The Innovation Hub

for Affordable Heating and Cooling

Final Sub-Project Knowledge Sharing report

# ACT Education Living Laboratory Final Report - Technology Evaluation and Operation

Project – LLS2

27 May 2022

The University of Wollongong

## About i-Hub

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

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

**This Project received funding from ARENA as part of ARENA's Advancing Renewables Program.
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Final Sub-Project Knowledge Sharing Report

This report is produced at the completion of each Living Lab sub-project and captures the breadth of activities and information produced in the sub-project including studio logistics. It makes use of cross referencing the individual reports produced in each sub-project rather than repeating information wholesale.

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| Lead organisation | University of Wollongong | | |
| Sub-Project number | LLS2 | | |
| Sub-Project commencement date | 1st July 2019 | Completion Date | 30th June 2022 |
| Report date | 27th May 2022 | | |
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## 1. Sub-Project Overview, Objectives and Importance to Market/Industry

### 1.1. i-Hub

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

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### 1.2. ACT Education Living Laboratories

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 independent validation.

The i-Hub ACT Schools living laboratory establishes 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.

The ACT Education living laboratories are:

**Amaroo**: Constructed from 2004, and fully operational since 2008, Amaroo is a large (GFA: 16,832 $m^2$) facility with over 1,800 students from preschool to year 10. Amaroo has a range of eco-friendly features, including a 600 kW solar array and a wind turbine. From this large venue two areas have been selected to participate in the living laboratory:

- Classrooms Years 6-10:
    - Gas boiler with hydronic in-slab heating.
    - Passive design for summer comfort with high and low BMS-integrated actuated windows.
    - Integrated building management system (BMS).
    - Retrofitted ceiling fans to upper level.

- Preschool:
  - Ducted gas heating to main classrooms (exchanged for electric heat pumps during project), with electric heating to offices;
  - Split system AC units;
  - Two identical transportable classrooms for side-by-side testing.

**Fadden:** Opened in 1984 with a gross floor area of 3,283 m2 and over 250 students. The main systems installed include:

- 10kW solar array.
- Ageing central gas boiler hydronically distributed to air handling units (AHU's) in each building/block.
- Evaporative coolers in learning areas.
- Retrofit split system reverse cycle air conditioning units in staff room.

**Majura:** Majura Primary School has two identical Hivve Transportable buildings with each building consisting of two mirrored classrooms, a staff office and a breakout room. Hivve transportable classrooms have many features designed to improve the thermal comfort and sustainability of these buildings. Features of a Hivve transportable include:

- Higher performance thermal envelope relative to minimum standards, notably including double glazing.
- An energy efficient split system air-conditioning unit.
- Rooftop PV generation, with the option of integrated battery storage.
- A monitoring and controls systems to manage energy use and indoor environment.

### 1.3. Living Laboratory Objectives

The i-Hub living laboratories activity stream has the objective to quantify (i.e. analyse measurable data) and qualify (i.e. develop insights into reasons, motivations and opinions) the potential for practical and cost-effective innovative technologies in educational settings to achieve a 30%+ reduction in energy demand/consumption and greenhouse gas emissions relative to business-as-usual (BAU).

Importantly, Australia's school stock used an estimated 8.8PJ of energy in 2020. The provision of, or demand for, thermally comfortable teaching environments through passive or active systems is a large driver for rising energy consumption in Australian schools. HVAC presents a significant energy and demand challenge to school communities and education departments with social, technical, economic and environmental consequences.

Approaches to the provision of 'Cool Schools' and renewable energy in schools still tends to happen in an ad-hoc and silo approach manner, often without holistic consideration of the occupants, buildings, technologies and electricity grid, and the management and control of that system.

## 2. Challenges Experienced and How These Were Overcome

Despite best planning efforts, this living laboratory project experienced several challenges during the establishment and operation phase, not least being the challenges arising from a global pandemic including the closing of schools and prohibiting of interstate travel. A selection of these challenges and the strategies implemented to overcome these are summarised below:

1. **Supply Chain Issues in Establishing Living Laboratory:** The Covid 19 pandemic shone a light on how interconnected the global supply chain is and sent ripples through many industries including the supply of monitoring and evaluation equipment resulting in increased procurement durations. The project had tight timeframes for establishing the living laboratory so that a nominal 12 months of baseline data could be collected followed by the trial of two technologies. Australian suppliers were sought for the majority of the required equipment with some equipment repurposed from other University of Wollongong projects.

