The Innovation Hub

for Affordable Heating and Cooling

Integrated Design Studios Document

Tropical Mixed-use Buildings

IDS 14 Knowledge Sharing Report (100% Milestone 7)

V1 – 27 May 2022

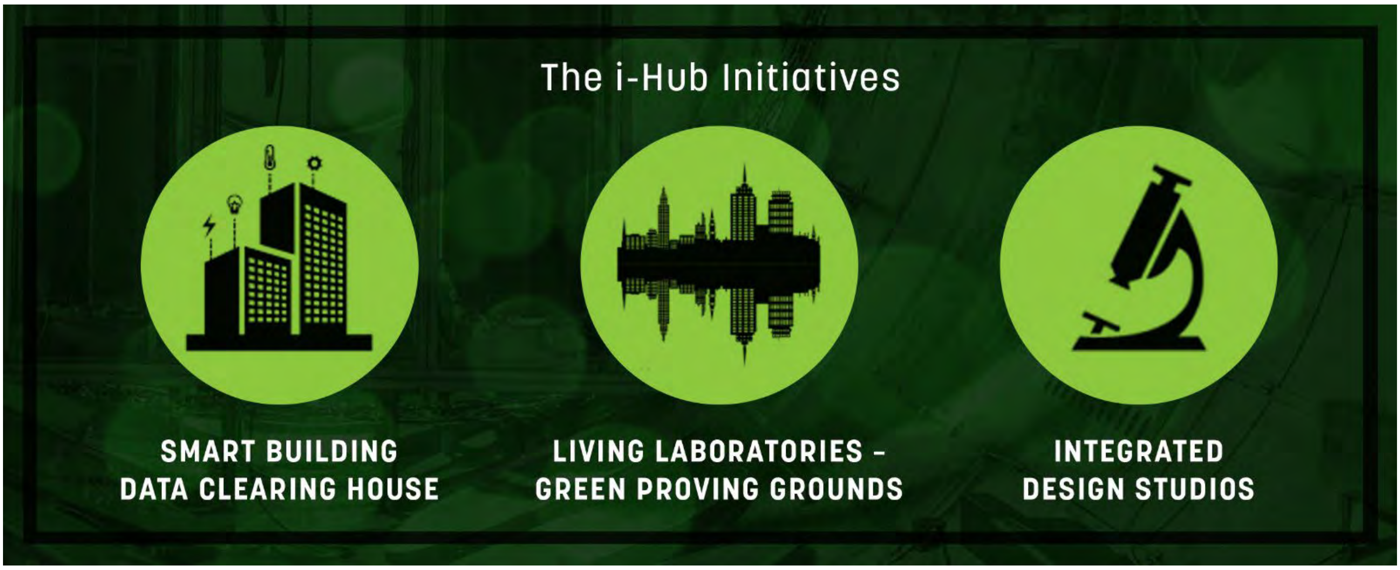
Queensland University of Technology

About i-Hub

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

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

This Project received funding from ARENA as part of ARENA's Advancing Renewables Program.
The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.



i-HUB Design Studio 14 Final Report (100% Milestone)

The Tropical Mixed-Use Building Integrated Design Studio (IDS 14), investigates design innovation in a mixed-use building typology that incorporates aged care. The climatic context is tropical Cairns (Queensland). The objective is to reduce net energy consumption through passive and active measures (e.g. the use of renewables and other energy technologies), whilst at the same time addressing the needs of different building occupants (including the elderly) and the whole-of-life focus of the client (Bolton Clarke). Over a period of 2 semesters (March – November 2021), a group of architecture and non-architecture students (mechanical/electrical engineering and construction management) worked with architecture, engineering and sustainability experts and the client to develop design solutions for this context.

High energy use in aged care facilities is attributed to their 24/7 operation, with a considerable portion of energy use attributed to space heating and/or cooling. The tropical climate of Cairns presents challenges in the design of buildings (passive design and materials selection); in the selection, design and operation of heating and cooling technologies; and in the utilisation of renewable energy and associated technologies to manage peak demand and greenhouse gas emissions.

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IMPORTANT NOTE: IDS13 and IDS14 were run concurrently, with the same client and industry consultants. This Knowledge Sharing Report and the equivalent IDS13 report contain some common information, in particular Section 2 (relating to learnings about mixed-use building typologies) and Section 4 (evaluation of the integrated design process). In addition, Appendix D of this report (and Appendix A of the IDS13 report) contains information that was in the previous 50% reports for IDS14 and 14 respectively (i.e. a detailed description of the IDS13/14 program and observations). This is repeated, for completion purposes, ensuring all IDS 14 information is contained in the one report.

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1 EXECUTIVE SUMMARY

The objective of the suite of integrated design studios conducted through the iHUB was to develop an enhanced understanding of the integrated design process and outputs, and its industry application. This specific IDS focused on a mixed-use building, incorporating aged care, in the tropical location of Cairns. Undertaken concurrently with IDS 13 (sub-tropical mixed-use buildings) in 2021, the combined studio involved 26 Master of Architecture students; 2 electrical engineering students; 1 mechanical engineering student; 3 construction management students; 6 industry consultants (mechanical engineering, energy modelling professionals, civil and environmental engineering, and construction management); 7 industry/academic professionals (architecture, architecture pedagogy, integrated systems, electrical engineering, architectural engineering); and client representatives (asset manager and project manager for Bolton Clarke). As the client for both contexts was a vertically integrated company that develops, owns and operates aged care facilities, designs requirements included consideration of whole-of-life (WOL) aspects and total-cost-of-ownership (TCOO) as well as net zero energy (NZE) and net zero carbon (NZC) considerations (encompassing the concepts of passive design to minimise space heating and cooling loads, selection of efficient and controllable space heating and cooling technologies, and the application of onsite renewable energy generation). The key findings from this process, relevant to the tropics, are presented here.

1.1 Mixed Use Buildings

Mixed-use building typologies present a number of challenges for achieving net zero energy, such as:

- There is no 'business as usual' (BAU) energy use intensity (EUI) data for this building typology. BAU estimation requires obtaining average EUI data for each of the building classes expected to be incorporated into the mixed-use building.
- Spaces within a mixed-use building can be used for different purposes (and by different classes of buildings) over time, so measurement of energy performance against BAU becomes even more problematic.
- There is no clear methodology for allocating energy consumption and generation data (whole and parts) for a mixed-use building, making it difficult to assign energy consumption costs, renewable energy generation benefits and demand response capabilities (who pays, who benefits, who decides?). It also presents challenges for the setting (and meeting) of net zero carbon or net zero energy goals (e.g. does it relate to all tenancies, or just common areas? Who decides on the target?)
- Mixed-use buildings that incorporate residential services present a unique problem in that the building is both a home and a workplace, creating additional challenges relating to HVAC technology selection, system sizing, design and operation.

1.2 Proposed Technology solutions and evaluation

The key technologies investigated in this IDS, and their indicative benefits, are summarised in Table 1-1. Note that these indicative savings are based on the specific assumptions for each of the feasibility assessments. It should also be noted that technology solutions examined for IDS13 (for the subtropics) and for other IDS projects (in temperate climates) may also be suitable for the tropics and for this mixed-building typology.

Table 1-1 Examined technologies and their impacts

Technology	Indicative demand reduction potential (compared with BAU)	Renewable Energy Potential	Co-Benefits
Hybrid green-solar roof	Could reduce building cooling load	Increase PV efficiency 3.6% Increase PV output 2-8%	Reduced heat transfer through the roof
Geothermal (Ground source) Heat Pumps for cooling	~30% reduction in cooling energy (but depends on local context)	This is a renewable energy technology	
Secondary roof	15.8% decrease in cooling energy ~21% reduction in peak cooling load (compared with double glazed building with no secondary roof)	Would increase the hosting capacity of PV and increase the % of load being met by PV	Increased thermal comfort (natural ventilation mode)
Hydronic cooling	80% reduction in yearly operation and maintenance (including energy costs)		Can meet cooling loads <50W/m² Lowest total cost of ownership
Rooftop PV Policy approach to net zero	NA	12-100% of BAU electricity load, depending on policy	
Solar-Hydrogen	66% reduction in BAU required	100% possible if sustainable construction methods significantly reduce demand	Reduced CO2e and diesel exhaust emissions, and less reliance on supply chain (for diesel generators)
Massed Timber – embodied carbon[1]	Needs modelling to determine impact on cooling load	-	Reduced CO2e

1.3 Application to industry

Five key factors, interrelated and interdependent, were identified as being important to successful outcomes from an integrated design process:

- A client brief that is open to being developed through the integrated design (ID) process, rather than pre-established
- A recognition of all participants, irrespective of profession, being equal co-designers, and a new or specialist role of integrated design facilitator or systems integrator.
- An early process whereby all participants gain an understanding and appreciation of each profession's language and design processes
- A range of communication strategies to capture different skills and methods used by the team
- A whole-system thinking approach that, from an energy perspective, considers the building, its services and technologies, and the energy systems that power it; as well as the human systems that inhabit the building and the climate in which the building and humans exist. It reaches beyond energy performance outcomes, but looks for multiple benefits from single solutions

The implementation of integrated design will require a suitable procurement instrument. The ID process is not well served by traditional procurement contracts (e.g. design and construct D&C), or even collaborative procurement contracts such as early contractor involvement (ECI). Integrated Project Delivery contracts

[1] Note: the inclusion of massed timber has significant impacts on the design process. Refer to Section 3.2.5.

appear more suitable, as they establish individual and group accountability. All parties accept, manage and share design and construction risks. Financial risks and rewards are shared through an agreed profit/incentive pool based on quantifiable project outcomes. An Alliance Contract is one such IPD contract type. An alternative contract type, suitable for integrated whole-life delivery projects, may be a Design-Build-Operate (DBO) contract. Refer to Table 4-1 for more information.

A proposed set of IDP Design Principles for NZE has been developed, based on Rocky Mountain Institute's Factor 10 Engineering Design Principles. This set of principles is proposed as a starting point for companies wishing to engage in integrated design. Refer to Section 4.2.2 for more information.

Table 1-2 Integrated Design Principles for Net-Zero Energy Buildings

Design phase	Integrated Design Principles for Net-Zero Energy Buildings
Before design starts	Establish a clear, shared, ambitious NZE goal and timeframe for achieving that goal. Consider including other related goals, such as resilience, adaptation, grid autonomy. Determine KPIs that reflect the goals, including ambitious energy efficiency.
	Convene a transdisciplinary design team (e.g. engineers, architects, construction contractor, building owner/manager/occupants, ID specialist/facilitator) with diverse skills and experiences.
	Avoid the linear march through traditional design phases (project objectives and aspirations; design concept development; master planning; design development; feasibility evaluation). ID is iterative, with successive stages informing earlier ideas.
	Implement an Integrated Project Delivery contract that rewards teams for meeting KPIs and providing savings, rather than producing documents.
Focus on the right problem	Understand the purpose of the building and the needs of the people who will occupy it. What energy services will be required and what environmental, regulatory, technical and social contexts are likely to exist over this period?
	Push past end-uses (e.g. HVAC), resulting services (e.g. comfort) and ultimate benefits (e.g. health, productivity) to understand the full range of ways to fulfill the purpose/s.
	Take a whole-of-life approach to designs and their consequences (i.e consider current and future occupants and environmental context).
	Establish BAU benchmarks for the KPIs, and whole-system, lifecycle value of savings (e.g. in kWh, kW, CO2e, HVAC kVa, PV kWp etc)
	Use science and the plethora of simulation and modelling tools available to determine the theoretical minimum amount of energy needed to provide the energy services (especially HVAC). Consider how far each practical design constraint (e.g. cost, safety, performance, accessibility) moves away from that theoretical minimum.
Design Integratively	Don't start with a familiar or previous design or conventional assumptions or methods. Start afresh with no preconceptions.
	Question all rules of thumb and assumptions. Require all proposed design options to demonstrate performance against the KPIs.
	Establish a hierarchy of approaches: super energy efficient building envelope (design and materials), building services (technologies and controls), and renewable energy (generation, storage, control). This will produce compounding savings upstream.
	Simplify systems and components, valuing passive solutions over active solutions wherever possible
	Think beyond current benefit:cost evaluations and minimum performance standards. Incorporate whole-of-life, total cost of ownership, and non-monetary value evaluations
	Create enhanced value by ensuring each part, subsystem or system provides multiple benefits.
	Optimise energy systems to meet the diverse annual and seasonal conditions (use and generation), and implement control strategies to minimise or shift peak demand and optimise self-consumption
	Incorporate technologies (e.g. integrated BMS, EMS) and processes (e.g. post occupancy evaluation) to inform design success and future designs.

2 MIXED USE BUILDINGS

This section discusses the definition of mixed-use buildings, the options presented through the IDS process, and the challenges that this building typology faces with regards to energy system design and operation.

2.1 Defining mixed-use buildings

This Integrated Design Studio (IDS14) and its companion IDS13, focused on mixed-use buildings in subtropical (IDS13) and tropical (IDS14) locations. Mixed-use buildings are buildings that have more than one classification according to the National Construction Code[2]. In the case of these studios, a key requirement was that the design needed to include an element of aged care (Class 9c; for example independent living units (ILUs – no care), assisted living units (ALUs – low/medium care), supported living units (SLU – medium care) or residential aged care (RAC – high care)). Other residential types were not excluded (e.g. apartments, Class 2). There were no restrictions on other building classes (e.g. offices (class 5), retail (class 6), education and public assembly (class 9b)) so long as it could be argued that proposed building uses would not adversely affect the living requirements of elderly persons. It was presumed that most building designs would include car parking (Class 7a).

As the client is a vertically integrated company that develops, owns and operates aged care facilities, additional requirements included consideration of whole-of-life (WOL) aspects and total-cost-of-ownership (TCOO). Net zero energy (NZE) and net zero carbon (NZC) were additional considerations, encompassing the concepts of passive design to minimise space heating and cooling loads, selection of efficient and controllable space heating and cooling technologies, and the application of onsite renewable energy generation. Onsite energy storage was optional.

2.2 Mixed-use options presented

The development site for IDS 14 is a greenfield site in Cairns, adjacent to an existing RAC (refer to Figure 2-1 for an aerial view of the site, and Figure 2-2 for the planning summary). The site allowed for consideration of a staged master plan redevelopment to incorporate mixed-use facilities as well as different approaches to aged care accommodation.

Figure 2-1 Aerial view of the Cairns site

[2] Refer to NCC 2019 Volume One Part A6 Building classification, especially A6.11 Multiple classifications.

Westcourt Cairns Site Location

Planning Summary

BOLTON CLARKE Be true to you

271 GATTON STREET & 72-84 TILLS STREET, WESTCOURT

The following table outlines the key planning controls that will apply to any future Retirement Facility or Residential Care Facility at the site.

Please note that the planning controls summarised below are Council's 'acceptable outcomes' only and there may be opportunities to discuss alternatives where this is supported by the site context. Urbis can review initial concept plans and provide our professional opinion about the prospects of securing approval for alternative design outcomes if required. However, for the purposes of your initial feasibility analysis, we recommend using the planning controls below as a starting point.

KEY PLANNING CONTROLS FOR CONCEPT DESIGN

BUILDING HEIGHT	• Maximum of 15m and 4 storeys

SETBACKS	• Frontage: Minimum 6 metres.
	• Side boundaries:
	  • For buildings 1 or 2 storeys, a minimum setback of 2.5m applies.
	  • For buildings 3 or 4 storeys, a minimum setback of 3.5m applies.

SITE COVER	• Maximum 40% of site area (being a combined building footprint of 7,249.2m²).
BUILDING DESIGN	• Building should reflect tropical building design principles including maximising cross breezes, minimise solar heat, and promote natural light (double barrelling units/rooms is avoided).

PRIVATE OPEN SPACE (FOR ILU'S)	• Each dwelling unit has a private open space that includes the following:
	  • Minimum dimension of 3 metres.
	  • Accessible from internal living spaces (not bedrooms).
	  • Is in the form of a balcony where above ground.

COMMUNAL OPEN SPACE	• Minimum 35% of site area (6,343.05m²). • Also needs to be demonstrated that the communal area is easily accessible and functional and includes recreation facilities.
LANDSCAPING	• Minimum 10% of the site is landscaped (being 1,812m²).
PRIVACY & SCREENING	• Where buildings are proposed within 2 metres of each other at ground floor level or within 9 metres above ground floor level, privacy is protected by: (a) sill heights being a minimum of 1.5 metres above floor level; or (b) fixed obscured glazing for any part of the window below 1.5 metres above floor level; or (c) fixed external screens.

SIGNIFICANT VEGETATION	• Aerial photography indicates there are several mature trees at the property. The Planning Scheme provides two options for mature trees on the site:
	  ○ Mature trees can be maintained and accommodated into the building design on site; or
	  ○ If the mature trees are unable to be retained, they are encouraged to be replaced as part of any future landscaping at the site.
	Note: The planning scheme does not define what a mature or significant tree is. This will be explored more in the full Due Diligence Report.

CAR PARKING	• Minimum car parking for a Retirement Facility: (see table below) • Minimum car parking for a Residential Care Facility: (see table below)
FLOODING	• The property is included within the Flood Inundation – Flood Plain area. The minimum habitable floor level is 300mm above the 1% AEP flood immunity level. Urbis will make enquiries with Cairns Regional Council to determine the habitable flood level applicable to this site.

Minimum car parking for a Retirement Facility:

Car Parking Rate	Self-contained Accommodation	All other accommodation
Per accommodation unit	1 space per unit	1 per 5 units
Visitor	0.25 per unit	0.25
Employee	0.5 per employee	0.5 per employee

Minimum car parking for a Residential Care Facility:

Car Parking Rate	
General	1 per 10 beds
Visitor	0.25 per bed
Employee	0.5 per employee

Figure 2-2 Planning summary for the Cairns site

The mixed-use building design options presented through the IDS process are shown in Table 2-1. These options demonstrate alternative approaches to those currently applied to aged care facilities, in particular options for intergenerational living, co-location of complementary services (e.g. aged care education and training and government services), greater utilisation of facilities by the surrounding community (e.g. community gardens, kitchens, library, health and fitness facilities), as well as 'typical' retail and office facilities found in existing aged care precincts (e.g. medical and allied health services, pharmacy, café, florist etc).

An example of the approach used to determine specific mixed uses is shown in Figure 2-3, identifying the different user groups and the types of facilities they could utilise. The challenges associated with this building typology, from an energy perspective, are discussed in the next section (and are the same for the IDS13 report).

Table 2-1 Mixed-Use building solutions proposed for Cairns

Mixed use proposals for Caboolture
ILUs and intergenerational apartments, shaded/undercover market stalls
RAC, community centre, gathering space, gym
RAC, community farm, plant nursery, library, health precinct (medical, allied health, fitness centre), childcare, library, gift shop
ILUs, government services (My Aged Care), aged care training, retail (coffee shop, pharmacy), allied health offices
SLU, RAC, community farm and kitchen, community health facilities, community multipurpose facilities, cafe
ALUs, ILUs, allied health, student accommodation, offices (medical, radiology)
RAC, SLUs, ILUs, TAFE facility (aged care training and research), student accommodation, retail (grocery), offices (medical), community hall

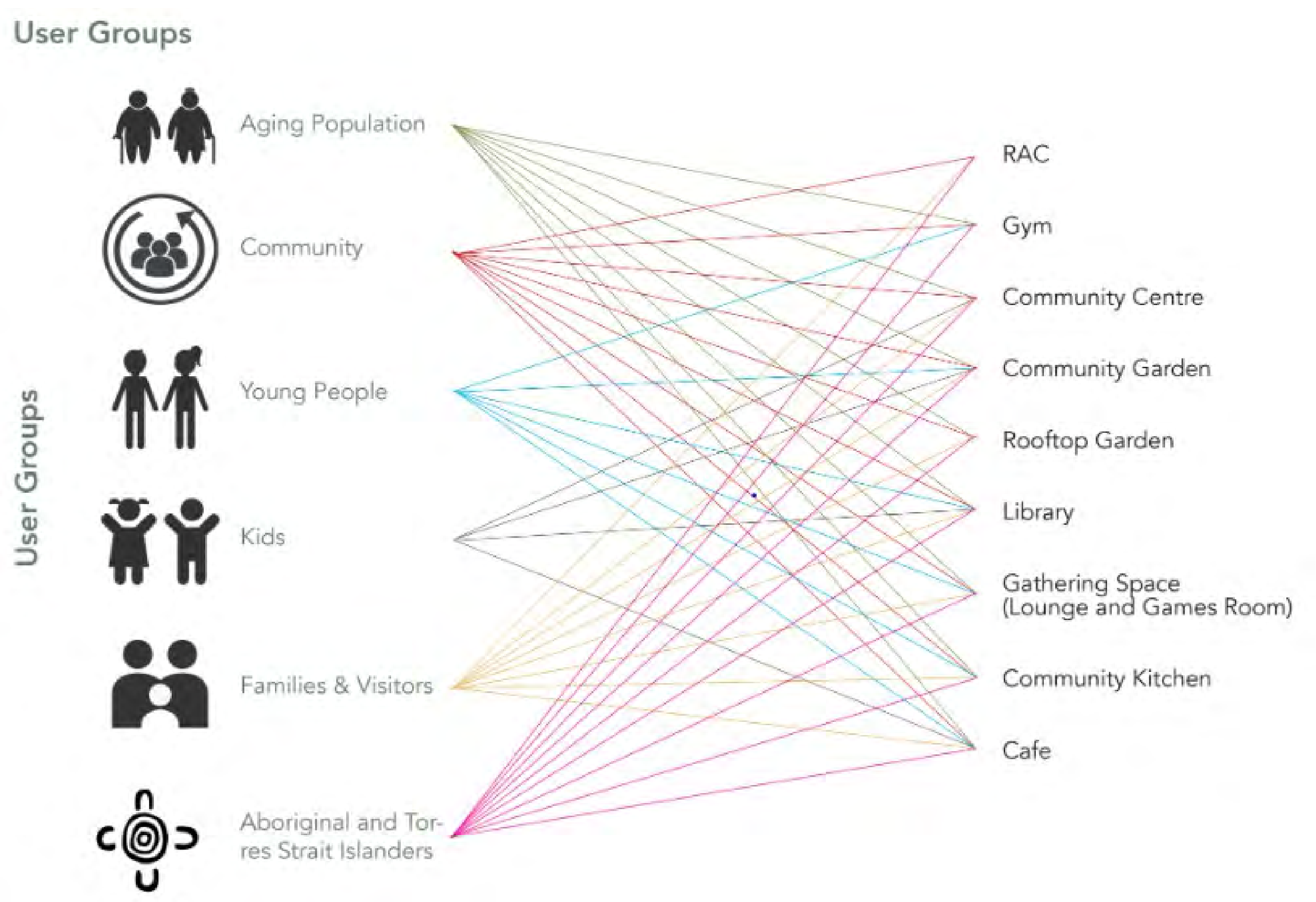


Figure 2-3 Proposed mixed-use amenities - Designer Olivia Dewi[3]

[3] One of the key elements of this design by Olivia was to consider adaptive architecture, i.e. buildings that adapt to both the environment and to future needs

2.3 Energy challenges for mixed-use buildings

As a building typology, mixed use buildings present some unique challenges relating to designing for net zero carbon / net zero energy. These challenges[4] include:

- To determine the building's energy needs and hence design appropriate energy systems**, there is a need to have reasonably robust energy use intensity (EUI) data** (e.g. kWh/m^2/year) for each of the building classes, before design begins. This can be problematic for a number of reasons:
  - There is no baseline energy use intensity (EUI) for mixed use buildings as a typology (For this IDS, an EUI of 30kWh/bed/day was used, as this is representative of EUI for aged care facilities in the region).
  - There are different classification systems assigned to buildings at the design, construction and/or certificate of occupancy stages, for example ANZSIC (economic classification), ABS (functional classification) and NCC (classification impacts, for example, structural, safety and energy performance requirements).
  - Building functions can change over time, as can the nature of occupants.
  - Even within one class (e.g. NCC Class 6 retail) the EUI can vary greatly, for example fast food outlets and supermarkets have much higher EUI than retail stores such as pharmacies, florists, gift shops, hair dressers etc (the types of retail you could envisage co-habiting with residential aged care).
  - Asset owners within one sector (e.g. education) can have different ways of calculating EUI (e.g. what is/isn't included as an education activity)
  - Some spaces in a mixed-use building may be used for different purposes at different times (e.g. may be Class 9b education/TAFE training during office hours, and recreation use by residents after hours / on weekends (nominally class 9c)). Conversely some activities, such as TAFE training, or medical services, may occur in spaces of a mixed-use building that are not specifically classified for that purpose (e.g. in resident rooms or in the communal gym).
  - Some spaces that would be classified as 9c in a residential aged care facility (e.g. allied health / medical practitioner treatment rooms) may need to be classified differently (e.g. Class 5) if the services provided are open to non-residents.
- **There is no clear methodology for allocating energy consumption and generation data in mixed use buildings**.
  - This creates challenges for assigning energy consumption costs, renewable energy generation benefits and demand response capabilities (who pays, who benefits, who decides?).
  - It also presents challenges for the setting (and meeting) of net zero carbon or net zero energy goals. For example, is a NZE goal related to the whole building (including all tenancies), just the common areas of the building, or the common areas and residential areas?
- **Mixed use buildings that incorporate residential services present a unique problem in that the building is both a home and a workplace.** This creates challenges relating to HVAC technology selection, system sizing, design and operation in particular:
  - Different thermal comfort needs and expectations of occupants – between elderly and not elderly; between sedentary and active occupants (metabolic rate); between expected level of personal control (adaptive capacity and personal preferences); and in clothing levels (e.g.

