Report

Living Lab Operations Manual: ACT Education

05 June 2020

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.

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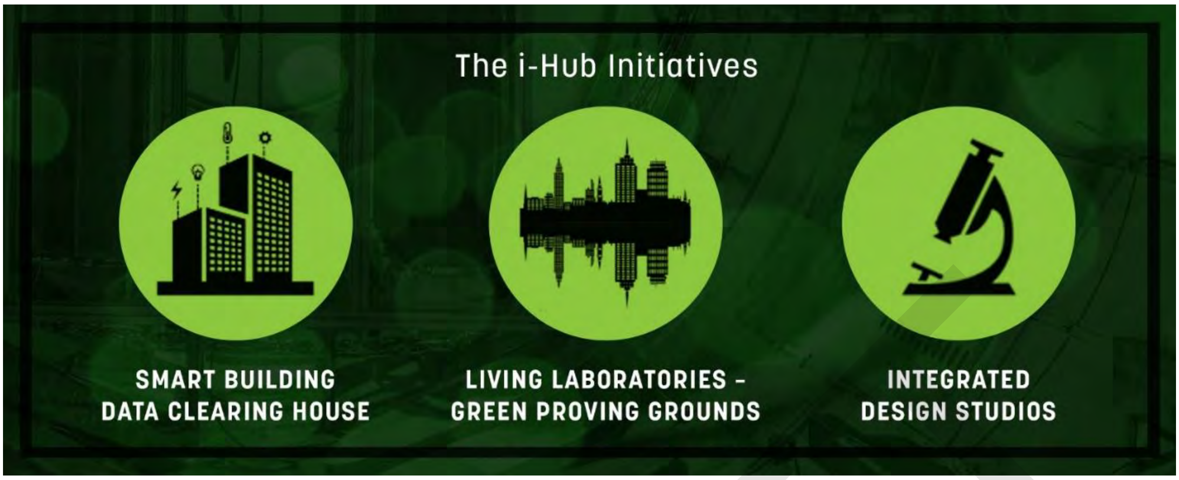

[i-Hub Education Living Laboratories: ACT Education Operations Manual]

The i-Hub Education Living Laboratories: ACT Education Operations Manual outlines the monitoring and evaluation techniques implemented in the ACT Education living laboratory facilities to meet the requirements of the i-Hub Education Renewable Energy and Enabling Technology Evaluation Framework.

Lead organisation

University of Wollongong (UOW)

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Please note, this a living document that will be iteratively updated during the establishment and operation of the foundation living laboratories. The above table only tracks major published updates. Please download the latest version from https://cloudstor.aarnet.edu.au/plus/s/f4xCnqxgfi6lyXJ/download

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1 Introduction[1]

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 validation. Many technologies can be tested over time.

The i-Hub ACT Education living laboratory establishes research-quality measurement and verification systems within existing school buildings 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 Education facilities, and deliver increased value for renewable energy, at the site and grid level.

The ACT Education living laboratories are:

- **Amaroo**: Opened in 2004 with a gross floor area of 16,832 m^2 and over 1,800 students. Renewable generation include a large array of solar panels and a wind turbine. Heating is supplied by gas boiler with hydronic system to in-slab heating and ducted gas heating, cooling provided by split system reverse cycle air conditioning units. Buildings fitted with actuator operated windows and integrated building management system (BMS).
- **Fadden**: Opened in 1984 with a gross floor area of 3,283 m^2 and over 250 students currently enrolled. Renewable generation consists of an array of solar panels. Heating is supplied by the original central gas boiler hydronically distributed to air handling units (AHU's) in each building/block. This system has had minimal capital expenditure and poses

[1] The ACT School living lab prospectus provides an introductory summary of this document.

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a high operational security risk to the school. There was no provision for mechanical cooling in the original construction, but the last decade has seen the progressive rollout of evaporative coolers in learning areas, and split system reverse cycle air conditioning units in staff rooms and special learning areas.

The i-Hub living laboratories activity stream has the objective to quantify (i.e. analyse measurable data) and qualify (i.e. develop insights into reasons, motivations and opinions) the potential for innovative technologies and the integration of technologies in educational settings to add value to renewable energy, enabling schools to transition to a net-zero energy/demand future while simultaneously contributing to occupant wellbeing, comfort and health. A nominal target of a 25% increase in the value of renewable energy for education, 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 approximately 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 that relatively minor adjustments of HVAC load timing can 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 Reliability and Emergency Reserve Trader (RERT) and Frequency Control Ancillary Services (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.

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2 Renewable Energy and Enabling Technology Service Evaluation Framework.

All i-Hub education living laboratories will be operated in accordance with the Renewable Energy and Enabling Technology and Services Evaluation Framework (REETSEF) for the Education Sector[2]. This framework 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. A technology upgrade can include the installation of an energy conservation measure that affects peak demand, or the installation of a distributed energy resource that can generate, store, or actively manage energy demand.

The current operations manual will detail the methods by which this REETSEF will be implemented for the ACT Education living laboratory.

The value of renewable energy accrues to a variety of stakeholders, and is considered to comprise:

1. Societal: The social value of renewable energy generation include net job creation, public health and social inclusiveness[3], however, monetary value can be attributed to avoided carbon emission ($/tCO2-e), and avoided air pollution ($/MWh). Societal benefits may primarily be influenced by additional renewable generation, or fuel switching from gas to electricity.

2. Electricity Network: Network benefits from education facility upgrades could include reduced peak demand and / or load shifting (i.e. a permanent change to the energy use profile), and demand response capacity (i.e. a temporary pre-arranged adjustment in energy consumption). Both benefits have a power (kW) and energy (kWh) component[4]. Potential additional benefits include exploring the aggregation of demand response capacity across multiple sites in order to participate in electricity market mechanisms that enhance grid stability and robustness, FCAS and RERT[5]. The ability to offer these ancillary services is a function of demand response capacity.

3. Facility owner / manager: The benefit to the facility may be reflected in the utility costs for all energy. This includes supply charges, consumption charges, peak demand charges and export benefits.

[2] The current version of the Education REETSEF can be downloaded at https://bit.ly/3a5YWmh.

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

[4] https://www.energyrating.gov.au/sites/default/files/2020-01/smart_appliance _decision_ris.pdf

[5] ARENA, 2019, Demand Response RERT Trial Year 1 Report.

2.1 Key Performance Indicator

Technology upgrades will be evaluated according to the key performance indicators (KPIs) defined in the REETSEF, summarised in Table 1. The following list is not exclusive, and additional KPI's can be calculated as appropriate for specific technologies. However, the following 10 KPI's should be calculated and published for the baseline and reporting period.

Table 1: Key performance indicators for technology upgrade evaluation

Benefit	KPI #	Name	Qualitative Description
Societal Benefits	KPI 1	Avoided GHG emission	Quantity (tCO2-e) and value ($) of greenhouse gas (GHG) emissions avoided due to the technology upgrade
	KPI 2	Avoided air pollution	Social benefit (cost value - $) due to avoided air pollution (PM_{10}, NO_x, and SO_2) impacting populations close to power station
Network Benefits	KPI 3	Peak 30 minute electricity demand	The highest 30 min electricity demand, reported monthly, seasonally and annually.
	KPI 4	Wholesale cost of peak 30 minute electricity demand	Wholesale cost of peak demand at the time of occurrence to determine if facility peak is co-incident with periods of network peak.
	KPI 5	Total self-consumption rate	How much of the generated renewable electricity is consumed on site (between 0 - 1). Self-consumption rate will be reported monthly, seasonally and annually
	KPI 6	HVAC self-consumption rate	How much of the generated renewable electricity is consumed by the HVAC systems (between 0 - 1).
	KPI 7	Net Facility Load Factor	Net Facility Load Factor is the average load divided by the peak load during a specified time period, and is a measure of how 'peaky' an energy use profile is.
	KPI 8	Demand response capacity	Will be characterised as available demand response (kW) for different time scales (e.g. 6 sec, 1 minute, 10 minutes, 1 hour, and 4 hour).
Sector Benefits	KPI 9	Energy cost	Quantification of changes to energy usage to the school, based on actual billing data for all energy sources, including demand, time of use and supply charges, along with renewable generation income (if any).
	KPI 10	Energy Intensity / Productivity	Calculation of energy intensity (kWh/m2) (kWh/EFTSL) (kWh/m2 conditioned)
Additional KPIs	KPI xx		Additional KPI's may also be calculated and reported, as relevant to specific technology, and as supported by available data. Additional KPIs may include, for example, operation and maintenance costs; or system run times (with implication for equipment lifetime).

2.2 Measurement and Verification (M&V)

2.2.1 M&V Techniques

The Measurement and Verification (M&V) techniques employed in this living laboratory are consistent with the i-Hub education REETSEF, which employ a level of research rigour at least in line with the International Performance Measurement and Verification Protocol (IPMVP). The underlying calculation principle in the REETSEF to determine change in a KPI is:

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

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

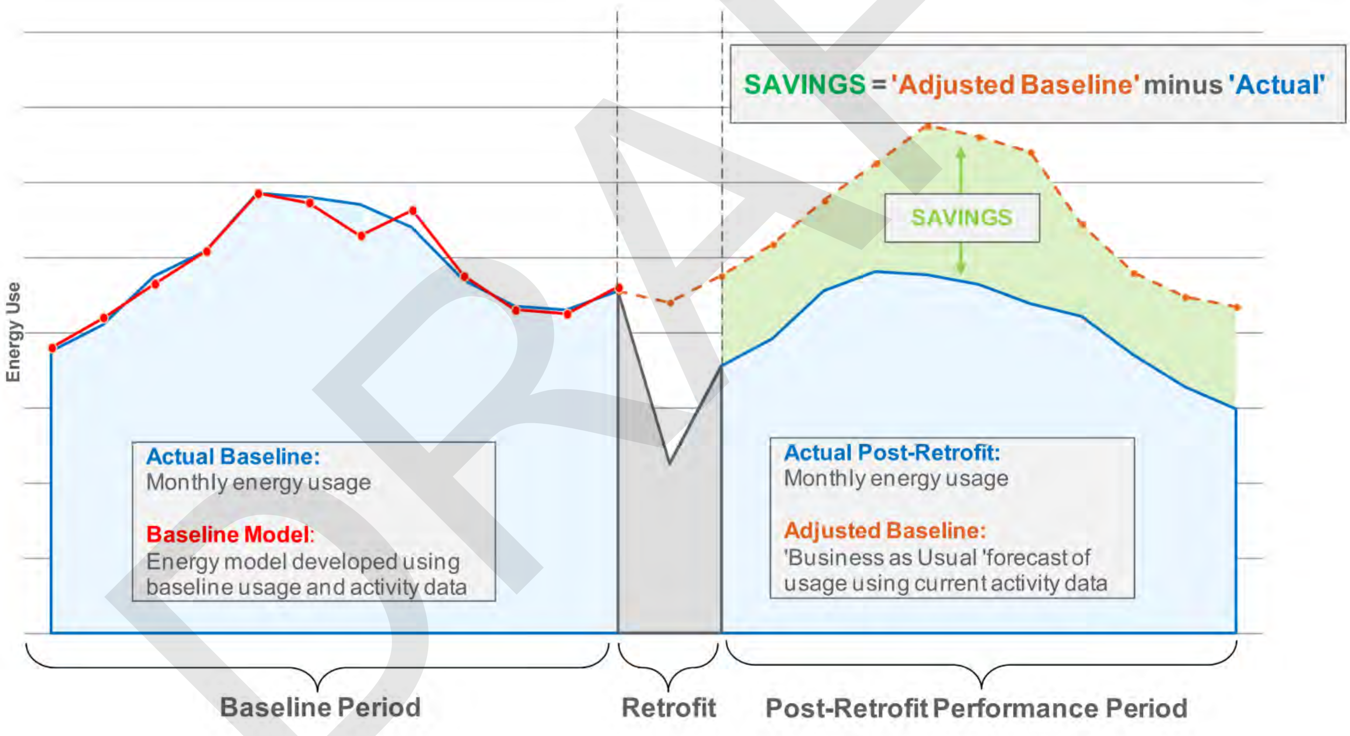

Figure 1: Illustration of the savings calculation principle, where differences are estimated between recorded values and the adjusted business as usual values, both from the post-retrofit period[6].

There are four M&V options outlined in the IPMVP, which are discussed in the REETSEF. All M&V within the ACT Education will be completed using a combination of *Option B: Full parameter measurement*, for detailed assessment of a retrofit performance, with higher level analysis also

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

being conducted including *Option C: Whole Facility (Building)*, or *Option D: Calibrated Simulation*, with a focus on change to value of renewable energy at the facility and sector-wide level.

Excerpt from IPMVP (2012): Overview of IPMVP Options	
IPMVP Option	**How Savings Are Calculated**
Option B. Retrofit Isolation: All Parameter Measurement Savings are determined by field measurement of the energy use of the ECM-affected system. Measurement frequency ranges from short-term to continuous, depending on the expected variations in the savings and the length of the reporting period.	Short-term or continuous measurements of baseline and reporting period energy, and/or engineering computations using measurements of proxies of energy use. Routine and non-routine adjustments as required.
Option C. Whole Facility Savings are determined by measuring energy use at the whole facility or sub-facility level. Continuous measurements of the entire facility's energy use are taken throughout the reporting period.	Analysis of whole facility baseline and reporting period (utility) meter data. Routine adjustments as required, using techniques such as simple comparison or regression analysis. Non-routine adjustments as required.
D. Calibrated Simulation Savings are determined through simulation of the energy use of the whole facility, or of a sub-facility. Simulation routines are demonstrated to adequately model actual energy performance measured in the facility. This Option usually requires considerable skill in calibrated simulation.	Energy use simulation, calibrated with hourly or monthly utility billing data. (Energy end use metering may be used to help refine input data.)

All methods require detailed and long term monitoring of key parameters and independent variables. Option B and C uses this data directly to create a regression model to estimate an adjusted post-retrofit business as usual value. Option D is typically recommended in the case that baseline data is not available; in this case, baseline data will be available. Option D can use the baseline period data to calibrate and verify a building performance simulation model of the facility, which can then be used to evaluate energy consumption under consistent conditions for both the pre-retrofit and post-retrofit configurations during the post-retrofit reporting period. The use of a validated and calibrated simulation will be better able to normalise for external conditions using representations of typical weather conditions compared to regression methods.

All retrofit assessments will use before and after comparison. Control and intervention comparison may be used in addition in the case that two comparable test units are able to be effectively isolated. The preferred analysis method is to monitor multiple functional space and use a combination of pre- and post- comparison and control- intervention pairs. In this case, one

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functional space would not receive an intervention, and would be used to validate the multi-variate regression model that is then used to adjust the baseline and reporting data for the intervention space.

2.2.2 Defining the measurement boundary

The measurement boundaries for measurement and verification of HVAC-related technology upgrades are normally defined in reference to:

- A piece of HVAC equipment or energy system, including all the spaces it serves.
- A separately zoned conditioned space, such as a room, group of rooms, which may contain multiple HVAC systems.

A visual summary of the generic measurement boundaries is provided in Figure 2.