2. **NSW Travel Restrictions:** Over the course of 2020 and 2021, Australia experienced numerous travel restrictions preventing the research team and potential technology providers from travelling to the ACT. The first of these restrictions resulted in long delays in establishing the living laboratory with monitoring equipment not installed until September of 2020. Historical energy data was gathered from the ACT Education Department to supplement this reduced baseline duration. Trusted relationships were built with the Building Services Officers (BSO's) at each site, enabling information gathering and equipment installation to occur during future travel restrictions. Additionally, temporary school closures resulted in modified energy and temperature patterns of the schools. To address these challenges, a selection of technologies were assessed for their potential to meet the objectives while enabling side by side comparisons to be made with similar spaces.

3. **New Ventilation Policies:** Covid-19 dramatically increased public awareness in the importance of ventilation with education departments adopting a 100% fresh air policy where mechanical systems were switched to 100% fresh air intake where available, and windows opened where mechanical systems were not present. This change in operations can impact the internal environment and energy required to maintain a comfortable temperature. This also produced challenges in evaluating some technologies. To overcome this challenge, the second technology trial (evaluating the replacement of a gas hydronic heated slab for electric split system air conditioning system) was conducted during school holidays and over weekends where window openings could be controlled without a risk to the occupants. In the absence of a room full of occupants, electric resistance heaters were used to simulate normal internal heat gains.

4. **Extended Government Procurement Times:** The internal approval and procurement processes for government bodies carry with them an inherent lengthy timeline when compared to private procurement. This raised a series of challenges for evaluating technologies that required infrastructure upgrades within short timeframe projects. To align with the project timeline, technologies with infrastructure upgrades were avoided to ensure the project was

completed on time. However, additional technologies are now in line to be evaluated over the next 18 months. Securing a longer duration project of approximately 5 years would enable more complex technologies to be evaluated while aligning with government procurement policies.

5. **Monitoring interruptions:** The installation of monitoring equipment within classrooms is not a difficult task, however, receiving consistent and reliable data from these devices was more complex than originally anticipated. The devices were placed in locations to best monitor IEQ conditions, however, this also exposed devices to students who are capable or removing them, interrupting the collection of baseline data. The monitoring devices used were selected not only for their accurate measurements but also for being inconspicuous. Additionally, where possible they were installed in areas where loss of the assets would be minimised.

   Communication networks also provided challenges where loss of data occurred when these networks failed. To mitigate data losses, alarms were introduced to alert the project team when network issues were detected, or devices going offline, so that the network could be reset and data collection could resume.

## 3. Summary of Lessons Learnt and Evaluation of the Sub-Project Impact

The living laboratories project consisted of four major phases: establishment of the living lab, baseline data analysis, first technology trial, and second technology trial. A summary of the lessons learnt and impact from each of these phases is presented below.

### 2.1. Establishing a Living Laboratory

Prior to determining the boundaries of the living laboratories, a Renewable Energy and Enabling Technology and Services Evaluation Framework (REETSEF) for the Education Sector was first created which defined the KPIs and methods of evaluation to be used to assess the impact of technology upgrades. This REETSEF examined previous living laboratories and green proving grounds which highlighted that a range of societal, electricity network, and facility owner/manager KPI's were required to assess the effectiveness of potential technologies.

Following this, an audit was performed on the schools and the REETSEF was applied to produce a living laboratory operations manual which details the type and position of all installed sensors. This process also highlighted some of the potential areas for improvement such as electrification of the dated gas heating systems. Links to these two reports can be found below.

*Renewable Energy and Enabling Technology and Services Evaluation Framework (REETSEF)*

*Living Lab Operations Manual: ACT Education*

## 2.2. Baseline Data Analysis

An extensive building monitoring system was installed within the Amaroo and Fadden schools consisting of Wattwatchers Auditor-6M metering-grade electrical energy monitoring, pulse output meters for gas consumption, and a combination of Nube iO Droplet DL-TH (temperature and humidity) and Elsys ERS CO2 (temperature, humidity, CO2, occupancy, and light level) sensors installed in most conditioned spaces within the living laboratories. These sensors communicate over either a LoRa wireless IoT network designed for very low power, long battery life with reasonably long-range wireless transmission, or in the case of Wattwatchers via the 3G network. Additionally, a Davis Instruments wireless integrated sensor suite plus with fan-aspirated radiation shield (model number 6328AU) weather station and data logger were installed on each site to collect localised weather data.

Data collection commenced in September 2020 with the energy data supplemented with 5 years of historical meter data collated via the ACT utility management system. This analysis revealed a strong alignment of energy consumption with potential solar generation with schools typically operating while the sun is shining. Gas was found to be the largest energy source for both sites consisting of more than 60% of the total energy consumption. This demonstrates a concentrated effort is required for the electrification of school heating systems which in turn raises challenges including upgrades to existing site sub-stations and distribution boards.

