achieve nearly 50% reduction in energy demand.

LLS1 has benchmarked energy usage of schools (by enrolment number, GFA, climate zone, geographical location, socio-economic status of the suburb, and type of energy usage) to compare energy usage across multiple Australian states. The baseline assessment has highlighted that the inclusion of Solar PV alone (on average) can reduce the net-energy usage by approximately 16%, while through the analysis of the data collected in this study it was shown that there are significant energy usage differences between schools of the same climate (on a per student basis). This demonstrates a significant potential for energy savings (e.g., in ACT there are schools that use ~45-50 kWh/m2 student and schools that use >120 kWh/m^2 student, i.e., this shows that a 65-70% potential for energy savings exist on a per student basis).

The first LLS2 technology trial evaluated the Hivve transportables in comparison to conventional transportables. The Hivve transportables demonstrated an improved thermal comfort and reduced energy consumption and with the inclusion of a battery system they are capable of being completely off-grid, thus reducing the operating greenhouse gas emissions to zero. The second evaluation of replacing existing and often ageing gas heating systems within the school sector with split system air conditioners demonstrated a significant reduction in energy consumption (4 to 7 times less energy). Additionally, with school operation hours aligning with solar gains, the electrification of heating also enables the coupling with Solar PV systems to reduce greenhouse gas emissions to potentially zero depending on the size of the school site and available PV space.

6.3 Outcomes that reduce peak demand and demand charges

Outcome 2 *is to reduce peak demand and demand charges as well as increase the hosting capacity of solar through load control combined with onsite renewable energy*. The following activity stream sub-projects contributed to achieving this outcome.

6.3.1 Data Clearing House

The Data Clearing House (DCH) provides a digital platform that enables software solutions for managing peak demand. Peak demand reduction can be achieved by reducing energy consumption at all times (energy efficiency), and/or by shifting demand at specific points in the day (demand response).

DCH1, DCH4, DCH5, DCH6.1, DCH7, DCH8 all addressed reduction of peak demand and demand charges using a variety of approaches including:

- onsite PV
- AC control
- battery storage
- pricing algorithms
- optimisation control
- existing onsite generation assets.

For example, in DCH8 (Exergenics chiller run-time optimization), the new chiller control schedule is modelled to reduce peak demand by 18%. Similarly, the DCH4 project has used a model predictive control App, for scheduling battery charging/discharging, which has reduced site demand charges by 6%.

6.3.2 Integrated Design Studios

For all IDS projects IDS01 to 14 the IDS design outputs include solutions involving energy reduction and generation along with conceptual consideration of battery storage and electrification of equipment contribute to management of peak demand. Net zero energy building designs will generally, by definition, minimise peak demand issues.

6.3.3 Living laboratories

LLHC2: The first technology trial evaluated direct exposure to the wholesale electricity spot market. Although by itself it does not reduce energy demand/consumption, this technology is observed to be an enabler of technology such as demand response where the consumer is able to seek larger economic benefits by reducing demand during peak events. This was explored in greater detail within the second technology trial where DNA Energy's DRM control system demonstrated the capacity for temperature set point flexing to pre-cool and pre-heat prior to forecasted high price events with DRED controls to quickly reduce energy consumption to avoid unexpected high price events and participate on the FCAS markets.

LLHC4: One of the digital twin technologies showed a peak demand reduction of 5.4% from the chiller plant only (not whole HVAC system). The onsite standby generators are also capable of participating in 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.

The LLHC5 project quantified hospital building thermal demand, HVAC energy use and peak demand in future climate scenarios and provided an assessment of DR market participation feasibility for hospital facilities. The QCH Living Lab has identified a 2.4MW (3MVA) demand response capability which can be used to achieve nearly 50% reduction in energy demand.

6.4 Outcomes that increase the value of open data platforms

Outcome 3 *is to increase the value of open data platforms and deliver innovation in the built environment to deliver energy savings.* The Data Clearing House activity stream sub-projects contributed to achieving this outcome.

6.4.1 Data Clearing House

This is the primary objective of the DCH activity stream. All DCH sub-projects are contributing to this outcome. The CSIRO led DCH1 sub-project developed the platform and coordinated sub-project interactions with the platform.

The current version of the Data Clearing House digital platform has onboarded up to 60 buildings, many outside of i-Hub sub-project agreements (i.e., not i-Hub funded). 7 Application developers are deploying 9 Applications across the platform. Various other building onboarding/deployment actors are developing APIs or training to connect to the DCH. The DCH platform is providing a rapidly growing innovation eco-system.

The DCH team is currently developing a business case and governance model for the platform to continue to develop and grow (see Section 8.3.1). DCH1 financial modelling suggests that the platform is competitive and cost effective.

6.5 Outcomes that improve developer and building owner decision making capabilities

Outcome 4 *is to improve developer and building owner decision making capabilities by demonstrating the value of non-monetary benefits of energy productivity measures.* The following activity stream sub-projects contributed to achieving this outcome.

6.5.1 Data Clearing House

The data clearing house digital platform empowers building owners to understand and use their building data to achieve a range of outcomes including energy productivity and energy saving but also non-monetary outcomes including verified emissions reductions, indoor air quality and thermal comfort ratings and a wide range of alternative use cases once a building is digital ready and DCH connected.

6.5.2 Integrated Design Studios

Different owner organisations involved in the studios were bought together with a diverse mix of consultants and academics including architects, engineers, and specialist technical subject experts. The diverse nature of the participants involved aided in studio ideation and many of the relationships formed have outlasted the duration of the studios in which they were formed.

Participants researched different technologies and strategies to implement within the structure, with immediate and lifetime returns being examined. The central precept of integrated design is design that meets many functions at the same time. Responsible design in terms of the technical (energy reduction being a primary measure), is one outcome considered. Others include indoor air quality, user experience, etc. Building owners/Clients were involved in the studios with one of the end goals being to demonstrate that technical benefits of reduced energy consumption can coexist with good architecture and user experience.

The central idea in integrated design is the design that satisfies multiple functions at the same time. Responsible design in terms of the technical (energy reduction being a primary measure), is one outcome considered. Others include indoor air quality, user experience etc. Clients are involved in the studios with one of the end goals being to demonstrate that technical benefits of reduced energy consumption can co-exist with good architecture and user experience.

A good example of enhancing owner's decision-making capabilities was the Ambulance Victoria studio where the client was able to amend internal policies around the design of facilities through improved understanding of what was possible in net zero design for their building typology. The IDSs generated design ideas for clients that were able to move towards net zero that in many cases had proven problematic beforehand. For Ambulance Victoria the demonstrated net zero feasibility produced by the IDS led to the organisation's first net zero prototype facility currently planned for construction in Mallacoota.

Clients and consultants have seen value in integrated design process and outcomes. ACT Schools (IDS02/03) have commissioned further work using some of the studio analysis as a base, Ambulance Victoria (IDS05) have used the studio analysis to inform internal policy and processes and it has helped initiate their first net zero prototype station. All three institutions have indicated intention to continue IDSs as a part of curriculum with industry prepared to provide support. The program will continue to identify clients who can benefit from the process and will also influence the way design happens in industry both through continued consultant involvement and also through the student designers involved who are making their way into industry.

6.5.3 Living Laboratories

The Renewable Energy and Enabling Technologies Roadmaps that have been produced by LLHC1 and LLS1 were developed to enable hospitals, residential aged care, and schools facilities to transition to a net-zero carbon (NZCE) future. The sector-wide roadmaps outline the potential for increased value of renewable energy and reduction in energy demand and recommendations for each sector regarding strategies and technologies to best tackle decarbonisation.

Several guides and frameworks have been established to assist owners in the upgrade or replacement of existing outdated and end-of-life assets and building stock, to maximise their impact on achieving energy and emissions reduction targets.

LLHC1 has produced a report on the co-benefits of energy and health actions, and proposed broad KPI areas that need to be considered.

LLS1 has produced a Whole of life (WOL) decision framework for the state Schools sector. The whole of life assessment guide has been developed to assist asset and procurement managers within the education sector to further assess the longevity and ongoing life of current HVAC assets, and offer strategies to better assist in assessing future HVAC technologies.

The Living Laboratory activity stream has documented, for owners and developers, the reasons for creating and the methodology of how to create a living laboratory. This may be the most impactful legacy of all.

LLHC5 has quantified hospital building thermal demand, HVAC energy use and peak demand in future climate scenarios and the kW and kWh impacts due to changes of HVAC settings to manage COVID risk. The project has also evaluated the renewable energy kW required to meet any quantified increase.

6.6 Outcomes that identify new technologies

***Outcome 5** is to identify new technologies that are able to contribute to the decarbonisation of commercial buildings over the next decade.* The following activity stream sub-projects contributed to achieving this outcome.

6.6.1 Data Clearing House

The Data Clearing House currently hosts 9 new digital software applications/algorithms that can contribute to the decarbonisation of buildings and enabling of renewable energy use including:

- Measurement & Verification
- PV efficiency analytics
- HVAC/Building efficiency analytics
- HVAC flexible demand control (thermostat offsets)
- HVAC flexible demand control (chiller staging)
- Battery Model Predictive Control
- ASHRAE 55 comfort
- Chiller staging and optimisation
- Precinct level 'transactive demand response' (flexible demand aggregation)

These technologies and services are available for delivery from the data clearing house, which is designed to be a trusted data institute and secure Apps marketplace.

6.6.2 Integrated Design Studios

For all IDS projects IDS01 to 14 the IDS design outputs explored novel and new ways of integrating existing technologies into architecture, i.e., new ways of realising energy saving benefits of existing technologies. A good example of this was in the use of photovoltaics to not only contribute to energy generation (and demand response), but to provide sun shading or noise amelioration improving building amenity.

6.6.3 Living laboratories

Overall, the Living Laboratories have tested and evaluated 11 new technologies or services, and demonstrated how these can be applied to contribute to the decarbonisation of commercial buildings in the education and healthcare sectors. The evaluation of all technologies or services have been document in 11 individual Technology Evaluation Reports (see Table 6):

1. Flow Power Electricity Spot Price Trading
2. DNA Energy: HVAC Demand Response
3. Synengco HVAC Plant Digital Twin
4. Application of Honeycomb Blinds
5. Exergenics: Stage 1 digital twin for QCH chiller primary system optimisation
6. GMG Thermal-XR Coating System – Graphene coating for refrigeration condenser units
7. Exergenics: Stage 2 optimised chiller staging
8. Buildings Alive Rapid Efficiency Feedback technology
9. Hivve Sustainable Modular Classrooms Envelope and Heating tests
10. Amaroo in-slab gas heating compared to split system air conditioning
11. Hivve Transportable Classrooms: Impact of Heat Recovery Ventilation on Energy Use and Indoor Air Quality

The results from these evaluations have fed into the sector-wide Roadmaps that have been produced for each sector.

Table 6: i-Hub Living Laboratory - Technology Evaluation Reports

i-Hub Living laboratory - Technology Evaluation Reports	
Flow Power Electricity Spot Price Trading	Trial was to evaluate the overall electricity cost savings potential for Warrigal Shell Cove living laboratory for Flow Power's pure wholesale pass-through product compared to the existing conventional electricity agreement.
DNA Energy: HVAC Demand Response	The evaluation explored the use of DNA Energy's DRM technology to reduce energy consumption during 5-minute spot price peak intervals using several methods, and the impact of this on thermal conditions within the Warrigal facility. Additional evaluation was also undertaken of the potential value of providing services to the FCAS Fast and Slow Raise markets, with the key consideration being the reliable response time of the combination of DNA devices and the existing Mitsubishi VRFs.
Synengco HVAC Plant Digital Twin	Fernhill's HVAC plant and building information was modelled with Sentient System to build a precise digital twin of Fernhill's HVAC 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
Application of Honeycomb Blinds	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 weather scenarios.
Exergenics: Stage 1 digital twin for QCH chiller primary system optimisation	This report details the trial of Exergenics' chiller system optimisation technology (PlantScore™) to the QCH chiller systems.
GMG Thermal-XR Coating System – Graphene coating for refrigeration condenser units	The Thermal-XR process of preparing, activating, coating and then maintaining the heat exchange surface of condenser coils was evaluated to quantify energy savings and assess long-term corrosion protection.

Exergenics: Stage 2 optimised chiller staging	This evaluation is a second stage evaluation of Exergenics digital twin and chiller optimisation at Queensland Children's Hospital Living Lab. For this stage, QCH's chiller system staging sequence is optimised to save energy, reduce emissions, improve resilience to climate change, and help futureproof our healthcare provision.
Buildings Alive Rapid Efficiency Feedback technology	Buildings Alive's Rapid Efficiency Feedback (REF) package was implemented at Centre for Children's Health Research building (CCHR) within QCH precinct. The aim of REF is to enable site personnel to make changes to achieve energy and financial savings through regular feedback and continuous improvement in building performance.
Hivve Sustainable Modular Classrooms Envelope and Heating tests	This evaluation report presents the results of an as-built performance evaluation of the thermal envelope and HVAC system of the Hivve transportables located at Majura, in comparison with the transportables buildings located at the i-Hub living laboratory sites, namely Amaroo and Fadden schools.
Amaroo in-slab gas heating compared to split system air conditioning	This report presents the results of an as-built performance evaluation of the in-slab gas hydronic heating system by sub-measuring the energy used in a classroom on the 2nd storey Amaroo General Learning Area (Building 8), and comparing it with the energy used by a newly installed split system air conditioner in a thermodynamically equivalent classroom on the same floor of the building.
Hivve Transportable Classrooms: Impact of Heat Recovery Ventilation on Energy Use and Indoor Air Quality	Provides an evaluation of two Hivve classrooms that had HRV retrofitted, in Sydney and Canberra (St Felix and Majura Schools respectively). The evaluation was designed to test the effectiveness of HRV systems, as well as the implication of the additional energy use for ventilation in grid connected and off-grid classrooms

6.6.4 Outcomes that increase available demand response

Outcome 6 *is to increase available demand response by identifying 100 MW of potential within the broader i-Hub portfolio.* The following activity stream sub-projects contributed to achieving this outcome.

6.6.5 Data Clearing House

DCH1 has developed the HVAC DR Resource Assessment and DR Atlas. The team has also performed a bottom-up perspective of the resource assessment. DCH1 has Identified around 250 MW of tradeable DR potential and around 1.5GW of emergency DR potential within the broader i-Hub portfolio of building typologies.

DCH sub-projects DCH1, DCH4, DCH5 and DCH6.1 are all demonstrating demand response approaches through the DCH platform see Table 7.

Table 7: DCH Demand Response approaches

Project	App Function
DCH1	**Flexible Demand App (thermostat)** The flexible demand App provides thermostat setpoint adjustments in response to forecast prices in the 5-minute spot market. Initial testing has highlighted the importance of mechanical control system dynamics for short term load shifting (rather than building thermal dynamics). Testing and refinement of the App is ongoing. The App is hosted on the Data Clearing House.
DCH4	**Flexible Demand App (chiller management)**

	The flexible demand controller resets the CHW Supply Setpoint (Stage 1) or moves to Stage 2 – shutting down a running chiller and/or load limits the chillers. Initial tests have been run in response to a DR event call signal. The call signal is generated through the DCH, and the DCH provides measurement and verification. The algorithm is coded through the BMS.
DCH4	**Flexible Demand App (battery management)** The flexible demand controller utilizes forecasts of site load, PV generation and tariff/price to decide when a battery should charge or discharge. The algorithms are hosted on the DCH and operate in real time, taking into account both the energy and demand charge components of the electricity tariff. The App has been in continuous operation since December 2021. Electricity costs savings are around 6%, driven mainly by savings in demand charges (rather than energy charges). The App also has a simple on/off thermostat offset adjustment function that can be called upon for additional flexible demand. But this has not been properly trialed yet.
DCH5	**Transactive Demand Response (TDR) App** The TDR App utilizes game theory to orchestrate the allocation of electricity between loads and generation sources, auctioning off electricity between competing loads (agents) to minimize overall pool prize. The algorithms are hosted on a Swinburne server but access weather and electricity price data from the DCH. Measurement and verification are performed on the DCH.