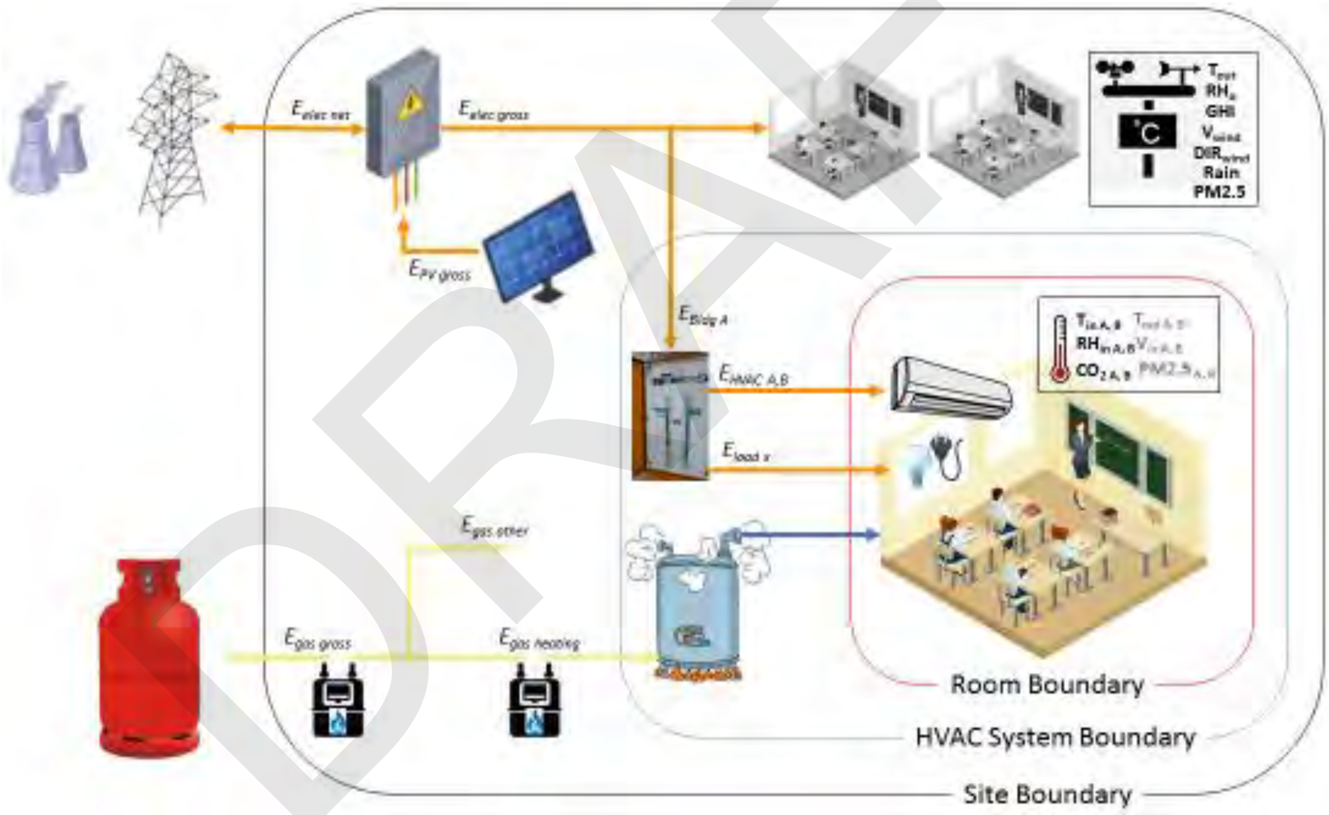

Figure 2: Generic monitoring approach for establishment of living laboratory

The measurement boundaries for each school are defined in this manual as follows:

– Amaroo Public School – Section 3.2.2, and Figure 4.
– Fadden Primary School – Section 4.2.2, and Figure 19.

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2.2.3 Data analysis and baseline adjustment methodologies

Appropriate data analysis and baseline adjustment techniques are described in the i-Hub education REETSEF. These methods are not prescriptive; however, it is essential that whichever data analysis techniques are employed, sufficient information is provided in the technical report, or made available as a data addendum, to allow independent verification of the appropriateness of the methods, and the validity of the results.

Routine adjustments that are anticipated in the Fadden and Amaroo Living Laboratories include weather, internal conditions and occupancy.

The use of school spaces is expected to vary year to year, based on changes in the practices of the teaching staff, and allocation of classrooms. Of primary relevance to the current project are changes to thermal comfort preferences and practices of the teachers in control of the monitored spaces, and the associated changes to the total energy consumption and consumption profile of the facility.

Adjustments for external weather conditions, internal environmental conditions, and occupancy create a requirement to monitor these constraints. An appropriate method for recording unanticipated changes is also required. Monitoring of internal and external conditions for Amaroo and Fadden are discussed in detail in Sections 3 and 4 respectively.

2.2.4 Post occupancy evaluation protocols

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

POE is a well-established building assessment tool, and there are numerous approaches that can be employed. There are several well-established standardised methods for conducting POE, which were originally designed for use in office buildings. These methods use standardised questionaries, and the results for a facility can be compared against the performance of other similar facilities in the database.

POE in the ACT Education living laboratory will be undertaken using either the BOSSA method[7], or the Building Use Studies Method[8], using concurrent 'right here, right now' physically parameter measurement. These will be conducted at least once during the baseline and reporting period; however, it is anticipated these will be completed seasonally during both periods.

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[7] http://www.bossasystem.com/

[8] busmethodology.org.uk/

3 Living Laboratory Description — Venue 1 — Amaroo School

3.1 Facilities description

3.1.1 Physical buildings

Constructed from 2004, and fully operational since 2008, Amaroo is a large (GFA: 16,832 m2) facility with over 1,800 students from preschool to year 10. The school is situated in the expanding northern suburbs of Canberra, as seen in Figure 3.

Figure 3: Amaroo School aerial view from the north featuring the 600kW solar array.

From this large school site two distinct areas have been selected to participate in the living laboratory, as outlined in Figure 4, each selected for their unique contribution to the overall i-Hub living laboratories project:

1. Preschool
2. High school (6-10)

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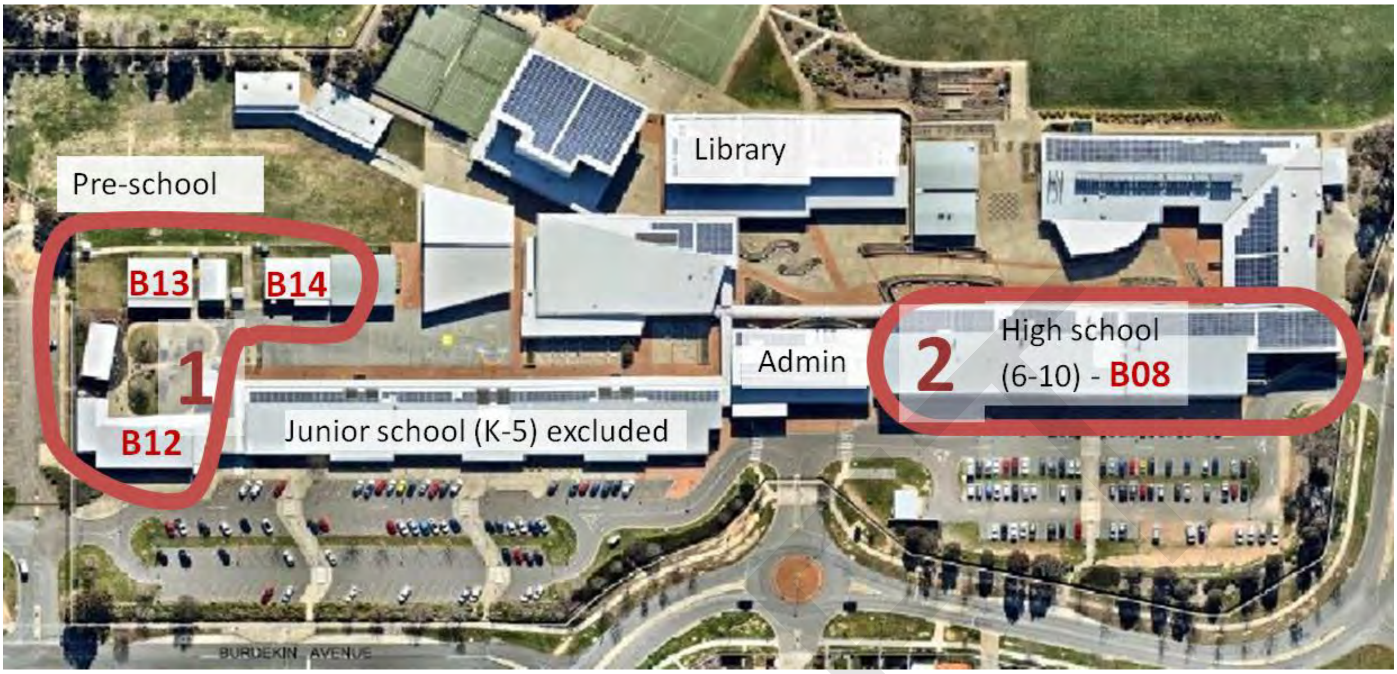

Figure 4: Amaroo School living laboratory measurement boundaries.

3.1.1.1 Classrooms Years 6-10

This two-level building design, featured in Figure 5, is based upon solar passive principles. The northerly orientation with deep eaves over large windows is well configured for solar activation of the large concrete slab thermal mass in winter, while being fully shaded throughout summer. Passive cooling is facilitated by high and low operable windows.


Figure 5: Amaroo School high school building B08, highlighting passive design principles with the automated high windows shown at the left. The two levels of year 6 to 8 classrooms are in the centre, while the similar year 9 to 10 block is in the background, with the technology, arts and sciences block jutting into the far left of view. The Administration block is at bottom right.

3.1.1.2 Preschool

The preschool was the last learning age group incorporated into the site, in 2008.

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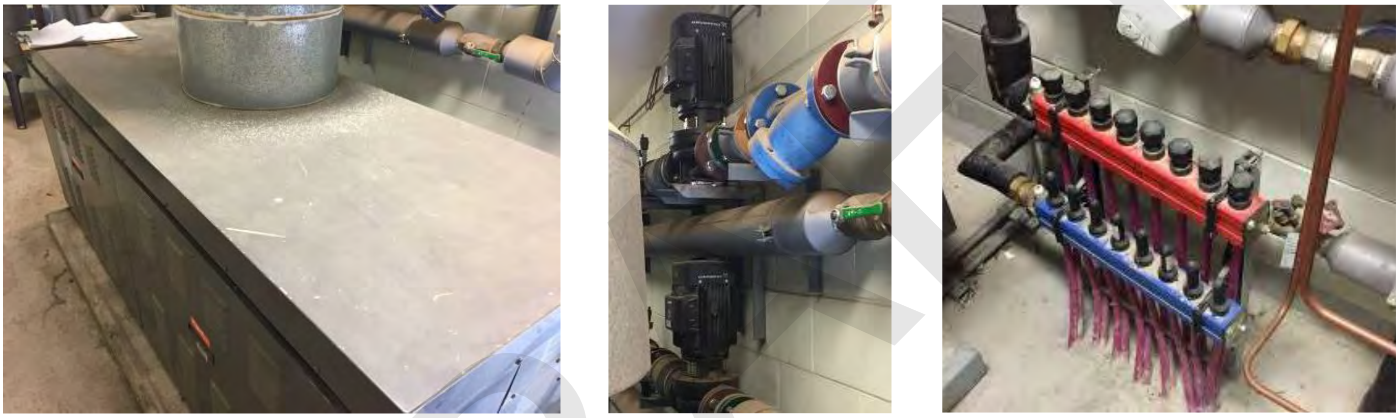
3.1.2 HVAC system

HVAC systems for Amaroo School were designed separately with varying approaches for each building as the site was developed to suit the varying requirements of each facility. The general approach for the site is for heating to be served from a gas boiler installed in each building, with hydronic distribution to either in-slab, FCUs or wall radiators. Cooling was generally a passive design.

3.1.2.1 Heating

The heating plant for the high school building, shown in Figure 6, is supplied from a natural gas boiler, which services the hydronic in-slab heating loops in individually adjustable zones throughout the building.



(a) (b) (c)

Figure 6:The main heating plant for Amaroo high school building: (a) the boiler; (b) hydronic recirculation pumps; (c) typical hydronic heating distribution zoning manifold (from the canteen).

Good winter solar access is provided through large northern windows into northern orientated rooms and the high clerestory windows below the peak of the building provide solar access into the southern row of rooms.

Supplementary AC units are installed in some rooms as described further below.

The preschool main building, B12, has a gas furnace ducted to the main classrooms (Figure 7), with electric heating to offices. The preschool transportable classrooms each have four separate split system AC units as illustrated in Figure 14.

Figure 7: Amaroo preschool gas furnace for ducted heating of B12 only.

3.1.2.2 Ventilation

The high school (B08) has a passive ventilation design approach for summer comfort with high and low BMS-integrated actuated windows (Figure 5). In practice, operational failure of these window actuators has introduced ongoing maintenance and thermal comfort challenges in this facility. The ACT Education Directorate recently installed ceiling fans to ameliorate this issue.

The preschool main building, B12, was also designed with passive cooling and no mechanical cooling is provided. The preschool transportable classrooms have operable windows for natural cross-flow ventilation. Ceiling fans are not provided in the preschool buildings.

3.1.2.3 Cooling

The passive cooling design was expected to provide for a comfortable naturally ventilated indoor environment with no provision for mechanical cooling in the original construction. In the context of the abovementioned issues with the window actuators and very recent introduction of ceiling fans, the school has additionally commenced to progressively install supplementary stand-alone AC units through this building.

The preschool transportable buildings (B13 and B14) have multiple split system AC units installed. The preschool main building (B12) has no mechanical cooling.

3.1.3 Control systems

A central Carrier BMS with comprehensive monitoring and control implemented serves the original site.

The various supplementary air conditioning units are individually controlled from the proprietary wall mounted controllers and are not integrated into any of the centralised control systems for the school.

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3.1.4 Renewable energy systems

An extensive 600kW array of rooftop solar panels was installed across the site in 2015 and may be seen in Figure 3. The PV array is owned by a joint venture for the first 20 years, after which the array is intended to be handed over to the school. The school effectively rents out the roof space to the joint venture and receives a fixed annual fee.

The PV system generation is gross metered separately for the joint venture. Although the solar PV generation capacity does not commercially belong to the school, the impact of the interactions between Amaroo HVAC operations, this large PV array and the grid are physically the same as if the PV generation was directly offsetting the school load and so it remains very relevant to this project and will be considered as such.

3.2 Living Laboratory description

The schematics and lists, as presented in the figures on pages 31 to 41, comprise the primary documentation for the real time monitoring system, with some supplementary explanatory notes included below.

3.2.1 Metering

The locations of the energy utility meters for the site are indicated in Figure 9. The preschool has independent metering for both electricity and gas.

Smart meters are attached to the electricity consumption and monitor consumption in 15-minure intervals with data remotely accessed from the ACT Government Enterprise Sustainability dashboard. The main school gas utility meter is located in an enclosure on the site boundary south of the hall. These meters are automatically uploaded to the dashboard on a monthly basis and manually shared by ACT Education Directorate with schools.

3.2.2 Measurement Boundaries and monitoring device layouts

The Amaroo School site is too large to be managed in a single living laboratory for this project, so two distinct areas have been selected to participate in the living laboratory, as outlined in Figure 4. Each area was selected for the unique offering it brings to the overall i-Hub living laboratories project:

3.2.2.1 High school (6-10)

- Passive heating with north facing solar activated slab and in-slab hydronic active heating.
- Passive cooling with ongoing issues, recent fan and AC installation as correction measures.
- Incorporates some admin offices with AC.

3.2.2.2 Preschool

- Ducted gas furnace with very high gas usage.

- Two identical transportable classrooms for side-by-side testing of room-scale technologies. Transportable classrooms are commonly utilised throughout Australian schools and are typically poorly insulated and fitted with standalone AC as the primary source of HVAC.

The measurement boundary for this site may be further sub-divided, to facilitate a range of potential technology upgrade evaluations, and may be usefully considered as four levels of monitoring, as below.

3.2.2.3 Site monitoring

Site monitoring is an essential requirement in order to evaluate the impact of HVAC technology upgrades upon the renewable generation at the site level. Site metering and monitoring layout is provided in Figure 9. Gross energy consumption (electricity and gas) and generation are measured at the utility meters, and external weather conditions are measured on site.

3.2.2.4 Building monitoring

The measurement boundaries for the Amaroo venue of this living laboratory are a selection of independent buildings. Building monitoring layouts are provided in Figure 10 through Figure 14.

3.2.2.5 HVAC appliance monitoring

Separately monitoring the energy input to each HVAC appliance is essential in order to evaluate the impact of an upgrade on any single HVAC unit, and in order to aggregate the total HVAC energy load for the site.

Heating gas consumption is independently monitored in real time at each boiler / furnace. The gas utility meter data may be used as a crosscheck.

All electrical HVAC loads are individually monitored wherever it is practical to do so, including water pumps, AHU fans, supplementary AC units, wall mounted electric heaters and exhaust ventilation fans. These individual loads may then be aggregated to a room-level, building-level or site-level as required.

3.2.2.6 Room monitoring

Indoor temperature is monitored for each conditioned space as a minimum requirement for this living laboratory. This is a requirement to ensure that indoor temperature service quality remains comparable between the reporting and baseline period, and that any differences in service quality may be compensated for in the model.

IEQ sensors are located at a height of nominally 1.1m above floor level in a location that does not receive direct sunlight at any time of the day in any season, not immediately adjacent to any glazing or heating/cooling outlets, preferably not on an external wall.

Similar to the building-level monitoring, some HVAC systems service individual rooms; for example: supplementary AC units and wall-mounted heaters. Where these are the only HVAC service for a room (that is, there is no hydronic heating service), then HVAC upgrades may be evaluated at a room-level.