[4] Some of these issues were raised in *Baseline Energy Consumption and Greenhouse Gas Emissions in Commercial Buildings in Australia: Part 2 – Appendixes*. November 2012. Council of Australian Governments (COAG) National Strategy on Energy Efficiency, while others have been observed in mixed-use buildings incorporating aged care.

sleeping and casual ‘at home’ clothing levels; casual clothing for common areas; work uniforms).

- If mechanically cooled or hybrid mode (passive and active cooling), there are challenges in designing a system to meet the diverse needs and determining hierarchy of needs (e.g. who gets to decide the design parameters, the operational parameters, the comfort parameters?) Are industry standards and practices (e.g. ASHRAE 55 or NCC Section J DTS or reference building) appropriate for mixed-use buildings?

> “Use physics, chemistry, or building science to determine the theoretical minimum amount of energy or resources needed to provide the chosen end-use or service. Then carefully consider how far each practical design constraint (e.g. cost, safety, performance, accessibility) moves you away from that theoretical minimum” 10Xe Principle 9

3 EVALUATION OF DESIGN SOLUTIONS

This section reports on the qualitative and quantitative evaluation of design solutions proposed for a mixed-use building (incorporating some element of aged care accommodation) in tropical Cairns, Queensland.

3.1 Initial evaluation of design solutions

Twelve design solutions were presented for the Cairns site. Initially these designs were evaluated qualitatively by 'experienced' design professionals (academics and consultants), using a 5 point Likert scale (1 = very little; 5 = a lot) to determine the extent to which each design met each of 8 design parameters, as shown in Table 3-1.

Table 3-1 Parameters for qualitative evaluation of design solutions

Design parameter	Explanation
Client needs	Whole of life cost and value
User needs	Health, wellness, connectivity (of residents and other users)
Climate responsiveness	Understanding of key climate conditions (e.g. seasonal temperature, humidity, solar radiation, wind speed and direction)
Mixed use typology	Appropriateness and diversity of classifications
Building services integration	Cooling load, HVAC technology and controls, energy demand, peak demand, energy and load management options, renewable energy potential
Innovation and creativity	
Codesign, integrated design	Extent to which there is evidence of integration of building services and energy issues within the overall design concept and solution
Evidence of performance outcomes	Evidence of using simulation or … tools to quantify internal conditions, HVAC loads, PV output etc…

In general, design solutions addressed client and user needs and mixed-use typologies reasonably well (scores 3-5, excluding energy issues). Roughly 75% of the designs incorporated a reasonable response to climate considerations (scores 3-5), demonstrating a stronger consideration of the climate context that colleagues designing for the subtropics. There was also a stronger consideration of building services integration (scores of 3-4) and codesign/integrated design (scores 3-4) compared to designs for the subtropics.

From an energy perspective, none of the designs included an assessment of the thermal load of the proposed building based on the design and materials selection. Most designs considered passive options such as orientation, shading and cross ventilation, but without modelling/evaluation of the effectiveness of each strategy. Some designs addressed, in a rudimentary manner, aspects of embodied energy of the main construction materials. Many of the designs incorporated a rudimentary analysis of the estimated electrical load of the building (based on the provided energy use intensity figure of 30kWh/bed/day), and hence provided some roof area to meet all or part of that load (based on the sun hours for Cairns, and specific PV panel types). From an economic perspective, none of the designs included an assessment of the economic viability of the various mixed-use tenancies proposed (this was out of scope of the studios), although a few designs included a construction cost estimate of the design.

Aside from the basic PV system sizing and output calculations, no design solutions presented evidence of validation / analysis of performance outcomes (in relation to energy use, indoor conditions, HVAC loads, peak demand etc).

The early-career architects were quite adept at traditional architectural responses to the client brief (e.g. site context, connectivity, form, detailed resolution of design drawings) but much less knowledgeable about, experienced in, and hence confident to include aspects that impact on energy performance indicators. This particularly included limited or simplistic demonstration of:

- An understanding of the seasonal and diurnal path of the sun, and design responses to control solar radiation into the internal spaces (e.g. shading, window to wall ratio, sizing and placement of windows)
- Seasonal differences in site wind speed and direction, and strategies to enhance natural ventilation/cooling and reduce unwanted wind
- Building physics (e.g. properties of materials, such as R value, U value, solar absorptance/reflectance) and the impact this has on internal heat gain/loss, and hence thermal comfort, HVAC technology options and energy use (consumption (kWh) and demand (kW))
- Evaluation methods and tools that could be used to quantify performance and assist in design choices

Similarly, the early-career engineers and construction professionals were proficient in applying standard industry methods, but less experienced in exploring non-standard methods or solutions. These engineers and construction professionals were also not conversant with simulation and design tools that could help validate performance and inform design.

In fairness to these early-career designers, however, this was their first experience in integrated design, and it was presented at the end of their training (when they had specific output requirements not directly related to IDS. For example, the early career architects were expected, within a 15 week period, to develop the design and present detailed design drawings for a complete multi-storey building.)

The key learning from this, for IDS in practice, is that experienced IDS practitioners need to develop and implement staged training/immersion for less experienced colleagues, over a period of time, to enable them to develop the knowledge and skills to successfully engage in integrated design. For universities, the key learning is that IDS would be better implemented much earlier in the respective architecture / engineering / construction management degrees, allowing emerging designers to develop and apply skills gradually.

Nevertheless, despite these limitations, a range of passive and active energy solutions were proposed. Some of these are explained in more detail in the following section. A few examples are shown below, demonstrating the multi-faceted approach used by the designers (trying to consider, within the overall ‘mixed-use building typology’, the client’s brief, occupant health and comfort, and energy from the perspective of embodied and operational energy, demand management, and renewable energy generation).

Phoebe Duckworth’s design (Figure 3-1) integrates passive design (especially orientation, shading, cross ventilation), a low energy cooling system (radiant hydronic cooling embedded in the ceiling), and rooftop PV in three orientations (east, north and west). The multiple orientations of PV are a reasonable response in this location and for this building typology, extending the solar day compared to north facing arrays only. The feasibility of hydronic cooling in the tropics is explored in section 3.2.2.

Quinlan Hatchett’s design (Figure 3-2) aims to optimise renewable energy generation by incorporating a hybrid green-solar roof. This hybrid solution has been reported to improve PV efficiency by an average of 3.6% in Sydney, resulting in an increase in average daily output of 13% above BAU[5]. In tropical locations, hybrid green-solar roofs (also known as green roof integrated photovoltaics), have had measured energy

[5] The study by UTS - “Green Rood & Solar Array – Comparative Research Project Final Report July 2021” can be found at https://opus.lib.uts.edu.au/handle/10453/150142

generation improvements ranging from a modest 1.7%[6] to 4.3 - 8.3%[7]. More data is required to determine the optimal distance between the green roof and the PVs, and to understand challenges such as rainwater runoff[8].

Figure 3-1 "ReGenesis" - Designer Phoebe Duckworth

Figure 3-2 “Westcourt Living” hybrid green-solar roof – Quinlan Hatchett

6 Osma-Pinto, G and Ordonez-Plata, G. 2019. Measuring factors influencing performance of rooftop PV panels in warm tropical climates. *Solar Energy*, Vol 185 pp 112-123. https://doi.org/10.1016/j.solener.2019.04.053

7 Hui, SCM and Chan. W. 2011. Integration of green roof and solar photovoltaic systems. 2011. *Proceedings of Joint Symposium 2011: Integrated Building Design in the New Era of Sustainability*, 22 November 2011. Hong Kong.

8 Jahanfar, A., Drake.J., Sleep, B., and Margolis,L. 2019. Evaluating the sharing effect of photovoltaic panels on green roof discharge reduction and plant growth. *Journal of Hydrology*, vol 568 pp 919-928. https://doi.org/10.1016/j.jhydrol.2018.11.019.

Flora Lau's design (Figure 3-3) incorporates internal vertical greening systems (VGS) – specifically indirect green façade system and modular trellis system - and an energy efficient Dedicated Outdoor Air System (DOAS[9]) for ventilation and dehumidification independently from air cooling. A DOAS appears to be an appropriate selection for the Cairns climate, where temperature extremes are not common[10], but high humidity is. Flora's roof plans show the placement of rooftop PVs, the green-wall outlets, and the placement of the DOAS. The area allocated for PVs is estimated to provide 57% of the site's energy (based on an assumption of 30kWh/pp/day and the building occupancy of 81 beds). Note that some research indicates that utilising VGS in humid climates could increase the rate of evapotranspiration, increasing overall humidity and decreasing thermal comfort[11]. The feasibility of VGS in Cairns has not been assessed in this report, but an evaluation of VGS is included in the IDS13 report.

Figure 3-3 'Komorebi' (upper image) showing the vertical greening systems emerging through the roof like a tree, and roof plan (lower images) showing PV (left), distribution of vertical green systems (middle) and DOAS - Designer Flora Lau

[9] A DOAS decouples the sensible and latent cooling functions of air handling systems, providing better ventilation. A DOAS combined with a high efficiency energy recovery ventilator (ERV) is reported internationally to significantly reduce a building's cooling load and can be paired with Variable Refrigerant Flow (VRF) or mini-split heat pumps to further reduce cooling loads and enhanced comfort. A DOAS has significantly higher capital costs (compared with 'standard' HVAC solutions) but has much lower operational costs. The feasibility of these options has not been checked for this location.

[10] Average annual temperature 23°C; average annual maximum temperature 29°C with 62% humidity; historical summer temperature maximums typically <32°C, but 10 occasions in the past decade where the maximum temperature has equalled or exceeded 35°C (all occurring Dec-Mar, half of them in February).

[11] Widiastuti, R., Zaini, J., & Caesarendra, W. (2020). Field measurement on the model of green facade systems and its effect to building indoor thermal comfort. *Measurement 166*, 108212-108227

William Marsden's design (Figure 3-4) first addresses energy criteria through passive means such as cross ventilation, solar path optimisation and the extensive use of vertical green systems (especially external facades), that are reported to reduce heat gain into the building and hence reduce air conditioning needs, as well as providing occupant visual and acoustic comfort and improved sense of well-being. (Refer to IDS13 report on the benefits of vertical greening systems.) His design proposes rooftop PV, geothermal HVAC cooling and hydrogen battery electric storage, though none of these are quantified and the feasibility of geothermal HVAC for cooling has not been evaluated. Some research in Asia, however, indicates that Ground Source Heat Pumps (GSHP) have been found to provide 30% energy savings compared to BAU in Bangkok[12]. GSHP technical feasibility in the tropics is reported to depend on daily fluctuations in the ambient temperature, and the subsurface temperature and/or groundwater flow in shallow aquifers.

Figure 3-4 Extensive green facade - designer William Marsden

3.2 Feasibility assessment of selected design solutions

This section examines some of the design solutions in more detail, providing some qualification and quantification of the feasibility of these solutions for this (and other) building typologies in this climate zone. In particular these evaluations attempt to identify the extent to which the proposed solutions can assist in moving towards net zero carbon targets.

One innovative (for Australia) design (Figure 3-5) utilised a secondary roof to minimise heat gain, provide shading and host a large PV array to provide 100% of the expected electrical demand for the building. Whilst not common in Australia, the use of a secondary roof can be seen in other hot-tropical climates as a passive cooling strategy, in essence a shade structure over the entire building. Tristan specified ceiling fans and hydronic cooling for thermal comfort. His design also addresses embodied energy through the application of

[12] Kasumi Yasukawa and Youhei Uchida, 2018. "Space Cooling by Ground Source Heat Pump in Tropical Asia" in *Renewable Geothermal Energy Explorations*, Editor Basel I Ismail. DOI 10.5772/intechopen.81114.

cross-laminated timber (CLT) for the main structural elements. These elements of his design are assessed in the following sections.

Section 3.2.1 evaluates the feasibility of the secondary roof, in terms of reducing internal heat loads. Section 3.2.2 explores radiant cooling feasibility and compares whole of life performance with chilled water and variable refrigerant systems. The next two sections evaluate the renewable energy potential from a PV policy impact perspective (Section 3.3.3) and from a whole of campus/precinct perspective incorporating PV and hydrogen (Section 3.3.4). Section 3.2.5 discusses the whole of life impact of massed timber and the implications of the integrated design process.

Figure 3-5 Secondary Roof – Designer Tristan Clark

3.2.1 *Secondary roof (Sherif Zedan)*

The analysis was done through creating an energy model (Figure 3-6) that simulates energy loads and consumption to perform a comparative analysis of the effect of adding a secondary roof on energy consumption and thermal heat gain.

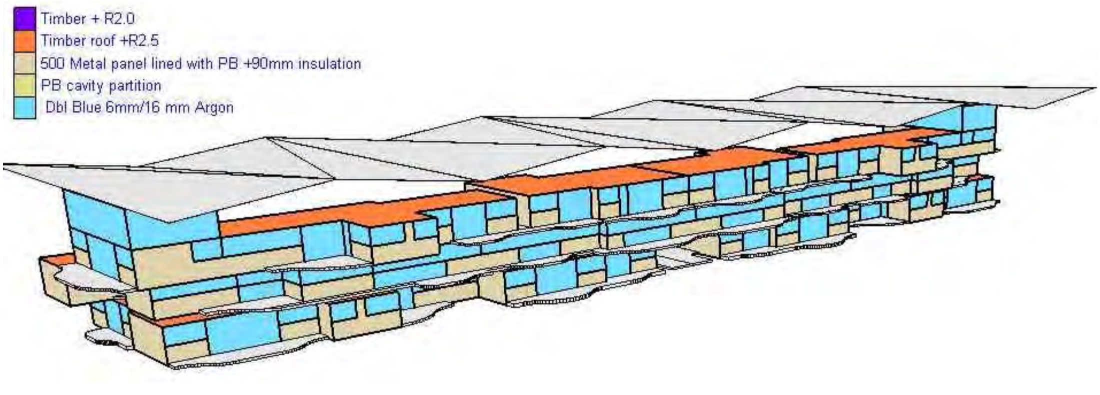


Figure 3-6 Building elements in the model

Figure 3-7 shows the solar incident in kWh/m^2 on building elements in the case of no secondary roof, 50% translucent secondary roof, and opaque secondary roof. The figure shows that the opaque secondary roof can reduce solar incident on the roof by almost 1800kWh/m^2, and about 500kWh/m^2 on the facades of the upper 2 levels. It has no effect on the lower level. The translucent secondary roof can contribute to reducing the solar incident on the roof by around 50% and has little to no effect on the facades.

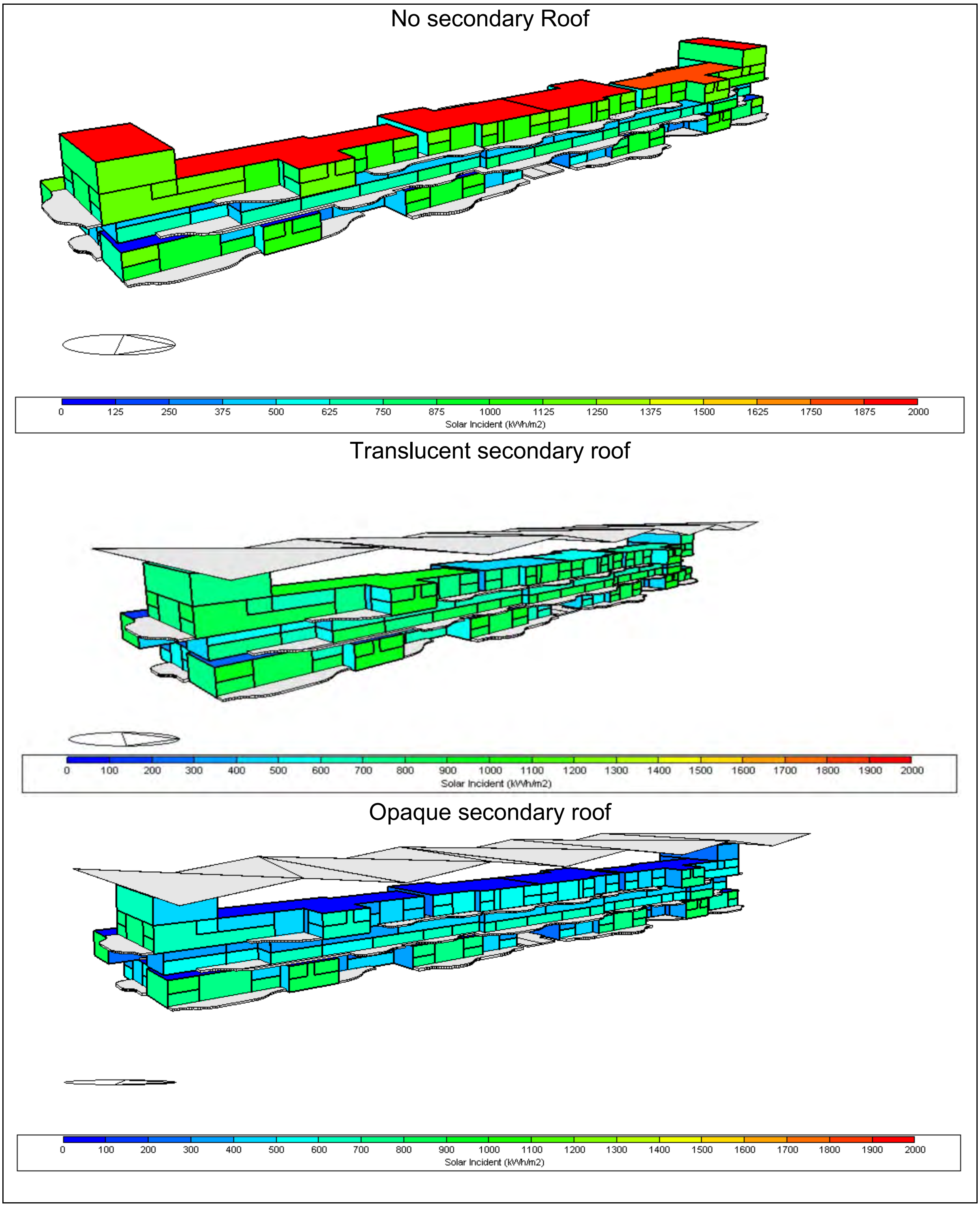


Figure 3-7: Effect of secondary roof on solar incident

Figure 3-8 shows that cooling energy is reduced by 15.8% when the opaque roof is added and by 7.7% when the translucent roof is added. Glazing heat gain is reduced by 35% when the opaque roof is added and by 15% when the translucent roof is added.

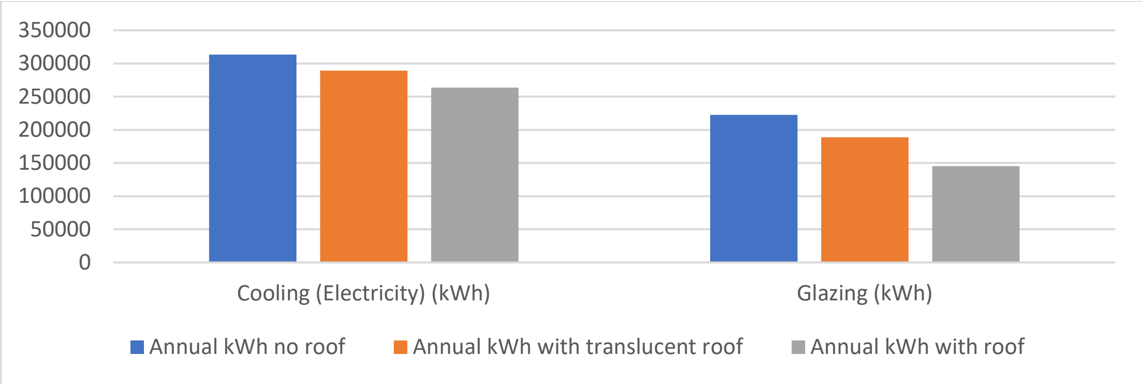


Figure 3-8 Effect of secondary roof on cooling demand (electricity) and heat gain through glazing

The roof, which is the second highest element in terms of heat gain (following the glazing) is responsible for 3700kWh heat gain without the secondary roof. The secondary roof significantly reduced heat gain through the primary roof and resulted in 6700kWh heat loss from the building through the primary roof when the opaque roof is used and in 2500kWh when the translucent roof is used (Figure 3-9).

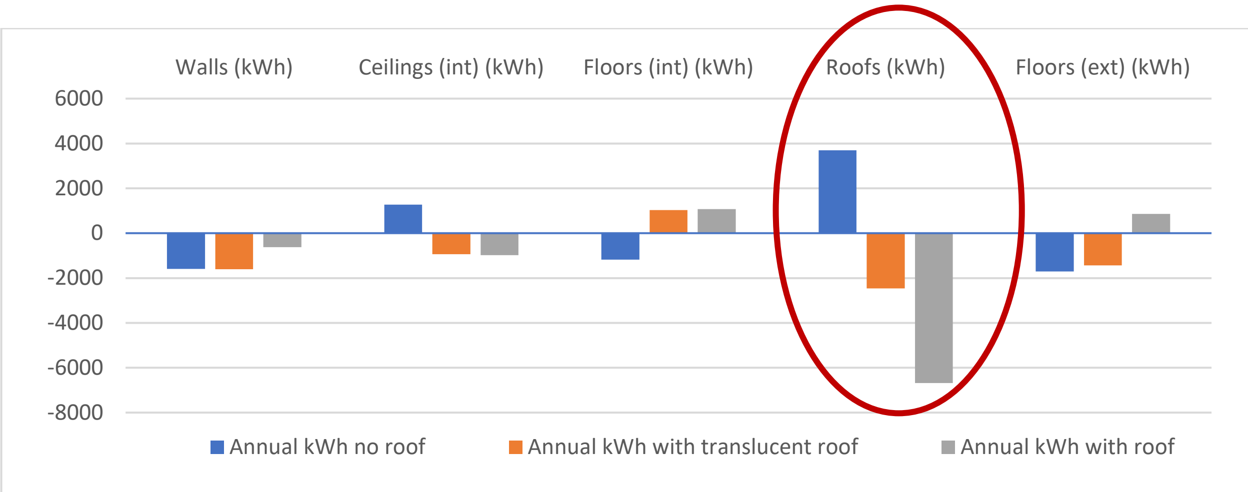
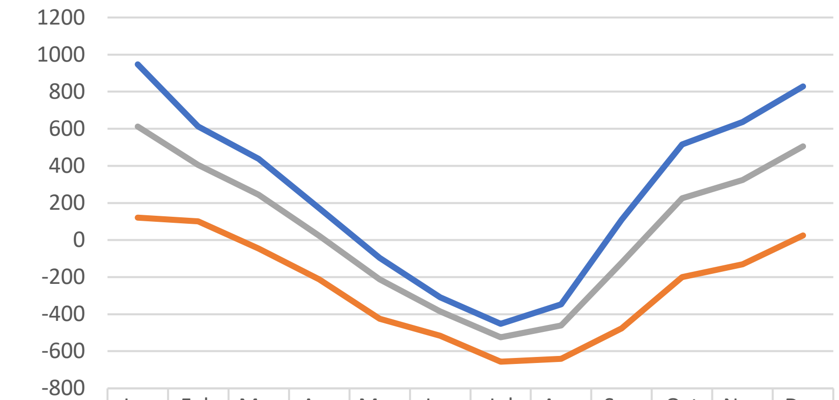


Figure 3-9 Effect of secondary roof on heat transfer through building elements

Figure 3-10 shows the monthly heat transfer through the roof with and without the secondary roof. The graph demonstrates that the opaque roof allows for up to 97% reduction in heat gain, whereas translucent roof provide around 39% reduction in heat gain in summer.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Roofs (kWh)	947	612	438	172	-96	-309	-452	-348	109	516	636	829
Opaque Roof (kWh)	121	100	-46	-212	-424	-516	-656	-640	-476	-200	-131	25
Translucent Roofs (kWh)	612	405	244	23	-212	-385	-524	-461	-122	225	323	506

Figure 3-10: Monthly heat transfer through roof

Monthly analysis of the heating and cooling electricity for the top level (Figure 3-11) shows that there is an average energy reduction of about 3000kWh/month with the opaque roof and 1400kWh/month with the translucent roof.

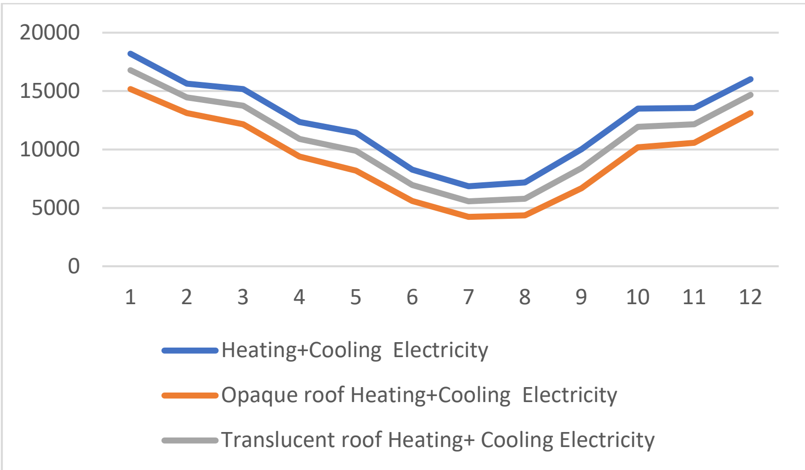


Figure 3-11: Monthly heating and cooling electricity kWh

The effect of using argon filled double glazing and single tinted glazing was analysed in conjunction with adding a secondary roof. Monthly analysis of heat gain through glazing (Figure 3-12) shows that adding the opaque roof can significantly reduce heat gain through glazing whether it is single or double. The heat gain of single glazing with the secondary roof is less than double glazing without roof by an average of 4181 kWh/month.