6.6.6 Integrated Design Studios

For all IDS projects IDS01 to 14 the reduced energy consumption and increased generation (compared to BAU) associated with the design solutions explored, point to pathways that will help increase/facilitate available demand response.

Significant reductions were demonstrated across most building typologies. The largest reductions (equal to over 300% of BAU) was in schools where the large roof area available for generation provided significant generation capacity. At the other end of the spectrum was the Data Centres typology where the very large BAU energy demands in operation dwarfed the reduction and generation available.

Reductions in excess of 25% BAU were applicable to the majority of building typologies examined (refer section 6.2).

6.6.7 Living laboratories

LLHC1 has identified DR potential in hospitals and aged care facilities, relating to their generators. Technical feasibility was examined by the LLHC5 project. LLHC1 has also discussed the QLD applicability of this DR capability with Energy Qld representing the network companies in Queensland.

LLHC2 first technology trial involved 250kW HVAC rated load being used for demand response. Demand response technologies were installed and demonstrated. If this data is extrapolated to the entire Warrigal portfolio or the whole aged-care sector, rated HVAC load would exceed several MW.

Participation on demand response was explored in detail in the second LLHC2 technology trial where DNA Energy's DRM control system demonstrated the capacity for temperature set point flexing to pre-cool and pre-heat prior to forecasted high price events with DRED controls to quickly reduce energy consumption to avoid unexpected high price events and participate on the FCAS markets.

The best indication of cost value that this study identified for FCAS was $69,000 potential value stream. This is contingent upon 6sec response time of condenser loads, however, necessarily aggregating these to 1MW trading increment at a multi-portfolio level is expected to manage this issue. The $69k would need to be shared with building owners likely to receive a minor portion, noting that FCAS markets are extremely volatile year to year and are very debatable as to their long-term prospects. However, this value stream exists for the trial evaluation period in the context of a site that has an annual electricity bill of $100k.

Creating demand response from existing HVAC loads, which are traditionally known as the major root cause of peak demand consumption events creates value for the grid with high renewables penetration.

LLHC4 QCH Living Lab has identified a 2.4MW (3MVA) demand response capability which can be used to achieve nearly 50% reduction in energy demand. There are about 130 major hospitals in Australia, with a potential of 300 to 600MW demand response capability. Note the number of Australian hospitals is growing.

LLHC5 Demand response market participation options were examined, and key risks, benefits and challenges were identified.

The options and feasibility for demand response participation have been evaluated and included in the Sector Roadmap.

6.7 Outcomes that make co-design a mainstream approach

***Outcome 7** is to change the industry paradigm to make co-design a mainstream approach to deliver lower cost and higher performance buildings.* This outcome was specifically targeted at the Integrated Design Studios activity stream. All 14 IDS sub-projects contributed to achieving this outcome.

6.7.1 Integrated Design Studios

This is a core tenet of the IDSs. The IDSs have been received well by industry and will continue in a self-funded form in all three institutions. The IDSs have demonstrated value in design outcomes (both in cost and performance), and have contributed to a growing industry wide discussion in this and related areas (such as regenerative design). A biennial symposium on integrated design has been mooted in Melbourne and is indicative of the changing mindsets around the value of integrated design approaches in the construction industry

The IDSs have demonstrated the benefits available in adopting co-design (or integrated design) approach in mainstream design. Better performing buildings on the technical (engineering) front, as well as on the architectural front. They have contributed to and supporting further growth of a wider integrated design movement by:

1. providing publicly available background materials supporting integrated design (reports, magazine articles, journal papers, recorded webinars/lectures, integrated design catalyst document)
2. raising awareness and encouraging discussion within industry (through live webinars and design symposiums).
3. exposing industry stakeholders to the benefits of integrated design and encouraging/providing a platform through which they can be involved in it.
4. exposing architecture and engineering students to the benefits of integrated design and supporting developing integrated design agendas in design faculties.
5. providing a forum in which interested parties from industry (i.e., Engineers Declare, and individuals - architectural engineers) can voice their support and interest. This group of interested individuals has the potential to carry integrated design further in industry through ongoing symposiums, industry engagement sessions, education, formation of integrated design peak bodies, etc.).

A range of industry professionals have been immersed in integrated design during the IDS activity. All in all 14 Integrated Design Studios were facilitated with each studio averaging:

1-2 client representatives

2-3 consulting engineers
2-4 consulting architects
12-16 students

A total of nine different building typologies are addressed with reports containing design ideas and identifying technical performance improvement opportunities by calculated comparisons against BAU baselines.

In addition to direct involvement on the studios many more industry professionals have been exposed to integrated design through the various i-Hub IDS webinars, the integrated design symposium that was delivered by i-Hub and the completed and scheduled invited speaker slots in design-related industry conferences to share the i-Hub learnings.

A ground swell of interest in integrated design and other related fields (regenerative design, sustainable living design, living futures design etc.) was evident in Melbourne especially. There has been informal discussion around continuing the integrated design symposium on a biennial basis.

This demonstrates the positive steps towards changing the design mindset in industry that the IDS activity set about to achieve. In the words on one designer at an integrated design talk hosted by Engineers and Architects Declare "Once you have tried integrated design, you can never go back!".

Material generated in the studios have been written up in studio design and knowledge sharing reports that are now publicly available. In addition to the material produced as a part of the fourteen building specific studios, three journal papers, twelve magazine articles, three webinars, an industry symposium and seven speaking slot presentations as a part of industry conferences have been delivered by the i-Hub IDS activity.

7 i-Hub Management and evaluation

7.1 Multi-project management

One of the unique things about i-Hub was its multi-project approach to delivering its target outcomes.

The i-Hub project was a single project funding agreement between ARENA and AIRAH. The i-Hub funding agreement ran from 19th November 2019 – 30th June 2022. The project was funded by Industry and government delivery partners, and ARENA. The project created three activity streams that comprised of 32 individual sub-projects.

AIRAH worked with the industry steering committee to evaluate all project proposals, create the individual sub-project agreements, and manage all 32 projects to delivery. In addition to project management, AIRAH focused on coordinating and delivering the knowledge sharing elements of the project and communicating with industry on progress and achievements. The outcomes from all of the individual sub-projects combined to achieve the overall i-Hub target outcomes.

AIRAH used a template approach to legal agreement, risk management, project evaluation and monitoring and project reporting. Template legal sub-project funding agreements were created for each activity stream reflecting the relevant requirements of the head funding agreement, back-to-back. Individual agreements were then negotiated with sub-project delivery partners and although negotiating legal details with teams was a time-consuming part of the delivery process the template approach facilitated the process and clearly highlighted to legal teams what could be changed and what could not.

Templates were also created for project applications, project risk management (including WHS management) project reporting and project monitoring and evaluation. Again having 32 project teams report in a standard format at specified reporting dates made it easier to find and communicate the required information . Quarterly reporting produced a lot of information and 6-monthly reporting (mid-milestone) would probably have been more effective for long duration projects (over 12 months) whereas quarterly reporting was more appropriate for shorter duration projects (less than 12 months). One of the disadvantages of the template approach and standardised reporting framework was that it locked all projects into the one reporting cycle.

7.2 Governance

The following governance structure was set up for i-Hub and overall, it worked well to deliver the project.

Activity Leaders Group (ALG) – Each of the three activity streams were assigned Activity Leaders who were responsible for coordinating and monitoring the sub-projects within their stream. The Activity Leaders Group comprised the project manager AIRAH and all activity leaders. The ALG met regularly throughout the program to co-ordinate on project delivery, discuss and manage emerging issues and to evaluate progress against sub-project and activity stream KPIs.

Industry Nominees Group (ING) – To ensure transparency and to manage any conflict-of-interest concerns, AIRAH invited six independent industry experts to participate in the i-Hub steering committee, as the Industry Nominees Group. An important role of the ING was to provide independent recommendations to ARENA on a range of issues including new sub-project merit evaluations generated by the i-Hub Steering Committee and annual and ongoing project management and delivery evaluations. Recommendations to approve (or not) proposed new i-Hub projects were produced by the ING, including any conditions of funding and outlining any particular expectations for the project. Two annual evaluations of i-Hub were completed to ensure that the project was meeting its short-term and medium-term KPIs and its target long-term outcomes. The ING met 12 times during the project delivery.

i-Hub Steering Committee – The entire i-Hub project was overseen by the i-Hub Steering Committee who role was to evaluate new project proposals, monitor sub-project and overall project delivery, and provide recommendations to AIRAH and ARENA. The i-Hub steering committee also assisted with reviewing sub-project technical and knowledge sharing documentation, suggesting improvements to proposals and approaches, and reviewing project delivery issues and proposed solutions as they arose. The i-Hub Steering Committee was made up of representatives from AIRAH and ARENA, the activity leaders and the industry nominees. The i-Hub Steering Committee met 11 times during the project delivery.

AIRAH – AIRAH was the designated leader and project manager for the entire i-Hub Project. AIRAH was also the Knowledge Sharing and communications manager for the project, promoting and delivering knowledge sharing throughout the project.

ARENA – ARENA was the major government funder for the project contributing 34% of the project total cost. ARENA provided contract management services and input into the i-Hub steering committee as well as providing evaluation and assessment functions.

7.3 Challenges experienced and how these were overcome

As with any research or demonstration project there were a variety of delivery issues that came up for individual sub-projects. The main challenges experienced during project delivery included time for delivery, Covid-19 impacts and restraints, complexities creating legal agreements for 32 projects, managing government procurement processes within limited project timelines and a wide range of sub-project delivery challenges including , suspension of face-to-face activities, building access and occupation levels, dealing with healthcare and other complex buildings, dealing with skills shortages, meeting reporting requirements, and a list of sub-project specific challenges all detailed in their knowledge sharing reports.

7.3.1 Time for delivery

Time was always a problem for i-Hub whose original 3 years delivery timeline was compressed down to 2.5 years. Three-year sub-projects and activities commenced in January 2020 with a scheduled finish date of June 2022. This meant that sub-project teams had to analyse their project delivery schedules for critical paths and re-adjust delivery schedules, paralleling activities to make up for the unavailable time.

Because time was so limited almost all of the i-Hub sub-projects (over 25 of them) continued up to the i-Hub project end date of June 2022. This has allowed only a limited time for synthesising and integrating the final project technical reports and knowledge sharing deliverables. An additional 6 months of i-Hub project time would have been useful for this, time to fully debrief sub-project teams and explore and integrate all of the tools and knowledge developed. The milestone delivery schedule approach, highlighting clearly which deliverables were scheduled to be submitted at which milestone date helped sub-project teams understand and meet their deadlines and contracted requirements. Where possible sub-projects were provided with minor variations to extend the delivery date for delayed deliverables. AIRAH provided all teams with clear expectations for final reporting and templates and style guides to help them be produced in a standard format.

7.3.2 Covid-19, impacts and restraints

The i-Hub funding agreement was executed between ARENA and AIRAH on 19th November 2019, nobody had ever heard of Covid-19. By March 2020 AIRAH had asked all sub-project teams to complete a Covid-19 specific risk review of the delivery plan. The challenges that the Covid-19 rules and regulations presented to project teams were many and varied. For Living laboratories and DCH sub-projects access to aged care, health care and education sites became particularly problematic, but access to all sites was more difficult and time consuming. Planned face-to-face design studios for the Integrated Design activity had to be moved online. Similarly, project management teams also moved online and stayed online for the duration of the i-hub Project.

All teams had to develop Covid-safe work plans and project delivery workarounds. Facility staff became technicians installing or verifying monitoring equipment under remote instruction. Covid impacted project delivery for all sub-projects. The availability of key project technology (monitors, batteries, technologies for testing) became limited as Covid impacted the supply chain and global transport logistics.

Delivery partners were all significantly affected by Covid and it has been noted that if the i-Hub project had been proposed in March 2020 (as opposed to March 2019) it is highly unlikely that such a project would have gone ahead/been approved or have even been proposed, due to the covid delivery risks and the restraints that had been placed on all involved organisations' finances. Several planned delivery partners were not able to participate in i-Hub because of those impacts.

7.3.3 Legal documentation

The multi-project delivery format meant that a separate legal agreement had to be created for each of the 32 sub-projects delivered under i-Hub. In order to reduce AIRAH's exposure to risk the AIRAH board required that each sub-project was covered by a legal agreement that reflected the relevant requirements of the head i-Hub funding agreement. In this way the responsibility for sub-project delivery was transferred from AIRAH to the delivery partners for each sub-project. This meant that a very detailed 30-page standard legal agreement template had to be created and agreed with all sub-project delivery partners.

There were around 65 separate delivery partners throughout the i-Hub sub-projects and negotiations with individual sub-project partner legal teams was one of the most time-consuming aspects of the project creation process. Being clear on what could and what could not be changed in the draft agreements helped AIRAH manage partner expectations.

Each legal agreement contained an Approved Project Plan. This detailed the delivery of the project and ensured that what was delivered by the sub-project team equated to what was reviewed and accepted by the i-Hub Steering Committee.

In general, the approach AIRAH took to documenting each sub-project's legal agreement was successful. The i-Hub legal documentation comprised the following main documents:

i-Hub funding agreement

During the project delivery period there were:

- 1 x i-Hub funding agreement – between AIRAH and ARENA
- 1 x Major Variation (to account for a budget adjustment due to the non-delivery of DCH6 stage 2)
- 7x Minor variations (to update the budget actuals at every Milestone)

i-Hub Sub-project agreements

During the project delivery period there were:

- 32 i-Hub Sub-project agreements – between AIRAH and sub-project partners
- 3 Major Variations to sub-projects (to include additional project scope and funding when related to approved new projects)
- 15 minor variations to sub-projects (to reschedule project tasks and deliverables or record changes to key staff)

- 0 disputes (no disputes on legal agreements to date)

7.3.4 Government procurement processes

One of the challenges that came up in several living laboratory and data clearing house sub-projects was meeting government procurement processes and standards. The spending of public funds generally follows a strict and documented procurement process which for several sub-projects was significantly more complex and time consuming than had originally been planned.

Government procurement departments tend to use a list of preferred contractors for the provision of technical installation services through a public tender process. So, when the tender is for a unique and innovative approach the process is more complex and time consuming to both specify and price. Many contractors will also tend to price unfamiliar, unusual, or innovative work higher, to address perceived delivery risks.

7.3.5 Global supply and logistics

The issues with the global supply chain and transport logistics impacted several projects that were delayed acquiring the required technology. The new battery banks for renewable energy storage and flexible demand, and the new heat recovery ventilation (HRV) units were particularly impacted.

While in most cases these issues were overcome by rescheduling project tasks and approaches, one building that participated was still waiting on the delivery of batteries after the project scheduled end date. Delays in the supply chain were difficult to mitigate and, in most cases, caused unavoidable delays to project delivery.

7.3.6 Dealing with healthcare buildings

A significant challenge, when working in an occupied healthcare building (aged care or hospital), was how to handle the living lab activities without being intrusive or causing disruption to the residents and staff. This required well communicated procedures and protocols to implement and the test the innovative technologies. Distribution of responsibilities across various departments, made the coordination process lengthy and time consuming, which was not accounted for in the initial planning.

7.3.7 Reporting

The level of reporting built into i-Hub was extensive and meeting the reporting requirements and ensuring sub-projects met their reporting requirements was a very time consuming and challenging project management task.

