The Innovation Hub

for Affordable Heating and Cooling

Knowledge Sharing Report

IDSKS Report on Combined Outcomes

Project IDKS

27 May 2022

The University of Melbourne

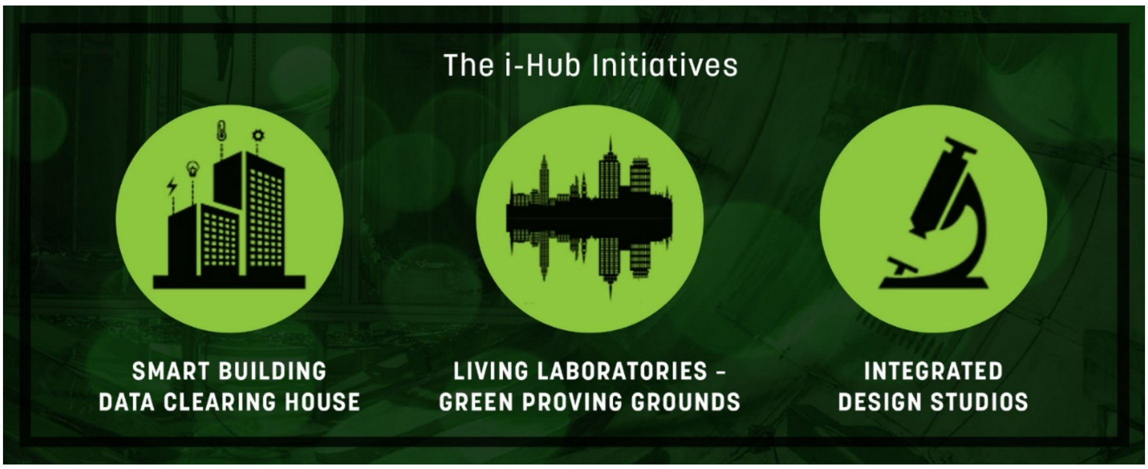
About i-Hub

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

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

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

Primary Project Partner



i-Hub IDS Knowledge Sharing Report on Combined Outcomes

The IDS-KS Knowledge Sharing Report on Combined Outcomes summarises key findings from the 14 individual IDS studios that were run over a period of two and a half years.

This document encompasses the Carbon Catalogue, as well as key learning on Integrated Design as part of the IDS studios held in the three participating academic institutions, The University of Melbourne, Queensland University of Technology, and the University of Wollongong.

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1. INTRODUCTION

1.1. IDS Activity Stream Overview

This summary report consolidates all findings taken from Integrated Design Studio (IDS) program undertaken by the University of Melbourne, the University of Wollongong and the Queensland University of Technology. The program represents one of three activity streams forming the wider Innovation Hub for Affordable Heating and Cooling (i-Hub), 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. i-Hub was 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 IDS program was initiated early 2020, after extensive preparation and stakeholder engagement, involving the academic institutions, the managing entity (AIRAH), the funding body (ARENA) and other collaborators and partners who would directly be involved in running and supporting the individual IDSs. The default setting for running the IDS was originally in person at the academic institutions, however various COVID-19 related lockdowns required some of the studios to be run online. A summary of all IDSs run as part of the program can be found in the table below:

Table 1-1 List of all IDS and their main project participants

Studio	Client/ Developer	Host University	Engineering	Architecture / Specialist Consultant
01 – Data Centres:	Next DC	University of Melbourne	Aurecon	Greenbox Architects
02 – Schools I	ACT Govt	University of Melbourne	Arup	Grimshaw Architects
03 – Schools II	ACT Govt	University of Melbourne	Jacobs	Jacobs
04 - Emergency Response Centres#	Ambulance Victoria	University of Melbourne	Atelier Ten	Ewers Architects
05 – Aquatic Centres	Banyule City Council, Yarra City Council, Brimbank Council	University of Melbourne	WSP	Alan Pears (Heat Pump specialist)
06 – Transportation Buildings (Stations)	LXRP, Fiona McLean Architecture, Cox Architects	University of Melbourne	WSP	Cox Architects
07 – Aged Care I (Small)	Active Community Group	University of Melbourne	Atelier Ten	Place Design
08 - Laboratories	CSIR	University of Melbourne	Atelier Ten	Designinc
09 – Multi-Purpose Buildings I – Indigenous Multi purpose facility.	Lightning Ridge Local Aboriginal Land Council	University of Wollongong	Stantec Australia, MIE Engineers	Edmiston Jones (AEJ)