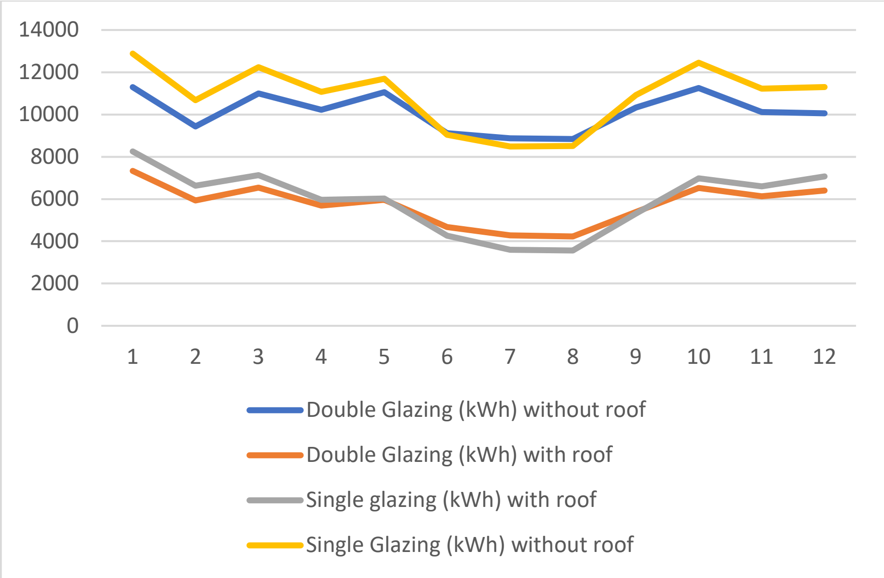


Figure 3-12: Monthly analysis of glazing/roof effect on heating and cooling energy kWh

Analysis of the cooling peak load (Table 3-2) shows that single glazing with secondary roof will result in 15% lower peak load when compared to double glazing (DG) without secondary roof. The 'best' solution in reducing peak cooling demands is double glazing with the opaque secondary roof, however the single glazed (SG) option with secondary roof may be more financially feasible. A full benefit-cost analysis (of the glazing options, the secondary roof, and electricity costs (kWh, kW)) would be required to confirm this.

Table 3-2 Cooling peak loads of different design configurations

	DG + no secondary roof	DG + translucent secondary roof	DG + opaque secondary roof	SG with opaque secondary roof
Total cooling Peak loads for level 3 (kW)	187.4	165.9	149.7	159
W/m2	49.7	44	39.7	42.2

Key findings from this feasibility analysis are:

- A secondary roof to the building can significantly reduce energy consumption (e.g. cooling energy reduction 15.8%) and heat gain through the building envelope (e.g. 97% reduction).
- As well as reducing heat transfer through the primary roof, the secondary roof can help shade the top two floors without impacting the operability of the windows or significantly reducing daylighting.
- For Cairns, an opaque secondary roof is significantly more effective than a translucent one, given the imperative to reduce solar heat gain.
- The secondary roof maximises the area available for PV, estimated to meet 100% of building demand (based on EUI 30kWh/bed/day).
- The secondary roof adds a strong design character to the building.
- A benefit:cost analysis could inform the relative impacts of single or double glazing in combination with a secondary roof.

3.2.2 Hydronic radiant cooling (Kurtis Hardacre, Tian Song, Zachary Chekroun)

3.2.2.1 Background to hydronic systems (Kurtis Hardacre)

Radiant cooling systems are systems that exchange a minimum of 50% of heat through thermal radiation They can be active (e.g. chilled beams that rely on ventilation airflow to induce an air current that passes over a cooling coil) or passive (relying on natural convection and radiation heat transfer). Passive radiant cooling can work in conjunction with separate mechanical ventilation to form a decoupled system. In this case, the sensible and latent loads are handled by separate equipment which can perform dedicated operations more efficiently. Radiant cooling systems have the potential to achieve significant energy savings while providing a high level of thermal comfort.

Hydronic systems are more efficient at distributing heating and cooling (than traditional direct expansion (DX) air conditioners) due to the higher specific heat capacity and density of water compared to air. In addition, the decoupling of sensible and latent loads through separate space heating or cooling and ventilation, allows HVAC components to handle the conditions more effectively. A typical DOAS configuration for example comprises of a ventilation system that deals with the entire latent load, supplying dehumidified outdoor air (OA) at the required ventilation rate. One advantage of this is the reduction in local pressurisation compared to a room that must be over-ventilated to handle the sensible load requirements. This helps to reduce bridging of airflow between rooms – a contributing factor to the spread of airborne viruses. Another benefit is the energy and material savings from using less ventilation and therefore smaller diameter ducting which also requires less ceiling space. However, greater care to control the indoor humidity level and higher chilled water temperature are required to ensure no condensation can form on the chilled surfaces.

3.2.2.2 Modelling of an advanced radiant cooling system (Kurtis Hardacre)

The effectiveness of radiant colling systems relies on large surface areas for radiation heat transfer. Typical radiant cooling panels must be operated above room dew point temperature to avoid the risk of condensation forming on the chilled surface. This makes them most suitable for arid climates, however the use of an air gap or non-conductive membrane to separate the panel from the ambient air eliminates convective heat transfer and the risk of condensation. A radiant cooling system with convection shielding membrane was modelled in Ansys Fluent using the Discrete Ordinates (DO) radiation model to capture the semi-transparent properties of the convection shielding membrane. The materials selected for the model were copper for the cooling panel and polyethylene for the infrared transparent membrane. Copper is a commonly used material for hydronic tubes due to its high thermal conductivity. Polyethylene is used for the membrane because of the material's transmissivity in the long-wave infrared (LWIR) band. Climate data from Cairns, including daily maximum temperature and relative humidity, was used to determine the critical dew point temperature. The methodology did not include the effect of natural convection.

The surface temperature at the membrane-room boundary was monitored to ensure it was maintained above the dew point. The system was modelled for a range of cooling panel temperatures and room conditions to determine the minimum possible supply water temperature without a risk of condensation at the membrane surface. A secondary model was constructed to solve for the radiation heat transfer from a human heat source to the cooling panel.

The results of the membrane surface temperature modelling show that for an ambient room temperature of 24°C and a dew point temperature of 16°C (RH=60%), a cooling panel temperature of 18°C can be used. This will result in a membrane surface temperature of 22.87°C which is within the recommended safe range of 1°C below dew point for condensation prevention.

In a situation mimicking a room with a window open on a hot humid day (outside ambient air temperature 28°C and RH 90%), the dew point temperature becomes 26°C and the cooling panel must be operated at a minimum temperature of 22°C to maintain a membrane temperature approximately one degree above the ambient temperature.

Results from the whole system thermal analysis show that for case 1 (ambient temperature of 24°C and relative humidity of 60%), the cooling panel produces 52W/m^2 with a supply water temperature of 14°C, and 67W/m^2 with 10°C supply water temperature. For case 2 (ambient temperature 28°C and RH 90%) the system, on its own, was not sufficient to maintain occupant comfort.

This analysis demonstrates the capacity of advanced hydronic radiant systems (with shielding membrane) to provide cooling in mild conditions, however they are not sufficient alone for hotter, more humid conditions.

3.2.2.3 Comparative analysis of hydronic cooling vs other cooling technologies (Tian Song, Zachary Chekroun)

While hydronic heating is used widely in Australia, hydronic cooling is rarely adopted. A whole of life (WOL) assessment was undertaken comparing a hydronic cooling system with chilled water and variable refrigerant systems, for Cairns (Appendix A). Key findings from this analysis include:

- The hydronic system delivered a maximum cooling limit of 50W/m^2, indicating the imperative to
    - Minimise building heat loads through
        - optimising a high-performance building envelope
        - utilising blinds for glazing exposed to the sun
    - Addressing occupant comfort needs through a variety of means
        - promoting air movement through ceiling fans
        - considering slightly raising the internal comfort settings (to 26-28°C)
- The hydronic system delivered a yearly cost reduction of 80% (operation and maintenance)
- The hydronic system had the highest capital cost (>50% more than other systems), but the lowest cost of ownership (Figure 3-13)

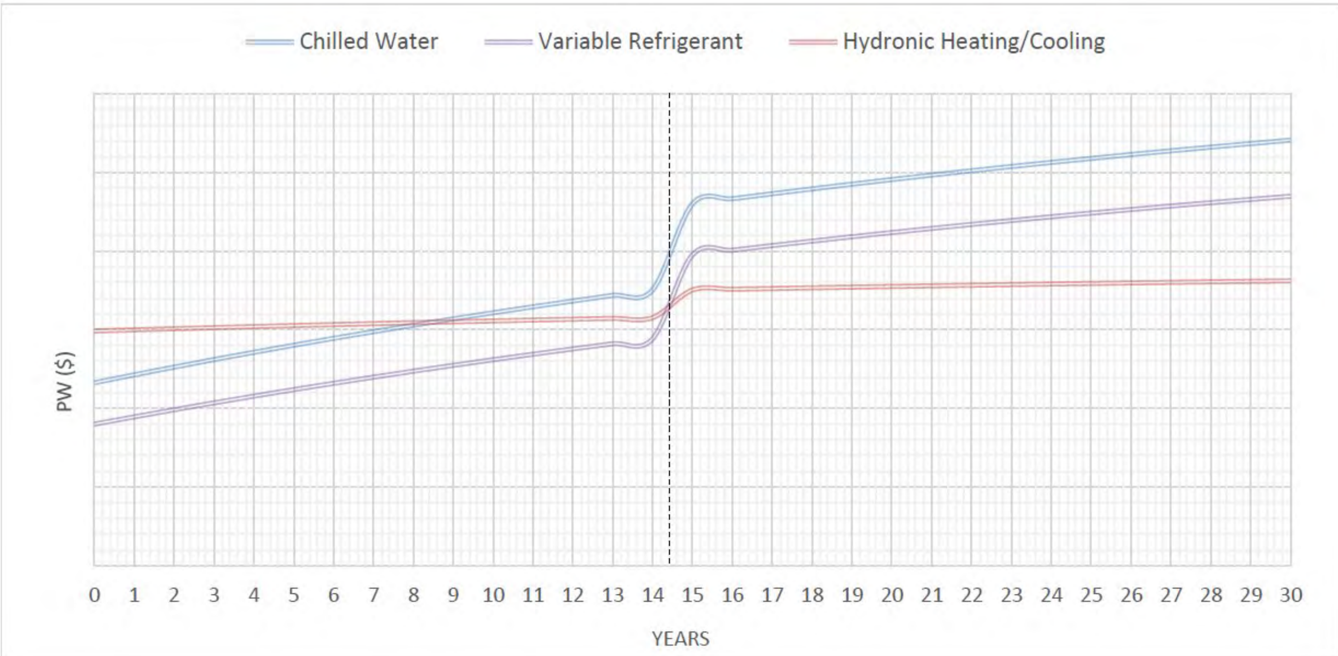


Figure 3-13 Whole of Life costing comparison of hydronic cooling, chilled water and variable refrigerant

3.2.3 *Impact of policy and practice on renewable energy potential (Aaron Liu)*

This section analyses the impact of renewable energy policy on the ability of aged care (or mixed-use building typologies including aged-care) in this climate to meet net-zero energy goals. It compares two policies:

- The Australian Renewable Energy (Electricity) Regulations 2001, that specifies that small solar renewable energy systems are no more than 100kW[13]. These systems are financially incentivised by the Small Scale Renewable Energy Scheme[14]
- The default minimum allowance of 5kW applied to solar inverter size for single phase electricity metered connections on normal low voltage distribution network [15]

This analysis compares an aged care facility whose PV system is capped at 100kWp, with an aged care facility that is considered a 'collection of households' and hence able to size PV systems based on the number of 'households' (i.e. beds) provided by the facility, within the same set of rules and incentives as are available to households. The analysis does not include large scale solar energy systems (>100kWp) as these have more complicated rules, pricing mechanisms and require more resources to build and operate[16].

The quantified baseline energy use intensity (EUI) of the case study aged care facility is 26.51kWh/bed/day. The facility has 132 beds (i.e. 132 'households'). The case study has a high electricity demand during the daytime (Figure 3-14), making it a prime candidate for maximising the utilisation of rooftop PV.

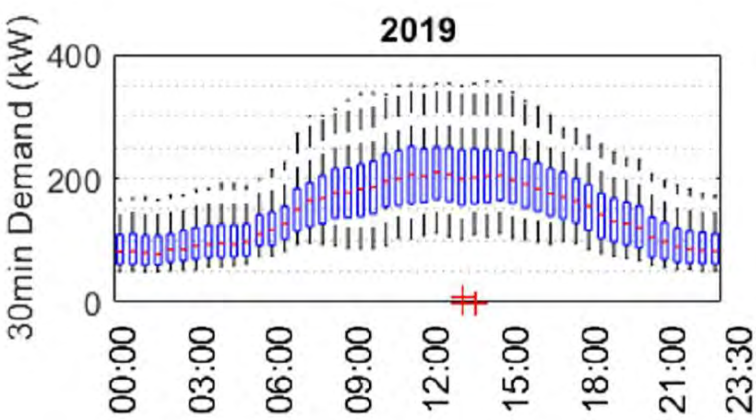


Figure 3-14 Electricity demand profile 2019

Four scenarios were compared, starting with a 100kWp system (scenario 1). Scenario 2 (net zero electricity) was calculated based on yearly electricity use and PV system generation capacity:

[13] Renewable Energy (Electricity) Regulations 2001, 2021. Federal Register of Legislation, Australia
[14] Australian Government Clean Energy Regulator, 2017. Renewable Energy Target Financial Incentives. http://www.cleanenergyregulator.gov.au/RET/How-to-participate-in-the-Renewable-Energy-Target/Financial-incentives
[15] Energy Networks Australia, 2019. National distributed energy resources grid connection guidelines – technical guidelines for low voltage embedded generation connections
[16] Australian Government Clean Energy Regulator, 2018. Large-scale Renewable Energy Target. http://www.cleanenergyregulator.gov.au/RET/About-the-Renewable-Energy-Target/How-the-scheme-works/Large-scale-Renewable-Energy-Target

$$\text{PV System Rating per bed} = \frac{\text{Yearly Electricity Use}/365/\text{bed number}}{\text{Mean Unit Daily Generation}}$$

The third scenario, best return on investment (ROI), was calculated based on an energy charge of $0.161/kWh; a demand charge of $23.708 / peak kW / month; and a Feed-in Tariff (FIT) of 0.060 / kWh. The fourth scenario, PV ratings per bed, considered 3kWp per bed and 5kWp per bed based on installation status, historical data and industry guidelines:

- December 2020, average small scale PV system rating reached 9kWp[17]. If we assume a typical three-bedroom dwelling, we could further assume 3kWp per bed. Alternatively, if we divide the total kWp by the average occupancy per household (2.5 persons), the system size would be 3.6kW/pp
- Australian national guidelines specify a default 5kVA allowance for embedded generation at each customer connected to a normal power network (single phase connection)[18]
- In 2019, typical residential PV system rating was 6.6kWp[19], equating to 2.64kW/pp.

Using a clustering algorithm, three typical days are identified for Cairns, each one with a different temperature, solar radiation and energy charge during daytime hours. The accuracy of these typical days was evaluated by comparing the differences between yearly bills calculated from typical days and the yearly bills calculated from the whole yearly datasets. The difference was 0.32%. The typical days, and their distribution, are shown in Table 3-3, including the PV system outputs costs and savings that were superimposed on each typical day. Note that almost 50% of the year the Cairns climate could be considered mild, resulting in a daytime energy charge of $300.

Table 3-3 Typical days for tropical Cairns

No.	Typical days	Max daily T (°C)	Daily solar output (kWh/kWp)	Daytime energy charge ($AUD)[20]	% of days in a year
1	Hot days	32.28	5.38	458.84	13.2%
2	Warm days	30.81	3.92	449.47	36.9%
3	Mild days	27.72	3.83	300.53	49.9%

PV system costing details used in the analysis are shown in Table 3-4.

Table 3-4 PV system costing details

Description	Parameters	Description	Parameters
Interest rate	3%	**PV inverter system**	$1200/kWp
PV system service life	25 years	**PV efficiency drop**	20% over 25 years
PV system yearly maintenance - labour	$200/10kWp in the base ear, subject to inflation	**PV system yearly maintenance - material**	$400/10kWp in the base year, subject to inflation

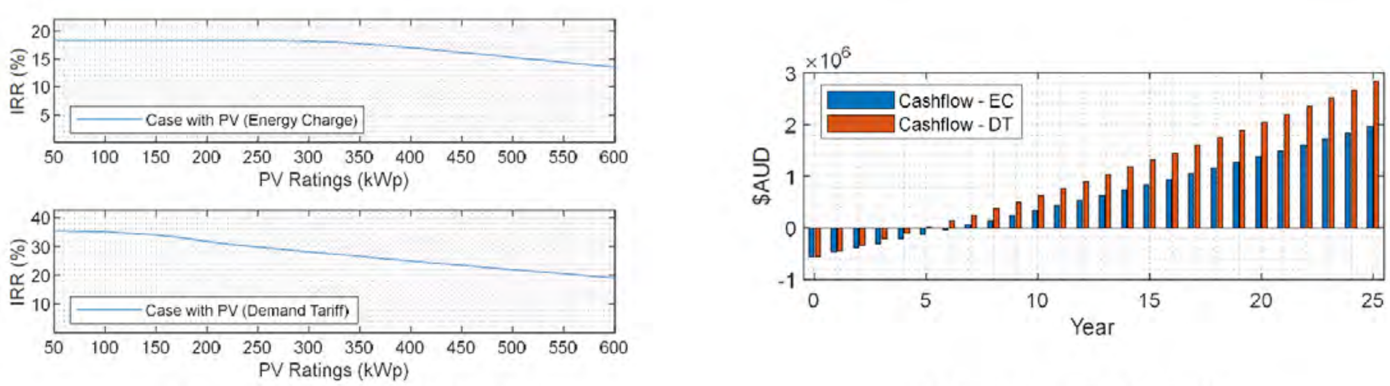
[17] Australian Energy Council, 2021. Solar Report Quarter 2, 2021, pp 1-13

[18] Energy Networks Australia, 2019. National distributed energy resources grid connection guidelines – technical guidelines for low voltage embedded generation connections

[19] Green Energy Markets, 2020. Projections for distributed energy resources – solar PV and stationary energy battery systems. Report for Australian Energy Market Operator.

[20] Energy charge is a component of demand tariff. Energy charge during daytime hours is the electrical energy charge for the community for each typical day's daytime consumption which can be offset by PV generation

The financial analysis was performed on PV systems rating from 50kWp to 600kWp. As seen in Figure 3-15, when only energy savings are considered (i.e. reduction of energy charge), PV systems never have an IRR above 18%. When both energy savings and demand reduction are considered, IRRs are above 30% to start with, and are maintained above 18% for the range of PV systems studied. The 550kWp PV system reaches positive cashflow by the 5th year and this rating is the largest PV sizing to meet the cashflow criterium. Cashflow is more positive when considering both energy and demand reduction, because aged care communities tend to have peak electricity demand during the day, coinciding with solar hours. For this case study, a 550kWp PV can achieve a positive cashflow by the fifth year and significant financial savings (~$3 million) by the end of the PV system lifetime (assumed to be 25 years).



(a) Internal Rate of Return

(b) Cashflow (PV=550kWp)

Figure 3-15 Financial KPIs for PV investment in Cairns

The results from analysis of the five scenarios are shown in Table 3-5 Comparison of renewable energy system size to load ratio under different scenarios

Table 3-5 Comparison of renewable energy system size to load ratio under different scenarios

	Scenario 1 Max. 100kWp	Scenario 2 Net zero electricity	Scenario 3 Best ROI	Scenario 4 Household size PV	Scenario 5 Household size PV
Average PV system output kWh/kWp/day	4.25	4.25	4.25	4.25	4.25
PV system size kWp	100	822	500	396	660
Equivalent to PV kWp/bed	0.76	6.23	4.2	3	5
% PV output meeting electricity needs	12%	100%	65%	47%	78%

A similar analysis was carried out for other climate zones (e.g. subtropical and warm temperate). If senior citizens living in aged care facilities were entitled to have 5kWp/bed, Australian aged care communities could produce 349% more renewable energy and further reduce 670,000 tonnes of carbon emissions, compared to the 100kWp per community scenario (Table 3-6).

Table 3-6 National implications for aged care communities

Policy allowance	Statistics (2020)	Total PV potential	Yearly energy generation[21]	Yearly emission reductions[22]	Yearly bill savings (AUD)[23]
100kWp per community	2,722 communities	272,200 kWp	397.4 GWh	269,446 ton	$39.7 mil
3kWp/bed	189,954 residents	569,862 kWp	832.0 GWh	564,095 ton	$83.2 mil
5kWp/bed	189,954 residents	949,770 kWp	1,386.7 GWh	940,158 ton	$138.7 mil

3.2.4 Solar-Hydrogen Feasibility (Jacob Pritchard, John Tuxworth)

3.2.4.1 Hydrogen vs diesel (Jacob Pritchard)

The Aged Care Act 1997 requires residential aged care facilities to ensure continued service to residents during an unexpected power outage[24]. Backup generation in a RAC facility is especially important for critical medical equipment, air conditioning, food services, communications, and maintaining safe lighting levels[25].

As the industrialised world progresses towards a net-zero future, it is necessary to examine all aspects of reliance on fossil fuels. Emergency backup diesel generators in aged care or hospital applications don't represent a large contribution to carbon emissions, as they experience limited, infrequent use. However, it is still important to consider alternatives for emergency backup energy, especially if an alternative has improved financial feasibility in addition to the potential for carbon emissions reductions.

Table 3-7 compares the key characteristics of diesel and hydrogen as energy carriers. It shows that, in theory at least, hydrogen is much more energy dense, has significantly lower environmental and health impacts, and has a longer storage life. The key challenge, as shown in this table, relates to storage.

A fuel cell would be required to convert hydrogen into heat and/or electricity. It is essentially the inverse of electrolysis, in that hydrogen and oxygen are combined to produce energy and water. Fuel cell electrical efficiencies typically fall into a range of 40-60%. When used for combined heat and power (CHP) applications, they can reach efficiencies of 85%[26].

[21] Assuming 1kWp PV generates 4kWh electricity per day across Australia
[22] In 2021, the Australian National Electricity Market's carbon intensity was 0.678 kg CO2-e/kWh
[23] Assuming 1kWh of electricity has a value of AU$0.10 through a combination of offsetting local energy consumption and earning a feed in tariff by exporting electricity to the grid
[24] Commonwealth of Australia. *Aged Care Act 1997*. https://www.legislation.gov.au/Details/C2021C00344
[25] The Torrens Resilience Institute. *Guidance for the Selection of Generators for Aged Care Homes*. Flinders University, Adelaide, 2017
[26] F. Badea and R.-A. Felseghi, "Hydrogen Fuel Cell Technologies for Sustainable Stationary Applications," in *Hydrogen Fuel Cell Technology for Stationary Applications*, B. Gheorghe, F. Raluca-Andreea, and A. Ioan, Eds. Hershey, PA, USA: IGI Global, 2021, ch. 7, pp. 166-185

Table 3-7 Comparison of diesel and hydrogen key characteristics

	Diesel	Hydrogen
Production	Fossil fuel, derived from ...	Grey hydrogen – produced via reforming natural gas or goal gasification[27] Blue hydrogen – as above, but paired with carbon capture and storage[28] Green hydrogen – produced via electrolysis using renewable energy[29]
Energy content	1L = ~ 9.7kWh[30] (1L weighs ~840g)	1kg = ~ 33kWh
Volumetric density **Specific volume**	~875kg/m^3 (at 15°C) ~ 1.14m^3/1000 kg	0.09 kg/m^3 (at atmospheric pressure) 11.9 m^3/kg at 20°C and 1 atm (hydrogen gas)
Storage life	6-12 months	Can be stored over long periods of time with minimal losses or need for recharging (depending on the state of the hydrogen and the storage method)
Storage	'Standard' fuel tanks	1kg occupies 11m^3 at room temperature and 1 atmospheric pressure. Reducing storage requires increasing pressure, decreasing temperature, or using a chemical or compound that attracts the hydrogen molecules, with low-energy reversibility
Health impacts from exhaust emissions	Contains known human carcinogens[31] May contribute to neurodegeneration and dementia-related diseases[32,33]	No emissions. High concentrations (e.g. leaks in a confined area) can cause an oxygen-deficient environment
Carbon footprint	2.6 kg of CO2 per litre of fuel consumed	Grey hydrogen 36.4 g CO2/MJ – 91 G CO2/MJ Green hydrogen <36.4 g CO2/MJ (renewable) Low-carbon hydrogen <36.4 g CO2/MJ (non-renewable)[34]

[27] Midilli, A., Kucuk, H., Topal, ME., Akbulut, U. and Dincer, I. 2021. A comprehensive review of hydrogen production from coal gasification: challenges and opportunities. *International Journal of Hydrogen Energy*, vol 36, No 50, pp 24385-25412. doi: 10.1186/s12989-017-0213-5

[28] Yu, M., Wang,K., Vredenburg,H. 2021. Insights into low-carbon hydrogen production methods: green, blue and aqua hydrogen. *International Journal of Hydrogen Energy*, vol 46, no 41, pp 21261-21273. https://doi.org/10.1016/j.ijhydene.2021.04.016.