7.3.8 Skills shortages

Towards the end of the delivery period, in 2022, skills shortages were becoming more evident and having an impact on some of the sub-projects ability to provide dedicated staff to deliver the project tasks. Generally sub-project partners were able to step in to complete the work.

7.4 Lessons Learnt

The AIRAH project management team documented several lessons learnt in the management and delivery of the i-Hub project. These lessons are documented in the i-Hub Lessons Learnt Reports:

- Lesson learnt #1 Contract Management – Developing multiple funding contracts
- Lesson learnt #2 Project Management – Standardised Reporting Templates and Timing
- Lesson learnt #3 Project Management – Outcome evaluation and KPIs
- Lesson learnt #4 Project Management – Dealing with Covid 19 impacts
- Lesson learnt #5 Risk Management – Large single or multiple small projects?

The i-Hub Lessons Learnt Reports can be accessed here [The Knowledge Hub - i-Hub (ihub.org.au)]
Every i-Hub sub-project has also documented individual lessons learned and these are all documented on the individual sub-project webpage. [i-Hub Initiatives - i-Hub (ihub.org.au)]

7.5 Evaluation of the overall Project

The operation, management and success of the i-Hub project was evaluated by the i-Hub steering committee every six months across three criteria:

1. Evaluation of i-Hub delivery
2. Evaluation of i-Hub KPIs
3. Evaluation of i-Hub outcomes.

Project evaluation reports were provided to ARENA annually, following verification by the i-Hub steering committee.

7.5.1 Evaluation of i-Hub delivery

The i-Hub project delivery was evaluated against the following criteria.

- Project delivery – in accordance with the i-Hub funding agreement
- Project deliverables – in accordance with the i-Hub funding agreement
- Project budget – in accordance with the i-Hub funding agreement.

In terms of its delivery, the i-Hub project has:

- Been delivered on time and within the allocated budget
- Managed 32 projects to completion
- Successfully completed all deliverables, including the provision of a range of legacy tools to industry
- Delivered all of the planned tools and information developed, so that it is now free to industry
- Achieved all of its short, medium and long-term KPIs
- Addressed and is progressing towards achieving all of its long term target outcomes
- Published a range of technical reports, knowledge sharing reports, journal papers and magazine articles.

The i-Hub project was delivered across seven Milestones and two annual evaluation gateways. Every Milestone and evaluation gateway was achieved by the due date, as outlined in Table 8.

Table 8: Achieved i-Hub Milestones

Milestone Number	Date due
M1	13 December 2019
M2	31 January 2020
M3	27 April 2020
Annual Evaluation	30 June 2020
M4	30 October 2020
M5	28 May 2021
Annual Evaluation	30 June 2021
M6	26 November 2021
M7	30 June 2022

7.5.2 Evaluation of i-Hub KPIs

Every sub-project had defined KPIs and Outcomes and a list of time-stamped KPIs for i-Hub were created for each activity stream for the purposes of monitoring and evaluation. Evaluation of project progress against KPIs was reported by the project delivery teams (PR1 to PR11) and verified/recorded in the i-Hub Activity leader summary report (ALS1-ALS8).

The i-Hub steering committee evaluated the progress of the i-Hub project towards achieving the stated KPIs, based on the evaluations produced every 6 months. Project evaluation reports were provided to ARENA annually, on the 1st of June 2020 and 1st June 2021 to help ARENA evaluate the progress of the i-Hub project at two delivery gateways, as required by the funding agreement.

The i-Hub project has met all its Key Performance Indicators and deliverables and achieved all its Milestones. The project has delivered on all its contracted knowledge sharing deliverables and is on track to achieve its stated objectives and outcomes. This has all been achieved within the allocated project timeline and within the projected budget costings.

7.6 Evaluation of i-Hub approach

Any evaluation should also consider the approach adopted by i-Hub to achieve its outcomes. The multi-level project comprised 32 individual sub-projects that were all managed by AIRAH and its partners to deliver on the overall i-Hub project outcomes (see Section 6).

When evaluating the overall project impact consideration is also given to the following criteria:

- Innovation
- Technical excellence
- Diversity
- Engagement
- Knowledge sharing

7.6.1 Innovation

It is what it says on the box, an innovation hub, and all of the tools and knowledge developed and demonstrated through the i-Hub project have displayed an innovative approach to using existing technologies and systems.

The data clearing house is an innovative approach to providing an open source digital platform and market place for building and HVAC energy performance and control. The platform is based on the innovative and award winning Senaps platform.

The living laboratories is an innovative approach to turning operating buildings into instrumented performance assessment spaces where technologies and services can be safely tested and evaluated in a real world setting and under fully monitored operating conditions. Any building can be a living laboratory and the five livings laboratories created by i-Hub have all been involved in evaluating a range of innovative products and services.

This is an innovate approach to evaluating and leveraging best in class technologies for sector and portfolio wide deployment. Trusted evaluation combined with proven performance and well understood application pathways could see innovative technologies and services rapidly deployed across a sector to help decarbonise buildings.

Figure 17: Innovation

While integrated design is not new concept, the approach that i-Hub took to integrated design was new and highly innovative. Combining owners of real buildings/projects with experienced designers and up and coming practitioners in a neutral design environment facilitated by a range of academic experts in a monitored environment allowed the processes of integrated design to be explored in depth. The process also produced a range of innovative design approaches that can be applied to new and refurbished buildings to help the building sector move to net zero carbon emissions.

7.6.2 Technical excellence

Technology is a strong focus for many of the i-Hub activities. The Data Clearing House platform is leveraged off a global world leading IoT platform and the DCH platform has been recognised internationally as a best in class platform of its kind, internationally.

The applications hosted on the Data Clearing House platform are all world leading examples of technical excellence in the digital/data space. Several have won industry awards including:

- Exergenics LL - AIRAH Awards winner - 2021
- Exergenics DCH - Energy Efficiency Council awards winner - 2022
- CSIRO/Data 61 Senaps - International awards winner – 2020

The integrated design studios produced a rage of technical designs that, when evaluated against a BAU benchmark, were shown to dramatically reduce the operating energy of the building. This was achieved for at least seven of the nine different building typologies.

The living laboratories bring high-level technology into real-world buildings both in terms of the performance and their interaction with buildings and occupants. The activity has shown industry that any building can be turned into a living laboratory and the model is already being replicated in other projects. The living laboratories independently evaluated 11 technologies and services and have provided building owners and managers with a range of tools outlining how to leverage HVAC, renewable energy and enabling technologies on their pathway to net zero buildings.

The results from the healthcare living labs will 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 long-term 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.

7.6.3 Diversity

The i-Hub Project has shown a depth of diversity throughout the delivery period. It has been a collaboration between research, academe, commonwealth, state and local governments and a variety of industry organisations that has delivered i-Hub.

The diversity of the i-Hub project is demonstrated by

- 65 different partner organisations comprising hundreds of individuals all came together to collaboratively develop and deliver i-Hub.
- 32 different technical sub-projects working in collaboration to contribute to the overall target i-Hub outcomes
- The range of building owners and typologies addressed across the projects from commercial office towers to local council libraries, from data centres to train stations, from hospitals to aged care.

7.6.4 Engagement

Engagement has been a significant focus of the i-Hub project bringing together government, academe, research and industry to collaborate in all i-Hub sub-projects. the list of project partners and participants is extensive and diverse.

In all 65 different organisations and companies participated in i-Hub project delivery across 32 delivery teams.

The knowledge sharing activities delivered by i-Hub including the forums and presentations, the online knowledge hub, the engagement videos and the variety of technical reports, journal papers and magazine articles

The five i-Hub summits are available as a series of 15 on-demand videos as well as the Integrated design symposium and a range of other video collateral developed by the i-Hub sub-project teams.

Presentations have been made at a range of industry and sector conferences and seminars, and this will continue into 2022.

Several journal articles have been published and several are being considered for publication and a range of articles have been published in several industry magazines. All teams are looking for additional ways to disseminate and build on the knowledge and tools developed.

For the living laboratory activities, a significant project impact has been in the expansion of i-Hub engagement into three significant areas:

1. Engagement with NABERS (through NABERS for Residential Aged Care and Retirement Living; NABERS for Hospitals; NABERS Accelerating Net Zero Buildings, and NABERS for Schools)
2. Engagement with the Australasian Health Infrastructure Alliance (AHIA) and the subsequent co-funding of LLHC5 to explore net zero energy and resilient hospitals
3. Engagement with the clinical side of healthcare through the Climate and Health Alliance (CAHA) and Doctors for the Environment Australia (DEA) and the inclusion of their perspectives and reports in the development of the Roadmap.

The Integrated Design Studios were essentially individual engagement projects, working out how to facilitate engagement between all of the stakeholders and actors on the delivery of a building. There has been considerable engagement with industry and the beginnings of the formation of an integrated design movement.

The Data Clearing House also engaged deeply with industry and government, looking at pathways to innovate within sector portfolios and unlock pathways to emissions reduction through integrating HVAC and energy control. The DCH team will continue to engage with building and portfolio owners and managers and innovative digital technical services providers to build the capacity and capability of the DCH platform into the future.

Material generated through all i-Hub sub-projects have been written up in technical and knowledge sharing reports that are now publicly available. In addition to the technical and knowledge sharing reports - a range of journal papers, magazine articles, webinars, and speaking slot presentations as a part of industry conferences have been delivered by the i-Hub sub-project teams.

7.7 Evaluation of Knowledge sharing

Knowledge sharing was always one of the most significant objectives of the i-Hub project, not just to demonstrate new technologies and new ways of doing things, but also taking the time to explain what was done and how it was achieved, to bring industry and others along on the i-Hub journey.

All i-Hub sub-projects were involved in documenting their own knowledge journey, including barriers that were encountered and how these were overcome. Every project produced lessons learnt reports documenting those smaller insights that were gained as the project was delivered. Technical reports and other collateral were also supported by individual Knowledge Sharing Reports produced by each project team to document the entire sub-project including signposts to the technical reports and insights developed.

- Knowledge Sharing Reports – Provide an overview of the project, highlights and signpost to all technical materials
- Technical Reports – Provide the in-depth explanation and insights into the specific project work
- Lessons Learnt Reports – Provide a summary of some of the lessons learned during project delivery.

i-Hub delivered regular Knowledge Sharing summits throughout the project period, with an online event held every 6 months for each of the three activity streams, allowing individual sub-project teams to share the knowledge and results of their work as they progressed.

- The i-Hub summits (i) though (v) are available as a series of videos
- The Integrated Design Symposium also available as a series of videos
- The i-Hub Outcomes videos – have been developed and published to promote the i-Hub Knowledge Sharing materials
- Conferences and webinars – i-Hub teams have been presenting at a variety of industry conferences and webinars
- Journal papers – Several published Journal papers and several under consideration for publication
- Magazine articles – a variety of short story format articles have been prepared/published to help share i-Hub stories

All of the i-Hub Knowledge Sharing materials are available on the i-Hub website via the individual project webpages or the i-Hub Knowledge Hub web page.

Home - i-Hub (ihub.org.au) The Knowledge Hub - i-Hub (ihub.org.au)

7.8 Evaluation of i-Hub outcomes

An evaluation of how i-Hub has achieved its target outcomes is provided in Section 6.

7.9 Evaluation of Project impact

In terms of its impact, the i-Hub project has met all its Key Performance Indicators and deliverables and achieved all its Milestones. The successful i-Hub project has the potential to be hugely impactful on the building and HVAC industry in the short-, medium- and long-term.

7.9.1 Immediate Impact

The **Data Clearing House** currently has over 50 buildings connected and utilising services, all these buildings are identifying or generating a range of energy savings and performance benefits as they access digital energy efficiency and renewable energy optimisation services through the platform. The Reference M&V application is deployed across multiple pilot buildings and, for many of these building owners, this is their first step towards unlocking opportunities from digitalising their building.

Many of the owners of the DCH pilot buildings such as Property NSW, Schools Infrastructure NSW, Metro North Health (MNH), City of Melbourne, City of Darwin, are continuing to roll out DCH to their portfolio of buildings for a range of end use cases. There is also participation from other state governments (Vic health, SA health) to utilise DCH for delivering energy efficiency improvement services. The MNH hospital now has access to automated REETSEF reporting (on key energy performance indicators) through the DCH.

The potential for HVAC related flexible demand response has been quantified nationally, and a range of demand response use cases are being demonstrated through the platform. This has helped building owners and technical service providers understand the value of integrating renewable energy and HVAC loads when accessing demand response market opportunities.

The DCH activity has supported the commercialisation and expansion of a range of innovative digital solutions. Digital services providers have access to a new open-source marketplace on the platform, with 9 separate digital services currently available to all DCH connected buildings.

The Data Clearing House platform has been selected by a consortium of European partners to host machine learning competitions under the ADRENALIN project supported under the 2021 Mission Innovation ERA-Net Call on Digital Transformation for Green Energy Transition

CSIRO is continuing to develop and expand the Data Clearing House platform and its user base. Many of the DCH sub-project teams/collaborating organisations are continuing to work together in the further development and deployment of the DCH Platform and marketplace.

Each individual **Integrated Design Studio** has involved an average of 16 masters level students, 1-2 representatives from building owner's organisations, 5-6 industry professionals (architects and engineers) and 2-3 academics. This equates to approximately 350 individuals and industry participants and professionals that have already been introduced to the philosophy of integrated design and the i-Hub IDS tools.

The building owners of the 14 projects included under the IDS program (NextDC, ACT Schools, Ambulance Victoria, Council Aquatic Centres, Aged Care Plus, CSIRO, Centre for Appropriate Technology, LXRP, and several community councils) have all benefitted from increased understanding of the importance of early design, passive design and parametric design and the integration of HVAC and renewable energy into building design. Many owners have already utilised some of the ideas coming out of the IDS program most notably ACT Schools and Ambulance Victoria who are both bringing forward the innovations into their current construction and refurbishment programmes. IDS04 informed the development of Ambulance Victoria's first zero carbon proto-type station planned to be built in Mallacoota.

The IDS activity has already created a range of connections between interested people and stakeholders throughout the building and HVAC&R industry. Following the successful IDS Integrated Design Symposium in 2021, a range of individuals and organisations have taken the first steps to organising a more formal advocacy group to promote the further application of integrated design processes into the Australian construction industry. Interest in being a part of this industry group has already been shown by Swinburne, Monash, Victoria and Deakin universities as well as by several passionate integrated design individuals from various architectural and engineering consultants. The ultimate realisation of this may be the formation of an integrated design industry body. Future repetitions of the symposium event have been mooted and collaboration with 'Engineers Declare' has established integrated design industry engagement sessions to further propagate integrated design in the interests of combatting climate change. The first of these sessions occurred as a part of the Regeneration Melbourne 2022 Conference.

The Integrated design studios have been well received by clients, consultants, student designers and academia. Continued delivery of IDS studios beyond i-Hub by each of the three Universities (UoM, UoW, QUT) demonstrates the inherent value they represent. This will continue to change design mindsets as student designers make their way into industry.

The tools and guidance developed by the IDS activity are freely available for industry to use and several organisations have already shown strong interest in their use. Current and previous versions of *The Catalyst for Integrated Design* document have already been provided to a variety of individuals and organisations and used by industry in setting up integrated design environments.

The Studio Outcomes Reports are referred to by people interested in building or creating more sustainable buildings. Learnings from the program have been incorporated into the IDS activity wide compendium of integrated design findings including the *Catalyst for Integrated Design*, the *Low Carbon design catalogue* and the cross-program knowledge sharing report as well as a range of papers and magazine articles produced.

Integrated design studios have demonstrated to industry the increase in the use of renewable energy (in meeting energy loads) possible from early engagement and passive and parametric design. They have demonstrated how improved building envelope, HVAC technology selection and operation, DR participation and renewable energy management, can all help facilities achieve net zero carbon emissions goals.