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3.2.3 Monitoring equipment details

The monitoring system design provides for remote automated access for regular (at least daily) updates of data from each sensor. An indicative sensor network diagram with physical device photos is presented in Figure 15. **Error! Reference source not found.** provides more specific technical details for each device with reference back to the monitoring equipment layout legend symbols.

A detailed list of each monitored parameter for this site is provided in

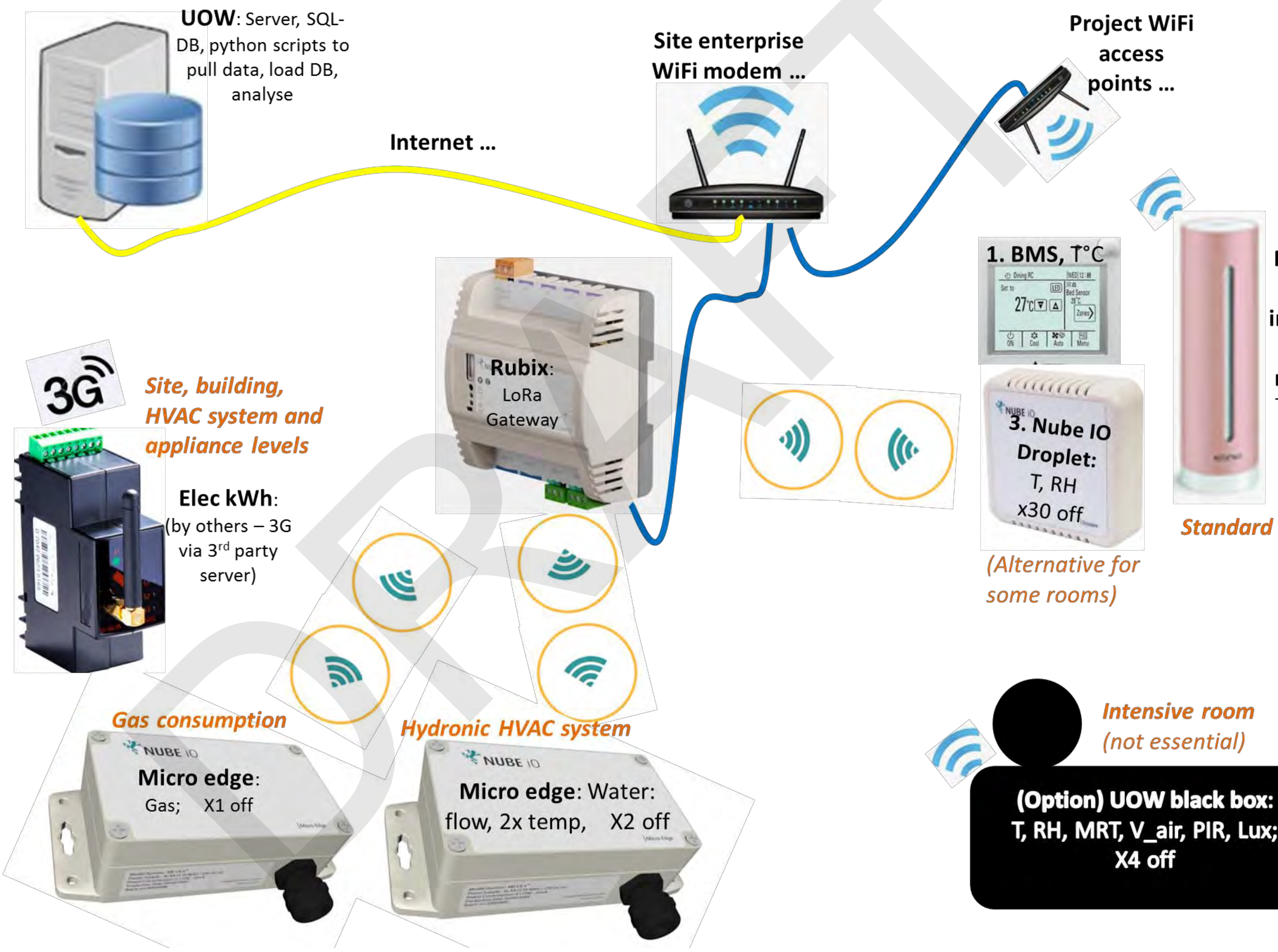

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Figure 15: Monitoring system generic network diagram with physical device photos represented.

Table 2: Monitoring device legend and details

Symbol	Device	Brand/Model	Photo	Parameters measured	Qty	Comms	Wireless range	Connection limits	Sar per
E	Electricity consumption	Wattwatchers / Auditor 6M		$E_{elec\ gross}$ (kWh - also V, A, kVA, PF, and more)	18	3G - Wattwatchers cloud - API	70 x 70 m x 3 storey building;	Unlimited devices	30 s 5 m
G	Gas consumption	Nube IO / MicroEdge		E gas site	1	LoRa private network - API	70 x 70 m x 3 storey building;	100 devices per gateway	5 m 15 … 2
Hy	Hydronic sub-sys energy	Nube IO / MicroEdge		$Q_{hyd\ A}$ $T_{hyd\ sup\ A}$ $T_{hyd\ ret\ A}$	9	LoRa private network - API	70 x 70 m x 3 storey building;	100 devices per gateway	5 m 15 … 2
IEQ	IEQ basic	Netatmo/ Smart indoor air monitor		$T_{A,B}$ $RH_{A,B}$ $CO_{2\ A,B}$ SPL	45	WiFi (enterprise WiFi issues)		Unlimited devices	5 m
T	Temperature - existing BMS			$T_{A,B}$	0				
	Weather station	Davis		T_{out} RH_{out} GHI V_{wind} Dir_{wind} Rain $PM\ 2\ 5_{out}$	1				
LoRa	Comms accessories	Nube IO / Rubix: LoRa Gateway			1			100 devices per gateway	

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Table 3. This list is generated from the HVAC equipment asset register, as well as the REETSEF parameter list. This parameter-based listing is converted to a monitoring device listing using the monitoring device information in

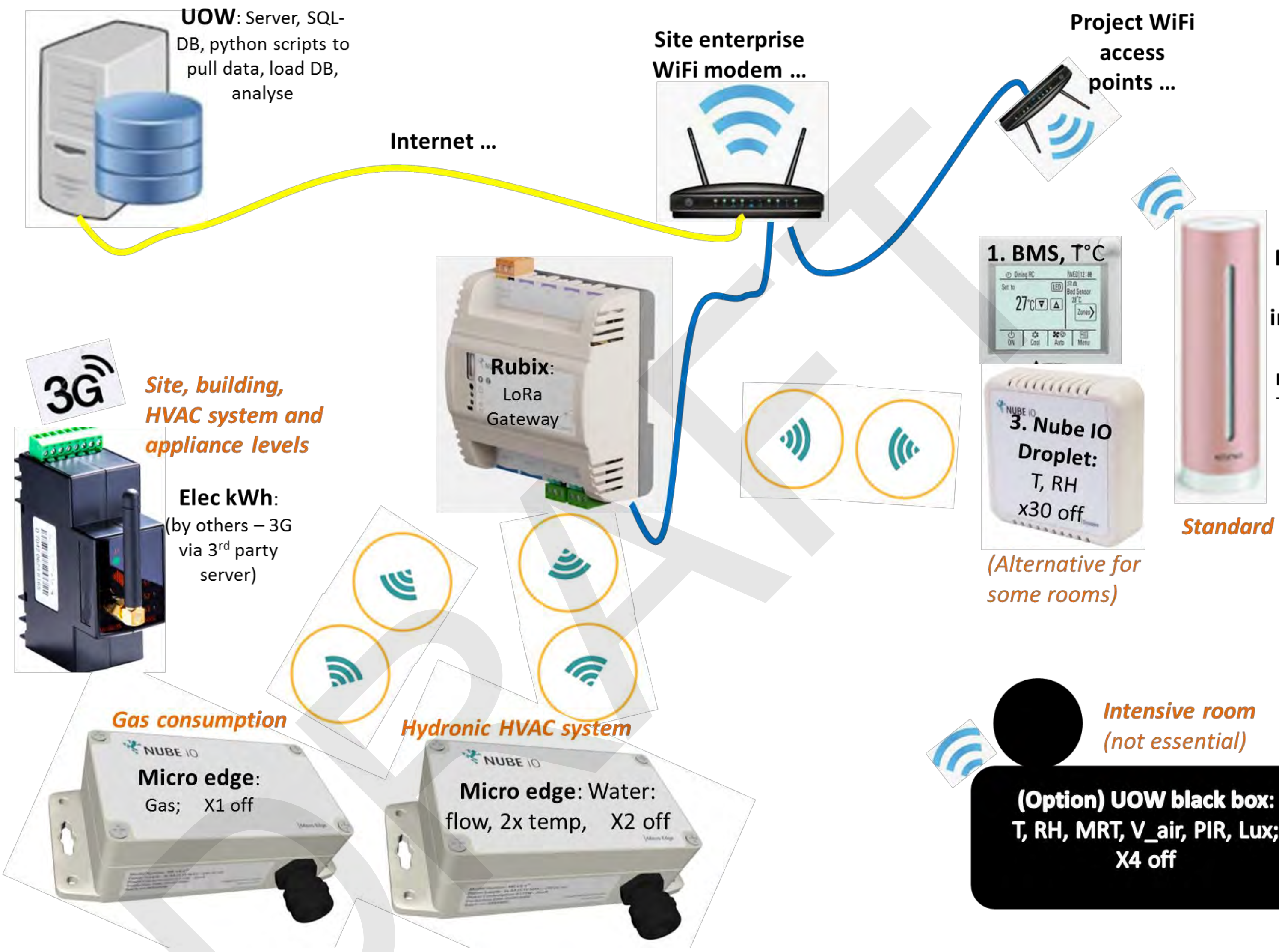

Figure 15: Monitoring system generic network diagram with physical device photos represented.

Table 2: Monitoring device legend and details

Symbol	Device	Brand/Model	Photo	Parameters measured	Qty	Comms	Wireless range	Connection limits	Sar per
E	Electricity consumption	Wattwatchers / Auditor 6M		$E_{elec\ gross}$ (kWh - also V, A, kVA, PF, and more)	18	3G - Wattwatchers cloud - API	70 x 70 m x 3 storey building;	Unlimited devices	30 5 m
G	Gas consumption	Nube IO / MicroEdge		E gas site	1	LoRa private network - API	70 x 70 m x 3 storey building;	100 devices per gateway	5 m 15 … 2
Hy	Hydronic sub-sys energy	Nube IO / MicroEdge		$Q_{hyd\ A}$ $T_{hyd\ sup\ A}$ $T_{hyd\ ret\ A}$	9	LoRa private network - API	70 x 70 m x 3 storey building;	100 devices per gateway	5 m 15 … 2
IEQ	IEQ basic	Netatmo/ Smart indoor air monitor		$T_{A,B}$ $RH_{A,B}$ $CO_{2\ A,B}$ SPL	45	WiFi (enterprise WiFi issues)		Unlimited devices	5 m
T	Temperature - existing BMS			$T_{A,B}$	0				
	Weather station	Davis		T_{out} RH_{out} GHI V_{wind} Dir_{wind} Rain PM 2 5 $_{out}$	1				
LoRa	Comms accessories	Nube IO / Rubix: LoRa Gateway			1			100 devices per gateway	

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Table 3, as presented in Table 4, with locations and quantities of each device.

Further details of each particular monitoring device are included below.

3.2.3.1 Electricity consumption

Each Auditor-6M has six channels, which may be configured variously to monitor:

- 3 phase gross consumption + 3 phase gross PV generation
- 3 phase load + 3 off single phase loads in a switchboard
- 6 off single phase loads

Many of these devices may be located in one switchboard.

The Wattwatchers devices have 3G SIM cards installed with an annual subscription fee for this service per device.

3.2.3.2 Gas consumption

Gas consumption is monitored using a gas meter with a pulse output in conjunction with a pulse input counter.

3.2.3.3 Hydronic heating sub-system energy consumption

The Nube IO MicroEdge incorporates three additional universal inputs. Two of these inputs have been configured for external temperature sensors, while the pulse input reads hydronic water flow through each air-handling unit.

3.2.3.4 IEQ sensor

A combination of Nube IO and Elsys ERS CO2 (IoT) sensors (Figure 15) are installed in every conditioned space within the living laboratory measurement boundary and communicate over the LoRa wireless IoT network designed for very low power, long battery life sensors with reasonably high range wireless transmission range. The Elsys ERS CO2 are configured to us the public LoRaWAN network and protocol, whereas, the Nube IO sensors employ the private LoRa RAW proprietary network. Both communicate to a central gateway installed on site via respective LoRaWAN chipsets.

⚠ **Warning!** The Elsys sensors use two 3.6V Lithium Thionyl Chloride batteries in an AA sized package, but with a very different chemistry and voltage to standard/alkaline 1.5V AA cells. These batteries are a very high energy density battery and should be handled with care by trained personnel.

IEQ detailed sensors are located at a height of nominally 1.1m above floor level in a location that does not receive direct sunlight at any time of the day in any season, not immediately adjacent to any glazing or heating/cooling outlets, preferably not on an external wall.

The Netatmo Smart Indoor Air Quality Monitor may be used as an alternative IEQ sensor including a CO_2 sensor where the LoRa wireless signal strength may be problematic.

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Warning! The Netatmo devices do not have any battery back up and do not store any data on-board. In order to maintain data continuity these devices must remain plugged into a dedicated GPO at all times, and remain connected to the local WiFi network.

3.2.3.5 BMS temperature sensor

The advent of the COVID-19 crisis forced the living laboratory design to consider more carefully what existing sensors may be adequate, if site access was made unavailable for the baseline period.

A Carrier brand central BMS serves the whole original school site with comprehensive monitoring and control implemented, including room temperature measurement in many rooms serviced by the central heating system. Many of the BMS sensors may serve as monitoring devices for the current project; however, site calibration will be required to establish this capability.

3.2.3.6 Weather station

A Davis Pro weather station and data logger are installed on site (see Figure 9) to collect localised weather data for the living laboratory.

Figure 8: Davis Pro weather station.

3.2.3.7 Communications accessories

The Nube IO Rubix Compute is a LoRa hub and gateway for the (IoT) sensors. The LoRa wireless network is designed for very low power and long battery life sensors with reasonably high range wireless transmission with excellent penetration through walls. The Nube iO sensors are not configured for the public LoRaWAN network and protocol, but are on a private LoRa RAW proprietary network with gateway(s) installed on site. The Elsys sensors use the same LoRa gateway, but via the additional LoRaWAN chipset.

The Netatmo IEQ devices may not be able to manage communications direct into an enterprise WiFi access point with all the security capabilities and requirements. In this case, additional home-style WiFi access points will be installed to provide coverage around the site with WiFi or LAN connection into the enterprise network.

3.2.4 Static data collection

The list of static data parameters required to determine the KPIs are listed in Table 5. This static data record should be completed during the initial site audit and may be repeated periodically during site visits as appropriate.