10 – Aged Care II (Large)	Lendlease	University of Wollongong	Stantec Australia, MIE Engineers, Arup	Cox Architects
11 – Community Centres	Wollongong City Council	University of Wollongong	T Stantec Australia, MIE Engineers, Arup	Cox Architects
12 – Multi-Purpose Buildings II – Indigenous Multi purpose facility.	Illawarra Local Aboriginal Land Council	University of Wollongong	Stantec Australia, MIE Engineers	Edmiston Jones (AEJ)
#13 & 14 – Mixed Use Buildings (Sub-Tropical & Tropical)	Bolton Clarke	QUT	Stantec Australia, JHA Engineers, Norman Disney Young/Tetra Tech, Hansen Yunken, The Built Environment Collective (BEC)	Fulton Trotter Architects

Work within the associated 14-15 week-long Integrated Design studios included design exploration exercises, and the development of design proposals. Architecture and Engineering students were typically interacting with their student tutor twice a week, and with the industry consultants on at least a weekly basis during early semester with more frequent support provided toward end of semester. A dedicated '*Catalyst for Integrated Design*' guideline underpinned the collaborative effort and helped in the joint development of common goals toward 'Net Zero' design. The studio sessions were observed by academics in each institution who analysed the integrated design process as it unfolded and subsequently interviewed participants to understand the inner workings and where the process was successful or not as the case may have been.

1.2. IDS Activity Stream Objectives

The IDS activity stream explored integrated design on two levels.

Testing of current integrated design theory from literature.

Integrated Design is not new, it occurs in industry currently however its implementation is sporadic and often poorly executed. The first of the level of exploration undertaken in the IDSs was in testing the theoretical knowledge that currently exists in literature in a practical applied environment.

A best practice '*Catalyst for Integrated Design*' document was produced through the study and consolidation of current literature on the subject. This best practice model was then tested and refined with practical learnings through the successive design studios carried out.

Exploring 'Net Zero' design across different building typologies.

The second level of exploration was in using integrated design to develop designs that explored the possibility of 'net zero' for the different building typologies used as case studies in the studios. This was done through encouraging the development of novel technologies for carbon reduction within a joint architect-engineer designer setting in academia, supported by industry consultants and technical specialists.

The IDS teams from all three academic institutions selected fourteen case study projects in total covering eight different building typologies. The resulting building typologies and associated learnings naturally fell into three main categories that became useful for the purposes of comparison, simple projects, complex projects, and specialist projects.

The IDS teams aimed for participation and active engagement of both Architecture and Engineering students, consultants, and clients for the duration of each IDS. This summary report addresses both, findings related to how to practically implement integrated design as well as the findings in relation to Zero Carbon strategies for the selected building typologies.

It was neither the goal, nor the ambition of the researchers to develop a comprehensive mapping of Zero Carbon characteristics across all major building typologies that occur in industry. As well as providing insight into appropriate net zero approaches for the specific typologies that were explored however, the spread of projects did enable a degree of mapping across projects leading to the aforementioned three project categories. This report presents these results.

1.3. Selected summary of Lessons Learned and main conclusions (Executive Summary)

The following lessons learned are a select summary providing a general overview. For a full description of the lessons learned on integrated design including a high level summary road map to implementing it on projects refer to the 'Catalyst for Integrated Design' document produced.

- The importance to establish a level playing field from which each participant benefits, characterised in this IDS by the replacement of professional specificity with mutual respect, and realised through integration in shared decision making and work efforts by working in groups.
- Clear articulation of common goals is a key priority, and in this IDS translating into clear assessment criteria and being upheld in an intelligible way through the integrated design development process.
- Maintaining focus on the common goal and how it translates at progressive design moments was achieved in this IDS by working in groups through to end of semester, with each group availing

themselves of the hands-on guidance from the studio tutor and industry consultants to navigate the unfamiliar design process.