The **Living Laboratories** activity has created 5 living laboratories and provided technology evaluations for 11 innovative technology devices and services.

Building owners such as the Queensland Children Hospital, Bolton Clark and Warrigal have all gained considerable insights into the renewable energy use and optimisation of energy and HVAC assets of their facilities. Many owners are rolling out those insights across their building portfolios. Bolton Clark will 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.

All living laboratories will continue to operate to inform their building owners transition to net zero with ACT Education and UOW for example, entering an agreement to continue the school's living laboratory (LLS2) for a further 18 months to conduct additional technology evaluations.

Following the i-Hub model, a new living laboratory (Carseldine Urban Village) has been established through the Renewable Affordable Clean Energy for 2030 (RACE2030) CRC, encompassing household and precinct HVAC control, renewable energy and storage, and DR capabilities.

The eleven technology providers have immediate access to technical collateral that validates the performance and application of their innovative products, helping them to provide accurate trusted information to potential clients.

Data collected from approximately 3700 primary schools across Australia has been analysed and has been used in the development of the NABERS rating tool for Schools.

The LL Knowledge Sharing activity has brought together all public health departments across all Australian States and Territories, with private sector healthcare providers, and facilities management and clinical services providers within healthcare, to examine energy impacts of future climate, pandemic mode ventilation and demand response participation, and collaborate on the development of the Sector reports.

The Sector reports have provided industry with ways to quantify and qualify HVAC and RE integration and demonstrated the potential to align health and energy co-benefits. Technical reports on future energy use and net zero energy and resilient hospitals were produced, and Life Cycle/Whole of Life Assessment KPIs for Schools developed. The two Roadmap publications (Healthcare and Schools) summarise all knowledge developed, all produced in collaboration with industry stakeholders.

Overall, **the i-Hub Project** involved around 600 individuals and 65 organisations collaborating to deliver the project. The employment costs were the dominant costs in the project representing 84% of the total project costs and resulting in over one hundred thousand hours worked across the project. In a sign of the success of the IDS studios, several students have gone on to be employed by the project partners for the studios in which they participated.

7.9.2 Long-term Impact

The **Data Clearing House** can help open up the pathway for any building to become a 'smart building'. Providing access to an innovative digital marketplace where connected buildings can access a range of energy-based applications and IoT/Cloud based analytical and management services, the DCH platform is a trusted and cost effective mechanism for digital services delivery and services development. The DCH platform shows owners how to integrate their HVAC systems and the building's energy assets to produce the most affordable/least emission operating profile.

As DCH continues to grow and, because it is based on the world leading Senaps framework it has a huge capacity to grow, more and more buildings and building owners will have the capacity to understand and control their energy use and emissions associated with building HVAC. Measurement and verification, energy efficiency, fault detection and diagnosis, flexible demand, optimisation of energy assets and demand response participation are all facilitated by the DCH platform.

CSIRO will continue to work with industry and government partners to build on the current DCH platform, exploring additional use cases, refining and expanding current service offerings and facilitating rollout across portfolios of buildings.

The **Integrated Design Studio** activity, and all of the tools and knowledge that has been developed and shared with industry, will possibly have the greatest impact, of all the i-Hub activities. Building better buildings is the first pillar of reducing emissions in the sector. The requirement is already there with minimum energy building regulations, government, corporate and building owner sustainability and net zero goals. The industry already understands that future buildings, the buildings that are being designed today, have to push hard to net zero. But the industry does not understand how to do it.

The Integrated Design studio activity is showing industry the way, by demonstrating how a large proportion of a building's emissions can simply be designed out, by integrating owner requirements, architecture, engineering and construction into the earliest stage of the design of the building. When the architecture, engineering and constructability evolve together, in an integrated way, new innovative approaches emerge to using (in many cases existing) technologies to meet multiple building needs. Net zero energy for most new buildings is achievable with current technology, and for specialised complex buildings other innovative emission reducing solutions that impact energy or provide additional co-benefits emerge through the process. A traditional building design, with designers that are siloed in a linear design process, has a much more difficult and expensive pathway to follow to achieve net zero.

Possibly the most immediate impact from i-Hub will be through the **Living Laboratories** activity. For existing buildings, the most immediate pathway to lower emissions and affordable heating and cooling is by adopting the latest technologies that can help reduce or improve energy use. The Living Laboratories activity is really showing the industry how to accelerate technology adoption and rollout by verifying performance and suitability in a specific application, prior to sector-wide roll out across a portfolio of buildings.

Any building in any sector can be a living laboratory and there should be Living Laboratories set up to address every building typology and every large sector portfolio. Living laboratories are tools to help show what technologies work best in which applications, and how a technology will interact with the building and its occupants. Living laboratories answer these questions and the i-Hub Living Laboratories have already tested 11 different technologies/digital services in a range of application environments, all documented in independent validated technology evaluation reports. These help create the links between technology providers and technology adopters and provide the information and trust to facilitate a wider roll-out.

The i-Hub Living Laboratories activity is showing two specific sectors, Healthcare (hospitals and aged care) and Education (schools), how they can move their buildings and operations onto a more sustainable footing. The sector-wide roadmaps provide specific net zero pathways for the healthcare and schools sectors, but most of the tools and knowledge outlined is also applicable to a range for other sectors and building typologies.

The industry, government, and building owners understand that the transition to net zero is a long and challenging path. i-Hub has taken some big steps along that path but there is much more work remaining to be done. In many ways we are still at the beginning of the journey, but the journey has been made easier for many because of what the i-Hub has produced.

The i-Hub has produced a range of tools and knowledge sharing information to help industry transition and the full impact of the project will only be understood once the final tools and information is released and used by industry for a time. The impact from the i-Hub project is not immediate but the potential for the three activities to help industry produce more efficient buildings with highly efficient HVAC, all powered by low carbon energy is huge. The world needs affordable building heating and cooling that is dependable, functional and has low or no emissions and i-Hub is lighting the way on how to fulfill that need.

8 What comes next?

8.1 Conclusions

i-Hub represents a very successful collaboration between academia, research, government and industry.

All i-Hub sub-projects were delivered on budget and completed on time in accordance with the project plan. The inclusive and transparent management approach was successful in helping the i-Hub project overcome the many significant barriers and obstacles that were encountered during project delivery.

The i-Hub projects have produced a vast amount of knowledge, data and a variety of tools to help the sector achieve affordable heating and cooling, low emission HVAC&R and net zero buildings. The i-Hub legacy tools have the potential to create large savings in the buildings and HVAC&R sectors through reduced energy use, increased renewable energy fractions, reduced emissions and more affordable heating and cooling.

There is more work to be done to help transition the building sector and HVAC&R industry to a low emission net zero trajectory. This section collates some of the future work and highlights potential future research needs.

8.2 i-Hub Legacy

8.2.1 Data Clearing House

The Data Clearing House (DCH) platform has been developed and demonstrated over the course of the ***i***-Hub project. It has reached TRL level sufficient for commercialization, and now has up to sixty buildings on the platform.

CSIRO have committed to continuing to manage and develop the DCH platform for the benefit of the industry until such time as it can become the self-sustaining and independent entity planned.

More specifically, the project partners will deliver legacy outcomes from specific building portfolio and application use cases as outlined in Table 9.

Table 9: DCH sub-project legacy outcomes

Project	Beneficiary	Outcome
DCH1 **DCH8**	CSIRO	CSIRO has committed to net zero by 2030. i-Hub projects support this vision by: • helping to provide a better quality of metering and monitoring capability, with which to identify energy saving opportunities. Based on positive results in the initial three DCH trial CSIRO buildings, CSIRO decided to expand use of the DCH across all sites. • Providing energy saving and flexible demand applications. The DCH8 Exergenics project ran smoothly and delivered good results. Based on positive results in the initial DCH trial building, CSIRO has decided to expand use of the Exergenics App to another two buildings
DCH4	Property NSW	The NSW NetZero Plan Stage 1 requires a 35% reduction in emissions by 2030. i-Hub projects support this vision by: • helping to provide a better quality of metering and monitoring capability, with which to identify energy saving opportunities. Based on positive results in the initial five DCH trial buildings, Property NSW decided to expand use of the DCH across a further six sites. • Validating the efficacy of different vendor solutions. For example, the Conserve IT PlantPro software has been trialed in a Property NSW building.

DCH5	Swinburne University	The Swinburne University Transactive Demand Response App is planned to be commercialized by the projects industry partners (Braemac and KIG). During the course of the project Swinburne also developed various other sensor device IP which may also be commercialisable. Negotiations have started on providing relevant licenses
DCH6.1	Schools NSW	The three-school trial of DCH with batteries, demand response and solar PV, has the potential to be rolled out through the NSW cooler classrooms program. Difficulties with battery supply chain and control system procurement have extensively delayed the project, and results are not available to fully validate the revised system design. However, the initial hypothesis remains valid, pointing to large amounts of cost-effective flexible load potential from schools. Modelling suggests that, after air conditioning has been deployed across schools, there would be around 670 MW of load shedding capability and 700MW of callable load potential. That this load sits with relatively few building owners (the state governments) and is relatively homogeneous, makes schools an attractive target.
DCH7	PrediQ	PrediQ is a small medium enterprise providing building automation and big data analytics solutions. DCH has provided a data platform to help scale their AI solutions.
DCH8	Exergenics	The DCH8 project has enabled Exergenics (another small medium enterprise) to trial and validate the efficacy of their chiller optimization software solution. This has helped them to win the 'Best of the Best' Proptech Startup of the year award in 2021.

8.2.2 Integrated design studios

Three Universities are now delivering Integrated Design Studios as part of their curricula and the industry is now well informed on the way and benefits of integrated design.

The Catalyst of integrated design and Carbon Catalogue will continue to be curated by the University of Melbourne to ensure the latest learnings are included.

Several of the owners involved in the program are utilising the ideas and process in the design of their new low emission sustainable buildings.

8.2.3 Living Laboratories

The five living laboratories are all available for ongoing testing and use. Collectively the laboratories have tested and documented 11 different technologies and services.

The i-Hub Living Laboratory model has been documented and demonstrated and there is evidence of other Living Laboratories now being developed in Australia, following the same i-Hub model.

The capacity for evaluating innovative technology and services and then rolling out energy efficiency and other interventions across a sector, portfolio or building typology is a very powerful agent for change. What the industry needs in order to secure investment in these technologies is trusted and proven benefits, the kind of collateral that can best be produced by Living Labs.

8.3 Future use

There is more work to be done to help facilitate net zero buildings and the transmission to low emission low carbon heating and cooling i-Hub will continue to share the knowledge and tools developed across the project and will facilitate ongoing discussions with industry at ARBS 2022 and with RACE 2030 CRC and Building 4.0 CRC to help ensure that these tools continue to get used and the knowledge developed built upon.

8.3.1 Data Clearing House

Commercialization/utilization of the Data Clearing House Platform will occur in a number of ways in order to drive national impact

Internet of Things (IoT) service for hardware suppliers

A number of companies have approached CSIRO with specific use-cases for the Data Clearing House as an IoT platform. These companies have hardware products/devices that they sell, for which they would like some 'back to base' data capture capability. This would enable them to better monitor and maintain their equipment in the field. These applications would involve relatively small-scale data capture. As such, they do not exploit the full capability of the DCH platform, but the DCH does provide some level of future proofing for these companies. In this pathway, the DCH would be provided as an instance under licence, or as a software service managed by CSIRO's IaaS partner.

Property industry data hub

It has always been a target to establish a not-for-profit 'data-institute,' tasked with managing an ecosystem of buildings and software providers on a common platform (illustrated in Figure 18).

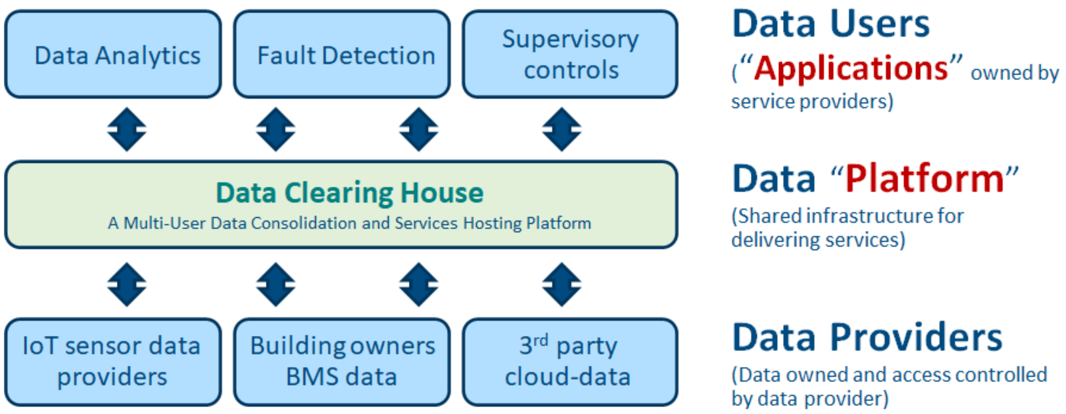


Figure 18: DCH Platform

This vision of a marketplace, connecting data owners with data users, was endorsed by the Data Clearing House Steering Committee. While an NFP model is not conducive to accessing venture capital, the model has the potential to address many of the barriers that have prevented scalable deployment of smart building services in the past.

The cost structures that underpin the model have been investigated and a financially self-sustaining service appears feasible. Typical of platform-based business models, the value of the model is strengthened when there are large numbers of buildings on the platform (looking for services) and large numbers of service providers (offering services). As a threshold for financial viability has probably not yet been reached, CSIRO expects to continue to operate the DCH platform in-house as a 'proto-business' (one of CSIRO's internal commercialization models) with day-to-day management of the service managed by CSIRO's IaaS partner

R&D data sandpit and standards test bed

CSIRO is Australia's national research agency. The Data Clearing House will be used to support CSIRO's ability to conduct cutting-edge industry-relevant Artificial Intelligence research in support of the energy transition. One aim will be to obtain deidentified data sets that can be used to train and test AI algorithms. By way of example, the Data Clearing House has been selected by a consortium of European partners to host machine learning competitions under the ADRENALIN project supported under the 2021 Mission Innovation ERA-Net Call on Digital Transformation for Green Energy Transition

8.3.2 Integrated Design Studios

The integrated design studios have been received well by universities, industry practitioners and clients alike. They are also in line with a larger push in academic circles to bridge silos across academia recognising that 'problems do not come in disciplines'. The rising popularity of double degrees bridging the fields of Humanities and Social Sciences (HASS), and Science, Technology, Engineering and Mathematics (STEM), of which architectural engineering is one are an example of this.

All three of the institutions involved in the IDS activity stream (UoM, UOW, QUT), intend to continue the integrated design studios in an unfunded format. Studios will include future clients and consultants (who have indicated willingness to be involved on a pro-bono basis), however will not go into the depth of investigation that the funded IDSs were able to go into in regard to feasibility vetting of the solutions.

University of Melbourne have completed further Integrated Design studios outside of the i-Hub project.

Bolton Clark will 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.

Ongoing activities

The Integrated Design Studios have amassed a large body of work around integrated design, and net zero design. Learnings have tested theoretical knowledge in practical design studio sessions, with practising architects and engineers across nine different building typologies.