The indoor environment and quality (IEQ) analysis between 28 September and 25 March highlighted thermal comfort issues in Amaroo with many spaces recording a considerable amount of time below 18°C with the hydronically heated slab having a large delay between being switched on and adequately heating the classrooms. Concentrations of $CO_2$ was also measured above a recommended level of 800 ppm for extended periods of time in many classrooms. In contrast, Fadden despite being a far older school was observed to have reasonable thermal comfort with most rooms having a mean temperature within an acceptable range. Spaces were also observed to have better $CO_2$ concentrations although peaks above recommended levels were still recorded. Greater detail of these results and can be found in the report via the link below.

*ACT Education Living Laboratory Monitoring and Baseline Data Analysis*

## 2.3. Hivve - Sustainable Modular Classrooms Envelope and Heating Tests

Transportable classrooms are a common feature of schools across Australia. These classrooms can be moved from school to school to assist in dealing with fluctuating demographics. The buildings are typically lightweight construction with basic thermal envelope specification to meet the minimum standards at the time of construction. Historically, they were designed with operable windows, shading and electric wall heaters to provide thermal comfort, however, new transportables are equipped with multiple split system AC for heating and cooling, and major projects are underway to retrofit split-systems to existing buildings. Hivve provides a high-performance transportable classroom which is fitted with improved passive features and efficient heating and cooling solution coupled with solar PV and optional integrated battery storage.

A number of Hivve transportables have been installed in schools around Australia, including two at Majura Public School in the ACT, which were evaluated against existing transportables at Amaroo and Fadden. A series of tests were undertaken, designed to test firstly the building thermal envelope and heating system in combination, and then to test the performance of the building envelope with no active heating or cooling. At the time of the evaluation, schools were unoccupied due to Covid restrictions which enabled a direct comparison between the spaces without the impact of varied occupancy profiles.

The test without active heating confirmed the impact of the improved thermal envelope for the Hivve transportables with both showing higher mean, minimum and maximum temperatures during the evaluation period even with cold outside temperatures. The Hivve transportables also showed a lower diurnal temperature variation. However, evaluating the transportables with active heating produced several challenges with a transportable at Fadden discovered to have a faulty air conditioning control board, and another transportable at Amaroo unable to reach the temperature setpoint due to being undersized and/or poor thermal performance of the building. This limited the comparison to only one transportable at Amaroo which demonstrated that the Hivve transportables used 13% and 2% less energy to maintain 25 °C when normalised by floor area, and 15% and 5% when normalised by heated volume for the evaluation period.

This technology trial highlighted the benefits of high performance transportables but also demonstrated the benefits of detailed sub-metering and ongoing monitoring of energy performance of air conditioning systems, as the issues detected in the existing non-Hivve air-conditioning systems are unlikely to have been identified during routine maintenance inspections. Additionally, the performance of AC split systems are continuing to improve, and model selection should be regularly revised to maintain higher performance results. Greater detail of how this trial was conducted and the results can be found in the technology evaluation report provided via the link provided below.

*Hivve Envelope_HVAC Transportable Evaluation*

### 2.4. Amaroo In-Slab Gas Heating Compared to Split System Air Conditioning

The control of internal conditions within school classrooms is an important issue, with much focus on achieving appropriate temperatures for effective learning, and more recently, ensuring sufficient fresh air for improving learning and minimising COVID risk. Providing these internal conditions through heating, ventilation and air-conditioning requires substantial energy, and has significant environmental implications. This technology trial examined the as-built performance evaluation of the thermal envelope and in-slab gas hydronic heating system of the 2nd storey Amaroo General Learning Area (Building 8), in comparison with a classroom that is heated by a newly installed split system air conditioner. The purpose of the testing was to quantify the benefits, issues and opportunities from the future replacement of gas systems towards all electric systems such as the split systems that have become a common retrofit in many school buildings.

To complete this evaluation, a split system air conditioning unit was installed in a classroom and the hydronic in slab heating loop to the classroom was isolated. Tests were performed during and after the Easter 2022 school holidays comparing two thermodynamically equivalent classrooms. During periods where the classroom was unoccupied, electric fan heaters were used to simulate heat gains from occupants and equipment.