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3.2.5 Monitoring equipment layouts and lists

The following pages constitute the package of schematics and tabled lists of monitoring systems, including:

- Device location plans (see Figure 9 to Figure 14)
- Monitoring parameter list (Table 2)
- Monitoring device list (Table 4)
- Static data collection list (Table 5)

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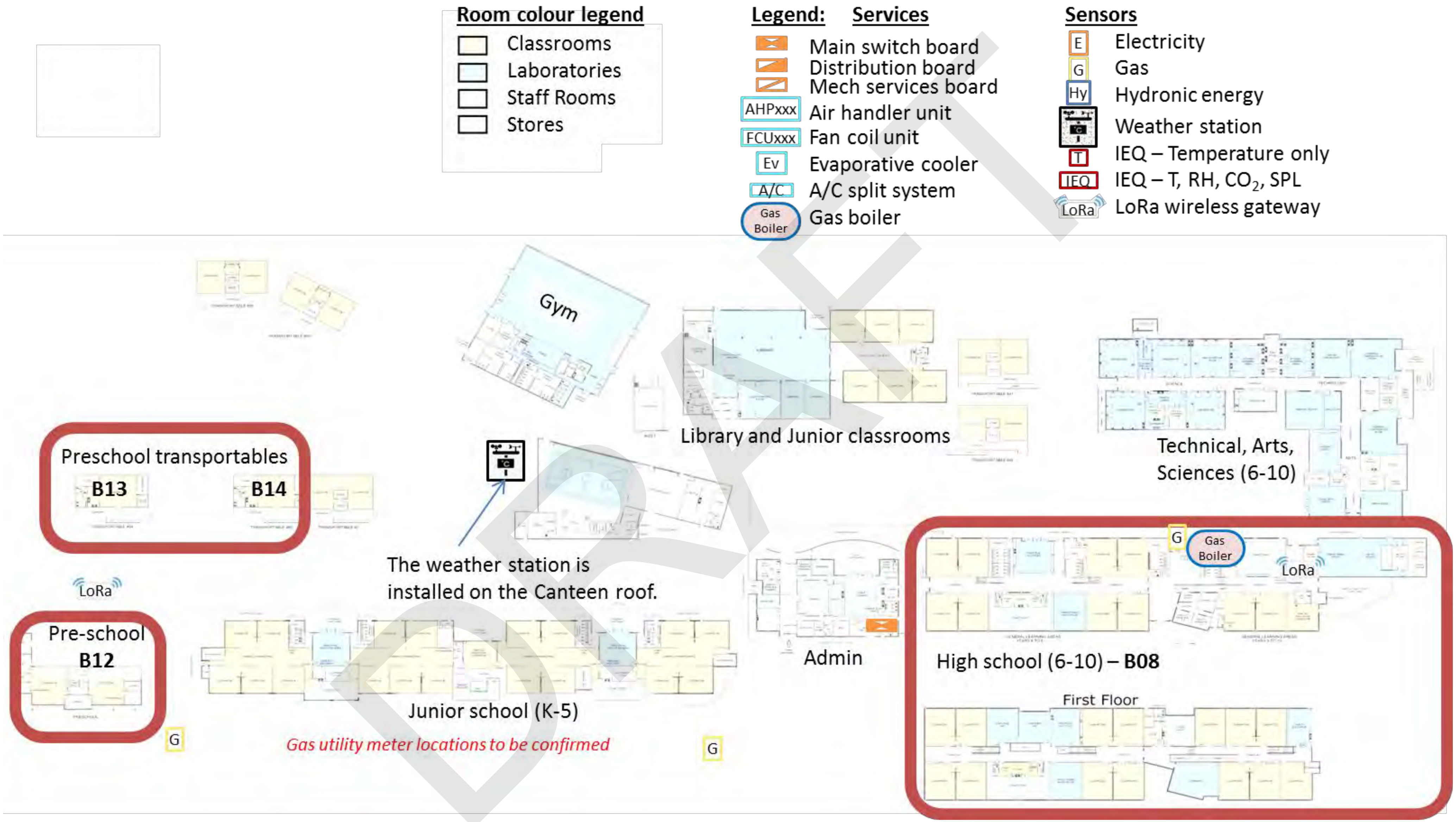

Figure 9: Amaroo School site metering and monitoring layout

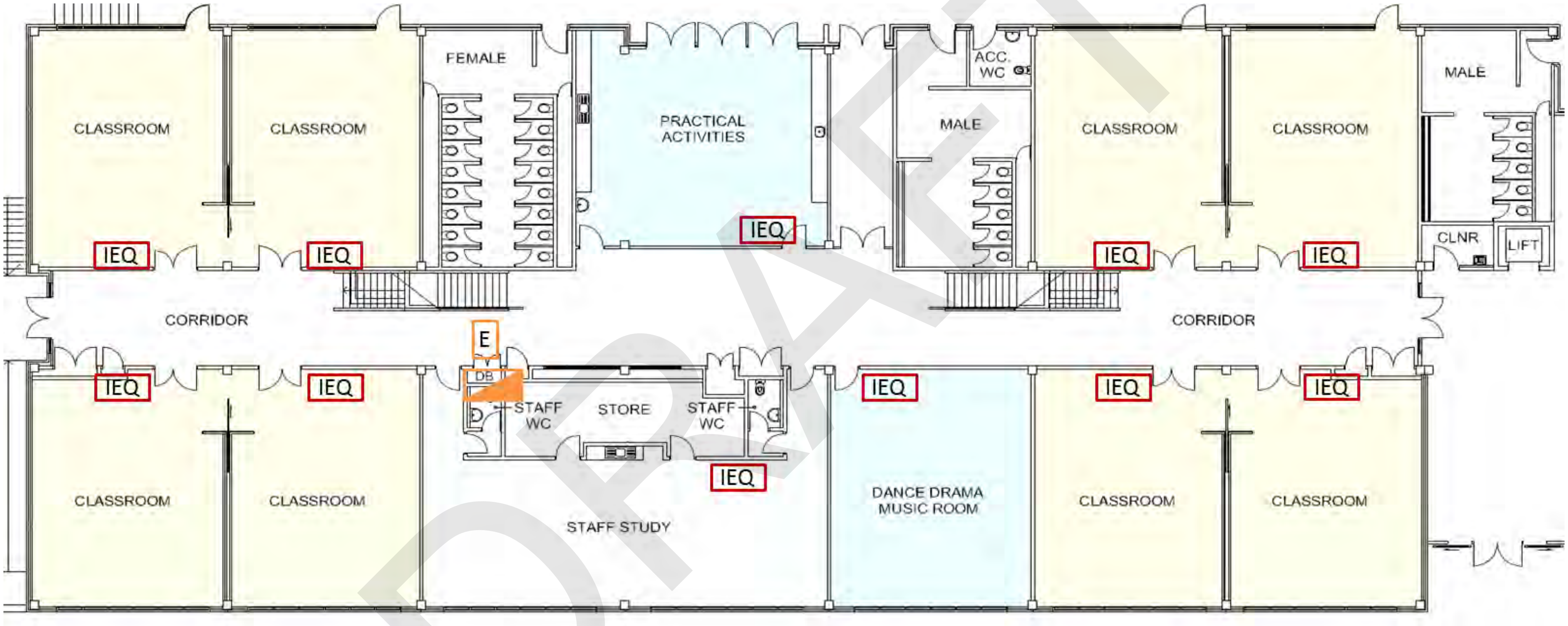

Figure 10: B08 - High school – years 6 to 8 ground floor west -- monitoring layout

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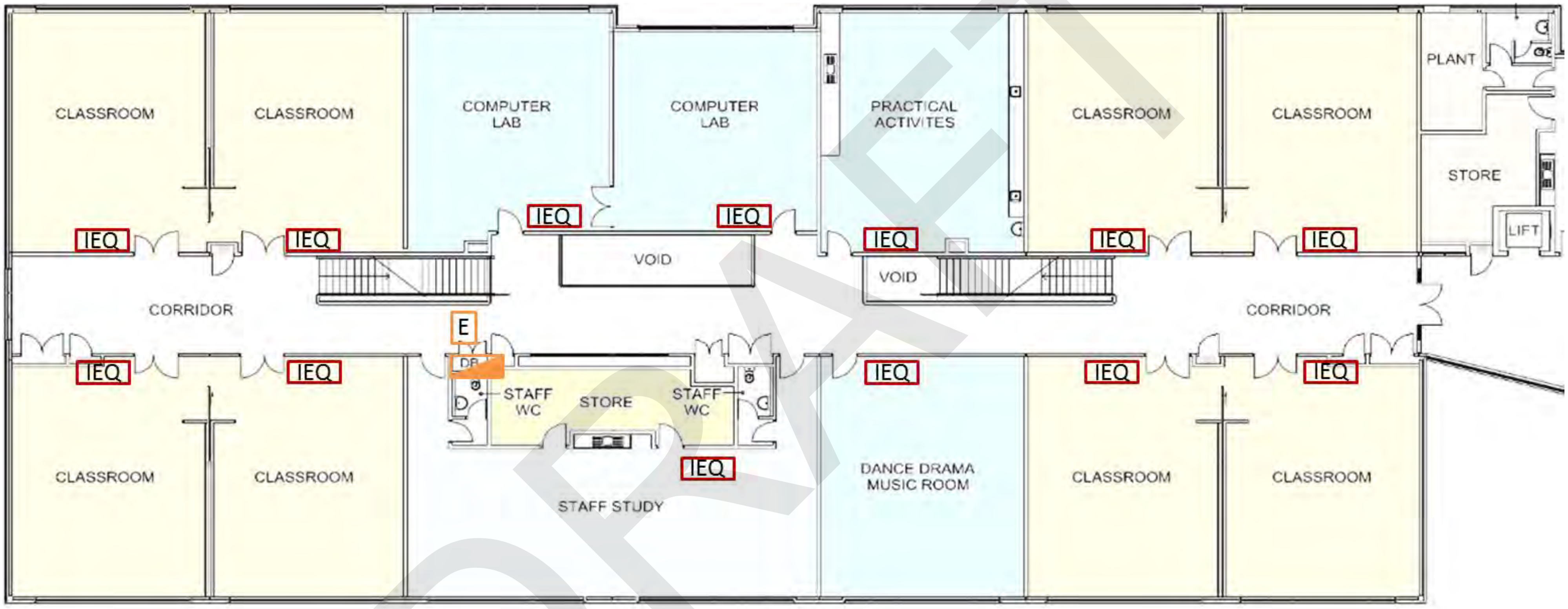

Figure 11: B08 - High school – years 6 to 8 first floor west -- monitoring layout.

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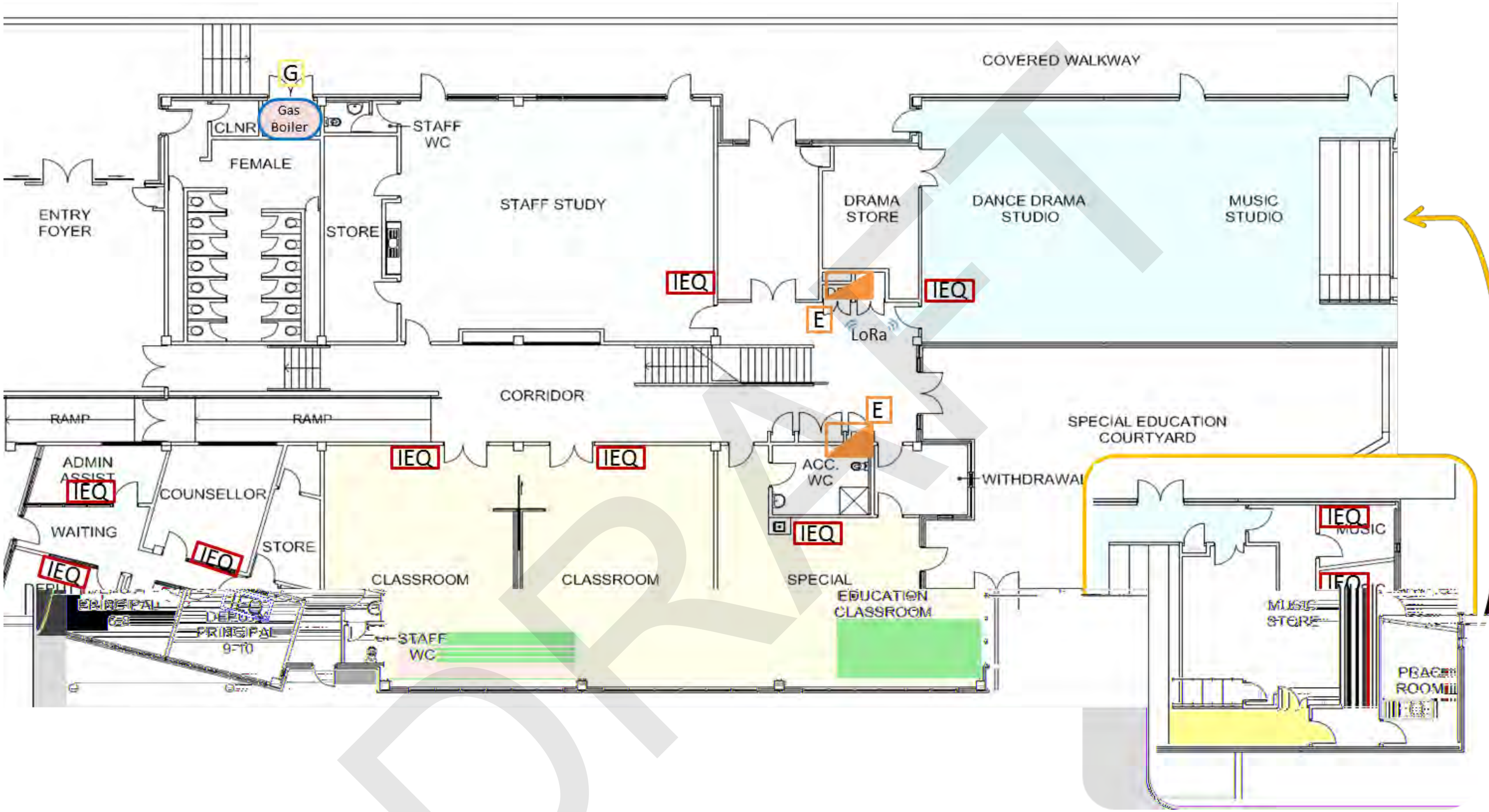

Figure 12: B08 - High school – years 9 to 10 ground floor east -- monitoring layout

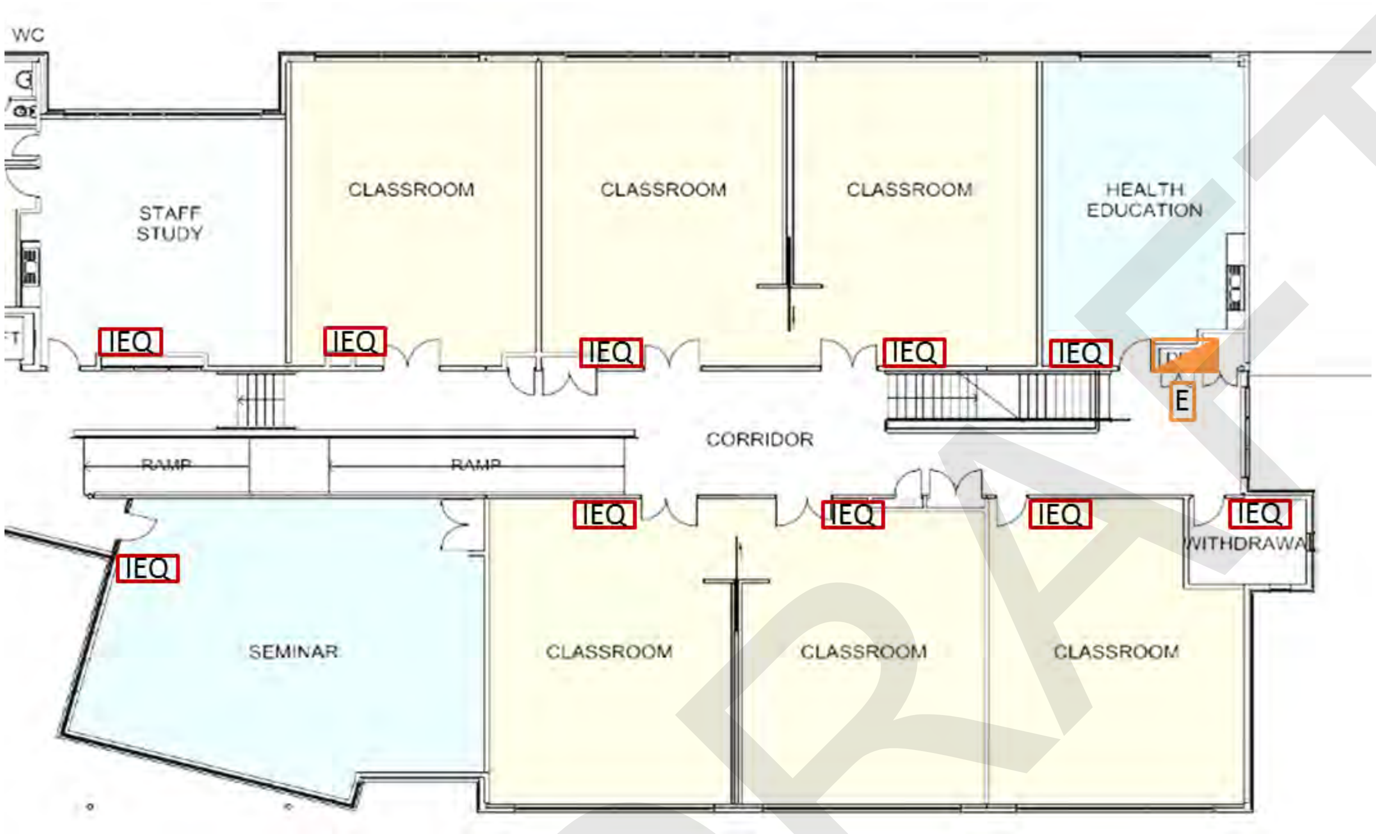

Figure 13: B08 - High school – years 9 to 10 first floor east -- monitoring layout