This material is a valuable pool of investigation and will be able to be drawn upon for some time by the institutions involved and by industry. Some of the continuing activities planned for the near future are:

- Continued knowledge sharing with industry and the public through various institutional and on-line media channels.
- Continue to publicise the 'Catalyst for Integrated Design' document encouraging building owners and industry groups to adopt principles of integrated design in the procurement of projects.
- Further articulate and publicise the 'Carbon Catalogue'. This document has the potential to be a stand-alone document providing guidance on where to start with net zero design.
- Participation in further conferences on integrated design and similar fields (regenerative design etc.). The next speaker slot planned is for the Air conditioning, Refrigeration and Building Services (ARBS) Exhibition 2022, planned for 16-18 August 2022.
- Continuation of integrated design studios in an unfunded form. All three institutions involved in i-Hub (The University of Melbourne, The University of Wollongong, and Queensland University of Technology), have indicated forward plans to continue the integrated design studios
- Continue to support the development of an 'inner circle' of integrated design interested people in Melbourne and potentially nationally. Interest in being a part of this industry group has already been shown by Swinburne, Monash, Victoria and Deakin universities as well as by a number of passionate

integrated design individuals from various architectural and engineering consultants. The ultimate realisation of this may be the formation of an integrated design industry body for Australia.

Catalyst for Integrated Design' and the 'Carbon Catalogue'

The two bodies of work to come from the IDSs that will be of most interest to industry are the 'Catalyst for Integrated Design', a guide on how to implement integrated design in industry, and the 'Carbon Catalogue', a roadmap on where to start with net zero design in various building typologies.

We anticipate further work promoting these documents and possibly extracting them from the reports to be published on-line in a stand-alone format.

8.3.3 Living Laboratories

LLS1: The University of Wollongong is discussing a collaboration with NABERS, to integrate the sector wide energy analysis within the NABERS Accelerate for Schools, to assist in developing a NABERS rating scheme within the education sector. This will utilise the findings of the education sector baseline and further assist the education sector in developing a more efficient schooling stock. Additionally, the knowledge sharing task group is anticipated to continue, with idea sharing and knowledge dissemination to continue as education directorates work towards a more energy efficient future.

LLS2: The University of Wollongong is negotiating with the ACT Education Department to extend the ACT Schools Living Laboratory trials for a further 18 months. This extension will include the continued evaluation of the trials documented in i-Hub to enable a continuous 12-month comparison against current business as usual. Additionally, two new technologies will be trialled, the first an electric heat pump replacement for an ageing gas boiler, and the second an advanced indirect evaporative cooler.

LLHC1: QUT/AIRAH support the recommendations of the DEA and Australian Medical Association (AMA) for the establishment of a national Sustainable Healthcare Unit (SHU) as a formal national collaboration vehicle for healthcare. The SHU would incorporate clinical perspectives (DEA, AMA and medical colleges), hospital asset management perspectives (AHIA and private hospitals); aged care providers and/or overarching bodies, the air conditioning industry (AIRAH), the renewable energy industry (e.g., Clean Energy Council), NABERS, the Energy Efficiency Council (IEE), and academia.

The networking that has been developed through LLHC1 is significant, and it would be beneficial to find ways of continuing. The SHU could potentially be co-funded through the Department of Industry Science Energy and Resources (DISER), ARENA, AHIA and others

LLHC2: The University of Wollongong has been conducting research in collaboration with Warrigal for numerous years, investigating thermal comfort, energy efficiency, and occupant wellbeing. It is anticipated that this relationship will continue into the future generating further benefits from the Living Laboratory with the option of future technology providers to evaluate their products or services within the facility.

LLHC3 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.

LLHC4: 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/.

The LLS1 and LLHC1 Knowledge Sharing Taskgroups formed will continue as an engagement group for both sectors.

8.4 Future/Additional research areas

The following are some of the information gaps that have been identified during the i-Hub project, these may be suitable areas for further research.

8.4.1 Building Models

Development / Approval of hospital and aged care 'model' buildings for use for NCC code development and design development by stakeholders (for optimising building envelope, and for selection and sizing of HVAC systems and renewable energy systems).

8.4.2 Climate files

Comprehensive comparison of different future Typical Meteorological Year (TMY) climate files available, in terms of their respective usefulness for health facility modelling and HVAC and PV system sizing.

Development of 'extreme weather' files for Australian contexts, perhaps based on the methodology developed through the International Energy Agency's IEA Annex 80.

8.4.3 Electrification of heat loads

A decision-making framework and guidelines for heat pump technologies, in the move for electrification of heat loads

8.4.4 Demand response

A deeper investigation of energy assets in healthcare facilities that could be utilised for DR (for load shifting, load curtailment).

A guideline for DR participation by healthcare facilities.

8.4.5 HVAC&R

A procurement guideline for HVAC in aged care facilities.

8.4.6 Next-gen BMS

A decision-making framework and/or guideline relating to the use of Digital Twins and Artificial Intelligence in predictive maintenance, demand response and predictive control.

8.4.7 Data Platform

Investigation of the value of the Data Clearing House platform and associated apps, to enable better benchmarking and energy optimisation in healthcare facilities.

8.4.8 Ventilation Effectiveness

Further investigation of the decay rate of airborne particles in HVAC systems; and the effectiveness of alternative ventilation strategies. (LLHC 5 and LLHC4 – Technical Report highlight the energy impact of current pandemic mode ventilation strategies and raise questions about the effectiveness of these strategies on containing contamination spread in healthcare facilities.)

Appendix A Knowledge Sharing Technical Reports

This Appendix provides a List (and links) to all public reports produced by i-Hub.

Table 10: Data Clearing House (DCH) – Knowledge Sharing Technical Reports

Smart Building Data Clearing House - i-Hub (ihub.org.au) The Knowledge Hub - i-Hub (ihub.org.au)

Project	Report Title	Purpose	Summary	Links
DCH1 M4	Report on initial national demand response potential modelling	Results from the initial modelling - analysis of the potential demand response available to a DCH type platform	This report: i) Estimates the magnitude of short-term electricity demand response that could be achieved from air-conditioning across Australia's commercial and residential building stock. ii) Evaluates the location and timing of the DR potential, particularly to identify DR potential that is coincident with peak demand on a given network substation.	Link
DCH1 M4	Knowledge sharing collateral produced for marketing the DCH 1.0 including: • DCH Videos • DCH user interface	Begin recruiting buildings by communicating the capability and availability of the system to potential DCH 1.0 users: building owners and managers	2 x User videos on DCH loaded onto i-Hub website.	Link
DCH1 M5	Technical Manual - DCH Integration Options	User information	Data Clearing House (DCH) supports ingestion of data from heterogeneous sources. Currently DCH provides three options for communicating with buildings. This document provides all necessary information to assist you with integrating your on-site hardware with DCH.	Link
DCH1 M6	API for DCH	Continue to attract new buildings and application developers	This document aims at detailing how app developers and users can acquire building model and timeseries data from DCH.	Link
DCH1 M6	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
DCH1 M7	DCH Product features Report	Knowledge sharing collateral produced for the DCH May 2022 release to communicate the capability and availability of the system to potential DCH users: building owners and managers	This document provides details of Data Clearing House digital platform features and functionalities, available through the release version May 2022. The document starts with a summary of DCH users and their expectations of the platform. Details of unique functionalities of the platform have been described. A summary of DCH features is provided for easy reference.	Link

DCH1 M7	Report: Assessment of Demand Response Potentials in Australian Non-Residential Buildings	Results from the final modelling - analysis of the national potential demand response available to a DCH 2.0 type platform	This report addresses the following questions: 1. To what extent can adjustment to building operating parameters contribute to demand response application in two reference building types.2. How the demand response potential varies by time of day, season, and climate zone. More specifically, the report looks at - • assessing demand response potential of Australian non-residential buildings (e.g., schools and offices) in response to 2°C thermostat setpoint adjustment. • estimating state-wide cooling electricity demand and DR potentials from school and office buildings for different temperature and hour of the day bands.	Link
DCH1 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	Provides an overview of the entire project including project analysis and evaluation, the challenges experienced and what might come next in terms of future work.	Link
DCH 2 M4	Report - Learnings from the use of FDD, Analytics and Demand Response Applications in the 3 trial buildings (hosted on the Digital Layer software platform DCH 1.0)	To inform DCH stage 2 development report, incorporating user feedback on the software	The purpose of this document is to expand on the technical details of the project, enabling stakeholders to gain a more detailed understanding of the project architecture and the various technologies that contribute. The Data Clearing House is built using IP from the Switch market-tested Digital Layer. We also introduce the concept of the Marketplace which enables the vision to expand this project to an entire ecosystem of application providers and we describe how the Switch Gateway is a technical enabler to get real-time IoT data, telemetry and control capability.	Link
DCH 2 M4	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
DCH2 M4	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub DCH2 – Data Clearing House sub-project.	Link
DCH3 M7	Technical Report: scope and boundaries of the analysis, external factors and limitations, clear utilisation pathway for other asset owners.	Report will provide clear guidance on the business case for alternative operating strategy(s) for the available energy and load assets, in terms of financial, life-cycle and environmental benefits (including the effects of bio-gas	This project seeks to understand how existing gas fired generation assets can operate in sync with on-site renewable generation and energy consumption to maximise life-cycle and environmental benefits while also providing useful support services to the grid. A business case for utilising and extending the lift of the existing gas engines as a demand response resource was prepared for the Collins Square site and extrapolated to verify the feasibility for other sites. The Data Clearing House was used to integrate the diverse data sources from discrete systems to enable the optimisation and analysis to be undertaken. Once collated on DCH, that data was fed into a purpose-built model to test the strategies and algorithms for a demand response operation in conjunction with HVAC and on-site PV.	Link

		as a fuel switching alternative).		
DCH3 M7	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
DCH3 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	Provides an overview of the entire project including project analysis and evaluation, the challenges experienced and what might come next in terms of future work.	Link
DCH4 M6	DCH integration and standardisation report.	The first key project task is to define data flows, preferred methodologies, standardisation and normalisation techniques. The project will test the various methodologies for data ingestions and this report describes the preferred processes identified, works undertaken and the outcomes.	Report on integration and standardisation of the onboarding process. Onboarding is the process of linking data sources from buildings/sites to the DCH cloud data platform, including building structure and layout information and buildings operations data from building energy systems, equipment, sensors, and actuators. Onboarding enables the DCH to federate data from a range of disparate building data sources and exploit the value-add features of the DCH4, such as the Building Services Layer that facilitates discovery and searchability of data, and end-use applications enabled by the DCH. Describes the four stages that onboarding the DCH4 buildings involves.	Link
DCH4 M6	Energy baselining technical report.	Reports the Historic and ongoing data collection from two sites and the ongoing monitoring and verification	One of the intents of the PNSW project is to enable PNSW to compare energy performance across its portfolio to improve operational energy efficiency and to identify energy related opportunities such as solar, battery and demand management and demand response opportunities. Historic and ongoing data collection from two sites (Prince Albert street, Lithgow) and how this data has been used to study the electrical energy use behaviour of these sites. Only site level energy use data has been used for this study.	Link
DCH4 M6	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
DCH4 M7	Stakeholder consultation and IoT forward plan report PNSW	Report draws together experiences of all stakeholders, from suppliers, CSIRO, IOT system users and third-party	Following the implementation and use of the IOT and DCH systems the stakeholder consultation and IoT forward plan report draws together experiences of all stakeholders, from suppliers, CSIRO, IOT system users and third-party integrators. This report summarises the project and presents the benefits of the project, describes where results differed from those expected and outlines, based on these results, the plan for the system going forward.	Link

		integrators and present the benefits.		
DCH4 M7	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
DCH4 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	Provides an overview of the entire project including project analysis and evaluation, the challenges experienced and what might come next in terms of future work.	Link
DCH5 M6	DCH5 Intermediate technical report	Intermediate technical report on the completion of the modelling, forecasting and data monitoring system installation.	This report provides an overview on the OpenTDR framework used for transactive demand response and illustrate the progress made in milestone M6 by elaborating on the system configurations of the experimental validation setup. A more detailed insight on the multi-agent-based game theoretic OpenTDR energy management algorithm is provided in this report. Followed by which a detailed explanation on the custom data monitoring devices developed for occupancy and CO2/RH/Temp monitoring is provided. Finally, different market scenario simulations to evaluate the performance of the openTDR framework are explained and the plan for the integration of the OpenTDR framework data points to the DCH senaps.io platform is outlined.	Link
DCH5 M6	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
DCH5 M7	Final technical report	Final Report on the completion of the project	Project report including the real-time data monitoring system on 2 buildings at Swinburne University of Technology, experimental implementation of developed TDR as well as the development of TDR-APP	Link
DCH5 M7	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
DCH5 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub DCH5 – Data Clearing House sub-project.	Link
DCH6.1 M5	Battery sizing analysis for NSW schools: Nimbin, Jamison and Singleton High	Detail the Battery sizing analysis for NSW schools:	This report describes modelling to calculate the annual electricity cost savings from installation of lithium ion battery storage systems in three NSW schools; Nimbin High School, Jamison High School, and Singleton High School. Each school has an existing solar photovoltaic system and approximately 1 year of electricity net export data was provided along with electricity tariff information for the analysis. Two different battery control strategies are compared alongside the base case (no battery storage system).	Link
DCH6.1 M5	Lessons learnt Report	Details selected lessons learned during the	Documents specific lessons that were learned during the delivery of the sub-project	Link

		delivery of the sub-project		
DCH6.1 M7	Report on operational testing and evaluation of control systems in each of the 3 schools	Demonstrate the performance of the system and, by economic feasibility analysis, the potential for positive economic returns for SINSW, leading to roll out of stage 2.	The modelling demonstrated that HVAC controls without battery consistently returns the best benefit cost ratio (BCR) for all three sites, of above 2x BCR. These results mirror the preliminary modelling work, undertaken prior to procurement of the batteries and additional solar PV on the three school sites covered in this report. By comparison, the modelled business case for battery storage systems for the purpose of energy arbitrage show a lower financial return, although this is improved by utilising batteries within the FCAS market (and wholesale spot pricing). The scenario with larger solar PV, without batteries or controls and using retail energy accounts, was also notable, showing an impressive BCR in its own right for two of the sites.	Link
DCH6.1 M7	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
DCH6.1 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub DCH6.1 – Data Clearing House sub-project.	Link
DCH7 M6	PV analytics and energy analytics applications development report	Detailing of application development and alignment to targeted outcomes.	This report details the development of applications deployed in the i-Hub sub project DCH7. The applications developed for this project focuses on PV analytics and Energy analytics for use across 5 City of Melbourne facilities connected to the i-HUB Data Clearing House (DCH). The report provides details on the methodology used to develop the applications, data points which will be retrieved from DCH along with the data techniques used to model each building.	Link 1 Link 2 Link 3
DCH7 M6	Building data models including VBIS tagging for 2 buildings report	Detailing of practical building modelling and connection of building model data to DCH for third party ingestion	This report focusses on the creation of the first two semantic building models for the DCH7 project by the CSIRO. These buildings are the Lady Huntingfield Early Learning and Family Services Centre and the Boyd School / community hub building. The semantic model schema used in DCH is an extension of the BRICK schema. This project has a particular focus on incorporating the VBIS tagging information into these BRICK models to allow applications access to more detailed information of the assets in buildings. The following sections discusses the processes for constructing the models for these two sites.	Link
DCH7 M6	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
DCH7 M7	Application implementation in trial buildings report	Details deployment and adoption of applications as applicable to trial buildings, challenges, and strategies to overcome.	This report covers semantic model creation, data onboarding, and application development as well as possible next steps. The report also provides details on how the deployed applications Improve the reliability of onsite PV generation through deployed PV system and HVAC analytics applications linked with DCH. Eight (8) applications have also been developed that can be mass deployable for repeatable results.	Link