- Participants – in particular the Engineering students struggled with a ‘brief under development’, expect clearly defined problems instead; addressed in this IDS by actively involving the engineers in articulating the engineering component of a return brief from each group and then following this through with the same group as the design development process unfolded through to end of semester.
- This IDS demonstrated that collaboration between the engineers and architects is upheld when engineers are fully engaged in design decision making and particularly when the engineers articulate their requirements in the return brief.
- The group dynamic had a strong influence on design collaboration by enabling the team to build relationships and a team identity. The group structure enabled good collaboration but did not drive it. This was more attributed to the studio context.
- Integrated design happens over a limited time window, but design challenges can be complex for students to navigate; this IDS actively encouraged keeping options open for as long as possible while designers grappled with understanding the full complexity of the integrated design challenge.
- In the context of a fast-track studio process, the more information provided up front was seen as key to helping students focus on what they are being asked to do.
- Balancing individual contributions to design co-authorship proved a challenge in some groups, but the engineer in each group constantly brought up the topic of sustainability, generating helpful conversations, and providing good scope for the engineering modelling to influence the design with some real evidence of environmental principles being integrated into the architectural form.
- The engineering students were there right through and that was seen as crucial, generating multiple opportunities for regular interaction, and enabling team members to bond more easily.
- For students’ first encounter with an integrated design challenge, the approach of immersing them into a strong contextual project space within which to develop ideas was perceived as a strong driver of collaborative and integrated outcomes.

Figure 1-1 The studio at work (UoM)

1.4. Challenges experienced and how they were overcome

During the duration of the IDS program various lockdowns were in place that affected the way the IDS activity streams could be delivered. Some studios were forced to move entirely to remote (on-line) delivery, others experienced limitations in terms of face-to-face engagement or site-visits (only a limited number of site visits were able to be undertaken). Due to extensive and fast-tracked preparatory work by the participating universities and project partners, the online format proved successful overall, but it was not without its challenges. The desired bonding between architecture and engineering students and in-person engagement with consultants was limited in comparison to the studios able to be delivered in face-to-face format. From an observation perspective, online delivery had some advantages as observers could act as a silent witness in the online meeting rooms and sessions were recorded. The students, the tutors, and the industry consultants took advantage of interactive online communication features to review and discuss design ideas both verbally, as well as by annotating sketches, plans/sections, and 3D models.

To facilitate communication and collaboration among studio participants, a common data environment was created by studio tutor on an online platform where all the information related to studio including the site information, site drawings, references for reading, and studio recordings were stored. This online folder was proved useful throughout online delivery acting as the single point of truth where all participants could refer to at any time to keep informed about recent updates and prevent miscommunications and loss of information.

Indicative of the challenges present in industry relating to the differences between architects and engineers in the way that they think, operate and carry out their business/work, challenges could be observed regarding a misalignment between the way that the architectural and engineering degrees operated.

The starting point for these differences was in the subjects offered by the Architecture Faculty (where six-hours-per-week studios are common, with students generally acting in an open ended manner spending much more time than this in completing their work), and those offered by the Engineering faculty (where a reduced time commitment, closer to three hours per week is required, and where students are more measured in their efforts tending to limit hours to those specified in the subject outline). Academics needed to find alternative ways to ensure engagement of Engineering Students in the IDS by searching for ways of aligning assessable deliverables and background tasks. Engineering participation in the IDS was low initially, exacerbated by a substantial number of Engineering students still being stuck overseas due to COVID. Such challenges were less prominent in cases where the IDS were run within dedicated Architectural Engineering streams where input from both the architecture side as well as the engineering side was a given. Many of the engineers who chose to take up the integrated design studios did so through an existing interest in building design and so a degree of self-selection of design orientated engineering students was present. While this may seem to indicate a bias in the type of designers participating in the study, the same self-selection of engineers desiring to be involved in integrated design is likely present in industry to some degree.