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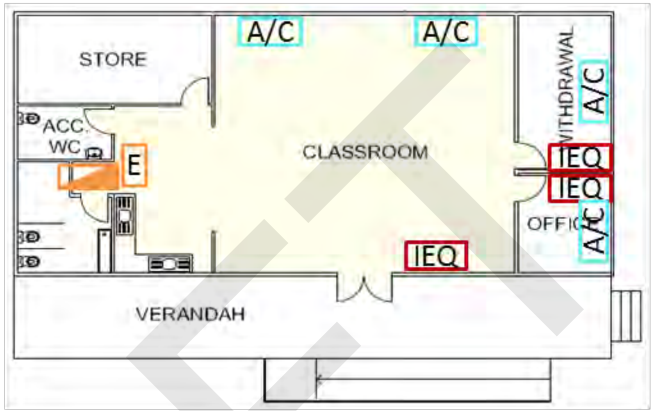
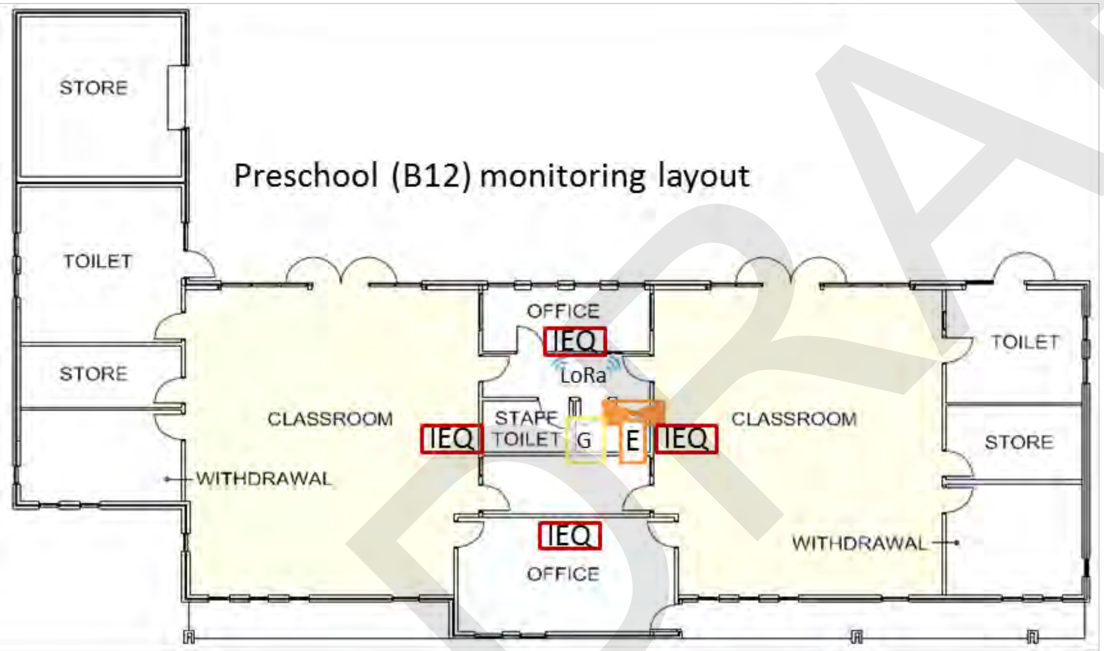
Preschool transportables (B13, B14) monitoring layout





Gas meter locations to be confirmed G

Figure 14: Amaroo preschool monitoring layout.

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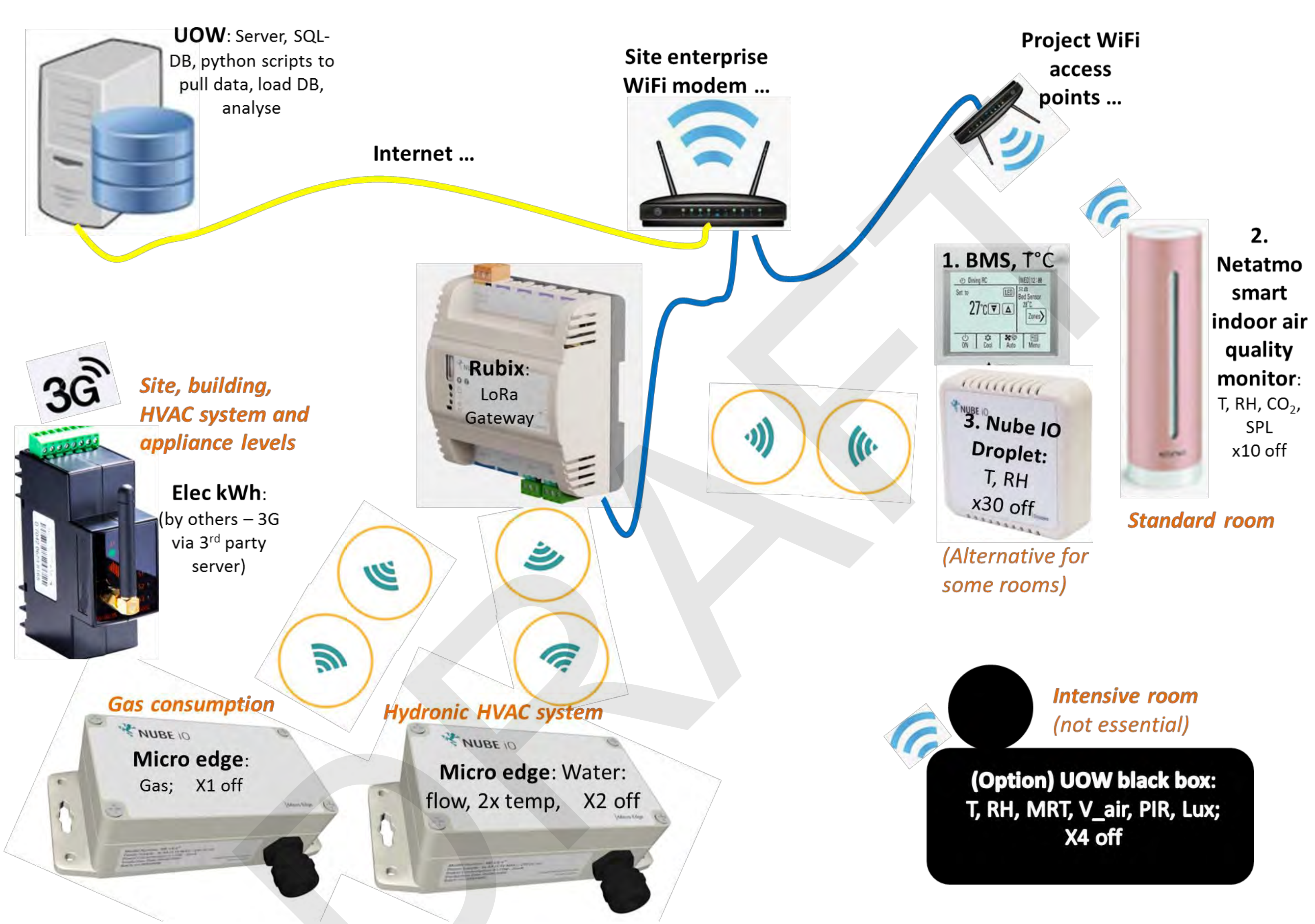

Figure 15: Monitoring system generic network diagram with physical device photos represented.

Table 2: Monitoring device legend and details

Symbol	Device	Brand/Model	Photo	Parameters measured	Qty	Comms	Wireless range	Connection limits	Sample period	Battery life or power	Comments, accessories required
E	Electricity consumption	Wattwatchers / Auditor 6M		$E_{elec\ gross}$ (kWh - also V, A, kVA, PF, and more)	18	3G - Wattwatchers cloud - API	70 x 70 m x 3 storey building;	Unlimited devices	30 sec, 5 min	Hard wired	
G	Gas consumption	Nube IO / MicroEdge		E gas site	1	LoRa private network - API	70 x 70 m x 3 storey building;	100 devices per gateway	5 min, 15 min, … 24 h	5+ year battery	Rubix LoRa Gateway; Gas meter with pulse output
Hy	Hydronic sub-sys energy	Nube IO / MicroEdge		$Q_{hyd\ A}$ $T_{hyd\ sup\ A}$ $T_{hyd\ ret\ A}$	9	LoRa private network - API	70 x 70 m x 3 storey building;	100 devices per gateway	5 min, 15 min, … 24 h	5+ year battery	Rubix LoRa Gateway; water meter with pulse output
IEQ	IEQ basic	Netatmo/ Smart indoor air monitor		$T_{A,B}$ $RH_{A,B}$ $CO_{2\ A,B}$ SPL	45	WiFi (enterprise WiFi issues)		Unlimited devices	5 min	Plug-in	WiFi access point
T	Temperature - existing BMS			$T_{A,B}$	0						
	Weather station	Davis		T_{out} RH_{out} GHI V_{wind} Dir_{wind} Rain PM 2 5 $_{out}$	1						
LoRa	Comms accessories	Nube IO / Rubix: LoRa Gateway			1			100 devices per gateway			

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Table 3: Amaroo monitoring list – by data parameter

Symbol	Description	Units	Quantity	Location	Sample period and remote/local
	Site monitoring				
$E_{gas\ site}$	Gas consumption for the site	*MJ*	1	Utility gas meter	5 min logger
$E_{elec\ gross}$	Electricity gross site demand	*kWh*		MSB	5 min gross logger
$E_{gas\ preschool}$	Gas consumption for the preschool site (separate meter)	*MJ*	1	Utility gas meter	5 min logger
$E_{elec\ preschool}$	Electricity gross site demand (separate meter)	*kWh*		MSB	5 min gross logger
$E_{PV\ gross}$	PV gross generation	*kWh*		MSB??	5 min logger
$E_{Wind\ gross}$	Wind turbine gross generation	*kWh*		MSB	5 min logger
T_{out}	Temperature outdoors	*°C*	1	Weather station	5 min logger
RH_{out}	Relative humidity outdoors	*%RH*	1	Weather station	5 min logger
GHI	Global Horizontal Irradiance	*W/m^2*	1	Weather station	5 min logger
V_{wind}	Wind speed	*m/s*	1	Weather station	5 min logger
Dir_{wind}	Wind direction	*Deg?*	1	Weather station	5 min logger
Rain	Rainfall	*mm*	1	Weather station	5 min logger
$PM\ 2\ 5_{out}$	Outdoor air quality - Particulate concentration	*ppm*	-	Weather station	60 min logger
	Building monitoring				
$E_{gas\ boiler\ A}$	Gas consumption for boiler ‘A’	*MJ*	2	Plant rooms	5 min logger
$E_{Building\ A}$	Building-level by DB. Spare channels for other HVAC appliances	*kWh*	5	DB	5 min logger
$E_{AC\ A,B}$	AC split system energy; spare channels on DB logger(s)	*kWh*	*5*	DB	
E_{HVAC}	Energy consumed by HVAC equipment	*kWh*	50	DB 6-10	5 min logger
$E_{FCU\ A,B}$	Fan coil unit fan energy?; use spare channels	*kWh*	*40?*	DB	BMS data
$E_{EXH\ A,B}$	Energy consumed by exhaust fan	*kWh*	*?*	DB	BMS data
$Q_{hyd\ A}$	Hydronic water flow at location ‘A’	*L*	0		Not required?
$T_{hyd\ in\ A}$	Temperature hydronic water supply for space ‘A’	*°C*	0		Not required?
$T_{hyd\ in\ A}$	Temperature hydronic water supply for space ‘A’	*°C*	0		Not required?
	Room-indoor monitoring				
$T_{A,B}$	Temperature indoors for building ‘A’, room ‘B’	*°C*	70		5 min logger
$RH_{A,B}$	Relative humidity indoors, building ‘A’, room ‘B’	*%RH*	70		5 min logger
$CO_{2\ A,B}$	Carbon dioxide concentration indoors	*ppm*	70	Case study rooms	5 min logger
SPL	Sound pressure level	*dBA*	70		None planned

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Table 4: Amaroo monitoring list - by device.

Device	Model	Configuration	Quantity	Location
Site monitoring				
Gas consumption			*1*	Boiler room
Electricity consumption		1,2,3-Demand, 4,5,6-PV	*1*	Main switch board (MSB)
Weather station			*1*	Canteen roof
Comms accessories			*3*	
High School (B08)				
Electricity consumption		WW1: 1-Total, 2-AC, 3-AC, 4-AC, 5-AC, 6-AC; WW2: 1-Boiler pump, 2-AC, 3-AC, 4-AC, 5-AC, 6-AC	*8*	DB at each end of each floor
Temperature - existing BMS			*46*	
IEQ basic			*12*	
Preschool (B12, B13, B14)				
Electricity consumption		1-Total, 2-AC1, 3-AC2, 4-, 5-, 6-Fans?	*1*	Elec distrib'n board (DB)
IEQ basic			*10*	
Temperature - existing BMS			*4*	
TOTALS				
Electricity consumption			**10**	
Gas consumption			**1**	
Hydronic sub-sys energy			**0**	
IEQ basic			**22**	
IEQ detailed			**0**	
Temperature - existing BMS			**50**	
Weather station			**1**	
Comms accessories			**3**	

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Table 5: Static data parameter list – Amaroo and Fadden.

Parameter description	Category	Site	Building	HVAC system	Room - standard	Room - intensive	Data collection frequency	Sampling period	Comment
Air speed - indoor - spot meas't	IEQ					x	Spot meas	Once	
Floor area - gross - total site	Normalising parameters	x					Static	Once	
Floor area - gross - total site - conditioned	Normalising parameters	x					Static	Once	
Floor area - gross - per meas't boundary	Normalising parameters			x			Static	Once	
Floor area - gross - per meas't boundary - conditioned	Normalising parameters			x			Static	Once	
Student population (census date) - by year	Normalising parameters	x					Static	12 months	
School event calendar - by year	Occupancy	x					Survey	12 months	School-specific pupil-free days, carnivals, etc.
School weekly schedule - by year	Occupancy	x					Survey	12 months	
School daily schedule - by year	Occupancy	x					Survey	12 months	
Occupancy survey	Occupancy					x	Survey	3 months	By monitored classroom periodically
POE	Occupancy				x	x	Survey	Before/Afte	
Extreme weather events	Occupancy	x					Survey	3 months	Bushfire, storm - potential impact on PV and occupancy
Building and equipment changes	Static factors		x			x	Survey	3 months	Shading, insulation, draught sealing, fenstration, lighting
HVAC equipment maintenance and fault logs	Static factors			x			Survey	3 months	
HVAC equipment list for demand response potential	Static factors	x					Survey	Before/Afte	
Energy tariff information	Static factors	x					Survey	12 months	

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4 Living Laboratory Description — Venue 2 – Fadden Primary School

4.1 Facilities description

4.1.1 Physical buildings

Fadden Primary School was opened in 1984 with a gross floor area of 3,283 m^2. The classrooms are arranged in four essentially identical ‘learning pods’, each consisting of four classrooms, an art room, a quiet room and a staff room. The naming of the buildings is as follows:

- B1 – Kurringai learning pod
- B2 – Murramarang learning pod
- B3 – Daintree learning pod
- B4 – Uluru learning pod
- B5 – Administration, library, special learning areas, canteen, services and hall

4.1.2 HVAC system

Fadden Primary School HVAC design is based upon the original central boiler for the site, which hydronically distributes heat to heating-only air handling units in each building. No mechanical cooling was provided in the original design and a progression of stand-alone cooling systems are now installed across the site. An outline of the mechanical services zoning is illustrated in Figure 20.

4.1.2.1 Heating

Heating is supplied from the original central boiler, which has been converted from oil to natural gas, but has otherwise received minimal capital expenditure. The boiler plant has now well exceeded the lifecycle expectation of 30 years (ACT Government, 2017) with multiple single points of failure posing a high operational security risk to the school.

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Figure 16: Central boiler and hydronic recirculation pump serving the Fadden Primary School site.

The hydronic heating is recirculated to heating-only air handling units in each block with locations indicated in Figure 21. Individual control is provided to regulate the heating for each area. The air-handling units are installed in plant rooms on mezzanine floors. Figure 17 shows two such air-handling units at the school.

Figure 17: Air handling units: a) A typical original air-handling units serving the learning pods mounted above the entry foyer; b) A recently replaced air-handling unit.

In addition to the hydronic-heating infrastructure, some non-teaching areas have standalone electric wall heaters installed from the 1980s through to the early 2000s. These heaters have no connection to a centralised controller.

4.1.2.2 Ventilation

Classrooms are furnished with openable windows for natural ventilation. However, the heating-only air-handling units were more commonly used for forced ventilation, which in summer would introduce warmer ambient air to the indoor spaces.

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The original specialised supplementary exhaust systems provided in the general-purpose hall, library and audio-visual room remain operational.