[29] Newborough, M., Cooley,G. 2020. Developments in the global hydrogen market: the spectrum of hydrogen colours. *Fuel Cells Bulletin*, vol 2020, no 11, pp 16-22. https://doi.org/10.1016/S1464-2859(20)30546-0.

[30] US Department of Energy. 2021. *Alternative Fuels Data Center – Fuel Properties Comparison*

[31] Sawant, AA., Shah, SD., Zhu, X., Miller, JW., Cocker, DR. 2007. Real-world emissions of carbonyl compounds from in-use heavy-duty diesel trucks and diesel Back-Up Generators (BUGS). *Atmospheric Environment*, Vol 41, No 21, pp 4535-4547. https://www.legislation.gov.au/Details/C2021C00344

[32] Hullmann, M et al. 2017. Diesel engine exhaust accelerates plaque formation in a mouse model of Alzheimer's disease. Particle and Fibre Toxicology, vol 14, no1. doi: 10.1186/s12989-017-0213-5

[33] Coburn, JL. 2018. *Diesel exhaust exposure induces microglial activation, suppresses adult neurogenesis and increases levels of neurodegenerative markers*. PhD, University of Washington, Ann Arbor, 13223939.

[34] Certifhy green hydrogen criteria. www.fch.europa.eu

3.2.4.2 Solar-hydrogen opportunities for the mixed-use precinct (John Tuxworth)

Consideration of solar-hydrogen energy opportunities for the 40,000m$_2$ site references the mixed-use 30,000m^2 GFA master plan developed by QUT Architectural Masters student, Tristan Clark (Figure 3-16). The key findings are presented here, with the full report in Appendix B.

Figure 3-16 Concept Masterplan - Designer Tristan Clark

Energy demand for the master planned proposal has been considered for two scenarios, being that associated with traditional construction practices, and sustainable construction practices facilitating increased energy efficiencies (66% reduction in demand). The site's estimated energy demand is shown in Table 3-8, based on measured historical data of 27kWh/bed/day for 'traditional construction' buildings.

Roof areas nominated by the proposed masterplan can accommodate a 5.2MW photovoltaic array, generating a mean daily 2,500kWh of electricity. This estimated solar output is less than the calculated energy demand based on the traditional construction case. Thus, additional ground-mounted photovoltaics and/or imported power would be required to meet the calculated demand if traditional design and construction is implemented (i.e. not addressing significant energy efficiency).

Table 3-8 Estimated Master Plan energy demand

Building Type	Plan Area m2	EMD KVA (kW)	Usage hrs	peak hrs /day	Av vs Max demand %	Days per wk	Est Mean kWh/day	Roof vs GFA reduction	Modified Mean	Est day-time use %	Est day-time use kWh/day	Night time kWh/day
Childcare	1379	110	10	3	80	5	678	0.94	637	80	510	168
Arts centre	4303	170	12	3	80	5	1,237	0.94	1,163	50	582	656
Library	2123	86	12	3	90	7	953	0.94	896	50	448	505
Corworking A	1010	86	12	3	90	5	681	0.94	640	80	512	169
Retail	1010	212	12	3	90	7	2,357	0.94	2,215	50	1,108	1,249
Residential aged care	1010	187	24	3	80	7	3,708	0.94	3,486	50	1,743	1,965
Mini golf	1010	43	4	3	90	7	167	0.94	157	30	47	120
Aquatic centre	2850	247	15	5	90	7	3,903	0.94	3,668	50	1,834	2,068
Coworking B	2341	91	12	3	90	5	723	0.94	680	50	340	383
College	2850	106	15	5	90	5	1,194	0.94	1,123	50	561	633
Restaurant	2470	85	12	3	70	7	789	0.94	741	50	371	418
Building A (Apartment)	1073	97	24	3	60	7	1,516	0.94	1,425	50	713	804
Building B (Apartment)	1176	97	24	3	60	7	1,516	0.94	1,425	50	713	804
Building C (Mixed Use)	848	641	24	3	60	7	10,000	1	10,000	50	5,000	5,000
Totals		**2,258**					**29,421**		**28,256**		**14,480**	**14,942**
				66% reduction for sustainable building practices					**18,649**		**4,923**	**5,080**

However, if sustainable construction practices were deployed, energy demand could feasibly be reduced by 66%[35], a significant reduction. Under this scenario, there is a potential role for hydrogen.

The day-time demand for the site was estimated and compared with the PV output. The PVs are capable of generating 5 times the daylight hours consumption (4923 kWh/day), with 19.968 kWh/day available for hydrogen production, storage and reuse. This excess supply is suitable to power a 2 or 2.5 MW hydrogen electrolyser which can fit in a 44ft shipping container. Novel low pressure metal hydride storage vessels can minimise storage volumes and stored pressure, negating the potential deficiencies associated with high-pressure storage.

It is envisaged that solar-hydrogen power generation is feasible to provide a net-zero, off-grid, sustainable power alternative to meet the estimated energy-efficient demand of the proposed masterplan. RAC security of supply (36 hours supply) can additionally be met by estimated hydrogen production.

Conceptual costings suggest a combined repayment period of 8 to 10 years.

A practical approach to further solar-hydrogen research for residential aged care would be to reduce the variables and estimations inherent with a conceptual master plan proposal. One option would be to focus on building modelling to assess the impact of energy efficiency measures to further refine solar-hydrogen feasibility. A detailed and specific analysis would additionally facilitate more accurate costings by a Quantity Surveyor.

Energy efficiency of hydrogen fuel cells increases when combined heat and power (CHP) is adopted. A detailed analysis could consider the further energy demand reductions achieved from CHP.

[35] https://new.gbca.orgau/news/gbca-media-releases/gbca-builds-powerful-and-positive-case-green-star/

3.2.5 Embodied Carbon and Construction Considerations of Mass Timber (Scott Butler)

The move to net zero carbon buildings needs to consider not only the carbon intensity of the energy used in the operational phase of buildings, but also the embodied carbon of building materials, i.e. the greenhouse gas emissions released during all stages of a products life. Refer to Figure 7-3 in the Appendix.

This section examines the current Australian design aspects and construction impacts associated with mass timber construction, mainly

- cross-laminated timber (CLT) – mainly used for surfaces
- glulam – mainly used for loadbearing frames (e.g. trusses, columns and beams)

3.2.5.1 Design and construction variables

Although used extensively overseas, mass timber is an emerging building solution within the Australian market. Although the underlying principles remain the same, due to the geographical size and varying legislative framework within the Australian states, there are variables that must be considered when incorporating mass timber construction into design and construction projects. The key findings of this analysis are presented below, while the whole report can be found in Appendix C.

A summary of the key variables to be addressed when considering mass timber is shown in Table 3-9.

3.2.5.2 Cost

Commercial construction is a cost sensitive industry where project feasibility dictates the scope of works, finishes and fixtures used and often the operational performance during the life cycle of the building. The selection of a structural framing system, whether traditional concrete or mass timber is made during the early design stage. This is a requirement as recent mass timber projects within Australian have shown that a significant financial premium is paid to include this material. To date, projects requiring a high green star rating or sustainable credentials have used mass timber including educational facilities such as universities and large corporation commercial offices.

A comparison of the cost of mass timber construction versus traditional concrete framed building has been undertaken which shows a cost premium for this emerging construction material.

Mass Timber (including combined CLT and Glulam) pricing = $2,800/m^3 supplied & installed

Concrete (concrete, pumping, reo, formwork, place & finish) pricing = $1,085/m^3 supplied & installed

Overall, for a full timber framed multi storey building a construction cost of $6,000 to $7,000/m^2 may be incurred. This m^2 rate would make these buildings some of the most expensive to construct. Therefore, on average, a full structural mass timber framed building is nearly three (3) times more expensive to build. This extra over cost of $1,715/m^3 will be offset in part by builder preliminary costs due to a quicker construction period.

Table 3-9 Summary of key variables to be addressed with mass timber

Issue		Brief explanation
Embodied carbon		Typical specification of <0.3 tonnes CO2e by gross floor area[36]
		Benchmarking can be undertaken using life cycle assessment (LCA) modelling
		Carbon saving of the material (compared with concrete or steel) needs to consider the carbon footprint of transport and shipping (e.g. if sourced from Europe)
Constructability	Life span	50 year structural integrity (structural design life of building frame)
	Fire rating	Minimum 90 minute fire resistant level (FRL) CLT char rates vary depending on application, cross section area, number of penetrations Glulam has ore consistent fire properties Local fire authorities will need to be involved early in the design stage, as they provide fire performance assessment required by the building certifier
	Fire and water	Wet areas, utility cupboards, HVAC plant, fire stairs and service risers require fire rated construction and may be affected by water ingress
	Services	A larger quantity of services will be exposed Aged care requires a more diverse array of services than multi-residential apartments CLT can accept floor and wall penetrations quite easily, using standard fire collars; penetrations through glulam need to be coordinated with a 3D model during the design phase Higher floor to floor heights will reduce the number of beam penetrations
	Vibration and acoustics	Timber susceptible to vibration and acoustic transmission
	Codes	European Codes generally used (because Australian Standards and Codes don't adequately cover mass timber construction in detail)
	Structural considerations	Cross sectional dimensions and manufacturer selection needs to be locked in early in the design phase Construction loading needs to be included, typically >3kpa of the structural engineered design capacity
	Connection	Consideration must be given to flexible connections of CLT to concrete/steel elements needed with tolerances to suit installation, building and thermal movement
	Product selection	Different timber species (e.g. European spruce vs Australian pine) have different visual, structural and certification characteristics which must be considered in the design phase.
	Onsite construction	Installation sequencing is critically important to limit site handling and ensure safety during erection

[36] European Standard EN15978:2011 – Sustainability of Construction Works, Assessment of Environmental Performance of Buildings

3.2.5.1 Timeframes

The use of mass timber onsite creates significant time savings during construction compared to traditionally framed, poured insitu concrete buildings. The key considerations affecting timeframes are summarised in Table 3-10.

Table 3-10 Considerations for timeframe impacts

Consideration	Explanation
Front-end design and development phase is significantly longer	Manufacturers will require a 3D BIM model to produce their shop drawings. Typically four (4) weeks required to draft and produce their fabrication model The 3D BIM model (construction issue drawings) will need to include virtually complete services design.
Fabrication and shipping	Typically 17-18 weeks from Europe (excluding current supply issues due to covid, industrial action, materials and labour shortage, and inclement weather)
Program savings	Dependent on amount of mass timber versus requirement and quantity of concrete elements needed for building core (lifts and fire stairs) and other structural elements to maintain building rigidity and fire rating.

3.2.5.2 Review of massed timber in IDS design solutions (Scott Butler + Wendy Miller)

A number of design solutions for the mixed-use building typologies were briefly reviewed with regard to how massed timber was incorporated in the design. Three common issues were evident:

- Designs sometimes only used a small portion of CLT which doesn't provide much benefit for embodied carbon or the construction program
- There seemed to be an over-reliance on product market material that focuses on benefits and not on the inherent construction, fir or certification issues that need to be resolved
- The impact of massed timber on the operational energy requirement for space heating and cooling was not considered

The first two issues have been addressed in the previous sections. The last issue is important in considering a whole of life net zero carbon target. Addressing operational carbon and embodied carbon separately does not lead to optimised solutions. Thermal mass is in important consideration in reducing the space heating and cooling demand in buildings in most climates. The thermal effectiveness of materials varies, as shown in Table 3-11), and the impact of structural building materials needs to be modelled during the design stage in order to determine the impact of the selection on energy use intensity for heating and cooling, and hence how it affects annual, seasonal and daily energy consumption, peak demand, selection of technologies and strategies for low carbon heating/cooling, and the sizing of renewable energy systems to meet that demand.

Table 3-11 Comparison of thermal mass effectiveness[37]

Material	Specific heat capacity J/kg.K	Thermal conductivity Kg/m^3	Density W/m.K	Effectiveness
Concrete	1000	1.13	2000	High
Timber	1200	0.035	35	Low
CLT	1300	0.13	480-500	Low-medium

[37] Derived from https://www.greenspec.co.uk/building-design/thermal-mass/

3.3 Summary of technology options and impacts

This section has shown that there are a range of design and technology solutions that can reduce energy demand and/or increase the renewable energy potential for mixed-use buildings (incorporating aged care) in the tropics. A summary of the findings of the technologies evaluated in this IDS14 is shown in Table 3-8. Note that these indicative savings are based on the specific assumptions for each of the feasibility assessments. It should also be noted that some technology solutions examined for IDS13 (for the subtropics) and for other IDS projects (in temperature climates) may also be suitable for the tropics and for this mixed-building typology.

Table 3-12 Summary of technology options and impacts - tropics

Technology	Indicative demand reduction potential (compared with BAU)	Renewable Energy Potential	Co-Benefits
Hybrid green-solar roof	Could reduce building cooling load	Increase PV efficiency 3.6% Increase PV output 2-8%	Reduced heat transfer through the roof
Geothermal (Ground source) Heat Pumps for cooling	~30% reduction in cooling energy (but depends on local context)	This is a renewable energy technology	
Secondary roof	15.8% decrease in cooling energy ~21% reduction in peak cooling load (compared with double glazed building with no secondary roof)	Would increase the hosting capacity of PV and increase the % of load being met by PV	Increased thermal comfort (natural ventilation mode)
Hydronic cooling	80% reduction in yearly operation and maintenance (including energy costs)		Can meet cooling loads <50W/m^2 Lowest total cost of ownership
Rooftop PV Policy approach to net zero	NA	12-100% of BAU electricity load, depending on policy	
Solar-Hydrogen	66% reduction in BAU required	100% possible if sustainable construction methods significantly reduce demand	Reduced CO2e and diesel exhaust emissions, and less reliance on supply chain (for diesel generators)
Massed Timber – embodied carbon	Needs modelling to determine impact on cooling load	-	Reduced CO2e

4 EVALUATION OF INTEGRATED DESIGN PROCESS

4.1 IDS Key Learnings

Five main factors were identified through the IDS13/14 process that are key to implementing integrated design. These factors, shown in Figure 4-1, are interrelated and interdependent. Some of the key issues, associated with each factor, are further explained below.

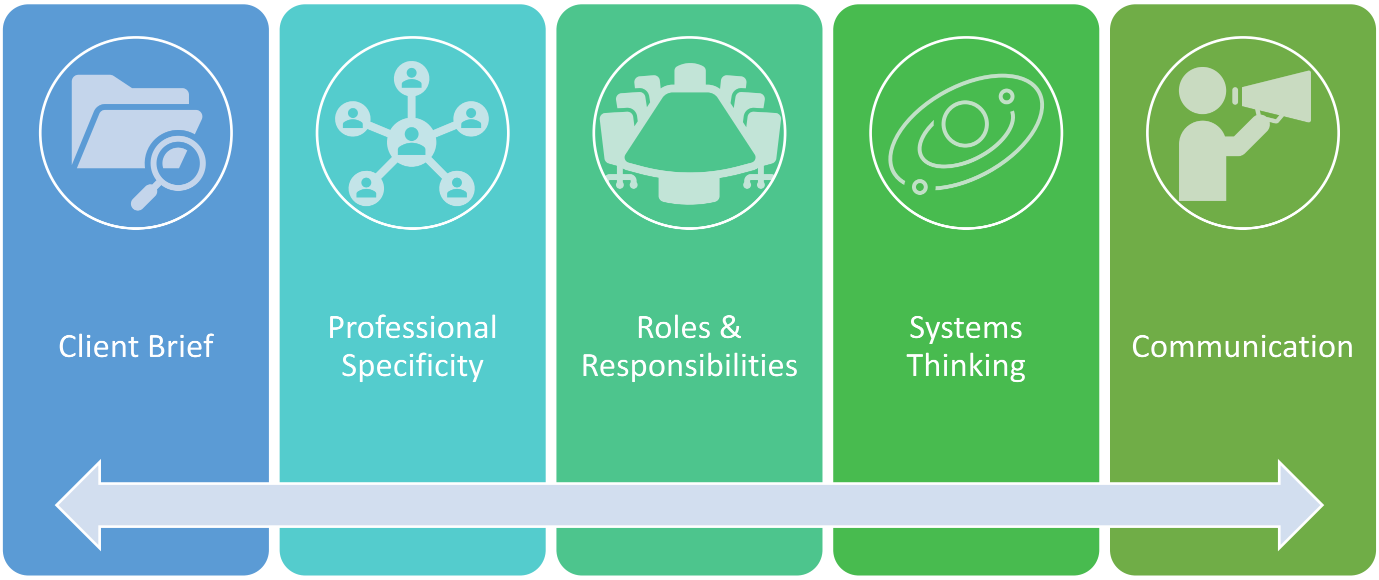


Figure 4-1 Five factors influencing IDS success

4.1.1 Client Brief

In current practice, the nature of the information provided by the client differs for each recipient, i.e. architects receive different information to engineers who receive different information to construction contractors. This is likely because of the current linear approach to design, with more and more detail provided as different professions are included in the process as it progresses. Each profession, as it engages in the process, adds more technical detail to the brief. This linear approach could be a barrier to creativity and innovation, particularly in the context of a rapidly changing environment with regard to energy technologies, carbon reduction requirements and a changing climate. It can also lead to significant rework, cost overruns and perverse outcomes (refer to Table 4-1). One could argue that having an Integrated Design process for the development of the initial brief would be beneficial in optimising design and implementation outcomes. Client inputs, at this very early stage, could include things such:

- purpose of the building (e.g. building classes; nature of occupants; occupancy times)
- general goals (social, environmental, economic)
- risk appetite (e.g. what Technology Readiness Level will proposed solutions need to meet)
- financial expectations (e.g. return on investment)
- the time span for considerations (e.g. does the client intend to own and operate the building? Over what time period?)
- any corporate, shareholder and regulatory reporting requirements

4.1.2 Roles and Responsibilities

A key component of an Integrated Design Studio is the recognition, acceptance and enabling of each participant to be a co-designer (as opposed to, for example, technical consultant subservient to designers). This will require, however, the assembled team to discuss and agree on decision making processes. This is likely to require a new role – that of an IDS coordinator or facilitator, possibly an independent third party who can facilitate the process in a neutral manner. This role would potentially suit an experienced project manager with an IDS background and/or a 'systems integrator' with excellent communication and collaboration skills and a firm grasp of social, environmental, economic and technical issues.

4.1.3 Professional specificity

The rich complexity of a building, within the context of net zero energy goals, requires a transdisciplinary team to cross-pollinate ideas and foster creativity. Bringing such a team together, however, may require providing opportunities for each participant to understand the terminology, thinking and design processes, and specific tools used by disciplines outside of their own. In particular, in this IDS, there was initially little knowledge of (and hence appreciation for) the role of energy modelling professionals, sustainability consultants and construction managers. In addition, designers and engineers often don't know what they don't know and are limited by previous knowledge and experience. This can lead to re-using previous solutions or design or assumptions. The ID process should question these preconceived approaches and start with a clean slate, It can do this through creating a space for innovation and sharing, without the constraints of having to produce an output immediately.

4.1.4 Systems thinking

This relates not only to understanding the complexity of the energy system (e.g. the climate, building envelope, HVAC technologies, renewable energy technologies and the broader electricity grid and markets), but also understanding and designing for building occupants (e.g. how the energy system solutions impact on indoor environment quality and occupant health and wellbeing).

4.1.5 Communication

A range of communication strategies and mediums is required to support, encourage and challenge design ideation; to effectively exchange information; and to develop respect, earn trust, promote vulnerability and openness, and demonstrate accountability. Non-verbal, verbal, written, graphic and digital mediums will be required, in both formal and informal communications. Active listening and critical inquiry are essential.

4.2 Application to industry

To encourage the application of the Integrated Design Process (IDP) in industry conceivably requires two key things: a procurement contract that enables IDP to take place, and a set of principles to guide the IDP. This section proposes ways forward for both of these aspects.

4.2.1 Contracting for IDS

In common practice, contractors (construction companies) can be engaged in the design process under several different procurement options, such as Early Contractor Involvement (ECI) or Design and Construct (D&C) contracts. Under these contracts a level of design has already been undertaken previously, and the client brief to these contractors includes principal project requirements (PPRs). It is up to the construction company to relate all design works back to the PPR; collaborate with the client and end users to gain a full understanding of the needs; analyse wants versus needs; evaluate design intent versus what is physically possible; and assess risk and opportunities.

The overall goal, of these contractors, is to ensure cost-effective value that aligns the design to achieving the best possible outcome for the client. Similar to the evolution of design that becomes more and more detailed over time, cost planning methods also differ from early-stage design to contract sum (Figure 4-2). For example, an elemental cost plan is generally based on $/m² for a particular type of building, using historical pricing data. This has a high level of uncertainty. An approximate quantities cost plan, at the next stage, includes trade package descriptions and rates, builder's preliminaries, and other fees and charges (e.g. consultants' and authorities' fees). Some risks and opportunities are identified.

By the time of the tender pricing, the details of the design should be advanced; 3D models created; specifications and schedules compiled; finishes specified; subcontractor pricing received; and the program of works completed. This removes a fair amount of uncertainty and lowers the risk for both builder and client. The inclusion of construction management in the IDS process under these procurement methods provides some level of risk management in optimising the cost-effective realisation of design intent.

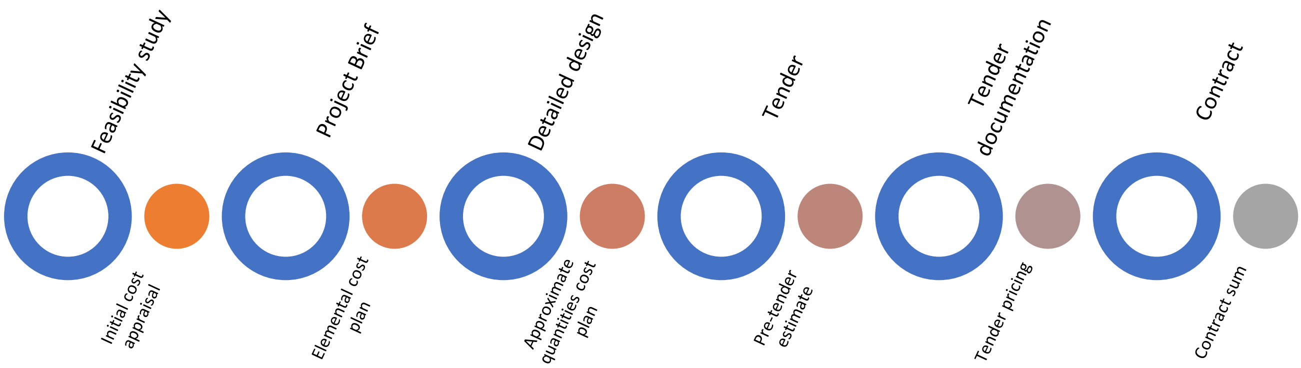


Figure 4-2 Construction major design stages (blue) and associated cost planning stages

The Integrated Design process, however, needs a different approach. One that enables construction contractors to be involved at a much earlier stage. An evaluation of three different types of contracting models is provided in, showing, at a high level, typical outcomes from each contracting model. From this evaluation, it appears that the third, the Integrated Project Delivery procurement model, is best suited for supporting the integrated design process, as it incorporates the client, architects, engineering and construction managers in a risk-sharing collaborative agreement from the very start of project ideation.

Table 4-1 Comparison of contracting models and outcomes

Contracting Models	Typical Outcomes
Traditional methods (e.g. fixed price contracts such as; lump sum, D&C, EPC)	• Contractor incentivised to submit a bid based on incomplete information, leading to perverse outcomes (exclusions, change orders, hidden exclusions); • Often results in cost (and time) overruns; • Parties attempt to transfer risks.
Collaborative Contracting (e.g. early contractor involvement (ECI), and managing contractor (MC))	• All parties given an incentive to see a project succeed; • Flexibility to cater for different levels of collaboration, and associated adjustments to price and risk; • Non-adversarial approach; • Shared liability; • Potential cost savings to all parties (not likely for small projects); • Contractor margins may be lower (but profit-sharing opportunity may be higher); • Contract establishment costs may be higher initially (but reduce with increased corporate learning).
Integrated Project Delivery (IDP) (In its pure form, a single, multi-party contract between owner, general contractor and designer/s)	• All parties accept, manage, and share design and construction risks; • Financial risks and rewards shared through an agreed profit/incentive pool based on quantifiable project outcomes; • Establishes individual and group accountability; • Encourages candid communication; • Cost dictates design; • Cost and design validation and optimisation happens as opportunities arise; • Coordination enhanced through use of BIM (for design coordination) and Project Management Information System (PMIS).
Sample Contracts to support Integrated Design	
NEC4 Design, Build and Operate Contract (DBO)[38]	• A contract for an integrated whole-life delivery solution; • Suitable for contracts extending into operational phase.
NEC4 Alliance Contract (an IDP type contract)[39]	• Multi-party contract for projects requiring deep collaboration between all project partners; • All partners have an equal voice; • Values shared performance instead of individual performance.