2. BACKGROUND TO THE IDS ACTIVITY STREAM

The studios within the IDS program provided broad coverage of the built environment gaining insights into the challenges and opportunities in several different building typologies:

- Data Centres
- Education
- Emergency Services (Response facilities)
- Aquatic Centres
- Aged Care
- Laboratories
- Multi-Purpose Buildings
- Transport Architecture
- Mixed Use Developments in Tropical/Sub-Tropical Climates

Several building typologies were explored in successive studios, or across more than one institution. This strategy enabled a level of depth in exploration as well a breadth. For example, the second iteration for a building typology carried out (say for example in schools), enabled designs to be progressed that avoided many of the pitfalls encountered in the first iteration thereby extending learnings past the original studio. In a similar vein by carrying out the same typology across different institutions (for example aged care), different perspectives arising from different participating designers and consultants were able to be gained and compared. The resulting body of knowledge gained provides comprehensive insight into issues and learnings greater than if studios were to be individual or stand alone.

2.1. Focus on Integrated Design

Academics from both Architecture as well as Engineering engaged jointly in intensive industry consultation to search for compelling case-study projects to investigate new technologies under the Integrated Design Studio banner.

To provide guidance for the format and programming of Design Studio activities, and in particular their interface with the investigation on integrated design, the IDS management updated their detailed manual titled: *'Catalyst for Integrated Design'.* Released approximately 2 weeks before the studio's commencement, the catalyst document combines aspects of design collaboration that cut across architecture and engineering disciplines to produce integrated outcomes. The manual first addresses overarching aspects of design integration to then delves into the specifics of environmental building performance, human comfort, and mechanical design systems. The manual ultimately assisted the studio tutor to coincide their activities for advancing design concepts with key milestones for addressing and integrating technologies throughout the semester.

The studio tutor proposed a detailed IDS schedule in week two of the semester, based on his experience as design studio leader within a 13-15-week semester, as well as preparatory conversations held with the industry consultants, the client and the academic participants. The schedule addressed the output requirements typically inherent to masters-level design studio teaching, and the specific IDS output requirements for exploring novel technologies to support a Net Zero Carbon design goal. In particular, the schedule mapped out the intensity and duration of engagement between the architecture students, engineering students, the regular architectural and engineering design consultants and guest consultants. After the initial online start-up workshops, the IDS moved into the period of bi-weekly 3-hour design review sessions. Next to the benefits for information exchange, the initial start-up workshops also fulfilled the essential task of introducing all key IDS participants to each other and facilitate social bonding, particularly between architecture and engineering students, and articulated the common goal of being involved in a design process above and beyond that of business-as-usual, and important precept to successful integrated design.

 

Figure 2-1 Joint start-up workshops and ESD Consultant Introduction (UoM)

Integrated design is the coming together of multiple disciplines to produce design solutions that meet 'whole of project' visions. Early observations in previous Integrated Design Studios (IDS's) show that not all designers are used to working in this way.

A two-part **Catalyst for Integrated Design** guideline formed the basis for studio engagement from the start of the IDS program. It contained the following key headings:

<u>Integrated Design Principles</u>

- Facilitate an environment that prioritises working on common goals over individual goals
- Establish trust among participants (open/non-judgmental/sensitized/willing/etc)
- Allow every participant to understand what's important to the others.
- Explain the process each participant (group) typically goes through, in order to derive their desired output.
- Understand why we often see things differently, and
- develop a common language that cuts across discipline silos (metaphors/analogies/co-experience)
- Call students 'designers' rather than architects and engineers. Engineering should empower architecture and vice versa
- Set common targets and instill a sense of joint ownership … and
- introduce a sense of shared responsibility across group participants
- Knowing in action/heuristics: discuss and advance integrated design solutions on the fly…
- start with educated guesses/rule of thumb, then verify validity of assumptions for preferred solutions

Design Co-author mindset: This aspect of design is sensitive to the relationship between individual designers which can be complex. Achieving an environment where all participants contribute in a co-authoring capacity to the project was observed to be difficult. Many of the subsequent learnings from the studios revolved around trying to encourage this outcome (I.e., the need for flexibility in catering for designer's different modes of working and communicating, and the introduction of small common tasks to improve bonding between disciplines and designers). The relationship between individual designers was observed to be a significant factor in shaping the integrated design response.