DCH7 M7	Demonstration video	Showcase the project and technologies	Demonstration video highlighting connected buildings, expected outcomes and deployed applications.	Link
DCH7 M7	Use case results report	Case study detailing project objectives and client outcomes achieved using DCH, VBIS standard and PrediQ applications.	This report covers semantic model creation, data onboarding, and application development as well as possible next steps. The report also provides details on how the deployed applications Improve the reliability of onsite PV generation through deployed PV system and HVAC analytics applications linked with DCH. Eight (8) applications have also been developed that can be mass deployable for repeatable results.	Link
DCH7 M7	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
DCH7 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub DCH7 – Data Clearing House sub-project.	Link
DCH8 M7	Final performance outcomes report (CSIRO)	Deployment and adoption of application as applicable to trial building.	CSIRO Synergy Building Preliminary M&V Report	Link
DCH8 M7	Knowledge sharing collateral (Exergenics)	Case study material detailing project objectives and client outcomes achieved through the use of DCH and PlantScore™ application.	Case study on the application of the Exergenics chiller app to the CSIRO Synergy Building.	Link
DCH8 M7	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
DCH8 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub DCH8 – Data Clearing House sub-project.	Link
DCH9 M7	DCH at Scale: On-boarding proof-of concept at a Queensland Hospital Site – Final project Report	Report documenting overall project	Report documenting overall project delivery including- Building Data Model DCH on-boarding workflow automation Business Case REETSEF reporting requirements and other user stories	Link
DCH9 M7	Lessons learnt Report	Details selected lessons learned during the	Documents specific lessons that were learned during the delivery of the sub-project	Link

		delivery of the sub-project		
DCH9 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub DCH9 – Data Clearing House sub-project.	Link
DCH10 M7	Report on Onboarding process (CDU)	Report documenting Onboarding process for old and new buildings in the Darwin region	This short report provides an overview of onboarding process for DCH10, which included the following objective - Onboard three buildings in Darwin region (two from Charles Darwin University (CDU) and one from City of Darwin (COD)) to the Data Clearing House (DCH) and record the onboarding experience.	Link
DCH10 M7	Knowledge sharing report - Energy use reduction, improving value of onsite generation (CDU/DLL)	Report documenting (1) Energy use analysis of pilot buildings to inform net zero pathway for these buildings (2) insights on parameters such as HVAC energy use and PV generation.	This report provides an overview regarding the energy simulation of the two buildings (Blue1 and Pink 9) at Charles Darwin University which have been considered as case studies for this project. These buildings have been onboarded to the DCH digital platform.	Link
DCH10 M7	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
DCH10 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub DCH10 – Data Clearing House sub-project.	Link

Table 11: Integrated Design Studios – Knowledge Sharing Technical Reports

[Integrated Design Studios - i-Hub (ihub.org.au)](#) [The Knowledge Hub - i-Hub (ihub.org.au)](#)

Project	Report Title	Purpose	Summary	Links
IDS01 M3	Documented IDS design process.	Provide a standardised framework where IDS can be delivered across multiple building topologies	This Guide documents a standardised framework where IDS can be delivered across multiple building topologies	Link
IDS01 M4	Studio Report	Technical Report articulating the nature of the innovations, the overall building solutions and the insights gained into the IDS processes, barriers and solutions	This report summarises all findings taken from IDS01. The fifteen design solutions presented highlight the breadth of opportunities in the design of Data Centres, in particular when stepping away from a purely functional, and construction-cost optimised design. Selected key ideas that emerged were: • Incorporation of renewable energy. • Capture and recycling of waste energy through adjacent symbiotic uses (Aquatic centres and greenhouses for example). • Incorporation of modular construction • Incorporation of self-building/updating mechanisms (gantry cranes etc that when combined with modular philosophies facilitate expansion or updating of technologies).	Link
IDS01 M4	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
IDS01 M4	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub IDS01 – Integrated Design Studio sub-project. The case study building typology used for IDS-01 is Data Centres. The rapid and continuing growth of the ICT industry means that data centres will be one of the worlds large energy users in the future. Significant opportunities exist for building strategies involving energy capture, generation (through renewables), and waste heat recovery	Link
IDS02 M4	Updated IDS design process.	Provide an update of framework where IDS can be delivered across multiple building topologies	This Updated Guide documents a standardised framework where IDS can be delivered across multiple building topologies	Link
IDS02 M4	Studio Report	Technical Report articulating the nature of the innovations, the overall building solutions and the insights	This report summarises all findings taken from IDS-02. The eleven design solutions highlight the breadth of opportunities in the design and refurbishment of School projects in the ACT climate. Design proposals embraced different aspects of environmental design both indoor, as well as outdoor, and they addressed these on refurbishment elements, as well as newly built components of the design. Moving from a standard practice existing building to incorporating best practice initiatives results in Energy Use Intensities	Link

		gained into the IDS processes, barriers and solutions	less than 40kWh/m2.yr, with reductions in energy demand ~58% and energy consumption >52%.	
IDS02 M4	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
IDS02 M4	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub IDS02 – Integrated Design Studio sub-project. Schools and the education sector represent almost 30% of all non-residential floor area in the built environment. As such any gains in renewables use and zero carbon initiatives able to be implemented in this typology will have significant impact. The studio brief included both refurbishment and new build components. Outcomes for industry include practical insight into how to enable integrated design in practice, along with design ideas and assessments of the potential for renewables and other zero carbon enabling initiatives on schools as a building.	Link
IDS03 M5	Studio Report	Technical Report articulating the nature of the innovations, the overall building solutions and the insights gained into the IDS processes, barriers and solutions	The IDS-03 ACT Schools Integrated Design Studio investigated design innovations to reduce net energy consumption through the use of renewables and other energy technologies. The results of the modelling indicated that by using a combination of building fabric improvements through increased insulation and improved performance glazing as well as updated efficient electric HVAC services and internal lighting the building energy use intensity can be reduced significantly.	Link
IDS03 M5	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
IDS03 M5	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub IDS03 – ACT Schools Integrated Design Studio sub-project. The following strategies were recommended: • Reduce the energy being used by improving building fabric performance and services. • Switch the energy fuel source by removing gas appliances and switching to electricity. • Add on-site renewables to offset the electrical energy demand. • Use carbon off sets or off-site renewables to offset the remaining energy demand.	Link
IDS04 M5	Studio Report	Technical Report articulating the nature of the innovations, the	The case study building typology used for IDS-04 is an Ambulance station. The design of this type of facility has a substantial impact on the environment due to the sheer number of stations existing across Victoria and beyond. Key systems which offered the greatest benefits include:	Link

		overall building solutions and the insights gained into the IDS processes, barriers and solutions	• Optimised Passive Solar principles for winter heating and summer control. • High-performance building fabric through enhanced U-values of the building fabric • Reduction in thermal bridging and airtightness construction quality Assurance • Mechanical ventilation with heat recovery for energy saving benefit in addition to other indoor environmental • quality and health benefits. • Photovoltaic panels were consistently applied across projects for on-site renewable energy generation. • • Selection of materials which minimise the impact of embodied carbon across the development.	
IDS04 M5	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
IDS04 M5	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub IDS04 – Integrated Design Studio sub-project. Zero carbon design was found to be possible for emergency response facilities along similar lines to the schools building typology. This was achieved through a combination of energy consumption (EUI) reduction (envelope, orientation, use of heat pumps etc.), and provision of locally generated renewable energy (typically solar PVs).	Link
IDS05 M5	Studio Report	Technical Report articulating the nature of the innovations, the overall building solutions and the insights gained into the IDS processes, barriers and solutions	Within this Aquatic Centre IDS, the key carbon reduction techniques included: • Part naturally heated outdoor pool • Solar PV Panels. Solar PV as shade structures. • Hydro botanic filter pond. • Piezoelectric Pad • Timber Structure (more rapidly renewable) • Polycarbonate Façade with a weaving texture of 60% opaque and 40% opaque sheets. • LED lighting. • Rainwater Harvesting. • Electric heat Pump. • Hydro-botanic filter pond. • Microinverter technology to harvest energy from gym equipment. • Piezoelectric energy system harvesting energy from foot traffic.	Link
IDS05 M5	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
IDS5 M5	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub IDS05 – Integrated Design Studio sub-project. Approximately one dozen individual Aquatic Centre projects were worked on as part of IDS-05, with each investigating novel concepts. The IDS resulted in 12 highly innovative noteworthy projects where both passive and active solutions were applied to address Net Zero goals.	Link

IDS06 M7	Studio Report	Technical Report articulating the nature of the innovations, the overall building solutions and the insights gained into the IDS processes, barriers and solutions	The case study building typology used for IDS-06 is Transport Buildings (Stations). Transport buildings operate in particularly demanding public environments. Issues of public realm and security means many of the functions are required 24/7 and during periods when staff are not occupying the buildings. As a result, energy consumption can be twice that of other public buildings. They are also usually fully integrated into the planning of the infrastructure networks they service and have evolved to hubs for commerce, retail and recreation often making the projects important focal points for local or regional regeneration. Their design as a result differs from most buildings in that the lead roles are more usually filled by engineers than architects. This arrangement made them particularly interesting in gaining insight into relations between the architects and engineers from different perspectives.	Link
IDS06 M7	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
IDS06 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub IDS06 – Integrated Design Studio sub-project.	Link
IDS07 M6	Studio Report	Technical Report articulating the nature of the innovations, the overall building solutions and the insights gained into the IDS processes, barriers and solutions	The case study building typology used for IDS-07 is aged care facilities. Work in the studio was able to show that energy savings of up to 60-70% could be achieved. This is especially significant considering the energy intensive typology which is inherent to aged-care homes. Key systems which were common across the studio which held the greatest benefits include: • Optimised Passive Solar principles for winter heating and summer control. • High-performance building fabric through reduced U- values of the building fabric • Reduction in thermal bridging and airtightness construction quality Assurance • Mechanical ventilation with heat recovery for energy saving benefit in addition to other indoor environmental quality and health benefits. • Photovoltaic panels were consistently applied across projects for on-site renewable energy generation. Selection of materials which minimise the impact of embodied carbon across the development.	Link
IDS07 M6	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
IDS07 M6	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub IDS06 – Integrated Design Studio sub-project. Energy savings strategies (through both improved efficiency and on-site generation) delivering up to 60-70% compared with business as usual (BAU) were identified as a part of this studio.	Link

IDS08 M7	Studio Report	Technical Report articulating the nature of the innovations, the overall building solutions and the insights gained into the IDS processes, barriers and solutions	The case study building typology used for IDS-08 is laboratory facilities. Laboratory and technical buildings are key infrastructure components in supporting knowledge economies. Viewed as industrial and highly function driven buildings, laboratories often give design aspects such as energy performance and sustainability a low priority, this is despite typically using as much as five times as much energy and water per sqm as a typical office building. In many cases this is deserved given the strict performance requirements around the spaces being provided, in many instances however it is not.	Link
IDS08 M7	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
IDS08 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub IDS08 – Integrated Design Studio sub-project.	Link
IDS09 M7	Studio Report	Technical Report articulating the nature of the innovations, the overall building solutions and the insights gained into the IDS processes, barriers and solutions	The IDS-09 Lightning Ridge Local Aboriginal Land Council (LALC) Multi-Purpose Building Integrated Design Studio investigates design innovation to reduce net energy consumption of a proposed multi-purpose community centre to be constructed in central Lightning Ridge, to be owned and operated by the Lightning Ridge Local Aboriginal Land Council (LRLALC). The team worked collaboratively to develop several design proposals for the client (The Dr. Steve Burroughs Foundation) who is acting on behalf of the LRLALC. These designs are conscious of the land councils concern towards environmental impact and energy usage, while also promoting inclusion within the community of Lightning Ridge and incorporating indigenous design principles.	Link
IDS09 M7	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
IDS09 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub IDS09 – Integrated Design Studio sub-project.	Link
IDS 10 M6	Studio Report	Technical Report articulating the nature of the innovations, the overall building solutions and the insights gained into the IDS processes,	The IDS10 Lendlease Residential Aged Care Integrated Design Studio investigated design innovations to reduce energy consumption of Lendlease's soon to be constructed residential aged care facility on the University of Wollongong's Health and Wellbeing Precinct. Passive design measures included • Natural and mixed mode ventilation • Improved glazing (e.g., double glazing) to reduce thermal gains • Interior green wall • Exterior and interior shading	Link

		barriers and solutions	• Consideration of thermal mass to equilibrate IEQ • Additional insulative materials within the building envelope (e.g., walls, roofs, etc.) Active design measures included • High efficiency HVAC systems • Energy Recovery Ventilation (ERV) • Additional PV systems • Efficient appliances • Building Management System (BMS) • Phase Change Materials (PCM) Temperature set point control and thermal zoning	
IDS 10 M6	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
IDS10 M6	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub IDS10 – Integrated Design Studio sub-project. Solutions investigated found that a 25% reduction is possible. These reductions were primarily due to passive strategies, though active strategies were still found to contribute to this overall reduction. The following strategies were recommended: • Reduction in net energy consumption through improvements to building fabric • Installation of ERV to reduce energy loss via ventilation • Inclusion of additional PV systems to offset energy consumption Operative systems reliant on electricity rather than gas to reduce carbon emissions	Link
IDS11 M6	Studio Report	Technical Report articulating the nature of the innovations, the overall building solutions and the insights gained into the IDS processes, barriers and solutions	The IDS-11 Wollongong City Council Ribbonwood Community Centre Integrated Design Studio investigates design innovation to reduce net energy consumption of Wollongong City Council (WCC) soon to be renovated Ribbonwood Community Centre in Dapto. Passive design measures included: • Improved glazing (e.g., double glazing) to reduce thermal gains • Window film to reduce solar gains • Additional window mesh to reduce solar gains • Additional insulative materials within the building envelope (e.g., walls, roofs, etc.) • Improved natural lighting • Passive shading (e.g., addition of louvers) • Green walls/Green façade • Improved airtightness to minimise air-changes Active design measures included: • Reduce lighting energy consumption (e.g., install LED's) • Increased size of active PV system • PDLC window film (activated via electric current) • Installation of a buffer tank to regulate internal comfort conditions • Phase Change Materials (i.e., thermal storage) • Solar Heating • PV windows (windows with embedded PV panels which permit light intrusion) • HVAC upgrades	Link 1 Link 2