4.2.2 *Integrated Design principles*

Factor Ten Engineering, developed by the Rocky Mountain Institute, demonstrated over a decade ago that very large energy and resources savings (a factor of 10) could be profitable though transforming design and engineering practice via whole-system thinking and integrative design. The Factor Ten Engineering Design Principles have been used as a basis for developing a set of Integrated Design Principles for Net Zero Energy Buildings. The ID process allows for the optimisation of the performance of buildings, bringing together diverse teams to understand how the parts work together as a system, then turning those links into synergies that optimise the performance outcomes of the whole system.

[38] https://www.neccontract.com/NEC4-Products/NEC4-Contracts/NEC4-Design-Build-and-Operate-Contract
[39] https://www.neccontract.com/NEC4-Products/NEC4-Contracts/NEC4-Alliance-Contract

Table 4-2 Applying Factor 10 Engineering Design Principles[40] to ID for net zero energy buildings

Design phase	Factor 10 Engineering Design Principles	Integrated Design Principles for Net-Zero Energy Buildings
Before design starts	**1.** Define shared and aggressive goals	Establish a clear, shared, ambitious NZE goal and timeframe for achieving that goal. Consider including other related goals, such as resilience, adaptation, grid autonomy. Determine KPIs that reflect the goals, including ambitious energy efficiency.
	2. Collaborate across disciplines	Convene a transdisciplinary design team (e.g. engineers, architects, construction contractor, building owner/manager/occupants, ID specialist/facilitator) with diverse skills and experiences.
	3. Design nonlinearly	Avoid the linear march through traditional design phases (project objectives and aspirations; design concept development; master planning; design development; feasibility evaluation). ID is iterative, with successive stages informing earlier ideas.
	4. Reward desired outcomes	Implement an Integrated Project Delivery contract that rewards teams for meeting KPIs and providing savings, rather than producing documents.
Focus on the right problem	**5.** Define the end-use	Understand the purpose of the building and the needs of the people who will occupy it. What energy services will be required and what environmental, regulatory, technical and social contexts are likely to exist over this period?
	6. Seek systemic causes and ultimate purposes	Push past end-uses (e.g. HVAC), resulting services (e.g. comfort) and ultimate benefits (e.g. health, productivity) to understand the full range of ways to fulfill the purpose/s.
	7. Optimise over time and space	Take a whole-of-life approach to designs and their consequences (i.e consider current and future occupants and environmental context).
	8. Establish baseline parametric values	Establish BAU benchmarks for the KPIs, and whole-system, lifecycle value of savings (e.g. in kWh, kW, CO2e, HVAC kVa, PV kWp etc)
	9. Establish the minimum resource theoretically required, then identify and minimise constraints to achieving that minimum in practice	Use science and the plethora of simulation and modelling tools available to determine the theoretical minimum amount of energy needed to provide the energy services (especially HVAC). Consider how far each practical design constraint (e.g. cost, safety, performance, accessibility) moves away from that theoretical minimum.
Design Integratively	**10.** Start with a clean sheet	Don't start with a familiar or previous design or conventional assumptions or methods. Start afresh with no preconceptions.
	11. Use measured data and explicit analysis, not assumptions and rules	Question all rules of thumb and assumptions. Require all proposed design options to demonstrate performance against the KPIs.
	12. Start downstream	Establish a hierarchy of approaches: super energy efficient building envelope (design and materials), building services (technologies and controls), and renewable energy (generation, storage, control). This will produce compounding savings upstream.
	13. Seek radical simplicity	Simplify systems and components, valuing passive solutions over active solutions wherever possible
	14. Tunnel through the cost barrier	Think beyond current benefit:cost evaluations and minimum performance standards. Incorporate whole-of-life, total cost of ownership, and non-monetary value evaluations
	15. Wring multiple benefits from single expenditures	Create enhanced value by ensuring each part, subsystem or system provides multiple benefits.
	16. Meet minimised peak demand; optimise over integrated demand	Optimise energy systems to meet the diverse annual and seasonal conditions (use and generation), and implement control strategies to minimise or shift peak demand and optimise self-consumption
	17. Include feedback in the design	Incorporate technologies (e.g. integrated BMS, EMS) and processes (e.g. post occupancy evaluation) to inform design success and future designs.

[40] 10xE Design Principles 1.0, Rocky Mountain Institute, August 2010

5 CONCLUSION

The combined IDS 13 and IDS 14 studios were delivered at QUT throughout 2021. The studios have involved 47 participants: 32 students from four different disciplines, four academic/professional studio leaders (architecture, engineering, and architectural engineering), six industry/professional consultants (engineering, ESD, and construction management), two client representatives, and three academic researchers.

The project implemented and evaluated a range of strategies to enhance integrated design aspects within the design of mixed-use building typologies in subtropical and tropical climates. It also fostered the development of design solutions that could reduce the carbon emissions of such buildings through reduced demand, HVAC controls and/or renewable energy and storage systems. The feasibility of some of these designs solutions has been evaluated for demand reduction, renewable energy contribution and other benefits. The key messages, from these designs and evaluations, are:

- Optimising the thermal performance of the building envelope through passive means is essential for unlocking the full value of solutions by dramatically reducing the cooling load. Parametric analysis tools are very helpful in the selection of key materials and performance characteristics to achieve this optimisation.
- Cooling loads in the subtropics and tropics can be reduced to such an extent as to open up the possibilities for a wider range of cooling technologies (e.g. radiant cooling), and/or peak load reductions, and the flow-on operational and environmental benefits from such solutions
- Renewable energy potential is then increased (i.e. the percentage of load met by rooftop PV increases), with the possibility of achieving net zero energy.

This project has also identified key aspects that support the IDS process and has proposed a procurement contract model that seems to be consistent with the intent and practice of IDS.

6 APPENDIX A – HYDRONIC COOLING (JHA ENGINEERING)

The full report is shown in the following page.

HYDRONIC HEATING & COOLING IN AGED CARE FACILITIES

By Tian Song, Zachary Chekroun

Hydronic heating is a widely used and a recognised method of delivering space heating within the Australian industry. It is often viewed as a luxury solution to our comfort heating needs. The use of hydronic cooling on the contrary is limited, and rarely adopted. Hydronic heating or cooling can be delivered through:

- Imbedded under floor systems
- Integrated ceiling or wall systems
- Modular radiator panels

For the purposes if this exercise, the hydronic method of heating and cooling will be defined by the passive nature in which heating or cooling is delivered into the space, and assessed against conventional air conditioners as part of the Bolton Clarke Cairns Aged Care Facility case study.

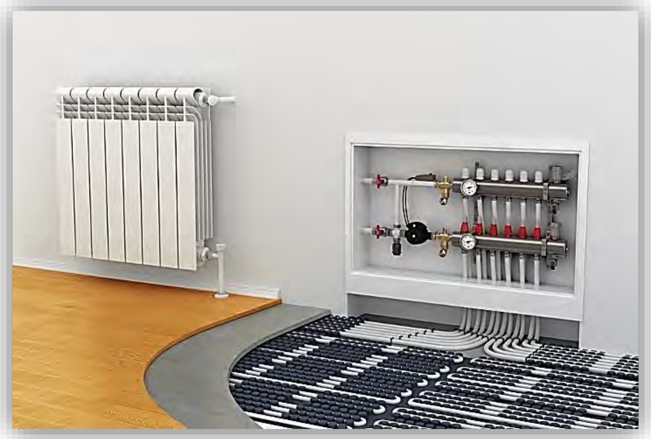


Figure 1 Rheem Commercial Hydronic System

BENEFITS OF HYDRONIC SYSTEMS

The passive nature of the heating and cooling distribution network within the structure and substructure means hydronic systems have less maintainable moving parts compared to conventional refrigerant based air conditioners. Hydronic systems for this case study delivered an 80% yearly cost reduction in on-going maintenance and running cost, while maintain a a longer economical life.

CONSTRAINTS OF HYDRONIC SYSTEMS

The passive nature of its heating and cooling distribution while beneficial for maintenance and energy, limits the amount or capacity it can deliver, when compared to conventional air conditioners. Hydronic heating and cooling delivered a maximum cooling limit of 50W/m^2, arguably less than 50% of a typical residential aged care building cooling demand requirement. In addition, the cost of implementing hydronic systems was over 50% higher when compared to its more conventional air conditioning systems.

Hydronic heating and cooling is best suited to facilities located within moderate climates that are well designed to pursue an agenda of sustainability and passive design.

MINIMISING COOLING DEMAND

A variety of methods were implemented to minimise the cooling demand within the case study to facilitate implementation of a hydronic cooling systems. This required:

- Increasing comfort condition to 26-28°C; likely acceptable due to slowing metabolism within aged care.
- Adoption of high performance facade systems, and well-considered shading schemes using architecture or planting.
- Utilising blinds for glazing that are exposed to sun.
- Introducing ceiling fans to promote air movement.

Hydronic cooling was able to be applied for the Cairns case study, using imbedded under floor cooling, with modular radiator panel and integrated ceiling systems.

MORE CHALLENGES?

Hydronic cooling in particular pose risks associated with condensation in humid and tropical / sub-tropical climates such as Cairns. This includes development of mould on wetted surfaces, slip risk on damp floors and the like which are of particular concern within aged care facilities. Careful consideration of hydronic fluid temperatures is required to mitigate this risk, further limiting its ability to deliver cooling. These risks explain in part the limited adoption within commercial projects. When coupled with the higher capital cost and impediments on the building design, can be swiftly discounted by design teams for projects at inception.

SO WHY USE HYDRONIC SYSTEMS AT ALL?

Hydronic heating and cooling systems have a place within the industry. While its capacity limitation are seen as an inherent liability, on the flip side, it can be viewed as a catalyst driving to significantly improve building and façade design to reduce the need for artificial heating and cooling.

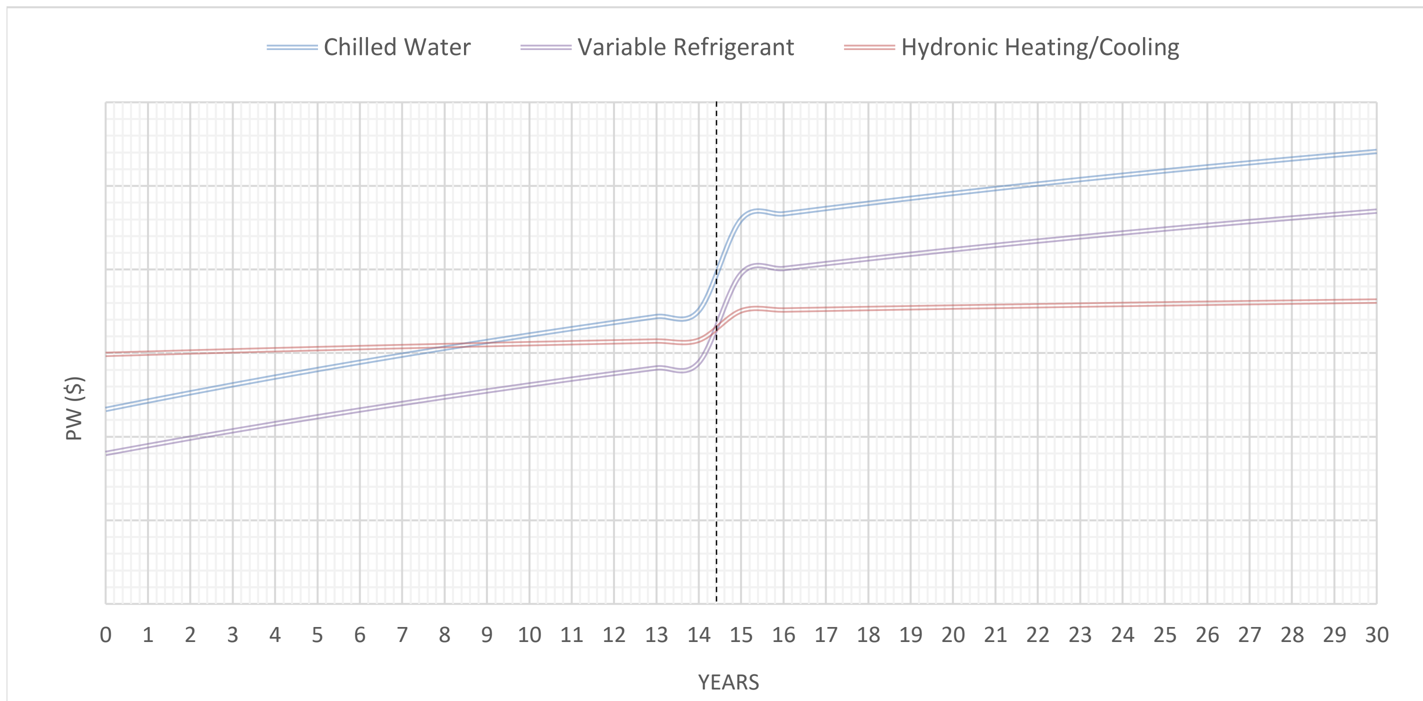
Facilities of the future may in fact regulate the demand of comfort control entirely through passive heating and cooling through its thermal mass using a network of imbedded hydronic systems in floors, walls, and the like. This pipework infrastructure will be able to recover heat from thermal mass exposed to the sun while delivering cooling, while other times inject heat into the structure and substructure for delivery of comfort to occupied spaces.

CASE STUDY WHOLE OF LIFE

A net present worth (NPV) whole of life (WOL) assessment was undertaken for the Cairns case study, which found that while the hydronic system had the highest capital cost, over an 8-15 year period, it overtook the conventional air conditioners to deliver the lowest owning cost to building owner.

It's lower maintenance cost, and reduced life cycle plant replacement costs deliver significant advantages over the more conventional air conditioning systems.

While hydronic cooling is not widely adopted or recommended, particularly in tropical and sub-tropical climates, there may come a time where the drive to minimise artificial heating and cooling, coupled with a long term view of plant asset, may in turn shine a favourable light on hydronic systems for the use of both heating and cooling.



7 APPENDIX B – SOLAR HYDROGEN OPPORTUNITIES (BEC)

The full report is contained in the following pages.

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QUT iHUB Integrated Design Studio 2021

Solar-Hydrogen Opportunities – Fanorha Mixed-Use Community, Cairns

May 2022

BEC PROJECT No: 7598

Document Control

Job No.: 7598
Job Title: QUT iHUB Integrated Design Studio 2021
Document Title: Solar Hydrogen Opportunities – Fanorha Mixed-Use Community, Cairns

Document Control

Date	Document	Revision	Author	Reviewer
15/5/22	Solar Hydrogen Opportunities – Fanorha Mixed-Use Community, Cairns	A	John Tuxworth	

Approval for Issue

Approved By	Approver Initials	Revision	Description	Date
John Tuxworth	JT	A		15/5/22

EXECUTIVE SUMMARY

This report has been prepared in support of the Innovation Hub for Affordable Heating & Cooling project (iHUB) - a joint initiative between the CSIRO, ARENA, Queensland University of Technology (QUT), the University of Melbourne, and the University of Wollongong.

Bolton Clark (previously RSL Care) supported QUT's Integrated Design Studio (IDS), contributing data and working with academics, the student project cohort, and other industry representatives (including Built Environment Collective (BEC)) to consider residential aged care (RAC) as an iHUB focus. This report details BEC's assessment of the solar efficacy, energy demand, and feasibility of hydrogen generation & reuse as an alternative sustainable power supply for a project site in the northern Queensland city of Cairns.

Consideration of solar-hydrogen energy opportunities for the 40,000m^2 site references the mixed-use 30,000m^2 GFA master plan developed by QUT Architectural Masters student, Tristan Clark, and incorporates a 132-bed Residential Aged Care (RAC) facility.

Energy demand for the master planned proposal has been considered for two scenarios, being that associated with traditional construction practices, and sustainable construction practices facilitating increased energy efficiencies.

The report identifies that estimated demand for the proposed development with consideration to traditional construction practices exceeds solar generation for roof-mounted photovoltaics. However, it is envisaged that solar-hydrogen power generation is feasible to provide a net-zero, off-grid, sustainable power alternative to meet the estimated energy-efficient demand of the proposed masterplan. RAC security of supply can additionally be met by estimated hydrogen production.

Roofed areas nominated by the proposed masterplan can accommodate a 5.2MW photovoltaic array, generating a mean daily 2,500 kWh of electricity. Excess supply is suitable to power a 2 or 2.5-MW hydrogen electrolyser which can fit in a 44 ft shipping container. Novel low pressure metal hydride storage vessels can minimise storage volumes and stored pressure, negating the potential deficiencies associated with high-pressure storage. Conceptual costings suggest a combined repayment period of 8 to 10 years.

A practical approach to further solar-hydrogen research for residential aged care would be to reduce the variables and estimations inherent with a conceptual master plan proposal. One option would be to focus specifically on a residential aged care building (such as Bolton Clark's new RAC building at Caboolture), instead of a conceptual mixed-use masterplan. Such a building could be modelled to assess the impact of energy efficiency measures to further refine solar-hydrogen feasibility. A detailed and specific analysis would additionally facilitate more accurate costings by a Quantity Surveyor.

Energy efficiency of hydrogen fuel cells increases when combined heat and power (CHP) is adopted. A detailed analysis for Boulton Clark's new Caboolture RAC could consider the further energy demand reductions achieved from CHP.

CONTENTS

RELIANCE ON DATA

In preparing this report, BEC has relied upon data, surveys, analysis, designs, plans and other information provided by the Client and/or other individuals and organisations. Except as otherwise stated in the report, BEC has not verified the accuracy or completeness of this data. To the extent that the statements, opinions, facts, information, conclusions and/or recommendations in the report are based in whole or in part on the data, those conclusions are contingent upon the accuracy and completeness of the data. BEC will not be liable in relation to incorrect conclusions should any data, information or condition be incorrect or have been concealed, withheld, misrepresented or otherwise not fully disclosed to BEC. Any quantities provided are based on estimates provided or obtained during site investigations.

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Where relevant, in undertaking detailed design, a Designer's duties are to:

- Ensure that a structure or work element is designed to be without risks to the health and safety of workers, end users and people in the vicinity;
- Provide a written safety report that identifies the hazards relating to the design so far as the designers are reasonably aware, to the Client.
- Make said information available if requested by persons who will use or handle substances, plant or structures at the workplace site for the purposes for which these were designed

The Designer may need to:

- Prepare a written report at each defined stage of the commission to inform the Client of design related hazards that create health and safety risks to persons associated with construction and operation of the facility or work element.
- At contract documentation stage, append a detailed Work Health and Safety Design Review report to the specification for the purpose of informing the Contractor of the particular risks to health and safety identified by the designers of each element of the Works. It may be appropriate for said report should detail how construction and operating risks have been mitigated through design.

For further information refer to:

- https://www.worksafe.qld.gov.au/__data/assets/pdf_file/0008/58193/safe-design-structurescop-2013.pdf
- https://www.safeworkaustralia.gov.au/system/files/documents/1702/how_to_manage_whs_risks.pdf

1. INTRODUCTION

1.1 RESEARCH PROJECT

The Innovation Hub for Affordable Heating & Cooling project (iHUB) is a joint initiative between the CSIRO, ARENA, Queensland University of Technology, the University of Melbourne, and the University of Wollongong. iHUB supports the Integrated Design Studio (IDS) at the Queensland University of Technology (QUT), with the intention of encouraging early collaboration between academia and professional industry representatives to optimise development outcomes. The IDS aims to *"…increase innovation at the conceptual design stage, develop an evidence base of net-zero energy buildings concepts [and] support knowledge development of the next generation of building professionals."* This IDS project involved collaboration between academic staff, engineering & construction management undergraduates, architectural Masters students, practicing architects, engineers, project managers, contractors, and residential aged care developer/owner/operator, Bolton Clark.

This report details an assessment of the solar efficacy, energy demand, and feasibility of hydrogen generation & reuse as an alternative sustainable power supply for a project site in the Northern Queensland city of Cairns, in the suburb of Westcourt (Q4870) Figure 1.

1.2 PROJECT SITE

The project site represented in Figure 1 is of some 40,000m^2 in area and accommodates both a green-field portion and the existing Farnorha Residential Aged Care (RAC) facility, owned and operated by Bolton Clarke (previously known as RSL Care).

It is understood that Bolton Clarke would favour redevelopment of the site to facilitate a multi-use, integrated community-focused outcome, hosting facilities not only for elderly residents but to facilitate engagement with the wider community.

Consideration of solar-hydrogen energy opportunities for the site references the master plan by QUT Architectural Masters student, Tristan Clark (Figure 2). Tristan's master plan replaces the existing Residential Aged Care (RAC) facility with a new Community Centre, and relocates a new RAC within the mixed-use development. The proposed Community Centre is a basement plus 3-storey structure, featuring a roof deck shaded by a photovoltaic covered parasol (Figure 3). The Community Centre as proposed features basement parking & services, an open market square with amenities at ground level, a mix of 1, 2 and 3-bedroom apartments at upper levels, and a roof-deck with lap pool, fitness centre and other resident amenities.

Development constraints proposed by QUT for the research project include:

- a total maximum building footprint of 40% of the total site area;
- minimum communal open space of 35% of total site area;
- minimum of 10% of site to be landscaped.

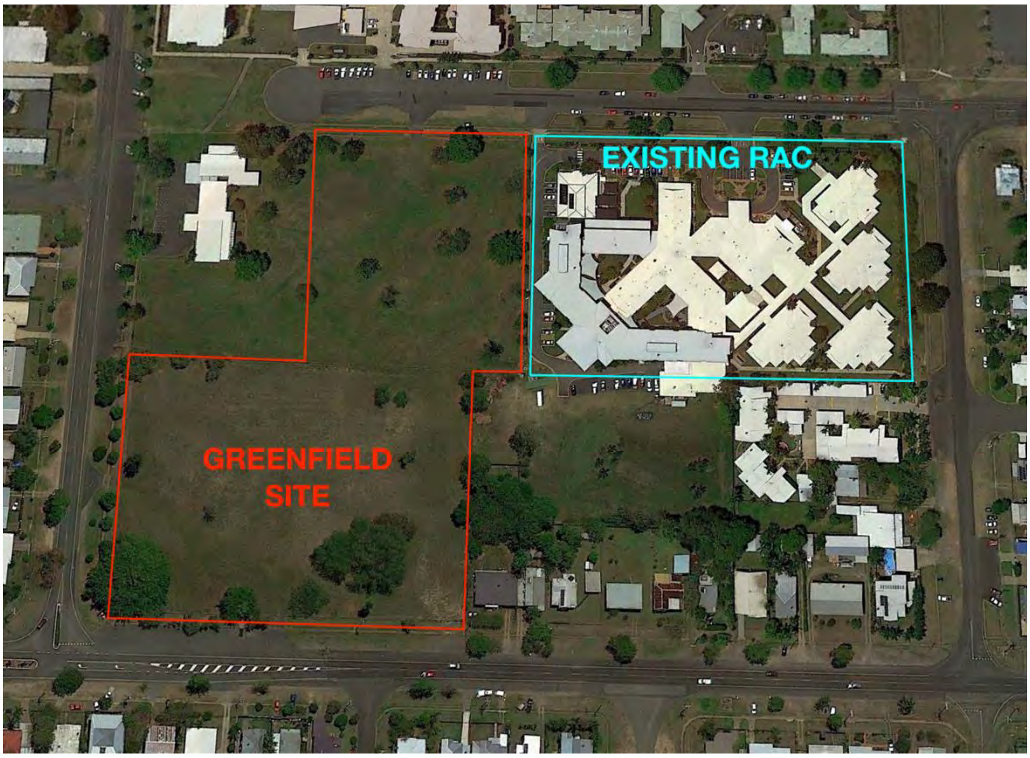


Figure 1: Aerial image of the proposed site

Figure 2: Proposed Master Plan by Tristan Clark

Figure 3: Community Centre Proposal designed by Architectural Masters student Tristan Clark

2. INVESTIGATIVE SCOPE

This report documents an assessment of the solar efficacy, energy demand, and the feasibility of hydrogen generation/storage/consumption as a sustainable alternative to commercial electrical utility supply. Energy demand for the master planned proposal has been considered for two scenarios, being:

1. traditional construction practices;
2. sustainable construction practices leading to increased energy efficiencies.

Conceptual (only) costings have also been provided to inform further research.

3. ENERGY REQUIREMENTS

3.1 DEMAND

Bolton Clarke owns, operates and maintains retirement living & aged care facilities across Australia. QUT has undertaken research into the energy demand requirements for residential aged care (RAC), and has recorded energy usage across a number of years at the existing 135-bed RAC at Farnorha (Figure 4). The mean energy use intensity with reference to this data is 26.51 kWh/bed/day. A mean daily demand of 27kWh/bed/day has been adopted by BEC as a benchmark in deriving the mean daily energy usage for the proposed master plan, per Table 1. In estimating energy demand BEC has calculated Gross Floor Area (GFA) from Tristan's multi-storey Community Hub drawings (Building C in Figure 2). For the purposes of this investigation the remainder of proposed buildings have been taken as single-storey, with (GFA) derived by applying a reduction factor to the coverage areas nominated in Figure 2. Of note is that the estimated energy demand is based on traditional construction techniques and building services installations. According to the Green Building Council of Australia (GBCA), Green Star rated buildings consume 66% less electricity than the average Australian building[1].