Earlier IDSs approach to bridging the discipline gap by encouraging the creation of good working relationships within small groups by both disciplines working together had been found to be a positive move towards alignment of thinking and design co-author mindset.

The adoption of design groups in IDSs proved successful with all groups in a studio evidencing collaborative behaviour. Observation of individual IDS groups at work (in the University of Melbourne Aged Care IDS) found most groups readily engaging within the group around common design challenges, particularly environmental and engineering aspects evidenced by use of a common language and displaying a sense of common ownership.

2.2. Focus on Zero Carbon Technologies

As a part of achieving the declared carbon reduction goals students and industry consultants explored different passive and active measures and technologies. They related to the design choices, construction effort, and embodied carbon of materials, but also to minimising operational aspects, such as heat-loss, energy use. The multi-disciplinarity required in achieving net zero outcomes proved to be a useful goal in encouraging integrated design to occur and in creating design scenarios in which to observe the many inputs required from each discipline. It is worth noting however that the nature of integrated design is to be all encompassing. Design initiatives were therefore not limited to the goal of carbon reduction but included other sustainability and functionality outcomes, I.e., responsible water collection and reuse, or occupant health and well-being outcomes etc.

Performative design principles

The following performative design principles were articulated in the catalyst for integrated design document:

- Address **environmental** building **performance** systemically across Architecture and Engineering
- Establish joint environmental **targets** per relevant building type à apply end-use performance metrics
  - o What are the mechanisms to address them in **early**-stage design?
  - o What are the mechanisms to address them in the **advanced** design stages?
- Develop an iterative Arch/Eng process for **optimising performance** (Optioneering)
- Search for integrated design responses to human **comfort** and environmental **loads** à understand how various aspects of the Arch and Eng design are connected.
- Search for **synergies** via design **innovation rather than** relying only on **mechanical** solutions (passive over active) … as part of that…
- foster **multi-functional design** – design elements in an integrated design should be doing more than one thing at once (at least 3 things).
- **Define** the **characteristics** that represent the '**integratedness**' of a design solution. That's what the success of this project should (also) be measured against!

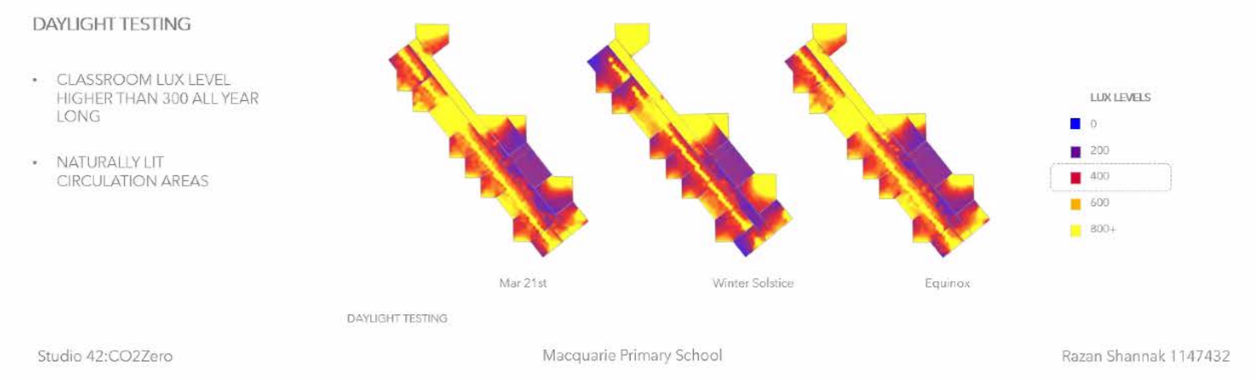

Figure 2-2 Daylight Testing – Razan Shannak (UoM)

2.3. Joint Industry-Academia Effort

Each IDS was joined by industry experts and consultants, with a proven track record in the design, delivery and operation of the building typology to be investigated. In addition, each IDS worked with an open-minded client, whose aim was to explore alternatives to conventional approaches in conceiving buildings/projects of each particular typology and redefine the design of these facilities with a more conscious approach towards Zero Carbon goals. Clients welcomed the opportunities to test unprecedented and novel technologies, brought into context with innovative design ideas. Clients remained involved intermittently through each studio, providing guidance and feedback, particularly at the mid-semester and end-of semester milestones for student assessment.