Across 3 days of unoccupied tests, the AC split system consumed 7.2 kWh (a minor portion of that was due to standby power) whereas the hydronic system consumed 41.5 kWh (when assuming an 80% efficiency as per boiler's specification; 33.2 kWh if the gas boiler is assumed to be 100% efficient). Similar results were obtained during the occupied periods. While longer side by side comparisons are needed during colder winter conditions, the electric AC split system was using energy at times of solar PV energy generation and required from 4 to 7 times less energy than the hydronic system (75-85% energy savings by replacing a gas system) based on the measurements taken during this evaluation.

For both, occupied and unoccupied comparisons, the AC split system operated typically 40-50% less compared to the hydronic system, usually reaching the set point faster, which was then maintained during daytime at relatively acceptable levels due to the passive energy features of the building.

This evaluation highlighted that the transition away from gas-fuelled HVAC systems in schools towards electric systems is important not only because of the obvious greenhouse gas emissions savings and the unlocking of the full potential of renewable energy supply, but also because it provides significant opportunities to reduce energy costs while maintaining and in some instances improving indoor thermal comfort. For greater detail please follow the link below to see the complete evaluation report.

AC split system versus gs hydronic system evaluation

### 2.5. Summary of Sub-Project Outcomes

Each sub-project was evaluated against a series of outcomes and KPIs. A summary of how the outcomes and KPI's associated with the ACT Education Living Laboratory sub-project have been achieved is provided below.

- *The establishment and operation of the ACT Schools i-Hub Living Laboratory (2 sites):* Two living laboratories were established, at Amaroo and Fadden schools with these later expanded to included a smaller living laboratory at Majura covering the Hivve transportables. Monitoring of sub-meter energy consumption and IEQ have been recorded from September 2020 to June 2022 with the expectation for an extended monitoring period of an additional 18 months following the conclusion of the i-Hub project.

- *Enable the Australian HVAC and building services industries to have their innovative technologies independently validated at ACT Schools LL facility with at least 2 technology assessments of emerging products/services validated and published:* A prospectus inviting potential technology providers was produced and distributed to a broad network. This alongside of various industry presentations attracted a number of potential technology providers. As detailed above, two independent technology trials were conducted during the project with the evaluation reports published on the i-Hub website. An additional two technology trials and an extension of the existing trials are currently planned to occur over the next 18 months.

- *Practical and cost-effective ways that Schools will be able to achieve a 30%+ reduction in energy demand/consumption and greenhouse gas emissions, through the use of new technologies relating to HVAC control, demand management, grid interoperability and renewable energy are demonstrated:* The first 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 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.

- *Information is promulgated to the wider industry through the Renewable Energy Knowledge Sharing Task-Group for Education and other pathways:* The evaluation reports have been shared via the i-Hub website and to various government departments and industry partners. In addition, the results of these trials have been presented to AIRAH hosted summits and to living lab hosts to illustrate how these technologies can form part of the solution to a carbon neutral future.

## 4. CONCLUSIONS

Australia's school stock consumes a considerable amount of energy, estimated at 8.8 PJ in 2020 with a significant proportion of this used for heating and cooling the facilities. Additionally, the demand for thermally comfortable teaching environments will likely see this consumption rise in the coming years. However, the operating hours of schools align well with typical daily solar profiles making them an ideal candidate to take advantage of solar PV and solar passive designs.

The i-Hub living laboratories activity stream sought to evaluate practical and cost-effective innovative technologies in educational settings to achieve a 30%+ reduction in energy demand/consumption and greenhouse gas emissions relative to business-as-usual (BAU). Two large living laboratories were established across the ACT with an invitation sent to industry inviting them to have their innovative technologies independently evaluated in a real-life setting.

The first evaluation examined Hivve's sustainable modular classrooms in comparison to more traditional transportables located at Amaroo and Fadden. Hivve's classrooms were observed to be more thermally stable and consume less energy than the traditional transportables. Additionally, Hivve's transportables are fitted with solar PV with an option for battery storage, enabling them to become net zero energy buildings and even be operated off grid in some climate locations. Through submetering a number of issues were detected in the existing non-Hivve air-conditioning systems which would not have been identified under normal maintenance routines, highlighting the importance of sub-meter systems to ensure continued efficient operation of installed HVAC systems.

The second evaluation examined the retrofitting of a conventional split system AC in replacement of the existing gas in-slab heating system for one classroom within Amaroo. The AC system was found to provide the same if not improved thermal comfort but with a significant reduction in hours of use and energy consumption. The electrification of the heating system reduced the operational greenhouse gas emissions for the classroom to zero given the ACT's 100% renewable energy supply. This electrification also enables better utilisation of the installed solar PV system.

Following i-Hub, the University of Wollongong is negotiating with the ACT Education Department to extend the Living Laboratory trials for a further 18 months. This extension will include the continued evaluation of the trials documented above 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.