3.1 EMERGENCY POWER PROVISION

Consultation with Bolton Clarke suggests that 36-hours of energy supply security is desirable for essential (if not all) services for residential aged care, & this has been considered by BEC in our energy options analysis. It is understood that a 280kVA generator is maintained at the Farnorha facility. With reference to historic 30-minute maximum demand profiles for the facility (Figure 4), some of which exceed 300kW, a larger generator may be required to facilitate 36-hours security for all RAC services.

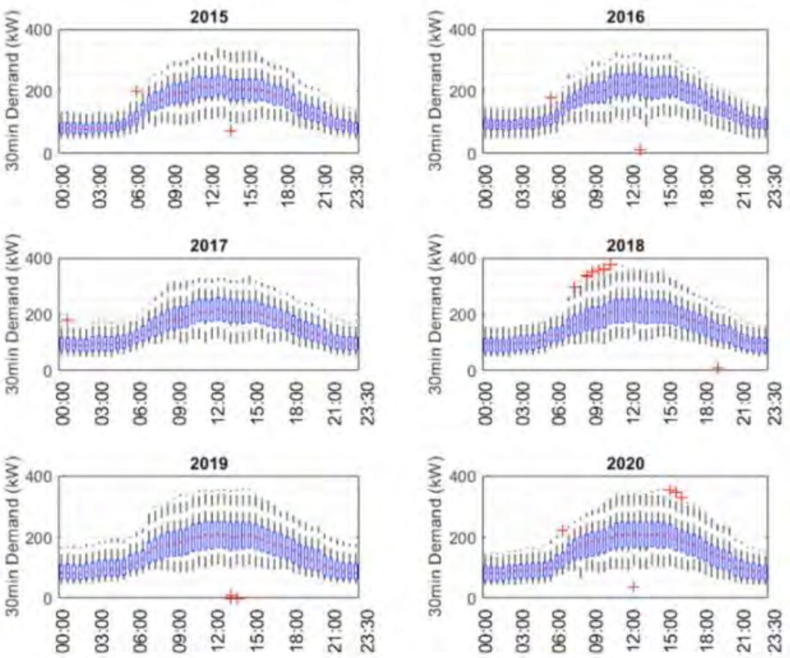


Figure 4: 30-minute maximum demand between 2015-2020,
from existing 132-bed RAC Farnorha community in Westcourt, Cairns (courtesy of Dr. Aaron Liu, QUT)

4. HYDROGEN PRODUCTION, STORAGE & REUSE

4.1 PRODUCTION

Hydrogen, as a storage medium or 'energy carrier', is produced from a primary source of energy e.g electricity, gas, or nuclear power. In comparison to other fuels (eg gasoline, diesel, LPG, etc), hydrogen has a very high energy density. At 33.3 kWh/kg, it is in the order of three times that of gasoline.

'Green' hydrogen is created by renewable energy sources, such as photovoltaics or wind, using electrolysis to split water into hydrogen and oxygen. 'Yellow' Hydrogen is a term used for hydrogen

[1] https://new.gbca.org.au/news/gbca-media-releases/gbca-builds-powerful-and-positive-case-green-star/

produced using only solar power as an energy source. Other 'colours' of hydrogen are produced via non-renewable resources, nuclear power, and/or result in the creation of $C0_2$ as a polluting by-product. An electrolyser is used to create 'green' or 'yellow' hydrogen using renewable energy, and water.

This report focuses on the production of 'yellow' hydrogen as a renewable energy source for the research project site.

Table 1: Estimated Master Plan Energy Demand

Building Type	Plan Area m2	EMD KVA (kW)	Usage hrs	peak hrs /day	Av vs Max demand %	Days per wk	Est Mean kWh/day	Roof vs GFA reduction	Modified Mean	Est day-time use %	Est day-time use kWh/day	Night time kWh/day
Childcare	1379	110	10	3	80	5	678	0.94	637	80	510	168
Arts centre	4303	170	12	3	80	5	1,237	0.94	1,163	50	582	656
Library	2123	86	12	3	90	7	953	0.94	896	50	448	505
Corworking A	1010	86	12	3	90	5	681	0.94	640	80	512	169
Retail	1010	212	12	3	90	7	2,357	0.94	2,215	50	1,108	1,249
Residential aged care	1010	187	24	3	80	7	3,708	0.94	3,486	50	1,743	1,965
Mini golf	1010	43	4	3	90	7	167	0.94	157	30	47	120
Aquatic centre	2850	247	15	5	90	7	3,903	0.94	3,668	50	1,834	2,068
Coworking B	2341	91	12	3	90	5	723	0.94	680	50	340	383
College	2850	106	15	5	90	5	1,194	0.94	1,123	50	561	633
Restaurant	2470	85	12	3	70	7	789	0.94	741	50	371	418
Building A (Apartment)	1073	97	24	3	60	7	1,516	0.94	1,425	50	713	804
Building B (Apartment)	1176	97	24	3	60	7	1,516	0.94	1,425	50	713	804
Building C (Mixed Use)	848	641	24	3	60	7	10,000	1	10,000	50	5,000	5,000
Totals		**2,258**					**29,421**		**28,256**		**14,480**	**14,942**
				66% reduction for sustainable building practices					**18,649**		**4,923**	**5,080**

4.2 STORAGE

Hydrogen gas is compressed and stored in pressure vessels for use in industry, transport, and the built environment. Higher pressures are typically used to achieve practical storage volumes, however, leakage can occur with higher-pressures in low-weight, carbon fibre-reinforced plastic vessels. Novel metal hydride storage canisters are available to achieve low-pressure, low-volume storage.

4.3 REUSE

There are two methods of using hydrogen to generate electrical and/or thermal power. It can be burned in a turbine, or converted into electricity (and water) using a fuel cell which converts the chemical energy into electrical energy. Fuel cell efficiencies vary dependant primarily on the electrolyte employed to convert chemical energy to electrical energy. The Californian Hydrogen Business Council nominates 60% efficiency as appropriate for distributed power generation for systems greater than 250kW, and with energy efficiencies up to 85% when utilising combined heat and power (CHP)[2].

BEC's analysis considers the use of fuel cells to convert hydrogen to electricity for the research project site. Refer to Figure 5 for a diagrammatic representation of the Solar Hydrogen energy cycle. With reference to Figure 5 and also Table 1 BEC has considered the viability of day-time energy requirements being met directly by photovoltaics, with excess available energy converted and stored as hydrogen for night-time and/or security of supply for the RCA.

[2] https://www.californiahydrogen.org/wp-content/uploads/files/doe_fuelcell_factsheet.pdf

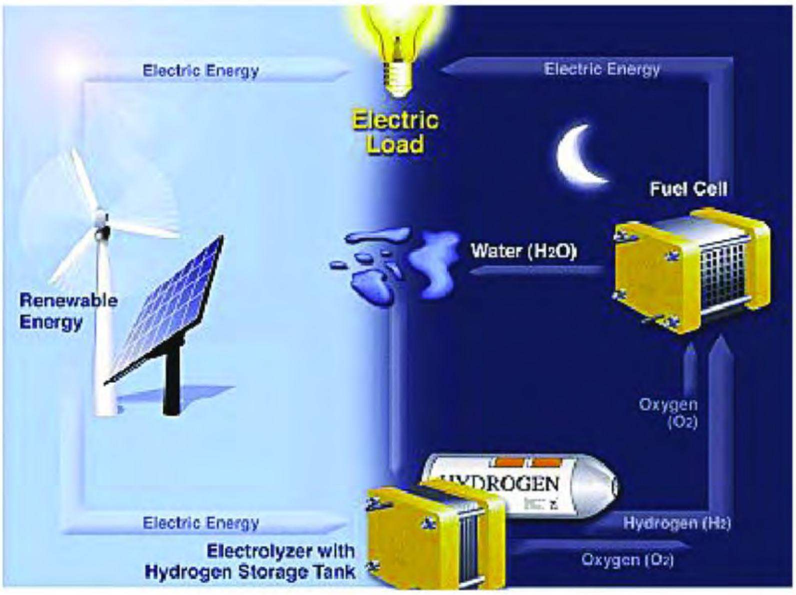


Figure 5: Solar Hydrogen energy cycle[3]

5. SOLAR EFFICACY VS DEMAND

BEC's estimated mean daily generated output from photovoltaics on roofed buildings identified by the proposed masterplan is 24,891 kWh/day (refer Appendix A). This figure is based on an 80% roof coverage of relevant areas per Figure 2, with the exception being the Community Centre (Building C), given that Tristan Clark has nominated a parasol roof with 100% photovoltaic coverage.

The estimated mean daily generated output from photovoltaics of 24,891 kWh/day is less than the calculated energy demand with consideration to traditional construction practices (28,256 kWh/day - Table 1). Thus, additional ground-mounted photovoltaics and/or imported power would be required to supplement the energy demand for this traditional construction case. However:

1. The adopted roof-mounted photovoltaic area is capable of generating nearly twice the calculated day-time energy demand (14,480 kWh/day) for traditional construction practices, with an estimated mean excess power of 10,441 kwh/day available for hydrogen production, storage and reuse (and/or for resale to the grid); or,
2. with consideration to stainable building practices photovoltaics are capable of generating 5 times the day-time demand (4,923 kWh/day), with 19,968 kwh/day available for hydrogen production, storage and reuse (and/or for resale to the grid).

The above figures are based on an average efficiency photovoltaic (300W), and 14% losses due to inverter and cable loss, slight dust on panels, and for panels not pointing True North. Additional losses would need

[3] Nsour, W., Taa'mneh, T., Ayadi, O., & Al Asfar, J. (2019). Design of Stand-Alone Proton Exchange Membrane Fuel Cell Hybrid System under Amman Climate. *20*, 1-10. https://doi.org/10.12911/22998993/111800

to be taken into account for sub-optimal panel orientation and/or angle, or overshadowing. Further detail is provided in Appendix A.

6. SOLAR-HYDROGEN FEASIBILITY

6.1 SUPPLY VS DEMAND

As identified in Section 5 of this report the adopted area of roof-mounted photovoltaics is inadequate to accommodate the total daily energy demand of the master planned site, in the instance that traditional construction practices are employed and typical energy efficiencies achieved. However, the potential efficiencies afforded by implementing sustainable building practices significantly reduce demand. Thus, two primary scenarios have been considered, whereby the feasibility of hydrogen production, storage & reuse as an alternative to commercial utility supply is considered with reference to:

Scenario 1: traditional construction practices;

Scenario 2: sustainable construction practices leading to increased energy efficiencies.

Table 2: Hydrogen production, storage & reuse scenarios

Metric	Case 1	Case 2
Mean energy avail for electrolyser (kwh/day)	10,411	19,968
Nom Electrolyser size (kW) to convert avail energy	1,349	2,587
Commercial electrolyser size (kW)	2,000	2,500
Hydrogen production Nm3/h	400	500
Hydrogen production kg/h	36	45
Hydrogen production kg/d	278	347
Energy density of hydrogen (kWh / kg)	33	33
Stored kWh	9,159	11,449
Fuel cell efficiency	60%	60%
Avail energy kWh	5,495	6,869
Fuel cell size (kW)	393	491
night-time demand (kWh/night)	14,942	5,080
Surplus Energy (kWh)	-9,446	1,789

Table 2 summarises BEC's consideration of hydrogen production, storage & reuse given the excess energy available after estimated daylight hours consumption. Commercial electrolyser sizes and efficiencies have been adopted with reference to available Cummins HyLYZER series[4], assuming excess solar production across a nominal 7.7-hours per day. The 2 and 2.5 MW electrolyser modules are the size of a 44ft shipping container. Fuel cells have been sized to meet demand across a nominal 14-hours per day where

[4] https://mart.cummins.com/imagelibrary/data/assetfiles/0071313.pdf

photovoltaics may not fully meet demand. A Molten Carbonate fuel cell (MCFC) would likely be appropriate for electric output less than 1 MW[5].

The estimated available energy from roof-mounted photovoltaics for the proposed masterplan is insufficient to cater for the night-time energy requirements envisaged for traditional construction practices /energy efficiencies. Fuel cell inefficiencies further compound this deficit of supply to 9,446 kWh/day.

A surplus of stored energy (1,789 kWh) is available with consideration to the mean daily demand assuming sustainable construction practices, suggesting that off-grid, net-zero energy opportunity is available.

With reference to Table 1 the mean daily energy demand for an energy efficient 132-bed RAC is 2,300 kWh/day. 36-hour security of supply would necessitate 3,450 kWh of excess stored energy which the proposed system could generate every second day. Additional emergency supply for the RAC can be achieved via optimization of hydrogen production and storage.

6.2 COST ESTIMATION

Conceptual capital costs for the solar-hydrogen system for the proposed 40,000m^2 master planned site are provided in Table 3:

Table 3: Capital Cost Estimation

Item	Conceptual Cost Estimate
Photovoltaic panels ($1/Watt x 5227 kW)	$5,227,200
Design & installation (assume 10%)	$ 522,720
Solar Subtotal	**$5,749,920**
Electrolyser (2.5MW)*	$6,590,909
Hydrogen Storage (low pressure metal hydride)*	$1,704,751
Fuel Cell	$853,762
Design & installation	$290,000
Hydrogen Subtotal	**$9,439,422**
TOTAL	**$15,189,342**

* Costs cross referenced against H2Gen 1.2MW system[6]

In recent years the repayment period for photovoltaic installation installations has been in the order of 2 to 4-years. Similar metrics are applicable to hydrogen power, such that the repayment period for the solar-hydrogen system is envisaged to be 8 to 10-years.

7. FURTHER RESEARCH OPPORTUNITIES

Analysis detailed by this report is based on the nominated site coverage of a conceptual (only) mixed-use masterplan for the Fanorha site, with estimated GFAs and number of stories (with the exception of the

[5] https://www.californiahydrogen.org/wp-content/uploads/files/doe_fuelcell_factsheet.pdf
[6] https://h2gen.com.au/wp-content/uploads/2021/08/AHG-Hyzon-Package-Brochure-July-2021-Final.pdf

Community Centre - Building C). Energy demands have been estimated with reference to traditional construction techniques, and a percentage reduction has been employed for energy efficient sustainable building practices.

A practical approach to further solar-hydrogen research for residential aged care would be to reduce variables and estimations. One option would be to focus specifically on a residential aged care building (such as Bolton Clark's new RAC building at Caboolture), instead of a mixed-use masterplan. Such a building could be modelled to assess the impact of energy efficiency measures and further refine solar-hydrogen feasibility. A detailed and specific analysis would additionally facilitate more accurate costings by a Quantity Surveyor.

As touched on in in Section 4.3 of this report, the energy efficiency of hydrogen fuel cells increases when combined heat and power (CHP) is adopted. A detailed analysis for Boulton Clark's new Caboolture RAC could consider the further energy demand reductions achieved from CHP eg for hot water.

8. CONCLUSION

Hydrogen is a viable alternative to other energy storage mechanisms, with 'green' or 'yellow' hydrogen being a significant sustainable zero-carbon emission solution. This report conceptually demonstrates that solar-hydrogen power generation is feasible to provide a net-zero, off-grid, sustainable power alternative to meet the estimated energy-efficient demand of the proposed masterplan. RAC security of supply can additionally be met by estimated hydrogen production.

Usage areas nominated by the proposed masterplan are able to accommodate a 5.2MW photovoltaic array, generating a mean daily 25,000 kWh of electricity. Excess supply is suitable to power a 2 or 2.5-MW hydrogen electrolyser which can fit in a 44 ft shipping container. Novel low pressure metal hydride storage vessels can minimise storage volumes and stored pressure, negating the potential deficiencies associated with high-pressure storage. Conceptual costings suggest a combined repayment period of 8 to 10 years.

1. APPENDIX A – SOLAR EFFICACY: ROOFED AREAS

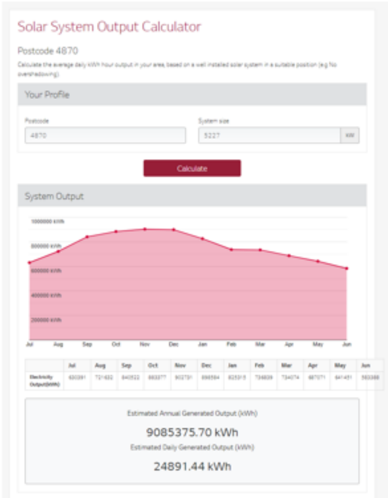
SOLAR SUPPLY
Case 1: **Roof area per master plan only**

Assumptions:

Panel wattage	300	W
Efficiency & shading losses	14%	included in Solar System Output Calculator. Additional 15% loss would be appropriate if significant shading or suboptimal panel angle or orientation
Panel Area	1.7	m2

https://www.lgenergy.com.au/calculator/suburb/aeroglen-qld/4870

Building Type	Coverage Area m2	Roofed	Assumed solar coverage %	Assumed solar coverage m2	System Size kW
Childcare	1,379	Yes	80	1,103	331
Tropical garden	4,303	No	0	-	-
Arts centre	2,123	Yes	80	1,698	510
Parterre garden	1,010	No	0	-	-
Library	1,010	Yes	80	808	242
Corworking A	1,010	Yes	80	808	242
Retail	1,010	Yes	80	808	242
Community garden	2,850	No	0	-	-
Existing Residential Aged	2,341	Yes	80	1,873	562
Mini golf	2,850	No	0	-	-
Aquatic centre	2,470	Yes	80	1,976	593
Coworking B	1,073	Yes	80	858	258
College	1,176	Yes	80	941	282
Restaurant	848	Yes	80	678	204
Building A	1,215	Yes	80	972	292
Building B	1,215	Yes	80	972	292
Building C	3,928	Yes	100	3,928	1,178
TOTALS	**31,811**			**17,424**	**5,227**



Estimated mean daily generated output	**24,891**	**Av kWh/day**
Excess for storage after day-time demand	**10,411**	**Av kWh/day**
Excess for storage after day-time demand	**19,968**	**Av kWh/day**

Capital Cost Estimation

Price per watt	$	1.00	/ Watt
Approx. Panel Cost	$	300	
Total Panel Cost	$	5,227,200	not inc. installation and inverters
Battery Storage	$	-	
Additional Expenses	$	522,720	assume 10% for engineering / installation
Total Cost	**$**	**5,749,920**	
	$	**231**	per kWh produced each day (on average)

Solar System Output Calculator uses sunlight data supplied by the Australian Bureau of Meteorology from most Australian weather stations from 1990 as an average. The output data are estimates only. Calculations allow for 14% losses due to inverter and cable loss, slight dust on panels, and for panels not pointing True North. If panels point straight West or East, are tilted to low or to high, a further reduction in output of up to 15% would be applicable

Built Environment Collective Pty Ltd

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8 APPENDIX C – MASS TIMBER CONSTRUCTION (HANSEN YUNKEN)

The full report is shown in the following pages.

IHUB MASS TIMBER CONSTRUCTION REPORT

Prepared by Scott Butler, Hansen Yunken, May 2022

INTRODUCTION

This report will examine the current Australian design aspects and construction impacts associated with mass timber construction, including CLT and Glulam. Although used extensively overseas, this material is an emerging building solution within the Australian market. Although the underlying principles remain the same, due to the geographical size and varying legislative framework within the Australian states, there are variables that must be considered when incorporating mass timber construction into design and construction projects, some of which are outlined below:

EMBODIED CARBON

The embodied energy of mass timber construction is an important consideration given this building material is not only used to for its aesthetic and decorative architectural use, but also to assist in providing an energy efficient project that meets strict environmental and sustainable benchmarks.

From the outset of a project, the embodied carbon criteria of building materials need to be considered and specified to ensure that consistent evaluation can occur throughout the life-cycle assessment. Typically, for mass timber, the embodied carbon can be specified to be less that 0.3 tonnes of CO_2 (global warming potential) by gross floor area. This measure is contained within the European Standard EN15978:2011 – Sustainability of Construction Works, Assessment of Environmental Performance of Buildings. A benchmarking exercise can be undertaken via LCA modelling to determine whether the embodied carbon within a proposed mass timber structural design can meet the specified targets.

Given the limited availability of mass timber manufacturing facilities within Australian, consideration must be given to determine the carbon saving offset by the carbon footprint incurred during transport and shipping from Europe.

CONSTRUCTABILITY

All buildings in Australia need to be designed to perform to a designated life expectancy depending on a category, being either short, normal or long. This category depends on the type of building, expected use and location. Typically, the structural design life for the frame of a building will be 50 years, no matter what material the structural frame is constructed from. To maintain this 50-year structural integrity a variety of factors needs to be considered, including:

Fire – Charring and other Factors

One of the most significant considerations with mass timber construction is the fire rating of the timber, how this is certified and the methods under which certification occurs. Mass timber relies heavily on timber charring during a fire, which provides a fire-resistant level. Under AS1530.4:2014 – Methods for Fire Tests on Building Materials, it assumes a minimum of 90-minute fire resistance or better for mass timber structural applications. It is noted that CLT wall and floor char rates are different depending on the application, cross sectional area, number of penetrations etc. CLT charring factors are complex, require testing and delamination occurs at varying rates depending on the manufacturers adhesive selection.

Glulam on the other hand chars at a consistent rate and is less likely to delaminate, thereby providing more consistent fire properties.

Local Fire Brigade intervention will need to be considered early during the design stage, as mass timber construction is relatively new to Australia, which will create an inherent authority approvals risk, as the local fire brigade provides a fire performance assessment as a concurrent agency which the building certifier relies upon prior to providing their Building Approval.

Where the charring rates of mass timber does not meet the fire engineering requirements, mass timber may need to be encapsulated within another fire resistant building material to increase the FRL. This encapsulation then detracts from the perceived aesthetic value that exposed timber provides to the architectural finish of the building. Otherwise, a complex performance solution will need to be developed requiring the use of a specialist fire engineer, who will create and fire engineering report for assessment by the building certifier, fire brigade and other project stakeholders.

Timber vs Fire and Water

Consideration should be given regarding how wet areas, utility cupboards, HVAC Plant, fire stairs and services risers are designed into mass timber construction, as these elements are effected by possible water ingress and require fire rated construction.

Services

The nature of mass timber requires a larger quantity of services to be exposed than traditional construction, where services are more readily concealed.

Unlike an office building, the nature of aged care facilities requires a diverse array of services more akin to a hospital than simpler construction like multi residential apartments. These services require more back of house utility space and cable/pipe pathways which traverse the full floor plate and vertically to multiple floors.

CLT accepts penetrations through floor and wall panels quite easily with through floor drainage being protected by standard fire collars. It is important to confirm that these collars are a tested and approved system for fire protection compliance.

Glulam is far more difficult to provide compliant penetrations as it is extremely difficult to install penetrations through structural beams, as there is a greater section loss of the charring rates which provide the required fire rating. Should penetrations in beams be approved, these must be fully coordinated within the 3D model during the design phase, included in the Glulam shop drawings with the holes cut in the factory during fabrication. Early resolution of service coordination is key.

High floor to floor heights needed to reduce the qty of beam penetrations for services. Ie: the services sit under the beams, not go through them.

Vibration and Acoustics

Timber is susceptible to vibration and acoustic transmission due to the high strength to weight ratio and low density. To overcome these issues, limiting spans, increasing slab thickness and application of topping screeds can be used.

Codes and Design Approach

Australian Standards and Codes don't adequately cover mass timber construction in great detail, so generally European Codes are used. This makes sense as a majority of mass timber elements used in Australia is imported from Europe using European timber such as Spruce. It should be noted that the Building Certifier needs to be made aware of this requirement. As the use of mass timber increases, it is expected that relevant Australia Standards will be developed that specifically outline the requirements and criteria for this method of construction. Until then AS1720.1 Timber structures Design Methods can be used.

Structural considerations

Particular attention needs to be given to the cross sectional area of mass timber, which may be in the order of: Glulam columns (400-500mm square) and beams (400-500mm wide, to match the columns and 800-1000mm in depth). CLT elements generally include slabs which are over 200mm thick, walls over 150mm thick. CLT floor plate panels are generally 1.25m or 2.25m wide and generally don't exceed 11.9m in length depending on the manufacturer's standard fabrication process and shipping container limitations. It is critical that cross sectional dimensions and therefore manufacturer selection is locked in during the early design phase.

Construction loading also needs to be allowed during construction for material storage, use of elevated work platforms required for work at height during construction, which typically can exceed 3kpa over and above the structural engineered design capacity.

Glulam – due to large beam depth/width commonly encountered in large buildings, Australian manufacturer can be limited to manufacturer these larger cross-sectional profiles. Therefore, European manufacturers are commonly used due to the prevalence of suppliers (using spruce), whilst CLT can be made in Australia (using pine). Different timber species will have different visual, structural and certification characteristics, and these must be considered by all project stakeholders.

Timber to timber connections and concrete to timber connections

Consideration must be given to flexible connections of CLT to concrete/steel elements needed with tolerances to suit installation, building and thermal movement.