IDS11 M6	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
IDS11 M6	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub IDS11 – Integrated Design Studio sub-project. A reduction in energy consumption and emissions was found to be possible for the retrofitted design of the Ribbonwood Community Centre, which is in keeping with the desires of Wollongong City Council, to achieve net zero emissions by 2030. Solutions investigated by the students were shown to successfully reduce energy consumption, with the consultant vetting report confirming that a saving between 25-30% is possible. These reductions were primarily due to passive and active strategies, with some being due to energy offsets due to the addition of more PV systems. The following strategies were recommended: • Reduction in net energy consumption through improvements to building fabric • Additional maintenance, cleaning and commissioning of existing HVAC to improve system efficiency • Installation of ERV to reduce energy loss via ventilation • Operational upgrades to reduce energy usage in unoccupied zones, or limiting energy expenditure to public areas • Inclusion of additional PV systems to offset energy consumption	Link
IDS12 M7	Studio Report	Technical Report articulating the nature of the innovations, the overall building solutions and the insights gained into the IDS processes, barriers and solutions	The IDS-12 Illawarra Local Aboriginal Land Council (LALC) Former Unanderra Police Station Redevelopment Integrated Design Studio investigates design innovation to reduce net energy consumption of a proposed redevelopment of the former police station located in Unanderra. The team worked collaboratively to develop several proposed designs for the client (the Illawarra Local Aboriginal Land Council). These designs are conscious of the land councils concern of environmental impact and energy usage, while also providing residential or retail opportunities for members of the surrounding community. The proposed redevelopment will be an ongoing asset for the land council, providing opportunities to the surrounding community and supply an ongoing revenue stream to assist with other new and ongoing community initiatives organised by the land council.	Link
IDS12 M7	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
IDS12 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub ID12 – Integrated Design Studio sub-project.	Link
IDS13 (inc. IDS14) M7	Studio Report	Technical Report articulating the nature of the innovations, the overall building	This project implemented and evaluated a range of strategies to enhance integrated design aspects within the design of mixed-use building typologies in subtropical and tropical climates. It also fostered the development of design solutions that could reduce the carbon emissions of such buildings through reduced demand, HVAC controls and/or renewable energy and storage systems. The feasibility of some	Link

		solutions and the insights gained into the IDS processes, barriers and solutions	of these designs solutions has been evaluated for demand reduction, renewable energy contribution and other benefits. The key messages, from these designs and evaluations, are outlined in this report.	
IDS14 (inc. IDS13) M7	Studio Report	Technical Report articulating the nature of the innovations, the overall building solutions and the insights gained into the IDS processes, barriers and solutions	This project implemented and evaluated a range of strategies to enhance integrated design aspects within the design of mixed-use building typologies in subtropical and tropical climates. It also fostered the development of design solutions that could reduce the carbon emissions of such buildings through reduced demand, HVAC controls and/or renewable energy and storage systems. The feasibility of some of these designs solutions has been evaluated for demand reduction, renewable energy contribution and other benefits. The key messages, from these designs and evaluations, are outlined in this report.	Link
IDS14 (inc. IDS13) M7	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
IDS14 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report publicly shares the technical content, the lessons learned and the final results and findings for i-Hub IDS14 – Integrated Design Studio sub-project.	Link
IDSKS M5 M7	Updated IDS design process.	Provide an update of framework for the IDS process	Catalyst for Integrated Design outlines the principles of integrated design that were uncovered through interrogating literature and the subsequent testing in design environments fell into four categories: - Client - Procurement and Planning - Culture Setting - Design Process Version 5.1	Link
IDSKS M7	Report on combined IDS outcomes and learnings	Cross programme report on combined IDS outcomes and learnings including recommendations for future work	This summary report consolidates all findings taken from Integrated Design Studio (IDS) program undertaken by the University of Melbourne, the University of Wollongong and the Queensland University of Technology. The studios within the IDS program provided broad coverage of the built environment gaining insights into the challenges and opportunities in nine different building typologies:	Link
IDSKS M7	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
IDSKS M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	This report summarises the full i-Hub Integrated Design Studios (IDS) Activity Stream. It is intended to be a first/main point of contact with the overall IDS activity stream, providing high level summaries of outcomes etc., and	Link

			importantly acting as a knowledge sharing road map providing links to the key reports and documents produced across the 14 studios undertaken.	

Table 12: Living Labs – Knowledge Sharing Technical Reports

[Living Laboratories - Green Proving Grounds - i-Hub (ihub.org.au)](#) [The Knowledge Hub - i-Hub (ihub.org.au)](#)

Project	Report Title	Purpose	Summary	Links
LLHC1 M3	Renewable Energy and Enabling Technology and Services Evaluation Frameworks for Healthcare (REETSEF).	Provide Healthcare sector with sector-wide analysis and framework for HealthCare Living Labs (i.e., Living Lab operation Guidelines)	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 upgrades. This report should be read in conjunction with the complementary report: Living Labs Healthcare Sector Baselines and Key Performance Indicators.	Link
LLHC1 M3	Technical Report: Sector Baseline Data and KPIs	Baseline data enables quantification of technology impact at a building level and extrapolation of sector wide impact	The aim of this report is to collate a range of existing energy key performance indicators (KPIs) and data for the healthcare sector domestically and internationally, in order to better understand (and hence manage) energy use and greenhouse gas emissions. The report reviews published literature, such as government and sector reports, industry papers and academic publications, collating and evaluating healthcare sector related key performance indicators (KPIs). The existing KPIs are evaluated in terms of their effectiveness in enabling renewable energy or energy storage; improving energy efficiency or productivity; reducing peak demand; and managing energy demand. Recommendations of how to select KPIs are provided at the end of the report.	Link
LLHC1 M5	Healthcare Sector: Examination of the potential to align health and energy co-benefits	Enhanced industry understanding of links between energy and health, improving the value proposition for energy efficiency / renewable energy	This report collates existing literature on the role of indoor environmental control in the health and well-being (and hence care plan) for occupants of Health Care facilities (HCFs) and extrapolates the implications for energy demand and resilience of HCFs. It proposes health-outcomes related KPIs for energy projects in the healthcare sector, using a systems-thinking approach for the evaluation of energy efficiency, demand management and renewable energy projects. It is hoped that a broader set of KPIs can help build a sound business case for energy efficiency and renewable energy projects in HCFs. The specific aim of this report is to move towards the (potential) development of new key performance indicators (KPIs) and metrics that link building services and energy performance (especially peak demand, renewable energy and resilience) to core health services (i.e., healthcare plans for occupants/patients).	Link
LLHC1 M7	Renewable Energy and Enabling Technologies and Services Roadmap for Healthcare	Roadmap can be utilised by healthcare sector in their policy and procedure processes and decisions regarding energy contracts, building design	This Renewable Energy and Enabling Technologies Roadmap for Healthcare is presented in the form of a practical guide to assist organisations to develop a bespoke renewable energy and enabling technologies and services implementation plan for individual healthcare buildings (that may also be part of a portfolio of assets). This plan – focusing on stationary energy use and supply in healthcare facilities - can be one part of a larger NZCE strategy that would also need to tackle emissions from non-energy sources (e.g., supplies, pharmaceuticals, waste). Healthcare facilities, for the purposes of this report, are defined as hospitals and aged care facilities. The strategies contained in this document could also be adapted to other types of healthcare facilities, such as general	Link

		and operation, and renewable energy investments	practice surgeries, allied health practices, day surgeries, pharmacies, independent living units etc. The roadmap consists of two parts: establishment of the framework (through which the plan will be actioned), and examination of the energy system options.	
LLHC1 M7	Lessons learnt Report	Details selected lessons learned	Documents specific lessons that were learned during the delivery of the sub-project	Link
LLHC1 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	Provides an overview of the entire project including project analysis and evaluation, the challenges experienced and what might come next in terms of future work.	Link
LLHC2 M3	Warrigal Living Lab - Prospectus and Manual	Companies are aware of the potential testing mechanisms and opportunities in this LL. Industry can prepare EOIs for testing.	A 'Living laboratory' is a user-centred open-innovation, ecosystem within collaborative partnerships. The Warrigal Shell Cove i-Hub Living Laboratory establishes research-quality measurement and verification systems within an existing aged care facility, HVAC services and occupants in order to observe and evaluate technology upgrades within the context of the daily life of the aged care ecosystem.	Link
LLHC2 M4	Technical Report: Warrigal Residential Care Home Living Laboratory Monitoring and Baseline Data Analysis	Stakeholders have an initial benchmarking framework.	This Technical Report details the as-installed monitoring and evaluation capabilities implemented in the Warrigal Residential Care Home to meet the requirements of the i-Hub Healthcare Renewable Energy and Enabling Technology Evaluation Framework, as well as an initial baseline data analysis, to demonstrate available data sources and analysis techniques.	Link
LLHC2 M5	Technical Report: Warrigal LL Operations Manual (REETSEF), and Baseline Data Analysed	Operations Manual (REETSEF) completed; Comprehensive baseline data acquired. Stakeholders have a detailed benchmarking framework.	The i-Hub Healthcare Living Laboratories: Warrigal Operations Manual outlines the monitoring and evaluation techniques implemented in the Warrigal living laboratory facility to meet the requirements of the i-Hub Healthcare Renewable Energy and Enabling Technology Evaluation Framework.	Link
LLHC2 M6	Technology Evaluation Report	Flow Power Electricity Spot Price Trading	Trial is to evaluate the overall electricity cost savings potential for Warrigal Shell Cove living laboratory for Flow Power's pure wholesale pass-through product compared to the existing conventional electricity agreement. The evaluation compares the electricity supply costs without any demand response control action. The evaluation must consider the relative costs over a period that adequately represents the wholesale market volatility. A separate evaluation is conducted to evaluate the cost savings of the combination of the wholesale market agreement and the active demand flexibility controls implemented by DNA Energy.	Link

LLHC2 M7	Technology Evaluation Report	DNA Energy: HVAC Demand Response	DNA Energy's Demand Response Mode (DRM/DRED) HVAC control technology was evaluated at the Warrigal Living Laboratory. The evaluation explored the use of DNA Energy's DRM technology to reduce energy consumption during 5-minute spot price peak intervals using several methods, and the impact of this on thermal conditions within the Warrigal facility. Additional evaluation was also undertaken of the potential value of providing services to the FCAS Fast and Slow Raise markets, with the key consideration being the reliable response time of the combination of DNA devices and the existing Mitsubishi VRFs. A key advantage of the DNA Energy HVAC demand response technology offering is the unique combination of wireless DRM controls being applied to the HVAC industry (where they are more typically being rolled out with grid-scale batteries at present) and having integrated market interfacing to both the wholesale spot price market and to FCAS Raise markets.	Link
LLHC2 M7	Lessons learnt Report	Details selected lessons learned	Documents specific lessons that were learned during the delivery of the sub-project	Link
LLHC2 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	Provides an overview of the entire project including project analysis and evaluation, the challenges experienced and what might come next in terms of future work.	Link
LLHC3 M3	Fernhill Living Lab - Prospectus and Manual	Companies are aware of the potential testing mechanisms and opportunities in this LL.	This prospectus provides basic information about Fernhill Residential Aged Care precinct and its energy use. The manual outlines the processes that will be followed in operating the Living Laboratory at Fernhill Residential Aged Care. Technology providers are advised to read this manual carefully to understand whether this facility is a suitable avenue for testing of their technology.	Link
LLHC3 M4	Technical Report: Fernhill LL Monitoring and Initial Baseline Data Analysis	Stakeholders have an initial benchmarking framework.	This report includes baseline energy performance data for the Fernhill Residential Aged Care facility in Caboolture. After providing a brief international and national context, it reports historical energy use from the existing buildings (hostels and nursing home) plus expected energy use of the new building (a multi-storey modern residential aged care facility that replaces the existing buildings).	Link
LLHC3 M4	Technical Report: Fernhill LL Operations Manual (REETSEF), and Baseline Data Analysed	Operations Manual (REETSEF) completed; Comprehensive baseline data acquired. Stakeholders have a detailed benchmarking framework.	This report includes baseline energy performance data for the Fernhill Residential Aged Care facility in Caboolture. After providing a brief international and national context, it reports historical energy use from the existing buildings (hostels and nursing home) plus expected energy use of the new building (a multi-storey modern residential aged care facility that replaces the existing buildings).	Link
LLHC3 M5	Technology Evaluation Report	Synengco HVAC Plant Digital Twin	A main component of the HVAC system at Fernhill is a chiller system of 3 chillers. Fernhill's HVAC plant and building information was modelled with Sentient System to build a precise digital twin of Fernhill's HVAC plant. This digital twin allowed monitoring the chiller performance compared to its design, predicting the plant performance via machine learning, and identifying control	Link

			improvement opportunities that can reduce energy consumption. This report focuses on building the digital twin and comparing the design to actual data. The trial uses weekly live data to keep training the model via machine learning over a six-month period to predict and optimise the plant performance.	
LLHC3 M6	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 reduces the thermal transmittance and solar heat gain through windows. Honeycomb blinds can help reduce heat gain/loss when operated correctly, they can keep internal spaces warm in winter and cool in summer, which leads to enhancing thermal comfort while reducing heating and cooling energy loads. 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 weather scenarios.	Link
LLHC3 M7	Lessons learnt Report	Details selected lessons learned	Documents specific lessons that were learned during the delivery of the sub-project	Link
LLHC3 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	Provides an overview of the entire project including project analysis and evaluation, the challenges experienced and what might come next in terms of future work.	Link
LLHC4 M3	Queensland Children's Hospital (QCH) Living Lab - Prospectus and Manual	Companies are aware of the potential testing mechanisms and opportunities in this LL. Industry can prepare EOIs for testing.	This prospectus provides basic information Queensland Children's Hospital precinct and its energy use. The manual outlines the processes that will be followed in operating the Living Laboratory at Queensland Children's Hospital. Technology providers are advised to read this manual carefully to understand whether this facility is a suitable avenue for testing of their technology.	Link
LLHC4 M3	Technical Report: Queensland Children's Hospital (QCH) LL Monitoring and Initial Baseline Data Analysis	Stakeholders have an initial benchmarking framework.	This report includes baseline energy performance data for the Queensland Children's Hospital precinct. It reports energy use in February 2020, detailed analysis of 2019 energy use, and historical trends (since Feb 2018)	Link
LLHC4 M4	Technical Report: Queensland Children's Hospital (QCH) LL Operations Manual (REETSEF),	Operations Manual (REETSEF) completed; Comprehensive baseline data acquired. Stakeholders have a detailed	This updated report includes baseline energy performance data for the Queensland Children's Hospital precinct. The prospectus provides basic information Queensland Children's Hospital precinct and its energy use. The manual outlines the processes that will be followed in operating the Living Laboratory at Queensland Children's Hospital.	Link

	and Baseline Data Analysed	benchmarking framework.		
LLHC4 M5	Technology Evaluation Report	Exergenics: Stage 1 digital twin for QCH chiller primary system optimisation	A main component of the HVAC system at QCH is a chiller system of 6 chillers. Through the operation optimisation of the chiller system, energy use and peak demand can potentially be reduced as well as providing controlling operational cost and limiting impact to the electricity network. This report details the trial of Exergenics' chiller system optimisation technology (PlantScore^{TM}) to the QCH chiller systems.	Link
LLHC4 M7	Technology Evaluation Report	GMG Thermal-XR Coating System – Graphene coating for refrigeration condenser units	GMG Thermal-XR graphene painting is designed to help protect a corroded coil with a thermally conductive coating and restore its heat exchange efficiency. The in-situ performance improvement of Thermal-XR on QCH outdoor condensers has been quantified in this report. The Thermal-XR process of preparing, activating, coating and then maintaining the heat exchange surface of condenser coils was evaluated to quantify energy savings and assess long-term corrosion protection.	Link
LLHC4 M7	Technology Evaluation Report	Exergenics: Stage 2 optimised chiller staging	This evaluation is a second stage evaluation of Exergenics digital twin and chiller optimisation at Queensland Children's Hospital Living Lab. For this stage, QCH's chiller system staging sequence is optimised to save energy, reduce emissions, improve resilience to climate change, and help futureproof our healthcare provision. The optimised chiller system staging created an energy saving of 24,000 kWh and emission reduction of 19 tonnes of CO2 in the project test period. The projected annual energy reduction is 187 MWh with a reduction of 150 tonnes CO2 emissions and an annual bill savings of $28,000. The simple payback period of the technology implementation is 1.5 years.	Link
LLHC4 M7	Technology Evaluation Report	Buildings Alive Rapid Efficiency Feedback technology	Buildings Alive's Rapid Efficiency Feedback (REF) package was implemented at Centre for Children's Health Research building (CCHR) within QCH precinct. The aim of REF is to enable site personnel to make changes to achieve energy and financial savings through regular feedback and continuous improvement in building performance. The outcomes of the project included establishment of energy baseline, identification of performance improvement opportunities and detection of data anomalies.	Link
LLHC4 M7	Technical Report – Analysis of Future Energy Use QCH	The technical report is evaluating a set of circumstances, and their impact on HVAC and future energy use on Queensland Children's Hospital (and hence the healthcare sector more broadly).	In this technical report four issues are evaluated for impact on hospital energy use: future climates; hospital electrification (space heating); ventilation effectiveness for aerosol distribution; and changes to the Australian Standards for sterilisation. This technical report is evaluating a set of circumstances, and their impact on HVAC and future energy use on Queensland Children's Hospital (and hence the healthcare sector more broadly). Key findings: 1. As the climate changes, 1°C temperature increase may lead to 2MWh electricity use increase per day). 2. In the business-as-usual scenario, the period 2040 and 2060 (i.e., 2050 climate file) will typically use about 5% more energy every year compared to 2021. 3. In the business-as-usual scenario, 20 years between 2080 and 2100 (2090 climate file) will typically use about 13% more energy every year compared to 2021.	Link