4.1.2.3 Cooling

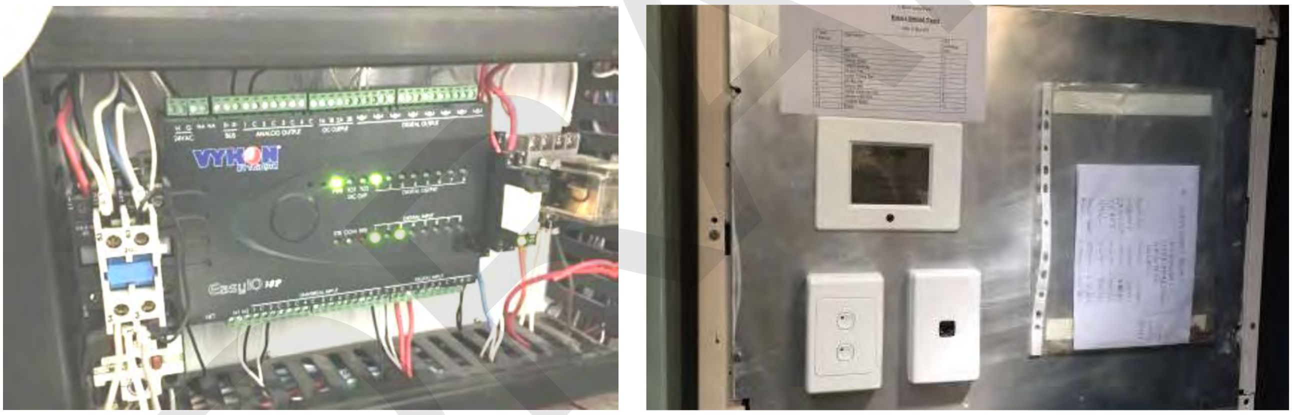
There was no provision for mechanical cooling in the original construction. The last decade has seen the progressive rollout of evaporative coolers in learning areas, and split system reverse cycle air conditioning units in staff rooms and special learning areas.

4.1.3 Control systems

The site has three separate building management control systems installed. An Easy IO BMS serves a part of the school services providing the most functionality. The Satchwell BMS system and C-bus lighting control system used for only very basic HVAC control.

The original mechanical services switchboards still provide basic control and indication.

The various evaporative cooling and supplementary air conditioning units are individually controlled from the proprietary wall mounted controllers and are not integrated into any of the centralised control systems for the school.



(a) (b)

Figure 18: Building management control systems installed: (a) Easy IO BMS, and (b) the C-bus lighting control system.

4.1.4 Renewable energy systems

An array of solar panels is installed on the roof of B1 (Figure 19).

4.2 Living Laboratory description

The schematics and lists, as presented in the figures on pages 4931 to 57 comprise the primary documentation for the real time monitoring system, with some supplementary explanatory notes included below.

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4.2.1 Metering

The locations of the energy utility meters for the site are indicated in Figure 19.

The smart electricity utility meter is located in the Main Switch Board in the Administration block. The total site consumption and solar PV system are gross metered at 15-minute interval with data remotely accessed from the ACT Education Envizi dashboard.

The gas utility meter is located in an enclosure on the site boundary northeast of the hall. This meter is manually recorded on a monthly basis and manually provided by ACT Education Directorate.

4.2.2 Measurement Boundaries

The measurement boundary of the living laboratory for Fadden Primary School encompasses the whole primary school, as depicted in Figure 19. The separately metered and distinct preschool on an adjacent site is excluded. This site boundary was selected due to the central boiler serving the whole site and the monitoring budget allowed for this scope.

The measurement boundary for this whole site may be further sub-divided, to facilitate a range of potential technology upgrade evaluations, and may be usefully considered as four levels of monitoring, with reference to Table 6.

4.2.2.1 Site monitoring

Site monitoring is an essential requirement in order to evaluate the impact of HVAC technology upgrades upon the renewable generation at the site level. Site monitoring will also be useful in this living laboratory to directly evaluate any technology upgrade to the central gas boiler system. Site metering and monitoring layout is provided in Figure 21. Gross energy consumption (electricity and gas) and generation are measured at the utility meters, and external weather conditions are measured on site.

4.2.2.2 Building monitoring

Building monitoring layouts are provided in Figure 22 through Figure 25.

Where ad hoc combinations of hydronic heating, supplementary air conditioning units, evaporative cooling units and wall mounted electric heaters are installed within a building, with minimal central monitoring or control, the interactions between the various HVAC systems will be unavoidable. This requires that the measurement boundary for potential technology upgrades of such HVAC equipment must be at the building level.

This building level monitoring may be especially useful for evaluating HVAC technology upgrades in the Administration, Hall, Library block (B5), where the most complex combinations of HVAC equipment are to be found. This building monitoring would also allow the evaluation of an upgrade to a single building, such as a heating and cooling air handler unit in one of the learning pods.

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Hydronic heating load measurement for each building is achieved by measuring the hydronic water supply and return temperatures as well as the water flow through each air handler unit. The AHUs are located in mezzanine plant rooms, and the hydronic sub-system sensor units are installed in these plant rooms.

Electricity sensors are typically installed in the electrical switchboards, distribution boards and mechanical services switch boards. There is generally one electrical distribution board per building as well as the separate mechanical services switchboards.

4.2.2.3 HVAC appliance monitoring

Separately monitoring the energy input to each HVAC appliance is essential in order to evaluate the impact of an upgrade on any single HVAC unit, and in order to aggregate the total HVAC energy load for the site.

Heating gas consumption is independently monitored in real time at the boiler (Figure 25). The gas utility meter data may be used as a crosscheck.

All electrical HVAC loads are individually monitored wherever it is practical to do so, including water pumps, AHU fans, supplementary AC units, evaporative cooling units, wall mounted electric heaters and exhaust ventilation fans, as listed in Table 6. These individual loads may then be aggregated to a room-level, building-level or site-level as required.

4.2.2.4 Room monitoring

Room monitoring layouts are provided in Figure 22 through Figure 25.

Indoor temperature is monitored for each conditioned space as a minimum requirement for this living laboratory. This is a requirement to ensure that indoor temperature service quality remains comparable between the reporting and baseline period, and that any differences is service quality may be compensated for in the model.

IEQ sensors are located at a height of nominally 1.1m above floor level in a location that does not receive direct sunlight at any time of the day in any season, not immediately adjacent to any glazing or heating/cooling outlets, preferably not on an external wall.

Similar to the building-level monitoring, some HVAC systems service individual rooms; for example: supplementary AC units, evaporative cooling units and wall-mounted heaters. Where these are the only HVAC service for a room (that is, there is no hydronic heating service), then HVAC upgrades may be evaluated at a room-level.

4.2.3 Monitoring equipment details

The monitoring system design provides for remote automated access for regular (at least daily) updates of data from each sensor. An indicative sensor network diagram with physical device photos is presented in Figure 15. **Error! Reference source not found.** provides more specific

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technical details for each device with reference back to the monitoring equipment layout legend symbols.

A detailed list of each monitored parameter for this site is provided in Table 6. This list is generated from the HVAC equipment asset register, as well as the REETSEF parameter list. This parameter-based listing is converted to a monitoring device listing using the monitoring device information in **Error! Reference source not found.**, as presented in Table 7: Fadden monitoring list - by device, with locations and quantities of each device.

Further details of each particular monitoring device are included below.

4.2.3.1 Electricity consumption

Each Auditor-6M has six channels, which may be configured variously to monitor:

- 3 phase gross consumption + 3 phase gross PV generation
- 3 phase load + 3 off single phase loads in a switchboard
- 6 off single phase loads

Many of these devices may be located in one switchboard.

The Wattwatchers devices have 3G SIM cards installed with an annual subscription fee for this service per device.

4.2.3.2 Gas consumption

Gas consumption is monitored using a gas meter with a pulse output in conjunction with a pulse input counter.

4.2.3.3 Hydronic heating sub-system energy consumption

The Nube IO MicroEdge incorporates three additional universal inputs. Two of these inputs have been configured for external temperature sensors, while the pulse input reads hydronic water flow through each air-handling unit.

4.2.3.4 IEQ sensor

Similarly, the IEQ sensors selected for the Fadden living laboratory are the same as selected for Amaroo. More detail can be found in Section 3.2.3.4.

4.2.3.5 BMS temperature sensor

The advent of the COVID-19 crisis has forced the living laboratory design to consider more carefully what existing sensors may be adequate, if site access was made unavailable for the baseline period. The very low level of BMS automation at Fadden does not offer any notable opportunities with existing BMS data.

4.2.3.6 Weather station

A Davis Pro weather station (Figure 8) and data logger are installed on site (Figure 21) to collect localised weather data for the living laboratory.

4.2.3.7 Communications accessories

Similarly, the communications accessories selected for the Fadden living laboratory are the same as selected for Amaroo. More detail can be found in Section 3.2.3.7.

4.2.4 Static data collection

The list of static data parameters required to determine the KPIs are listed in Table 5. This static data collection should be completed during the initial site audit and should be repeated periodically during site visits as indicated in the table.

4.2.5 Monitoring equipment layouts and lists

The following pages constitute the package of schematics and tabled lists of monitoring systems, including:

- Device location plans (see Figure 19 to Figure 25)
- Monitoring parameter list (Table 6)
- Monitoring device list (Table 7)
- Static data collection list (identical to Amaroo, see Table 5)

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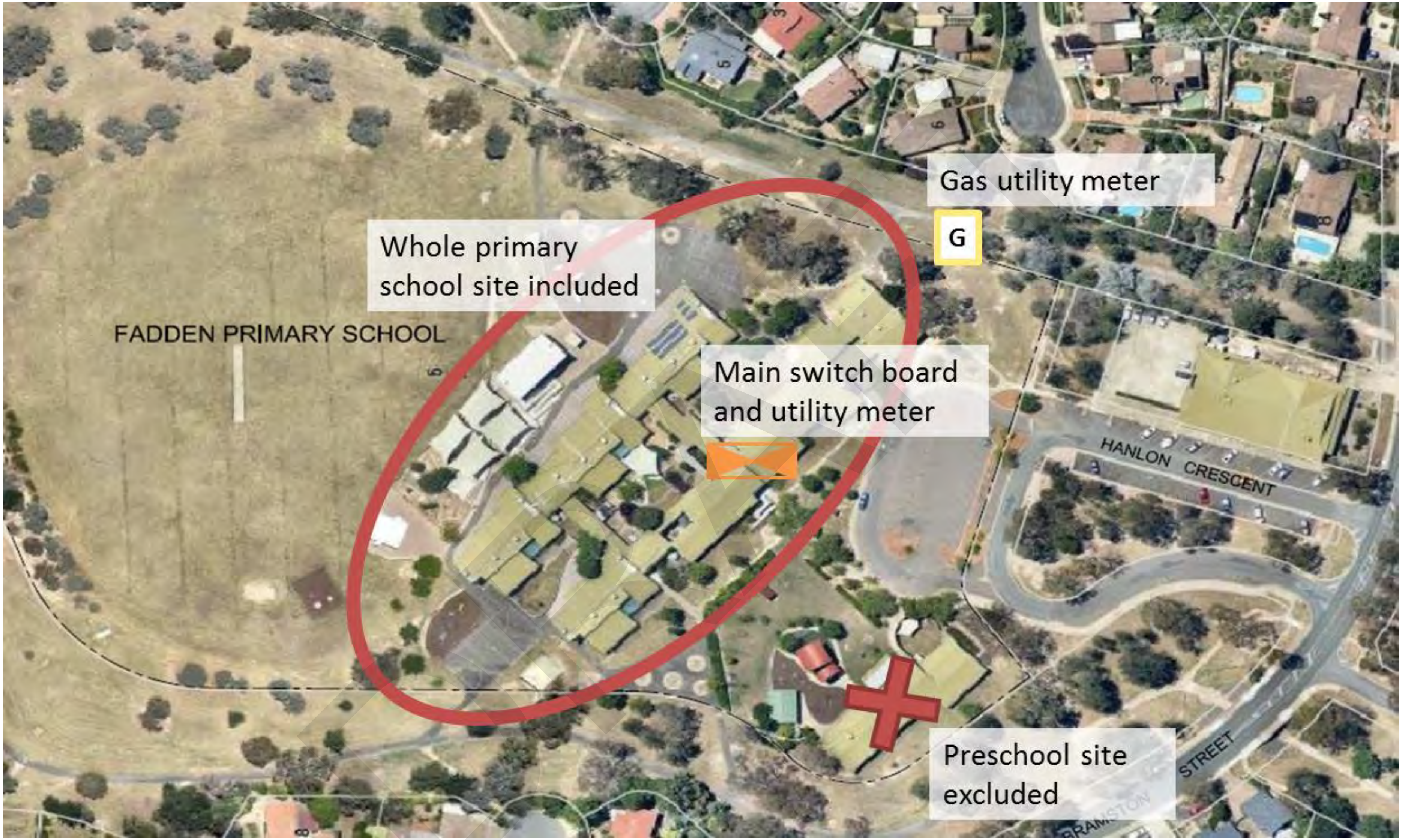

Figure 19: Fadden Primary School living laboratory measurement boundary.

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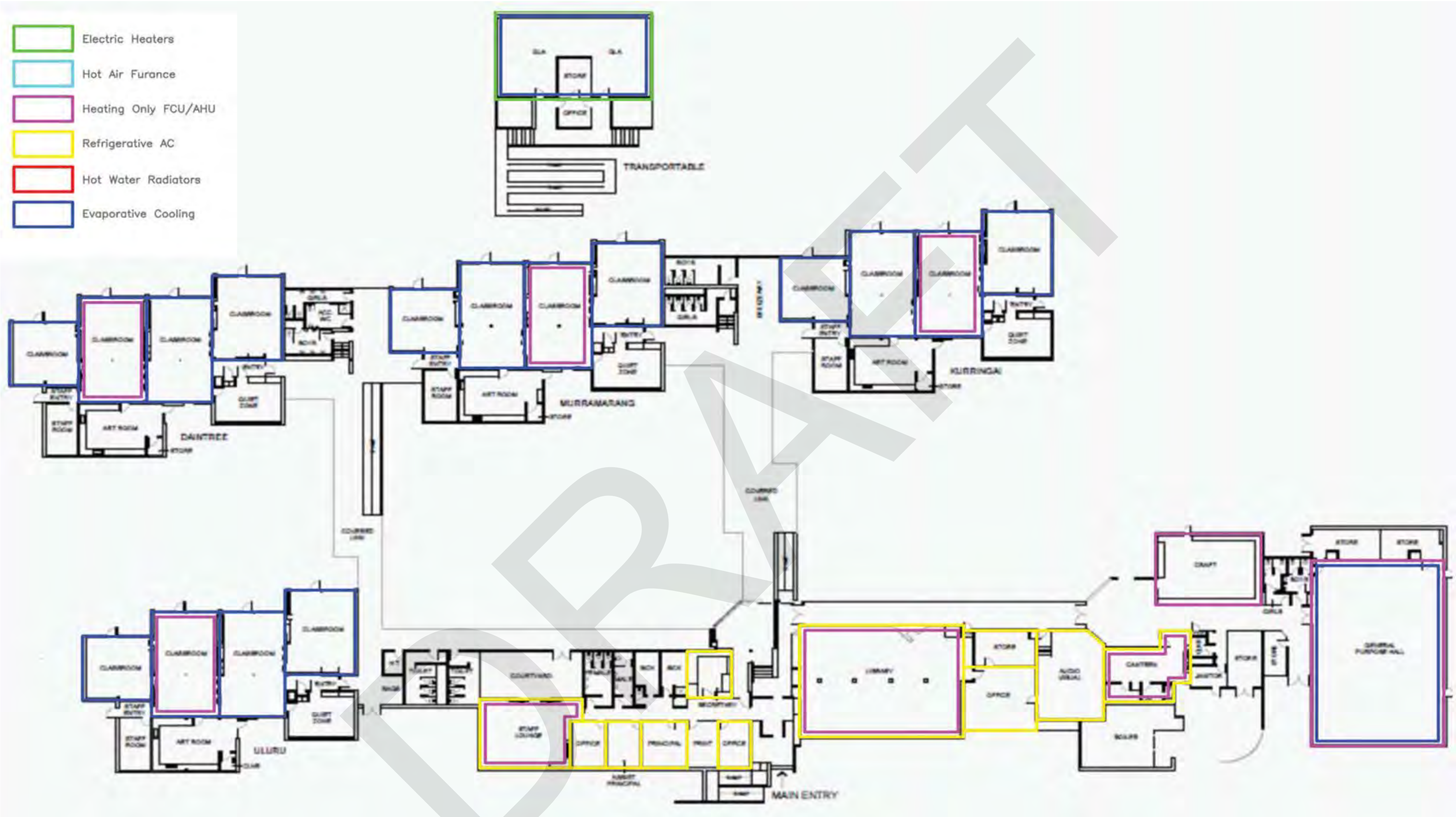