Onsite Construction

Installation sequencing is critically important to ensure limited site handling, with builders preferring a "just in time" delivery". Additionally, warehousing will be required to unload containers and sort mass timber elements prior to delivery to site. These warehouses will generally be off-site and must be under cover to prevent deterioration of timber exposed to the weather for lengthy periods of time. The aim is to minimise handling, with designed engineered lifting points into the mass timber elements to ensure safety compliance during erection with propping arrangements and safety in design considered.

Sanding, painting and patching – the timber can very quickly sustain sun damage which will bleach and whiten the appearance. When multiple timber species are used such as between CLT (pine or spruce) and Glulam (spruce) the visual appearance of the natural timber will also be different, so designers need to have an open mind of what the finished product will be like.

Temp propping will be required during construction for beam and column installation, so holes will be left within the finished elements which need to be plugged and sanded back. This, plus the discolouration of the prop base plate left during construction can also impair the visual appearance of the timber.

To comply with the National Construction Code for waterproofing, it is a fundamental requirement for wet areas such as bathrooms, amenities, laundries etc to have a compliant waterproofing system with the floor finishes laid to falls. This requirement can have a significant impact of the mass timber floor system where a set-down with the structural floor plate is required. These set-downs then impact the structural capacity of the timber member, effect the floor to floor fire rating and should the waterproof membrane fail, can create significant long term maintenance issues, thereby possibly reducing the 50 year design life.

COST

Commercial construction is a cost sensitive industry where project feasibility dictates the scope of works, finishes and fixtures used and often the operational performance during the life cycle of the building. The selection of a structural framing system, whether traditional concrete or mass timber is made during the early design stage. This is a requirement as recent mass timber projects within Australian have shown that a significant financial premium is paid to include this material. To date, projects requiring a high green star rating or sustainable credentials have used mass timber including educational facilities such as universities and large corporation commercial offices.

A comparison of the cost of mass timber construction versus traditional concrete framed building has been undertaken which shows a cost premium for this emerging construction material.

Mass Timber (including combined CLT and Glulam) pricing = $2,800/m3 supplied & install

Concrete (including concrete, pumping, reo, formwork, place & finish) pricing = $1,085/m3 supplied and installed

Overall, for a full timber framed multi storey building a construction cost of $6,000 to $7,000/m2 may be incurred. This m2 rate would make these buildings some of the most expensive to construct.

Therefore, on average a full structural mass timber framed building is nearly three (3) times more expensive to build. This extra over cost of $1,715/m3 will be offset in part by builder preliminary costs due to a quicker construction period.

TIMEFRAMES

The use of mass timber onsite creates significant time savings during construction compared to traditionally framed, poured insitu concrete buildings. But the front-end design and development phase of the project is significantly longer due to the requirement for shop drawings to be commenced on at the end of the construction issue drawings which includes all services design being virtually complete. Manufacturers of mass timber will require a 3D BIM model from which to base their shop drawings on, which will typically take in the order of four (4) weeks to draft and produce their fabrication model.

Fabrication and shipping, typically from Europe may take 17-18 weeks. The current conditions for international shipping has experienced lengthy delays due to covid, industrial action, materials and labour shortage, inclement weather in many major ports. These delays will impact the supply of mass timber to local construction sites within Australia.

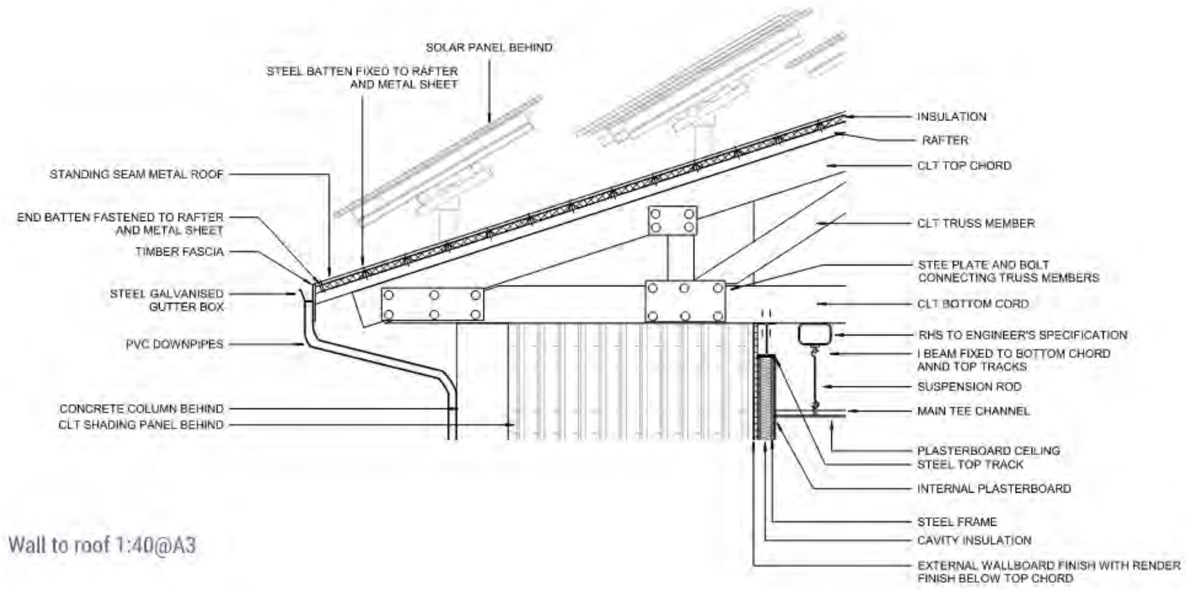
On a recent Hansen Yuncken mass timber project, a four-storey university project was constructed in 19 working days, but only after the lift and stair core was constructed to its full height using traditional concrete methods.

Program savings may be limited depending on amount of mass timber versus the requirement and quantity of concrete elements needed for the building core (lifts and fire stairs) and other structural elements to maintain building rigidity and fire rating. Concrete cores may de-risk the fire rating (fire stairs, services risers etc) and wet areas (amenities), but traditional construction timeframes will then be experienced as the mass timber elements can only be erected after the major concrete elements are completed.

STUDENT EXAMPLES

A review of students work has been undertaken with the following comments noted:

Darian - Cairns


SOLAR PANEL BEHIND
STEEL BATTEN FIXED TO RAFTER AND METAL SHEET
STANDING SEAM METAL ROOF
END BATTEN FASTENED TO RAFTER AND METAL SHEET
TIMBER FASCIA
STEEL GALVANISED GUTTER BOX
PVC DOWNPIPES
CONCRETE COLUMN BEHIND
CLT SHADING PANEL BEHIND
INSULATION
RAFTER
CLT TOP CHORD
CLT TRUSS MEMBER
STEE PLATE AND BOLT CONNECTING TRUSS MEMBERS
CLT BOTTOM CORD
RHS TO ENGINEER'S SPECIFICATION
I BEAM FIXED TO BOTTOM CHORD ANND TOP TRACKS
SUSPENSION ROD
MAIN TEE CHANNEL
PLASTERBOARD CEILING
STEEL TOP TRACK
INTERNAL PLASTERBOARD
STEEL FRAME
CAVITY INSULATION
EXTERNAL WALLBOARD FINISH WITH RENDER FINISH BELOW TOP CHORD
Wall to roof 1:40@A3

9 APPENDIX D – PROJECT CONTEXT AND INITIAL FINDINGS

9.1 About the client - Bolton Clarke

The client, Bolton Clarke, is a vertically integrated not-for-profit organisation who develops, owns and operates buildings that incorporate various aspects of aged care. The client's core mission is to improve the health, independence, and quality of life of its elderly clientele. This mission must be achieved in a financially viable manner, which includes a 'whole of life' approach to building assets, and an integration of aged care facilities into the community, for example through mixed-use buildings. This studio was based on a site in Cairns (a greenfield site adjacent to an existing facility). Site details are shown in Figure 2-1 and Figure 2-2.

9.2 Studio Inception

A planning meeting was held with non-student project participants prior to the first studio. This meeting, involving the client, academics and consultants, was used to establish a common understanding of the purpose, objectives and scope of the project, as well as to establish the professional relationships required to enable collaboration between all parties. Similar studio inception activities were understaken in each stage, with a focus on developing interpersonal relationships and building respect for other disciplinary knowledge:

- Stage 1 - week 1: activities to introduce the engineering and construction management students to each other and their academic guides;
- Stage 1 - week 3: introducing the client, consultants and non-architectural students and academics;
- Stage 2 - week 1: engineering and construction management students introducting themselves and their discipline interest to architecture students; and
- Stage 2 - week 2: introducing the client to the architecture students; and introducing the design thinking process to non-architecture students.

9.3 Client Engagement and Constraints

Bolton Clarke was open to innovation and creativity in terms of building typology (mixed use), building form, building materials and energy technologies, and did not wish to impose its current practices and perceptions on solution ideation. This openness, however, came with four key constraints regarding technology and design solutions:

- Proposed solutions needed to be proven (not experimental or emerging);
- Proposed solutions needed to show a return on investment (not necessarily financial; life-time cost of ownership was important, as was any quantification or qualification of additional non-financial benefits, e.g. health and welfare of occupants);
- Proposed solutions needed to consider and take into account the effect on elderly residents; and
- Proposed solutions needed to conform to environmentally sustainable design (ESD) principles adopted by Bolton Clarke. Net-zero energy is not currently a goal of the client.

The client was involved in the concept development of the studio, and at key points during both stages: presenting a project brief (stage 1 and stage 2); responding to questions about the brief; providing feedback on early concept development; and evaluating final design solutions.

9.4 Design studio program

Note that this section is the same for both IDS 13 and IDS 14.

9.4.1 Objectives of this interdisciplinary collaborative design process

The objectives of this IDS process were to produce innovative and detailed design solutions that:

- Are people-centred, improving residents' health, independence and quality of life, taking into account nine priority dimensions (Figure 7-1);
- Integrate technical and functional performance and 'constructability' with the many other design aspects of mixed-use buildings (Figure 7-2);
- Appropriately address the tropical and sub-tropical climatic contexts (Figure 7-1 and Figure 7-2);
- Demonstrate understanding of architectural, engineering and construction interdependencies resulting in prioritisation of passive solutions over mechanical and electrical solutions;
- Present an integrated systems approach to energy services that considers the:
    - Competing needs of building occupants (at any one time and over the life of the building),
    - Provision of energy services, energy supply and demand technologies and profiles, and
    - Interactions with other buildings, the electricity grid and the energy market;
- Enable flexible management of cooling demand and optimisation of renewable energy, as a step towards (near) net zero energy buildings; and
- Evaluate proposed solutions from a whole-of-life perspective that includes constructability, operation, maintenance, refurbishment and end-of-life (Figure 7-3).

Figure 7-1 Nine Priority Dimensions for Aged Care Design (Source: Burton, Iftikhar, 2021)

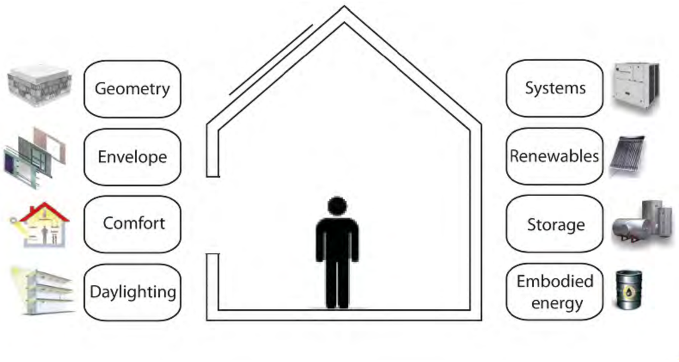


Figure 7-2 Architectural, engineering and construction interdependencies

(Source: Modelling, Design and Optimisation of Net-Zero Buildings, 2015)

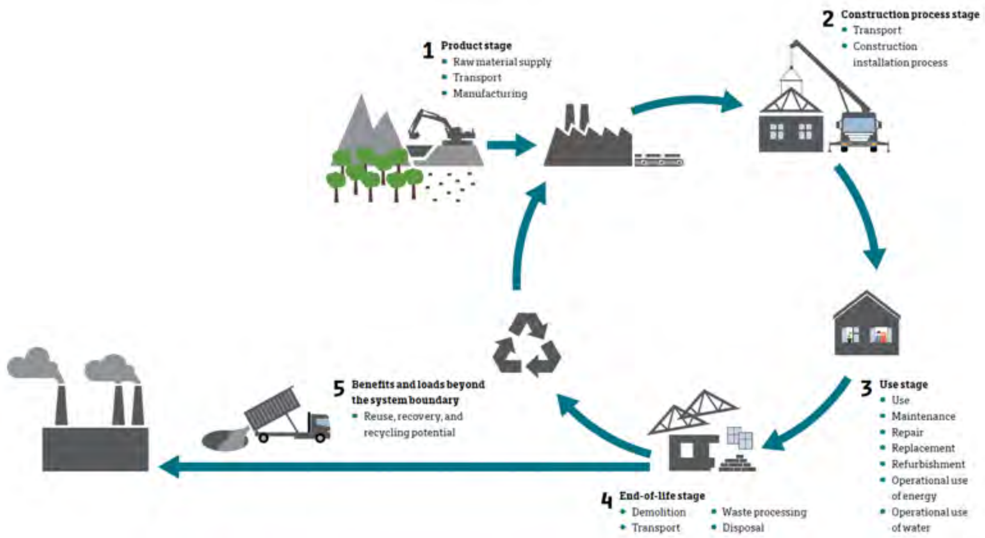


Figure 7-3 Whole of life considerations (Source: Introduction to LCA of Buildings, 2016)

9.4.2 Set up for collaborative design integration

The IDS 13 and 14 programs expanded previous IDS processes by adding sustainability and construction management domains into the process. They provided a low-risk environment for emerging professionals and seasoned professionals from multiple disciplines representing the design-construct process of a building. This mixed-discipline, mixed-experience team worked collaboratively on common goals whilst closely observing the key moments/instances that lead to integrated design outcomes. As with the initial IDS projects, the intent of IDS 13 and 14 is to examine how early career and experienced professionals engage in both the process and outputs of strategic co-design. This IDS structure incorporated the six levels of learning as presented in the modified Bloom's Taxonomy: remember, understand, apply, analyse, evaluate and create.

IDS 13 and 14 were operated in conjunction (because of the same client) and in separate groups (because of the differences in climatic and site contexts). The projects consisted of the bringing together of final year engineering and construction management honours students (4th year emerging building services and construction professionals undertaking their thesis project over two semesters), Master of Architecture students (5th year emerging designers undertaking their studio requirement over one intensive semester), experienced practitioners in the same fields, and academics with industry expertise.

This report presents activities relating to the joint activities and preliminary outputs relating specifically to the Caboolture (sub-tropical) context.

9.4.3 Integrated Design Process development

The IDS process was undertaken in 2 stages to optimise the involvement of early-career non-architecture disciplines with minimal design experience. Stage 1 represented real-world practice where emerging professionals in mechanical or electrical engineering, and in construction management, are incorporated into a consultancy via a graduate program or similar. These young professionals learned about the nature of the profession from more experienced professionals, and also how non-architecture consultancies are integrated in building design and construction projects. This knowledge and understanding were expected to develop over time, to enable future participation in integrated design projects (e.g. when an engineering consultancy, construction management company and architecture firm combine with a client on a specific brief.) Table 1 outlines the development of knowledge and understanding of these emerging professionals (the first two stages of Bloom's Taxonomy). This approach enabled them to contribute to the co-design workshops with architecture professionals and emerging practitioners more successfully, in stage 2.

Stage 1 participants joined emerging and practicing architects in Stage 2 to develop integrated solutions that responded to the client brief and IDS objectives. Stage 2 incorporated different studio types (e.g. co-design workshops and strategic workshops), with a range of activities to test and evaluate strategies for enhancing the co-design process. Stage 2 outputs were expected to be detailed design solutions (from the architecture students) and detailed technology specific reports (from the engineering and construction management students). The Stage 2 process is shown in Table 2. Note that the activities in the shaded cells are yet to be undertaken. They will be presented in the final IDS report (milestone 7).

The total student participants of the IDS 13 and 14 included:

- 26 Master of Architecture Students (13 students for the Caboolture project);
- 2 Bachelor of Electrical Engineering students (1 for the Caboolture project);
- 1 Bachelor of Mechanical Engineering student (None for the Caboolture project); and
- 3 Bachelor of Urban Design (Construction Management) students (1 for the Caboolture project).

Academic leads and consultants worked across both project contexts (Cairns and Caboolture), whereas student participants selected one site context on which to focus their design solution.

The IDS concurrently managed both student academic outcomes, as well as IDS project outcomes, both within the context of the client brief and with the participation of a multidisciplinary team of co-designers (Table 8-3).

Table 8-1 Stage 1 Development of knowledge and understanding (non-architecture participants)

<table>
<tr><th>Week</th><th>Studio type</th><th>Learning Activities</th></tr>
<tr><td>1</td><td>Co-design workshop (engineering and construction management students, and academics)</td><td>• Introduction to project
• Relationship building
• Mind maps</td></tr>
<tr><td>2</td><td>Co-design workshop (engineering and construction management students, and academics)</td><td>• Background research</td></tr>
<tr><td>3</td><td colspan="2">Combined Workshop (client and ENG/CM students, professionals, and academics)
FOCUS: Understanding the client brief and building users
• Relationship / Trust building</td></tr>
<tr><td>4</td><td>Co-design workshop (engineering and construction management students, and academics)</td><td>• Topic investigation</td></tr>
<tr><td>5</td><td colspan="2">Combined Workshop (client and ENG/CM students, professionals, and academics)
FOCUS: Discussion forum on health and sustainability
• Presentations on Air Quality and Health; Energy Efficiency; Thermal Comfort; Building Simulation; Sustainability Rating Schemes
• Discussion regarding implication for IDS process
• Padlet: implication for the 2 design sites</td></tr>
<tr><td>6</td><td>Co-design workshop (engineering and construction management students, and academics)</td><td>• WELL Building Standard</td></tr>
<tr><td>7</td><td colspan="2">Combined Workshop (client and ENG/CM students, professionals, and academics)
FOCUS: Climate / HVAC / energy modelling</td></tr>
<tr><td>8</td><td>Co-design workshop (engineering and construction management students, and academics)</td><td>• NABERS / Green Star</td></tr>
<tr><td>9</td><td colspan="2">Combined Workshop (client and ENG/CM students, professionals, and academics)
FOCUS: Construction management, project management, cost estimation</td></tr>
<tr><td>10</td><td>Co-design workshop (engineering and construction management students, and academics)</td><td>• Pragmatic solutions</td></tr>
<tr><td>11</td><td colspan="2">Combined Workshop (client and ENG/CM students, professionals, and academics)
FOCUS: How to evaluate options; Integration</td></tr>
<tr><td>12</td><td>Co-design workshop (engineering and construction management students, and academics)</td><td>• Own work; academic / group feedback</td></tr>
<tr><td>13</td><td colspan="2">• Student presentations of early research / analysis / design ideas</td></tr>
<tr><td>15</td><td colspan="2">• Student presentations (Engineering) to broader engineering group</td></tr>
<tr><td>Post-semester</td><td colspan="2">• Reflective Workshop (capture the IDS process learnings)</td></tr>
</table>

Table 8-2 Stage 2 IDS application, analysis, evaluation, creation (all participants)

Week	Studio type	Learning Activities
1	Co-design Workshop (all students / academics)	• Meet and greet • Existing perceptions of climate, age, energy • Non-architecture early design idea • Understanding old age
2	Strategic Workshop (all participants) **FOCUS: Client brief** • Relationship and trust building • Client brief (interview / Q&A) • Understanding the 9 design principles	
3	Own work (public holiday)	
4	Strategic Workshop (all participants **FOCUS: Analysis of sites/users and functional agenda** • Developing empathy • Feasibility analysis of early ideas • Understanding the 9 design principles	
5	Co-design Workshop (all students / academics)	• Early design ideas
6	Co-design Workshop (all students / academics)	• Schematic design ideas; concept plan
7	Presentation of concepts to client and feedback	
8	Strategic Workshop (all participants) **FOCUS: Integration** • Design development: discussion and critique	
9	Co-design Workshop (all students / academics)	• Finalisation of schematic design
10	Strategic Workshop (all participants) **FOCUS: Feasibility (evidence to support viability of solutions)** • Design development: discussion and critique	
11	Co-design Workshop (all students / academics)	• Design development: detailing
12	Co-design Workshop (all students / academics)	• Design development: detailing
13	Co-design Workshop (all students / academics)	• Finalise design / reports • Revisit perceptions
14	Reflective Workshop (capture IDS process learnings)	
15	Presentation of design solutions to client, consultants and academics	
Post semester	Selection of 4-6 design solutions for each site Feasibility Assessment / Vetting of selected design solutions	
	Evaluating IDS process and outputs	

Table 8-3 Academic and Industry Co-Designers

Role	Name and Key Responsibility	Specialty
Project Managers	Associate Professor Wendy Miller (overall program)	Systems thinking; buildings; energy
	Associate Professor Lindy Burton (IDS process, outputs, industry application)	Architectural professional practice; BaSE Mindset; health architecture
Project Fellow	Dr Naima Iftikhar	Architectural professional practice; Architectural pedagogy
Studio Leads (architecture)	Adjunct Professor Paul Trotter (guide architecture students)	Architectural Practice (professional)
	Adjunct Professor Mark Trotter (guide architecture students)	Architectural Practice (professional)
Academic Leads (non-architecture)	Dr Aaron Liu (guide engineering students)	Electrical engineer; renewable energy
	Dr Sherif Zedan (guide construction management students)	Architectural engineer; energy modeller; stakeholder management
Client (Bolton Clarke)	James Mantis (Client representative)	Asset management
	James Chiou (Client brief)	Project management
Consultants / Co-designers	Tian Song, JHA Engineering	Mechanical engineer (professional)
	Patrick Chambers, Stantec Australia	Mechanical engineer (professional)
	Nikki Parker, NDY	Energy modelling / ESD (professional)
	Andrew Williams	Energy modelling / ESD (professional)
	John Tuxworth, BEC	Construction, performance ratings (professional)
	Scott Butler, Hansen Yuncken	Construction Management (professional)

9.5 Preliminary Findings

9.5.1 Stage 1 Observations

9.5.1.1 Roles within the studio

There were three main roles within this stage: *early career co-designers* (engineering and construction management students with no previous professional building design experience); *academic co-designers* (responsible for guiding the students and for contributing to design ideation based on their academic and professional/industry experience); and *experienced professional/industry co-designers* (responsible for sharing knowledge and experience about building services and sustainability within the general design and construction context, and the specific aged care and mixed use building context).

9.5.1.2 The Client Brief

The role of the client was to provide the context for all co-designers (early career and experienced). The client brief was not as detailed as what would typically be presented for architects, to facilitate and support creative design ideation. This brief was more of an introduction to the company (Bolton Clarke) and its goals and objectives; its current projects (involving innovation and mixed-use typologies); and a broad introduction to the site context (Fernhill, Caboolture). This was done through a mixture of PowerPoint presentation, video and Q&A.

9.5.1.3 Understanding professional specificity

Because the early career co-designers had not been academically engaged in a design studio previously, it was important that they be exposed to the specific roles and responsibilities undertaken by different construction professionals. In particular, mechanical engineering and sustainability co-designers discussed their role in understanding the climatic context as it impacts on occupants and building services; modelling the thermal performance of the building envelope (to determine the cooling and heating load); and designing an appropriate HVAC system. The construction management co-designer discussed his role in project management and practical considerations in the implementation of construction and building services onsite. It was important to expand the 'professional specificity' beyond architects and engineers, to explicitly include building modelling professionals; sustainability professionals; and construction and project management professionals.

9.5.1.4 Emergence of systems thinking and ideation

A key activity of stage 1 was a workshop exploring the links between health and sustainability (including carbon emissions from energy use). As shown in Table 3-1, this workshop commenced with an industry presentation on air quality and health; energy efficiency; thermal comfort; building simulation; and sustainability rating schemes. This led to a discussion on the implication of systems thinking for the IDS process. Participants used on online ideation platform (Padlet) to present their ideas. Issues and ideation emerged in 5 key themes as shown in Figure 7-4: (1) indoor environment/health (white); (2) architectural design (purple); (3) climatic context (pink); (4) energy issues (green); and (5) legislation and codes (blue). Because there were no architects or architectural students involved in this stage, early career co-designers gravitated towards specific areas of focus for their core thesis:

- Renewable energy systems and storage (electrical engineers);
- Cooling systems (mechanical engineer); and
- Green walling systems, embodied energy, and material performance (construction management).

The intent was that these students would become "subject matter experts" that could contribute to integrated design solutions with the architecture co-designers in stage 2.