LLHC4 M7	Lessons learnt Report	Details selected lessons learned	Documents specific lessons that were learned during the delivery of the sub-project	Link
LLHC4 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	Provides an overview of the entire project including project analysis and evaluation, the challenges experienced and what might come next in terms of future work.	Link
LLHC5 M7	Healthcare Living Laboratories: Net Zero Energy and Resilient Hospitals – considerations of future climate, pandemics, and demand management	This document is presented to AHIA for consideration for guidelines or processes to supplement the Australasian Health Facility Design Guidelines.	This report considers four key questions: 1. How will hospitals perform in future climates, with respect to the energy requirements for heating and cooling in particular? 2. What are the energy implications of changes to HVAC operation strategies as advised in response to COVID-19? 3. What are the impacts of the energy changes (from Q1 above) on net zero energy goals, in particular the role of renewable energy? 4. What opportunities are available to hospitals (and aged care facilities) to participate in Demand Response markets utilising their generator assets? (Section 6) This report can be used to inform the Australasian Health Facilities Guidelines for the benefit of both public and private health facilities. Other organisations are also able to utilise this report to inform the design and operation of their healthcare facilities.	Link
LLHC5 M7	Lessons learnt Report	Details selected lessons learned	Documents specific lessons that were learned during the delivery of the sub-project	Link
LLHC5 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	Provides an overview of the entire project including project analysis and evaluation, the challenges experienced and what might come next in terms of future work.	Link
LLS1 M3	Renewable Energy and Enabling Technology and Services Evaluation Framework (REETSEF) for Education (Schools).	Provide Education (Schools) sector with sector-wide analysis and framework for Schools Living Labs (i.e., Living Lab operation Guidelines)	This Renewable Energy and Enabling Technology and Services Evaluation Framework (REETSEF) for the Education Sector defines the KPIs and methods of evaluation to be used to assess the impact of a technology upgrade on the value of renewable energy to an educational facility under the i-Hub living laboratory activity stream. This report should be read in conjunction with the complementary report: Living Labs Education Sector Baselines and Key Performance Indicators.	Link
LLS1 M3	Technical Report: Sector Baseline Data and KPIs	Baseline data enables quantification of technology impact at a building level and extrapolation of sector wide impact	This Baseline Report for education facilities presents electricity and gas consumption data assembled through a review of published literature (government and sector reports as well as academic publications) together with an analysis of data provided by the senior director of infrastructure and capital works for the education department in the ACT Government. This review provides existing KPIs already employed in the literature. The existing KPIs are evaluated in terms of their effectiveness in enabling renewable energy or energy efficiency technologies, reducing peak demand and energy use. Recommendations on principles to select KPIs are provided at the end of the report before the conclusion section.	Link
LLS1 M5	Interim Report: Life Cycle/Whole of Life	Enhanced schools sector understanding of LCA/WOL	This report provides a brief, user-friendly guide to the assessment of HVAC technologies for decision makers in the schools' sector, with an emphasis on technologies that increase the value of renewable energy generation. Many of the key performance indicators	Link

	Assessment KPIs	KPIs, improving the value proposition for energy efficiency / renewable energy	identified in the i-Hub Renewable Energy and Enabling Technology Service Evaluation Framework (REETSEF) are designed to support the assessment of technology improvements at the network and societal level, with consideration of benefits to the individual school limited to reduced energy consumption and utility costs. This report is designed to provide an easy-to-use guide for sector stakeholders to implement a Whole of Life design and assessment approach to compare costs and benefits of alternative HVAC technologies.	
LLS1 M7	Living Labs Educational Sector Energy Baseline and Key Performance Report – Analysis of energy consumption in Australian Schools	Summarises the analysis of energy consumption in Australian Schools	This addendum report has summarised the compilation and analysis of energy use data for 3,701 public primary schools across five jurisdictions in Australia, covering approximately 82% of the population. Mean energy consumption was found to be 38.0 kWh/m2/yr, or 542 kWh/student/yr. Substantial variations were identified between jurisdictions, although differences were lower when greenhouse gas emissions were considered, rather than energy use, due to substantial variation in the use of gas across states. Of the schools in the database for which information on the presence of solar PV systems was available, 64% had a solar PV array installed against 37% that did not. Schools with solar PV had an average net energy usage 16% lower than schools without solar, suggesting existing PV systems were undersized. Gas was present in 31% of the schools in the current database, however, this varied significantly across the jurisdictions. Energy consumption was notably higher on a per m2 basis for schools with gas present (mean of 45.3 kWh/m2/yr vs 33.1 kWh/m2/yr for schools without gas).	Link
LLS1 M7	Renewable Energy and Enabling Technologies and Services Roadmap for Schools.	Roadmap can be utilised by Education (Schools) sector in their policy and decisions regarding energy contracts, building design and operation, and renewable energy investments	The Renewable Energy and Enabling Technology and Services Roadmap for Educational (school) facilities provides high-level strategic principles for the schools sector to assist with policy and planning decisions to support decarbonisation through energy contracts, building design, operation and refurbishment, and renewable energy investments.	Link
LLS1 M7	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
LLS1 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	Provides an overview of the entire project including project analysis and evaluation, the challenges experienced and what might come next in terms of future work.	Link
LLS2 M3	ACT Schools Living Lab -	Companies are aware of the potential	A 'Living laboratory' is a user-centred open-innovation, ecosystem within collaborative partnerships. The i-Hub ACT Schools living laboratory establishes research-quality measurement and	Link

	Prospectus and Manual	testing mechanisms and opportunities in this LL.	verification systems within existing school buildings, HVAC services and occupants in order to observe and evaluate technology upgrades within the context of the daily life of these school ecosystems. The technology upgrades trialled in this living laboratory will be selected from promising electric heating and cooling strategies that increase the energy flexibility of ACT schools facilities, and deliver increased value for renewable energy, at the site and grid level.	
LLS2 M4	Technical Report: ACT Schools LL Monitoring and Initial Baseline Data Analysis	Stakeholders have an initial benchmarking framework.	This Technical Report: ACT Schools Living Laboratory Monitoring and Initial Baseline Data Analysis details the as-installed monitoring and evaluation capabilities implemented in the ACT Education living laboratory facilities to meet the requirements of the i-Hub Education Renewable Energy and Enabling Technology Evaluation Framework, as well as an initial baseline data analysis, to demonstrate available data sources and analysis techniques.	Link
LLS2 M5	Technical Report: ACT Schools LL Operations Manual (REETSEF), and Baseline Data Analysed	Operations Manual (REETSEF) completed; Comprehensive baseline data acquired. Stakeholders have a detailed benchmarking framework.	The i-Hub Education Living Laboratories: ACT Schools Operations Manual outlines the monitoring and evaluation techniques implemented in the ACT Schools living laboratory facilities to meet the requirements of the i-Hub Education Renewable Energy and Enabling Technology Evaluation Framework.	Link
LLS2 M6	Technology Evaluation Report	Hivve Sustainable Modular Classrooms Envelope and Heating tests	This evaluation report presents the results of an as-built performance evaluation of the thermal envelope and HVAC system of the Hivve transportables located at Majura, in comparison with the transportables buildings located at the i-Hub living laboratory sites, namely Amaroo and Fadden schools. The comparison of transportables included an older building with a very modern efficient AC unit at Fadden, and two more recently constructed transportables at Amaroo that appear identical yet have remarkably different energy performance; one has an efficient AC and good thermal envelope, while the other is around five years older and has a poorer thermal envelope and a less efficient AC unit.	Link
LLS2 M7	Technology Evaluation Report	Amaroo in-slab gas heating compared to split system air conditioning	This report presents the results of an as-built performance evaluation of the in-slab gas hydronic heating system by sub-measuring the energy used in a classroom on the 2nd storey Amaroo General Learning Area (Building 8) and comparing it with the energy used by a newly installed split system air conditioner in a thermodynamically equivalent classroom on the same floor of the building. An additional comparison is also included in the study to quantify the energy implications for the existing gas-fuelled hydronic heating systems when windows remain open (e.g., to adhere to COVID-19 guidelines) against the energy used by the same system in a control room with windows closed.	Link
LLS2 M7	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link

LLS2 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	Provides an overview of the entire project including project analysis and evaluation, the challenges experienced and what might come next in terms of future work.	Link
LLS3 M7	Technology Evaluation Report	Hivve Transportable Classrooms: Impact of Heat Recovery Ventilation on Energy Use and Indoor Air Quality	Provides an evaluation of two Hivve classrooms that had HRV retrofitted, in Sydney and Canberra (St Felix and Majura Schools respectively). The evaluation was designed to test the effectiveness of HRV systems, as well as the implication of the additional energy use for ventilation in grid connected and off-grid classrooms. The evaluation included both pre- and post- and side-by-side evaluation of two HRV units installed in Hivve transportables in Bankstown (St Felix) and Canberra (Majura). Within the constraints of the evaluation period, there are several important findings.	Link
LLS3 M7	Lessons learnt Report	Details selected lessons learned during the delivery of the sub-project	Documents specific lessons that were learned during the delivery of the sub-project	Link
LLS3 M7	Sub-project knowledge sharing report	Summarises the project and its outcomes	Provides an overview of the entire project including project analysis and evaluation, the challenges experienced and what might come next in terms of future work.	Link

Appendix B Acronyms

This Appendix lists the meaning of the acronyms used in this report.

AC	Air Conditioning
AFDD	Automated Fault Detection and Diagnosis
AHIA	Australasian Health Infrastructure Alliance
AIRAH	Australian Institute of Refrigeration, Air Conditioning and Heating
ALG	Activity Leaders Group
AMA	Australian Medical Association
ARBS	Air conditioning, Refrigeration and Building Services
ARENA	Australian Renewable Energy Agency
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAU	Business as Usual
BCR	Benefit Cost Ratio
BMS	Building Management Systems
CAHA	Climate and Health Alliance
DEA	Doctors for the Environment Australia
CCHR	Centre for Children's Health Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCH	Data Clearing House
DISER	Department of Industry Science Energy and Resources
DER	Distributed Energy Resources
DR	Demand Response
DRM	Demand Response Mode
ERV	Energy Recovery Ventilation
EUI	Energy Use Intensity
FCAS	Frequency Control Ancillary Services
FDD	Fault Detection and Diagnosis
GHG	Greenhouse Gas
HCF	Health Care facilities
HRV	Heat Recovery Ventilator
IDS	Integrated Design Studio
IEA	International Energy Agency
IEQ	Indoor Environment Quality
ING	Industry Nominees Group
IPMVP	International Performance Measurement and Verification Protocol
IOT	Internet of things
IT	Information Technology
HASS	Humanities and Social Sciences
HVAC&R	Heating, Ventilation, Air Conditioning and Refrigeration
ILALC	Illawarra Local Aboriginal Land Council
KPI	Key Performance Indicator
LALC	Local Aboriginal Land Council
LRLALC	Lightning Ridge Local Aboriginal Land Council
LL	Living Laboratories
M&V	Measurement and Verification

MNH	Metro North Health
NABERS	National Australian Built Environment Rating System
NEM	National Electricity Market
NZCE	Net Zero Carbon Emissions
O&M	Operation and Maintenance
PRIME	Professionalism, Regulation, Information, Measurement, and Emission abatement
PV	Photovoltaic
QCH	Queensland Children's Hospital
QUT	Queensland University of Technology
RACE	Renewable Affordable Clean Energy
REETSEF	Renewable Energy and Enabling Technology and Services Evaluation Framework
REF	Rapid Efficiency Feedback
RERT	Reliability and Emergency Reserve Trader
SaaS	Software-as-a-Service
SHU	Sustainable Healthcare Unit
STEM	Science, Technology, Engineering and Mathematics
TDR	Transactive Demand Response
TMY	Typical Meteorological Year
UOM	University of Melbourne
UOW	University of Wollongong
WCC	Wollongong City Council

Appendix C The i-Hub Team

This Appendix lists key members of the i-Hub delivery team.

AIRAH Project Management Team

Tony Gleeson – i-Hub Chair
Vince Aherne – i-Hub Project Leader
Sami Zeng– i-Hub financial manager
Matt Dillon– i-Hub communications manager
Brendan Pejkovic – i-Hub events manager

ARENA

Lyndon Collier – ARENA contract administration
Peter Haenke – ARENA technical liaison

Activity Leaders

Stephen White CSIRO - DCH
Wendy Miller QUT - LL
Georgios Kokogiannakis - LL
Brendon McNiven - IDS
Lu Aye - IDS

Industry Nominees

Phil Cowling - Cromwell Property Group
Nathan Groenhout - Global IQ Group
Stephen Humphries - AEMO
Luke Menzel – Energy Efficiency Council
Kriston Symons - ARUP
Troy Wilson - Consultant

Project Managers

Subbu Sethuvenkatraman, CSIRO
Caoimhin Ardren, DeltaQ
Kuldip Bajracharya, Property NSW
Mehdi Seyedmahmoudian, Swinburne University of Technology
Sonia Auld, DET NSW
TK Wang, VBIS
Iain Stewart, Exergenics
Arne Hanson, Buildings Evolved
Suresh Thennadil, Charles Darwin University
Clayton McDowell, University of Wollongong
Aaron Liu, Queensland University of Technology
Sherif Zedan, Queensland University of Technology
Dominik Holzer, The University of Melbourne

Partners and Participants

Data Clearing House

Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH)

Commonwealth Scientific and Industrial Research Organisation (CSIRO)

- Switch Automation
- DeltaQ
- Walker Asset Services
- CopperTree Analytics Australia
- Property NSW - Dept. Planning, Industry and Environment
- AM Building Efficiency
- Swinburne University of Technology
- KIG Energy
- Braemac
- Department of Education, School Infrastructure NSW
- Buildings Evolved
- Virtual Buildings Information System
- PrediQ
- City of Melbourne
- Exergenics
- Charles Darwin University
- City of Darwin
- Metro North Health
- Bar-tech Automation Pty Ltd

Integrated Design Studios

Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH)
The University of Melbourne
University of Wollongong
Queensland University of Technology

- Aurecon
- Greenbox Architecture
- NextDC
- Arup Australia
- Grimshaw Architects
- ACT Government Infrastructure and Capital Works – Education
- Jacobs
- Atelier 10
- Ewers Architecture
- Ambulance Victoria
- WSP Australia
- Büro North
- Banyule City Council
- Yarra City Council
- Moreland Council
- Brimbank Council
- Cox Architects
- LXRP (Level Crossing Removal Project)
- Place Design

- Active Community Group
- DesignInc Architects
- Commonwealth Scientific and Industrial Research Organisation (CSIRO)
- Dr. Steve Burroughs Foundation
- Stantec Australia
- MIEngineers
- Edmiston Jones
- Lendlease
- Wollongong City Council
- Illawarra LALC
- Bolton Clarke
- JHA Consulting Engineers
- NDY/Tetra Tech
- Hansen Yuncken
- Built Environment Collective
- Fulton Trotter Architects

Living Laboratories

Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH)
Queensland University of Technology
University of Wollongong

- Warrigal
- Bolton Clarke
- Children's Health Queensland
- Sustainable Buildings Research Centre (SBRC)
- Synengco
- Steinel Australia
- Australasian Health Infrastructure Alliance
- Uniting Care
- Mater Group
- Stantec Australia
- ACT Schools
- Environment, Planning and Sustainable Development, ACT Government
- CSIRO
- University of Melbourne
- ACT Education Directorate
- Hivve Sustainable Schools