Figure 20: Fadden mechanical services zone drawing (ACT Government, 2017)

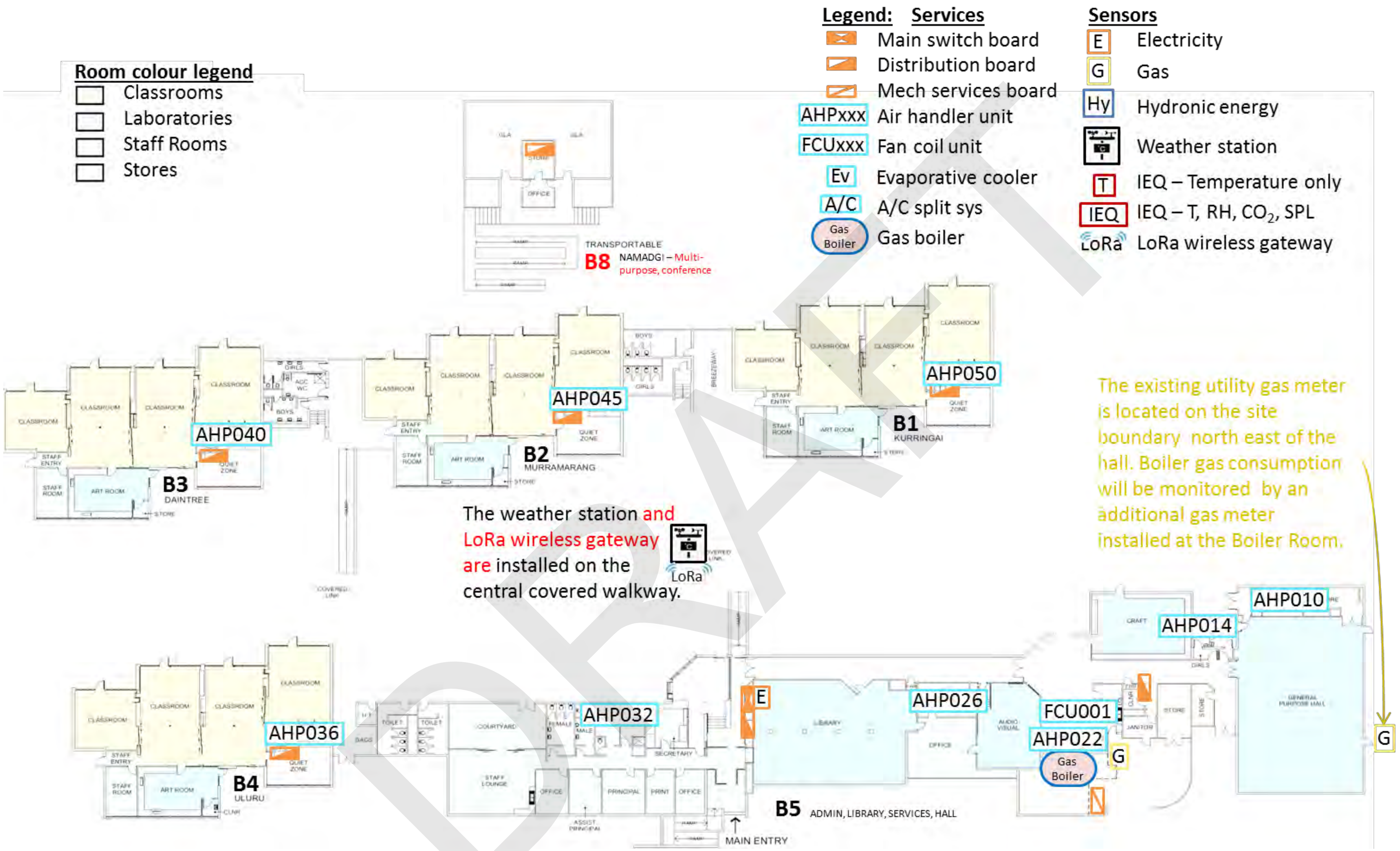

Figure 21: Fadden Primary School site metering and monitoring layout

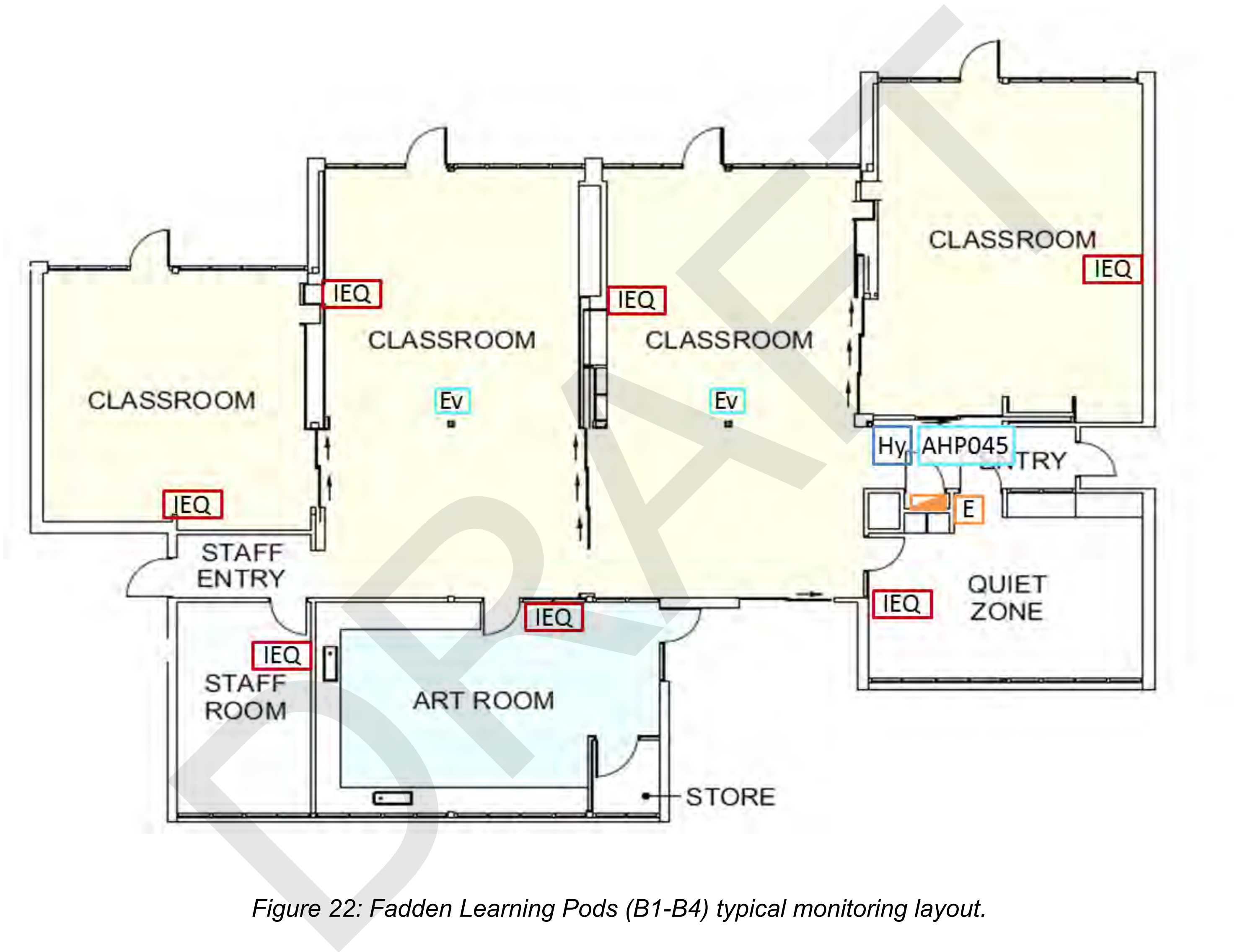

Figure 22: Fadden Learning Pods (B1-B4) typical monitoring layout.

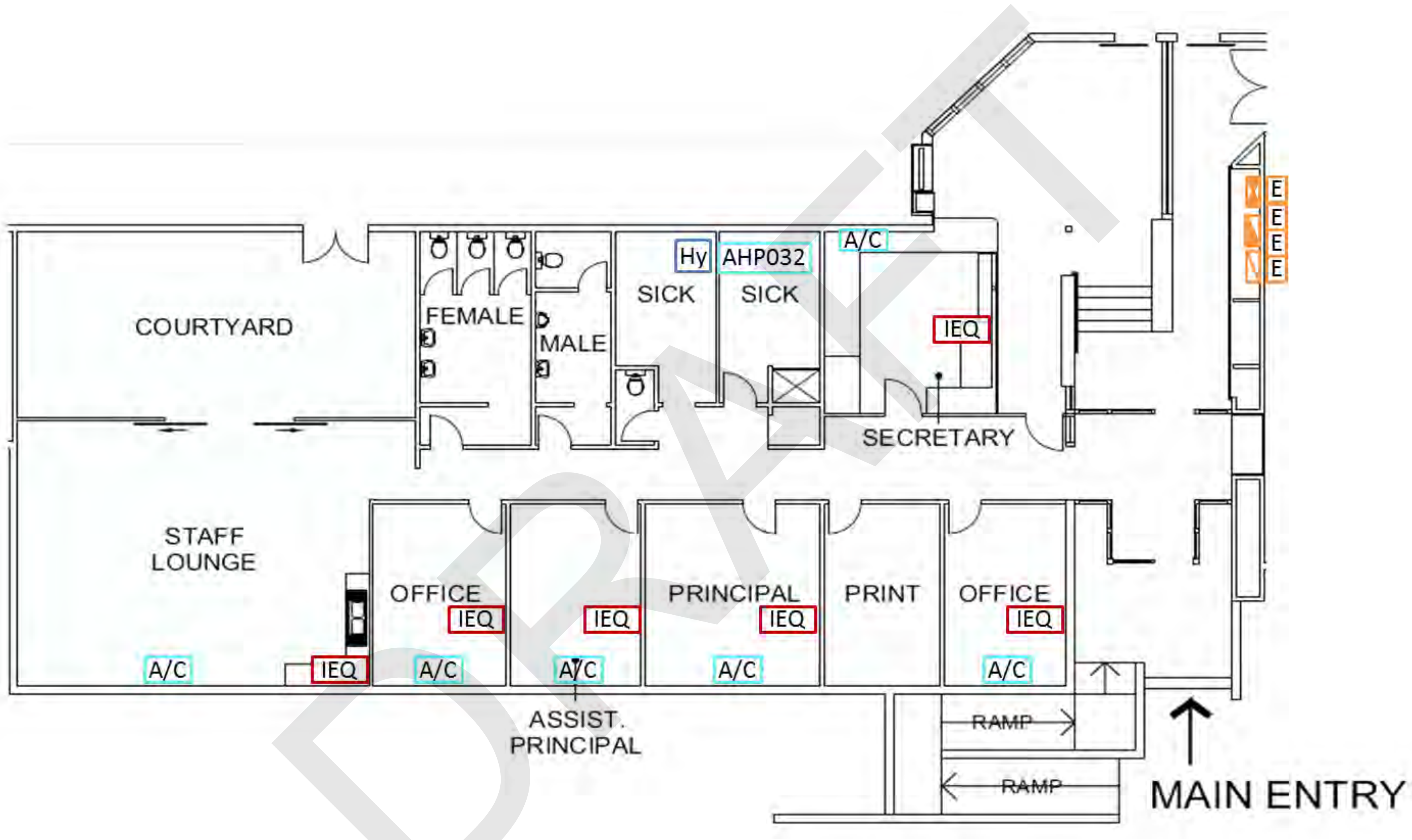

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Figure 23: Fadden Administration Block (B5) monitoring layout.

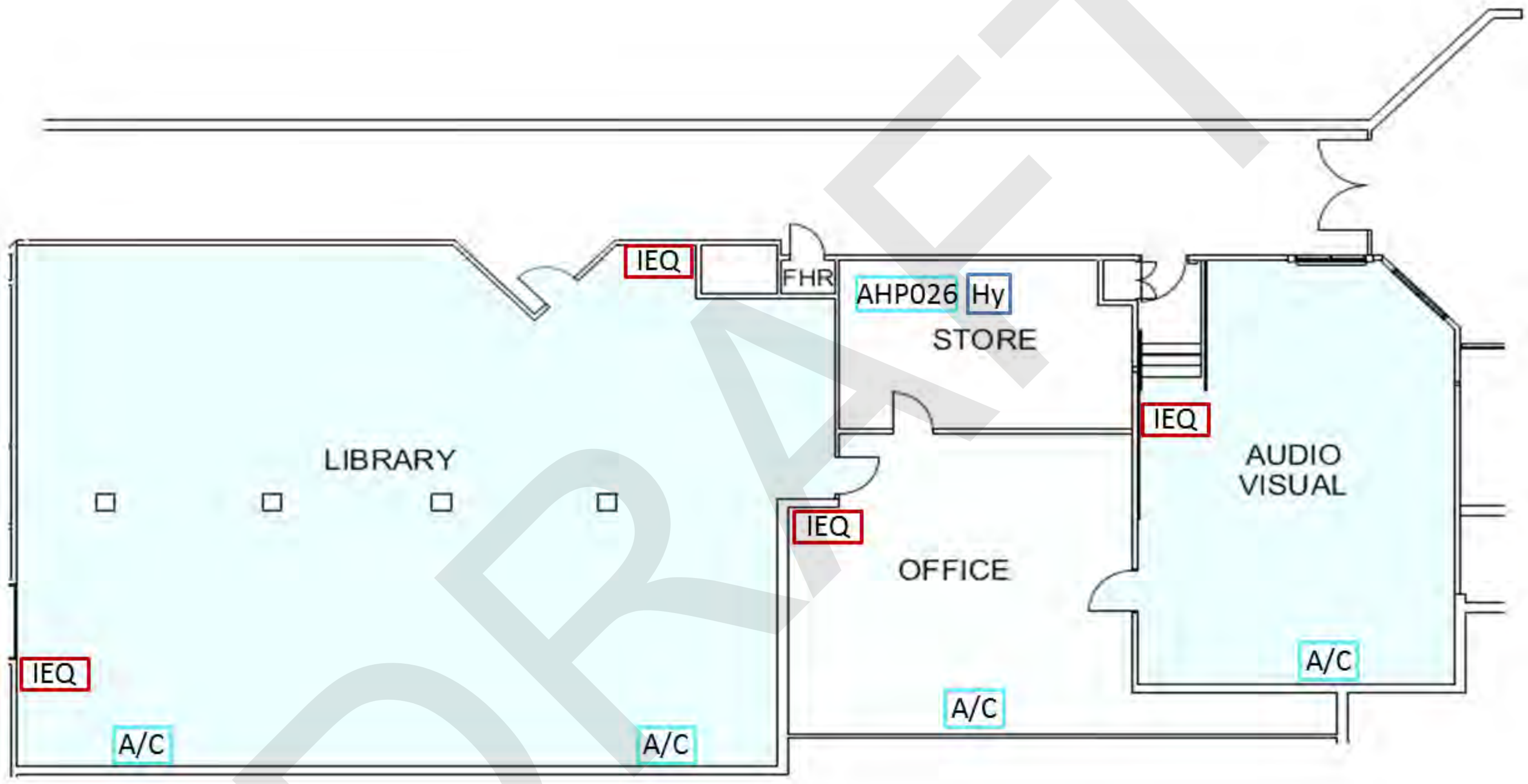

Figure 24: Fadden Library and AV Room (B5) monitoring layout.