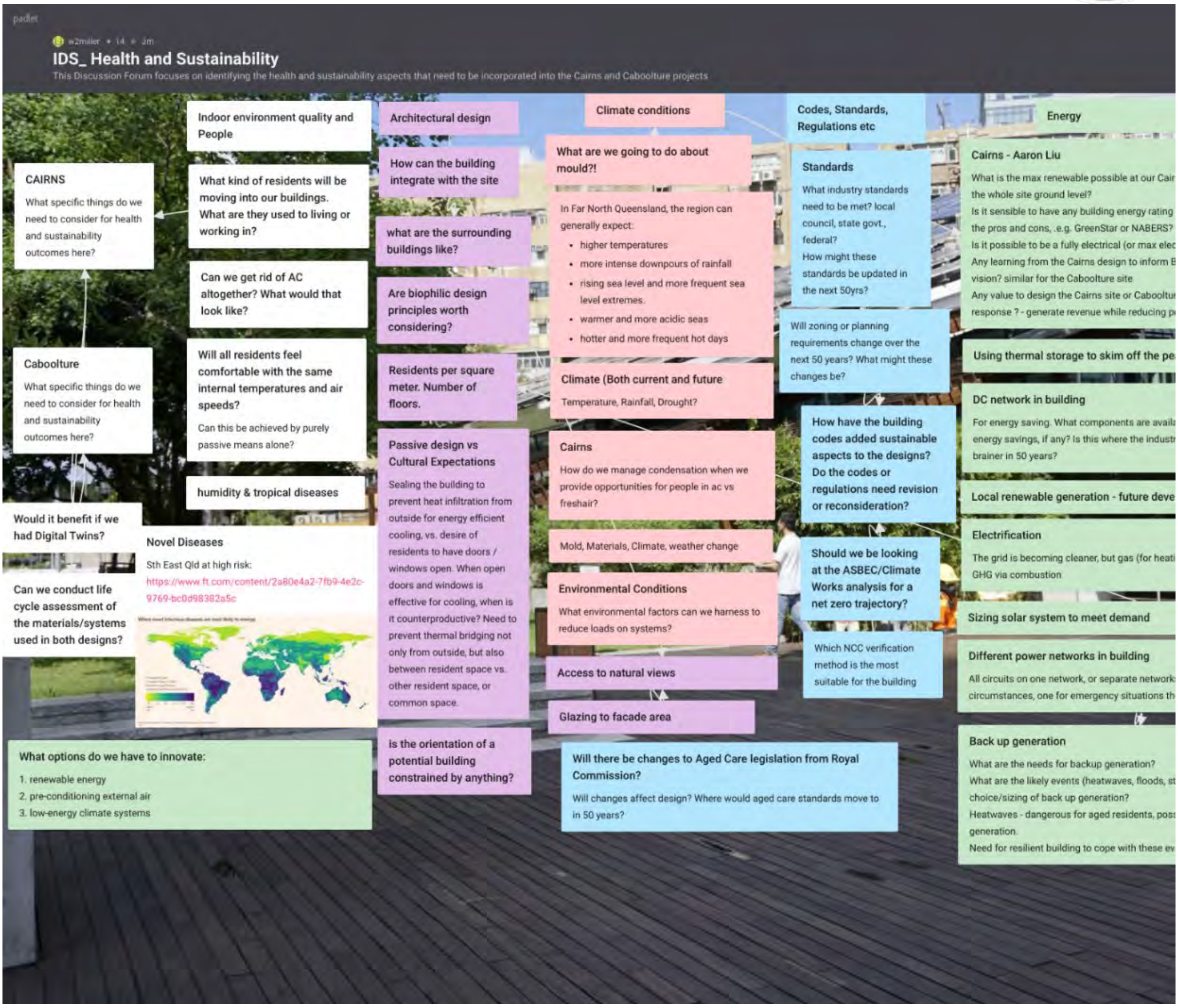


Figure 7-4 Systems-thinking themes emerging from health and energy workshop

9.5.1.5 Feedback from participants

A reflective workshop was held at the end of this stage, to capture the experiences and perspectives of all participants. This section reports on five key areas revealed in this workshop.

9.5.1.6 Goals and benefits

The goals of the project revolved around energy reduction and renewable energy targets (the goals of the iHUB project), in addition to the goals of the client. This involved working with key stakeholders on solutions within the limitations set by the client:

- Design must be based on existing, commercially available technology;
- Design must provide a return on investment (not necessarily restricted to economic return);
- Design must account for effect on aged residents, especially those with dementia; and
- Design must conform to environmental sustainability design (ESD) principles, including embodied and operational carbon.

This required developing an understanding of the project brief (e.g. site information, sustainability drivers, costs) and the roles that different professions could play in design solutions.

The benefits of this stage were identified as:

- Knowledge sharing and discourse;
- Collaboration across disciplines and between teaching, future of industry and current industry;
- Consolidation of several ideas into a practical and improvised process;
- Learning from the expertise of others;
- Consideration of role of indoor air quality in response to the pandemic; and
- Employability and networking opportunities (from students' perspectives).

9.5.1.7 Process strategies

A range of strategies were utilised during the process, each having a different purpose.

- *Mind maps* were used by students and academics to explore the project brief and consider real-world ideas about buildings in tropical and sub-tropical climates. The mind maps were discussed further in relation to individual students' projects (providing ideas about project scope).
- *Active questioning* (group) and *research* (personal) were used to provide further insights into the client's brief, development agenda and specific site constraints; and consideration of these alongside iHUB stakeholder objectives.
- *Technical presentations* (by industry) on ESD rating tools (e.g. NABERS, Green Star, WELL) and energy simulation tools, *and discussions* on their role in quantifying and optimising performance outcomes.
- *Presentations to client* (by students) on early and developing ESD strategies and ideas.
- *Discussion Forum* and *Collaborative Bulletin Board* (Padlet) were used to explore the links between health and sustainability, incorporating ideas on energy demand, HVAC, air quality, comfort and health. The focus of this strategy was on identifying co-benefits (multiple benefits of single solutions).
- *Individual feedback* was provided by academics and consultants to the students, enabling development of project drafts and refinement of focus of their project for ESD and net zero energy outcomes.
- *Industry sharing real world experience (*e.g. case study on RAC project, incorporating key learnings about project management, construction management and cost estimation; application of life cycle assessment; low energy design).

9.5.1.8 New knowledge uncovered

Student participants reported a range of new knowledge (for them) acquired during stage 1 of the IDS (Figure 7-5).

Note: students continued to build on this knowledge during stage 2, to undertake assessment of some of these topics, and to communicate this knowledge to architecture co-designers.

Figure 7-5 New knowledge acquired by students in stage 1

9.5.1.9 Opportunities and challenges

Opportunities and challenges were perceived by students, academics, and consultants, as summarised in Table 7-4. The common challenges faced by all three groups of participants were time, and the breaking down of discipline and experience barriers. The common opportunity was the interdisciplinary collaboration and collegiality (developed over time) that resulted in the sharing of knowledge and ideas.

Table 8-4 Opportunities and Challenges from IDS Stage 1

Opportunities	Challenges
Students	
• To work with multiple disciplines and different experience levels and backgrounds for a rich input on projects; • Encouragement from teachers and consultants on students' ideas/voices; • Refining the research focus and information gathering based off professional feedback; and • Gaining an insight about the collaborative process of project meetings to satisfy a client's brief.	• At the beginning and majority of the semester for the IDS process, different professions were grouped according to disciplines; • Less contact time with industry consultants; • Limited industry knowledge, by students, as certain concepts considered simple for consultants were new for student; and • A field trip would have helped students.
Academics	
• A risk-free environment (no risks in making mistakes); • Interactive discussions; • A student gained employment through this IDS stage (real-world impact); • Aspects considered for future collaboration; • Exploration of proven technology for sustainability outputs; • Overcoming students' fear of trying something new; • Real-world authentic learning experiences; and • Generous sharing of ideas and feedback from consultants.	• Lack of quantitative analysis due to lack of actual building designs; • Getting students to engage with consultants; • Getting students to focus on activities outside of the deliverable scope (i.e. assessment scope); • Time constraints in schedule for students to identify their topics without accumulating knowledge; and • Little discussion with client about the feasibility of topics.
Consultants	
• Collegial response; • Early involvement of engineers in the process; • Sharing of ideas between disciplines and levels of experience and knowledge; • Clear defined expectations and roles; • Educate clients on benefits about design disciplines earlier collaboration in the design process; and • Small working groups that promote equal participation from student/consultant/teacher to explore selected topics through a multidisciplinary collaboration.	• Time; • No architectural form; • Students needing to choose topics before learning about them; • Roles were perceived as 'students' versus 'consultants'; • Commercial objectives of client; • Green is considered synonymous with expensive; • Scope of the consultants' role and responsibilities during the IDS; and • Lack of understanding of each other's silos, culture and relationships.

9.5.1.10 The future of IDS in practice and pedagogy in delivering sustainability outcomes

Transdisciplinary practices in the professions/industry can provide positive results, through breaking down silos and working collaboratively, to create changes in practice-based culture, comprehension and communication. This requires an early co-operative design approach when conceiving a building design that requires sustainability performance outcomes. (Note: some procurement models are discussed and compared in Section 6.4). Other suggestions to drive IDS development and inclusion in practice and pedagogy are listed below (in no particular order):

- Government mandating of sustainability outcomes for buildings;
- A unified construction program;

- Advancement in technology such as BIM/BEM that informs all stakeholders about impacts of decisions on multiple aspects instantly;
- Assessment of future weather impact and future optimisation to accommodate the impacts must be considered;
- Utilisation of machine learning to predict the future performance under certain conditions and provide best solutions to optimise cost, energy, etc.;
- A “people first” approach with buildings acting as a means to support the healing of people;
- Equating “green design” with “affordable design” [note: this requires a whole-of-life cost and value approach and consideration of ESD as just as significant as revenue];
- Built environment must work with nature and be conceived as part of the natural environment—climate change will impact on both, and the climate catastrophe must be averted;
- Future designs must value aesthetics, resources, experiences, society, community, materials and quality of the environment;
- Introduction and education must be the first step towards change. It must involve the full lifecycle of the design team;
- Clear articulation of project ambitions is required; and
- Decision making must balance a range of components including cost, carbon, resilience, and adaptability.

9.5.2 Stage 2 Observations

The IDS-14 process was guided (curated) by two main types of workshops, studio (co-design) workshops and strategic workshops. Participant interactions during these workshops were observed.

9.5.2.1 Roles within the studio

Initially the students, academics and consultants perceived their roles distinctly as learners, teachers and industry professionals. Over time, the design studio workshops impacted students’ perceptions of roles, which enabled them to break away from the rigid identity of their roles as recipients of knowledge only, and towards critical and active participants in a co-design process. Students’ roles thus transitioned to active critical thinkers and explorers of knowledge and solutions. Academics acted as mediators between consultants and students, while being facilitators of the IDS process. The consultants were considered as expert reviewers with real-world experience, to empower students with knowledge.

9.5.2.2 Communication

Communication occurred between students; between students and academics and/or consultants; and between academics and consultants. Communication barriers were observed in the early stages in particular, due to discipline specific terminologies (e.g. unfamiliarity with terminology, and different meanings applied to terminology), as well as lack of rapport between participants who were unknown to one another. It took students (early career co-designers) 3 to 4 weeks to begin active discussions, and to confidently ask questions of the consultants, other students and academics.

Communication was not restricted to verbal gestures, but included sharing and exploration of key ideas and issues, using graphic approaches such as drawing and making, and presentation of digital images and resources. During the design studio workshops, architecture students utilised active communication and critical querying from fellow students (architecture and other disciplines), and academics. In the strategic workshops, the architecture students engaged in active listening, and received feedback from consultants (both early-career and experienced co-designers) to challenge and improve their projects. This further emphasises the initial perceived imbalances of the roles, due to expert knowledge (or lack of it) on a certain topic under discussion.

During the earlier stages of the project, when architecture students didn't have specific building masses to discuss and share, the communication focused on exploring the territories of the professions. However, as the design projects developed further in the later stages of the semester, the forms of communication extended to include graphical and digital presentation styles, as well.

9.5.2.3 Feedback from participants

Following is a selection of feedback provided by engineering and architecture students, and one of the consultant/academics:

Electrical Engineering Student:

> *"This project challenged students within their own discipline, but to also regard the other professions when attempting to implement their own design. The design of the energy generation system for net zero electrical emissions, along with onsite storage options, was a discipline specific investigation. The incorporation of other professions, all with different expertise challenged the way participants thought when approaching building design and promoted a more collaborative process over individuals."*

Electrical Engineering Student:

> *"Engineering students and construction management students were assisting [architecture students to design their buildings], by providing [our] expertise to each student that required it. This included finding the total amount of PV required for their designs to be net-zero emissions, giving recommendations on orientation and angling, along with the feasibility of any experimental panel placement that they might be interested in. This altered [my] research focus, as the IDS required each discipline to work together... [my] initial research concentrated on PV cells and hybrid storage systems ... [but the needs of architecture students meant that] the research expanded to [incorporate the requirements for] MSB's [main switch boards] and DBs [distribution boards] and generators... another student [architecture] was willing to let their design be investigated for the electrical requirements."*

Architecture Student:

> "*I am in my fifth year of the architectural degree and this studio challenged me to rethink the design process, as I have always engaged in a traditional studio model. I had to consider ESD principles, real building design systems, and their integration for a sustainable outcome for my site. All of these design challenges, coupled with rapport building and consensus building across various disciplines, refined my design development for minimising the carbon footprint."*

Consultant/Academic:

> *"Students had to deal with a whole range of new species of disciplines, and to articulate their thinking to a diverse range of professionals. The integration of consultants and client in the earlier stages of the projects, allowed the architecture students to focus on the real-world constraints of the site, and to think about how energy efficiency could be improved with consideration of long-term implications, for the future impact of the building on the occupants' comfort and health.'*

9.5.3 Lessons from studio observations

9.5.3.1 Integrated Design fostered at all phases of design development

The different phases of design development utilised different strategies or opportunities for integrated design, as elaborated upon, below.

9.5.3.1.1 Project objectives and aspirations phase

The initial process in Stage 2 (all participants in the studio), was focused on understanding the project objectives and aspirations. This phase included: introduction of the project; an explanation of the nine IDS Priority Dimensions (Figure 7-1); site allocations (for architecture students); creating site-based teams and connections between architecture and non-architecture co-designers; and understanding the client's brief, values, and aspirations for sustainability and community.

9.5.3.1.2 Design concept development phase

The design concept development phase which followed, required student co-designers to further understand the site constraints, project brief, context and community needs. This phase included: collective learning of discipline specific vocabulary and design approaches; establishing individual project briefs and methods in which co-designers contribute to individual projects; research and understanding of the technicalities of building systems and services, and ESD solutions; developing spatial layouts and mixed-use needs; consideration of specific parameters and components, which are not usually considered in the early project stages; developing a shared vision/mission for community and sustainability; goal setting; and open-ended problem solving.

9.5.3.1.3 Master planning phase

The master planning phase required the architecture students to finalise the functional aspects of spaces. This phase included: consideration of building services/systems; consultants' demonstration modelling on energy consumption and feasibility of projects and services; consensus building about ideas between stakeholders; exploring building and systems' performance parameters in specific sites/climates; developing shared vision/mission for community and sustainability; integrating the nine IDS Priority Dimensions to achieve project outcomes; and continued acquisition of technical knowledge from participants and through individual research.

9.5.3.1.4 Design development phase

Half-way through stage 2, all non-student participants (including the client) provided feedback to individual students' early design development ideas. This phase included: studio leaders (professional practising architects) presentation of their own practice and projects; expanding knowledge and skills in orientation of buildings and spatial layouts; applying passive design principles; understanding both HVAC systems and natural ventilation options (mechanical services); green screens/walls/facades and their impacts on energy efficiency; inclusive design considerations; the importance of embodied energy of materials; the application of regenerative design; the integration of renewable energy (e.g. sun and wind); water conservation considerations; and methods to reduce energy demand and carbon emissions. All co-designers were provided with opportunities to participate through asking/answering specific systems/services design queries. This phase incorporated a 'whole to parts – parts to whole' approach, with all disciplines involved in the enquiry and knowledge development.

9.5.3.1.5 Feasibility evaluation phase

This feasibility evaluation phase was not implemented as well as the earlier phases, as only fairly rudimentary evaluation was undertaken by most projects. This phase included participants asking/answering specific questions about:

- the feasibility of practical applications;
- the implementation of projects and services;
- appropriate architectural and engineering solutions, for specific contexts; and
- consideration, by all parties, of the extent to which proposed design solutions were addressing the client and iHUB project objectives.

While some students undertook individual feasibility assessments (e.g. sizing and cost analysis of renewable energy system; or basic climate analysis to inform passive design strategies), no architectural designs were simulated for thermal performance. This was because the designs were resolved too late in the process for this to be undertaken by consultants, and the students did not have the training to do so themselves.

9.5.3.2 Evolving interactions between participants throughout the IDS process

The interactions between the stakeholders also evolved as the integration process unfolded through the design phases explained in the previous section. The nature of the interactions over the entire project progressively changed, as shown in Figure 7-6. Note that “shared leadership and responsibility” and “enquiry, reflection and adaptation”, established in the early phase, continued through all the phases.

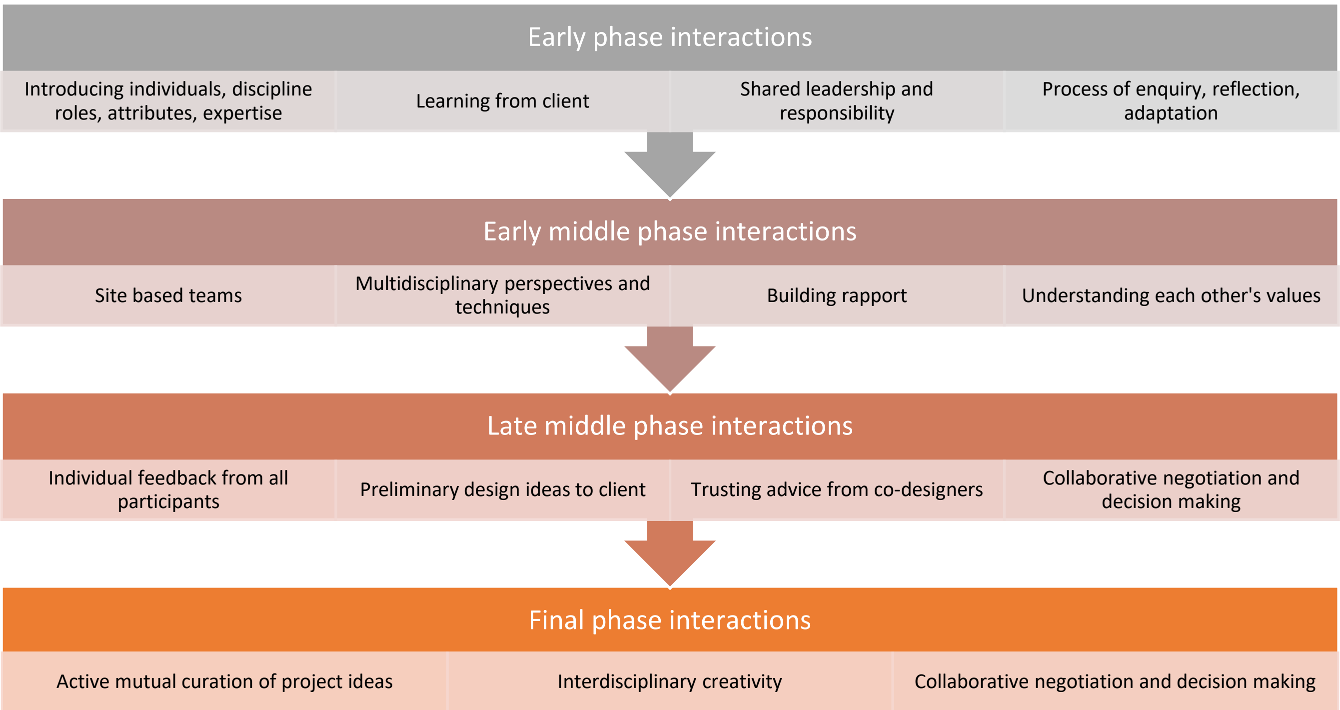


Figure 7-6 Changing nature of participant interactions

9.5.3.3 Changing roles of participants throughout the IDS process

The roles of the stakeholders evolved, as the process and interactions were expanded. Individual participants were, at various times, perceived as: collaborator; leader (of change/transformation of ideas); manager (of individual projects); critic; innovator; critical thinker; facilitator; learner; explorer; researcher; designer; co-designer; active curator; decision maker; and/or creator.

9.5.4 Participant feedback

9.5.4.1 Optimising collaborations for different phases

The whole-of-group collaborations actively and effectively facilitated the earlier phase of stage 2, and specifically constituted interdisciplinary groups were formed for each site context (Cairns and Caboolture). As the architecture projects progressed towards the design development phase of the buildings, individual and one-on-one collaborations were preferred, given the nature and complexity of factors emerging in individual projects. The presentations by consultants on energy modelling and specific components of building systems, enabled student collaborators to refine the focus of their individual projects. In the early to middle and end phases, there was a shift and transformation of the nature of collaborations from being scheduled and discursive to organic. This allowed the multidisciplinary teams working on similar sites to develop the individual components of their projects, in an iterative back-and-forth manner. Opportunities for collaborations were explored beyond the face-to-face mode, resulting in some teams setting up virtual collaborative places (e.g. MS Teams, Facebook groups and Google docs sharing).

9.5.4.2 Ratio of architecture and non-architecture participants

Participants noted that the ratio of the non-architecture to architecture co-designers was imbalanced (14 non-architecture co-designers (6 early-career and 8 experienced) to 26 architecture co-designers). This led to group-based collaborations but was perceived by architecture students as impacting (negatively) on their individual project outcomes.

9.5.5 Opportunities and challenges impacting the IDS process

9.5.5.1 Opportunities

A range of opportunities were identified:

- Authentic learning opportunity, establishing a practical real-world problem-solving mindset;
- Interaction with (a real) client;
- Developing a systems-thinking approach to projects;
- One-to-one rotating meetings with consultants;
- Exploring and addressing diverse dimensions not usually considered in traditional projects;
- Detailed designs/project outcomes aligned with AIRAH/ARENA sustainability goals; and
- Professional readiness, including interdisciplinary team collaboration skills for professional practice.

9.5.5.2 Challenges

The early phases of stage 2 had three main challenges:

- Lack of an architectural design as a focus for discussions with non-architecture participants;
- Lack of knowledge or understanding on each discipline’s expertise; and
- Issues relating to dealing with interdisciplinary working dynamics.

The challenges of the middle and later phases were different:

- Complexity of aspects to deal with;
- Constraints relating to time management of activities;
- Need for ongoing “lectures” from experienced co-designers about building services/systems;
- Continuing need to [remind participants] of the aspirations for sustainability and iHUB outputs;
- Lack of shared responsibility of design outputs and authorship, due to no team contracts/agreements; and
- Perceived lack of one-on-one time to consult with studio leaders, consultants and academics.

9.5.6 Value of the experience

9.5.6.1 For students

Three students gained employment as a result of participation in this IDS:

- 1 student (engineer) as an immediate part time position, and an ongoing post-graduation position with a participating consultancy;
- 1 student (engineer) as a 'graduate of engineering' position with a participating consultancy;
- 1 student (construction management) in a graduate position with a global construction company, starting in the design team responsible for coordinating onsite construction consistency, with the client brief and 'as designed' drawings.

Following is a selection of feedback provided by engineering and construction management students:

Electrical Engineering Student:

> *"After the IDS process, I feel that a better understanding of the goals and performance objectives of a vertically integrated client have been understood... The iHUB IDS project was a valuable professional experience and has given me skills and created opportunities for me that another thesis project would not have."*

Electrical Engineering Student:

> *"This project combined an industry partner in Bolton-Clarke with a government entity in ARENA to challenge students within their own discipline, but to also regard the other professions when attempting to implement their own design. The design of the energy generation system for net zero electrical emissions, along with onsite storage options, was a discipline specific investigation. The incorporation of other professions all with different expertise challenged the way participants thought when approaching building design, and promoted a more collaborative process over individuals."*

Construction Management Student:

> "*Thanks again for your support throughout the year and effort in providing this opportunity. I really learned a lot and enjoyed the process.*"

9.5.6.2 For university

This IDS project (13 and 14) has provided multiple benefits to QUT, including:

- Offering an authentic learning experience to participating students;
- Providing an opportunity for cross-disciplinary and interdisciplinary collaboration between students, and between schools within the Engineering Faculty;
- Further deepening of existing industry relationships and establishment of new relationships;
- Enhancing the 'job readiness' of graduates; and
- Potential avenues of further research (in pedagogy and in technical ESD solutions).

9.5.6.3 Future considerations for the IDS process in university settings

A number of possible options have been considered for improving the IDS implementation in a university setting.

- Incorporate aspects of IDS (e.g. interdisciplinary and multidisciplinary interaction) earlier in the engineering and built environment degree programs. This action could gradually build the knowledge and technical skills in ESD, building services and system design and evaluation processes and tools, as well as collaboration skills;

- Reserve ‘full’ IDS projects for advanced students (e.g. final year undergrad or master degree) who have pre-requisite skills and experience to contribute meaningfully;
- Revise assessment processes for these units (at all stages of the degree) to allow for, and encourage, collaborative outputs as opposed to individual outputs;
- Incorporate more architectural engineering / building science / building services into engineering, architecture and construction management degrees;
- Consider modelling collaborative work ‘contracts’ on an Integrated Project Delivery model, where project members share responsibility (and risk) for the project, and allocate specific tasks and performance deliverables;
- Build a “repository” of a suite of suitable teaching and engagement resources that can be utilised for multiple purposes / units / courses;
- Foster industry relationships to continue engagement in authentic learning experiences; and
- Revisiting the process of IDS delivery to learn from experience.