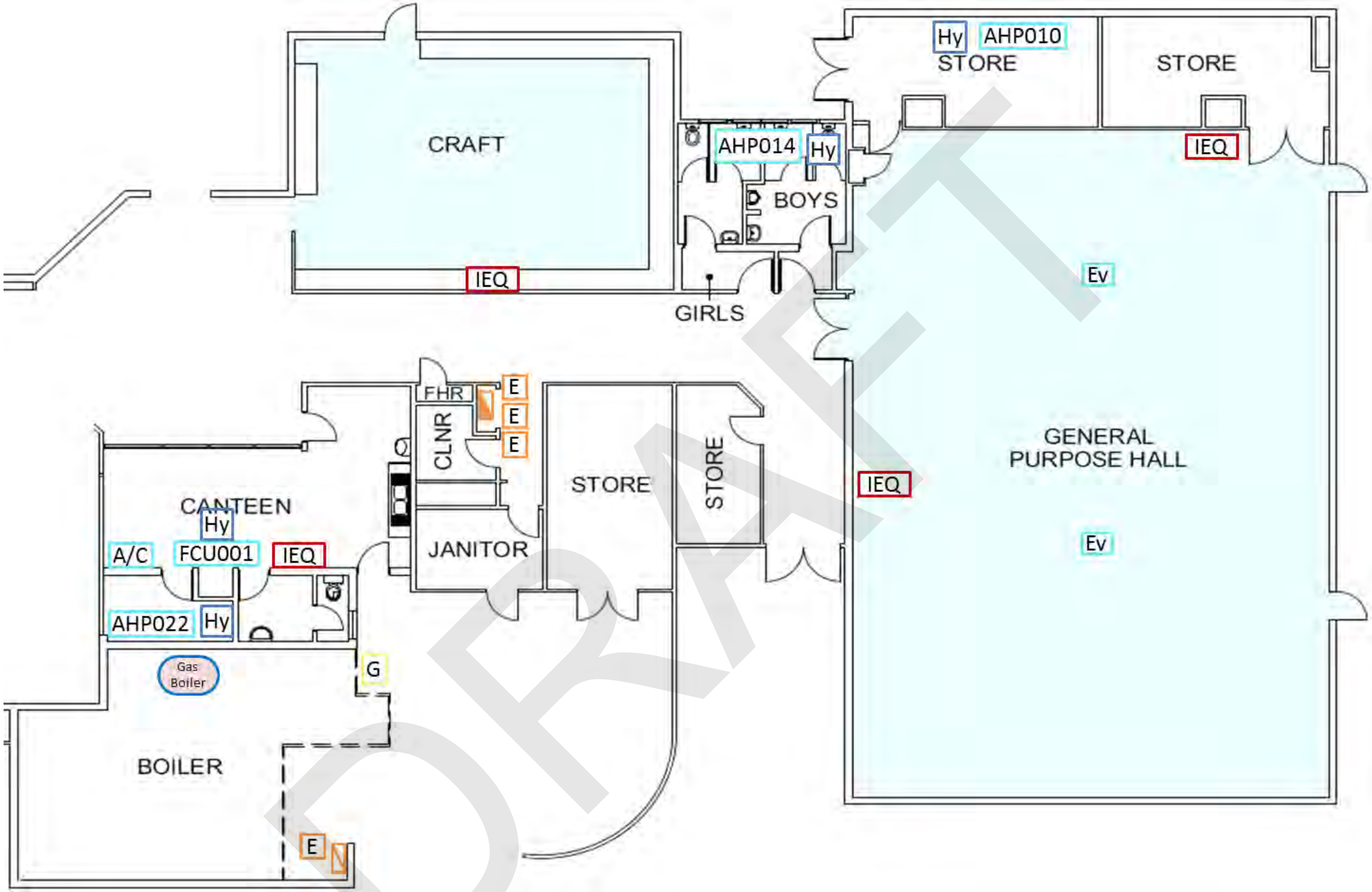

Figure 25: Fadden hall, craft and services (B5) monitoring layout.

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Table 6: Fadden monitoring list – by data parameter

Symbol	Description	Units	Quantity	Location	Sample period and remote/local
	Site monitoring				
$E_{gas\ boiler}$	Gas consumption for site-wide boiler	*MJ*	*1*	Boiler room	5 min remote
$E_{elec\ gross}$	Electricity gross site demand	*kWh*	*1*	MSB	15 min utility
$E_{PV\ gross}$	PV gross generation	*kWh*	*1*	MSB	15 min utility
T_{out}	Temperature outdoors	*°C*	*1*	Weather station	5 min remote
RH_{out}	Relative humidity outdoors	*%RH*	*1*	Weather station	5 min remote
GHI	Global Horizontal Irradiance	*W/m^2*	*1*	Weather station	5 min remote
V_{wind}	Wind speed	*m/s*	*1*	Weather station	5 min remote
Dir_{wind}	Wind direction	*Deg?*	*1*	Weather station	5 min remote
Rain	Rainfall	*mm*	*1*	Weather station	60 min remote
$PM\ 2\ 5_{out}$	Outdoor air quality - Particulate concentration	*ppm*	-	Weather station	60 min remote
	Building-monitoring				
$E_{DB\ 1\text{-}6}$	Building-level electricity consumption by distribution board	*kWh*	*6*	DB	5 min remote
$E_{AC\ A,B}$	AC split system energy; use spare channels on DB logger(s)	*kWh*	*15*	DB	5 min remote
$E_{AHU\ 1\text{-}9\ /\ FCU\ 1}$	Air handling unit fan energy	*kWh*	*9*	MSSB	5 min remote
$E_{EvapCool\ A,B}$	Rooftop evaporative cooler fan energy; use spare DB channels	*kWh*	*15*	DB	5 min remote
$E_{EXH\ A,B}$	Energy consumed by exhaust fan	*kWh*	*12*	DB	5 min remote
$Q_{hyd\ A}$	Hydronic water flow at location 'A'	*L*	*9*	Plant room	5 min remote
$T_{hyd\ in\ A}$	Temperature hydronic water supply for space 'A'	*°C*	*9*	Plant room	5 min remote
$T_{hyd\ in\ A}$	Temperature hydronic water supply for space 'A'	*°C*	*9*	Plant room	5 min remote
	Room-indoor monitoring				
$T_{A,B}$	Temperature indoors for building 'A', room 'B'	*°C*	*47*	Each space	10 min remote
$RH_{A,B}$	Relative humidity indoors, building 'A', room 'B'	*%RH*	*47*	Each space	10 min remote
$CO_{2\ A,B}$	Carbon dioxide concentration indoors	*ppm*	*16*	Each space	10 min remote
SPL	Sound pressure level	*dBA*		Each space	10 min remote

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Table 7: Fadden monitoring list - by device.

Device	Model	Configuration	Quantity	Location
Site monitoring				
Gas consumption			*1*	Boiler room
Electricity consumption		1,2,3-Demand, 4,5,6-PV	*1*	Main switch board (MSB)
Weather station			*1*	Central covered walkway
Comms accessories			*1*	Central covered walkway
Learning Pods (B1-4)				
Electricity consumption		1-Total, 2-AHU, 3-Evap1, 4-Evap2, 5-AC1, 6-Fans?	*8*	Elec distrib'n board (DB)
Hydronic sub-sys energy			*4*	Plant room
IEQ basic			*28*	
Admin (B5)				
Electricity consumption		1-Total, 2-AHU, 3-Evap1, 4-Evap2, 5-AC1, 6-Fans?	*4*	MSB, DB1, MSSB1
Hydronic sub-sys energy			*1*	Plant room
IEQ basic			*6*	
Library and AV (B5)				
Hydronic sub-sys energy			*1*	Plant room
IEQ basic			*4*	
Canteen, Hall, Boiler (B5)				
Electricity consumption		1-Total, 2-AHU, 3-AHU, 4-AHU, 5-AHU, 6-ExhFan	*1*	DB2
Electricity consumption		1,2-AC_Lib, 3-AC_Canteen, 4-AC_Office, 5-AC_AV, 6-ExhFan	*1*	DB2
Electricity consumption		1,2,3,4-Evap, 5-ExhFan?, 6-Ceiling fans?	*1*	DB2
Electricity consumption		1-Total, 2-AHU?, 3-Pump1, 4-Pump2, 5-, 6-	*1*	MSSB (Boiler)
Hydronic sub-sys energy			*3*	Plant rooms - mezzanine
IEQ basic			*4*	
Namadgi transportable				
Electricity consumption		1-Total, 2-AC1, 3-AC2, 4-AC3, 5-AC4, 6-Fans?	*1*	Elec distrib'n board (DB)
IEQ basic			*3*	

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5 ETHICS PROTOCOLS

All research conducted in public institutions that involves human participants must be approved by an accredited Human Research Ethics Committee (HREC). The purpose of HRECs is to protect the welfare and rights of the participants in the research. HRECs review research proposals to ensure that they meet ethical standards and guidelines, most notably the National Statement on Ethical Conduct in Human Research and the Privacy Act 1988.

Any research completed with ACT Education must have permission to proceed from the ACT Education directorate.

Restrictions on research work dictated by ethics protocols should be clearly understood by prospective technology providers. Potentially relevant protocols will be provided during the EOI process, including:

- LLS2 Education (Schools) Living Laboratories: ACT Education – Stage 1 Building Audits
- LLS2 Education (Schools) Living Laboratories: ACT Education – Stage 2 Building Monitoring

In general terms, relevant consideration will include:

- Determine, and obtain where required, appropriate Working with Children or Vulnerable People checks for research staff and contractor;
- Ensure all research participants been appropriately informed about the potential risk, harm, discomfort or inconvenience that may occur through participation in the research. In particular, consideration should be given to any potentially identifiable information.
- Obtain written consent, including where appropriate from a parent or guardian, from all participants. This is particularly important if post-occupancy evaluation will include surveys of school children.
- Limit the impact of the research on students and staff, for example by visiting and undertaking the research during periods when the disruption to the daily operation will be minimal (e.g. after hours, weekends, or school holidays).
- Is their potential for monitoring data to be used to identify individual participants? Ensure all necessary precautions and safeguards are implemented to protect privacy.

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6 RISK MANAGEMENT PROTOCOLS

All research undertaken in ACT Education living laboratories must undertake a thorough risk assessment, and establish appropriate processes for management of all identified risks. Three different risk assessments are required for testing in the living laboratory schools:

- The University of Wollongong has completed an overarching risk assessment for all living laboratories operating under the i-Hub REETSEF. This document will be provided to technology providers during the EOI process.
- A second risk assessment will be completed between the University of Wollongong and ACT Education Directorate for the specific operation of each living laboratory facility (Fadden and Amaroo). This document will be provided to technology providers during the EOI process.
- A third risk assessment will be required to be completed collaboratively between the technology provider, University of Wollongong, and ACT Education Directorate. This will be completed following the EOI process, and will cover the specifics of the installation, testing and removal of the technology by the technology provider.

Some key principles for appropriate risk management in the ACT Education living laboratories include:

- At all times, ACT Education Directorate shall have the overriding decision on the acceptability of risks and proposed management protocols.
- All suppliers, installers and contractors should be appropriately licenced and maintain appropriate insurances. Ideally, providers will be accredited according to industry best practice schemes as available.
- All contractors engaged should provide Safe Work Method Statements (SWMS's) for all work to be undertaken.
- Where possible, all works should be conducted outside of regular school hours, during periods of low occupancy.
- All contractors and researchers should have valid Working With Vulnerable People registrations.

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7 INTELLECTUAL PROPERTY PROTOCOLS

It is central to achieving the i-Hub objectives that the outcomes of the ACT Education living laboratory be made publicly available in a form that supports relevant stakeholders to take decisions on the appropriate upgrade strategies for their facilities. Therefore, **it is a requirement of i-HUB funding that all test results be made public** (without the disclosure of pre-existing commercial-in-confidence material). The i-Hub project will establish a Renewable Energy Knowledge Sharing Task-Group for Schools to guide the dissemination of project findings.

Intellectual property provisions will be clearly laid out in specific clauses of the collaboration agreement between the University of Wollongong and the technology provider. These provisions will be consistent with the head funding agreement between the ARENA, AIRAH and the University of Wollongong, as well as the Collaboration Agreement between University of Wollongong and ACT Education Directorate.

The basic principles outlined in these agreements are:

- Each Party's Background IP remains the property of the Party, but a license will be granted for all parties to use Background IP for the conduct of this project;
- Project IP will be owned upon creation by the University, but a license will be granted for use in the conduct of the Project and for Internal Purposes only;
- It is acknowledged that the purpose of the Project is the generation and dissemination of knowledge in renewable technology for the benefit of the Australian public;
- Receiving parties must maintain the confidence of the Confidential Information and must prevent its unauthorised disclosure to, or use by any other third party.

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8 TECHNOLOGY RELIABILITY AND DEGRADATION PROTOCOLS

ACT Education have not identified energy systems that have critical components (i.e. requiring an uninterruptable power supply) in either of these facilities.

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9 TECHNOLOGY SELECTION PROCESS

The ACT Education living laboratory is designed to facilitate the testing of a wide range of technologies. Once baseline data collection has been established a call for expressions of interest will be publicised for potential technology providers. EOIs may for testing be submitted to the i-Hub generally, or specifically for testing in the ACT Education living laboratory. It is anticipated that i-Hub will facilitate EOI request at least annually; and ACT Education will hold EOI rounds, or approach providers directly if a specific system is approaching end-of-life.

All technologies being proposed for testing will be assessed with regard to their technology readiness level (TRL) or level of technology maturity. Only technologies at deployment stage (levels 7-9) are eligible for testing in the ACT Education Living Labs. Refer to Figure 4.

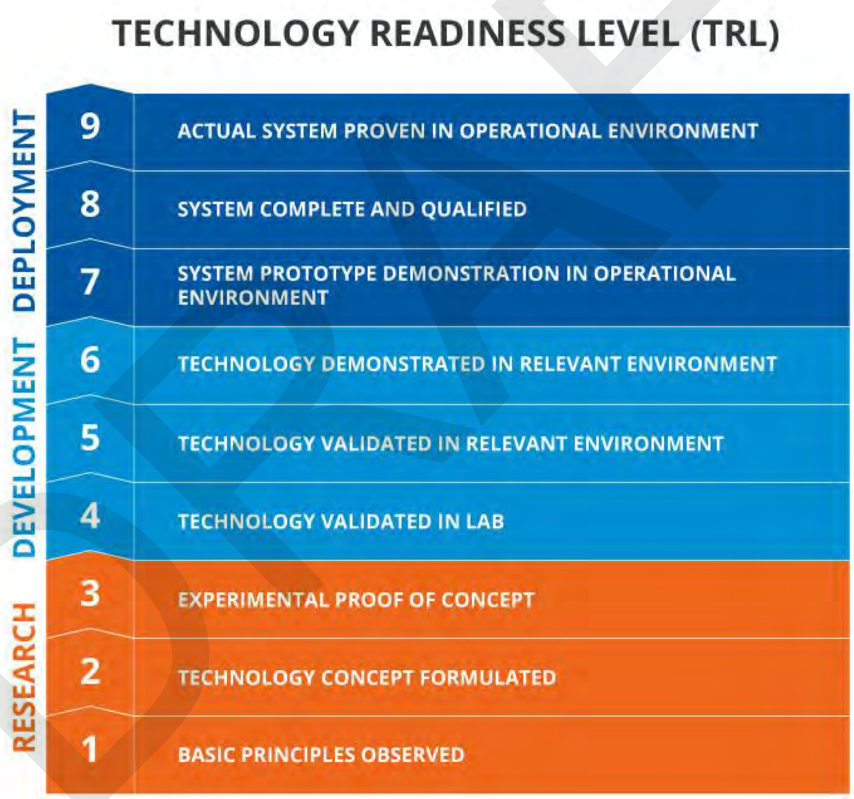

Figure 26 Technology Readiness Levels[9]

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

Potential technologies will be required to meet a range of engineering and risk management criteria. Eligible technologies will then be assessed according to the following criteria:

- For i-HUB, the key ranking criteria will be innovation (prioritising highly innovative solutions at the early stage of the technology curve) and performance (that is, the likelihood to be able to deliver a 25% increase in the value of renewable energy).
- For each sector, the ranking criteria is deployment, i.e. what is the potential for the technology to be widely deployed within the specific sector, and what would be the likely associated carbon savings of this deployment.
- For the specific Living Lab, the ranking criteria are cost saving, project value, and technical risk.

After submission of the initial EOI, an eligibility assessment will be completed to ensure the potential technology meets basic business, engineering and risk criteria. The details of this will be partially determined by the living laboratory host organisation, and part by the evaluation provider. This cover issues such as:

- Business registration and taxation status
- Relevant insurances, such as Public liability, Professional Indemnity Product warranties
- Technology risk management plan
- Workplace Health and Safety and Environment Plan
- Work Method Plan / Statement
- Evidence of compliance with relevant standards and legislation

After the initial assessment, potential providers will be asked to meet with the evaluation and host organisations, to facilitate a technical evaluation of the proposed technology, and identified key risks. The evaluation team will then complete an assessment of each technology, with recommendations provided to the i-Hub steering committee.

Technology providers will then be invited to formally agree to testing in the living laboratory. This will require the development of detailed risk management plans and safe work method statements, and detailed site investigation with the host organisation. In some instances, technology providers may be required to pay a living lab bond. The amount of this bond is to reflect the level of risk and cost associated with removal of the technology at the end of the test period, should the technology provider become insolvent.

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