There was a strong consensus among the participating IDS consultants that linking their professional experiences to the studio via case studies and current industry practice workshops and/or discussions, assisted students to understand how innovation and integrated design occurs. Students were able to realise how current industry practices and processes get applied in relation to issues such as climate change, budgetary constraints, building maintenance and project lifecycle etc. It allowed students to see opportunities for departing from industry 'business as usual' in a realistic and achievable way to improve built environment outcomes.

Studio tutors were actively curating the cross-disciplinary processes unfolding within the studio as they worked with the students to encourage them to understand how their design ideas could be adapted in fulfilment of both architectural and engineering aspects of the brief. The consultant team and studio tutors all identified the proficiency of their fellow team members in discussing aspects across disciplines to support students in their interrogation and integration of design and engineering considerations.

'The engineering consultants helped the students to understand the technical aspects by challenging them to understand how they would work in that design and to help the students identify suitable modifications.'

2.4. Focus on Experimentation and Innovation

This mix between willingness to experiment from the students, paired with a high degree of expertise provided by the consultants greatly benefited the conversations and design approaches in the studios.

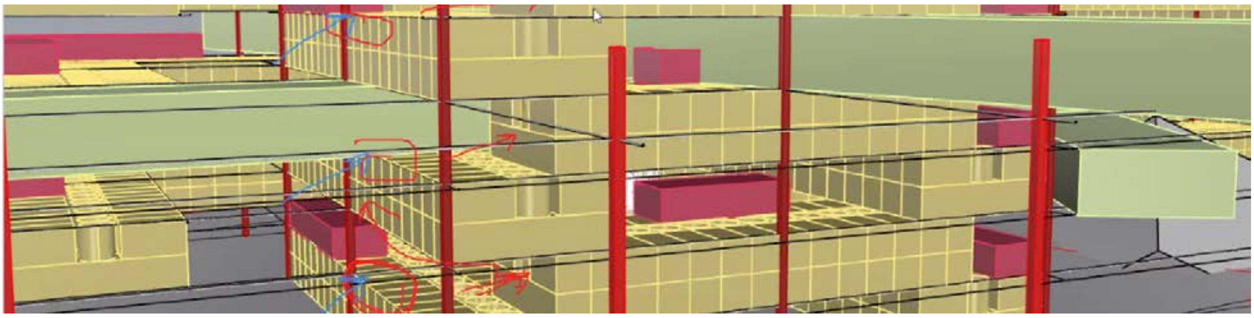

Figure 2-3 Data Centre WIP – Pan Shi (UoM)

Following on from the mid-semester reviews, the engineering consultants continued to provide, once or twice a week, one-on-one engineering feedback in the form of environmental design tutorials with students able to participate either as individuals or groups. Designers were guided through the process of modelling and testing their design proposition for its performance against common 'Net Zero carbon' parameters. Students used the engineers' feedback from these tutorials to inform a refined version of their final design iteration, which optimised the performance of each of their designs to bring them closer to the 'Net Zero carbon' goal.

2.5. Feasibility Vetting

The 14 weeklong studio sessions in each IDS were intended to be dynamic, creative, exploratory environments. Emphasis was put on pushing boundaries toward zero energy buildings, and challenging current thinking. As such, not all ideas produced were expected to be immediately usable. In order to complement the exploration during the studios, further feasibility work with the consultants and client occurred for each studio, to establish the ideas worth carrying forward. Successful ideas were developed to concept level, providing the client with the opportunity to take them further into detailed design and implementation should they wish to do so.

The participating Engineers in each IDS were contracted to carry the design ideas further to investigate their feasibility in a practical sense. The process of assessing the various design outcomes was known as feasibility vetting and generally culminated in the production of a feasibility vetting report for each studio.

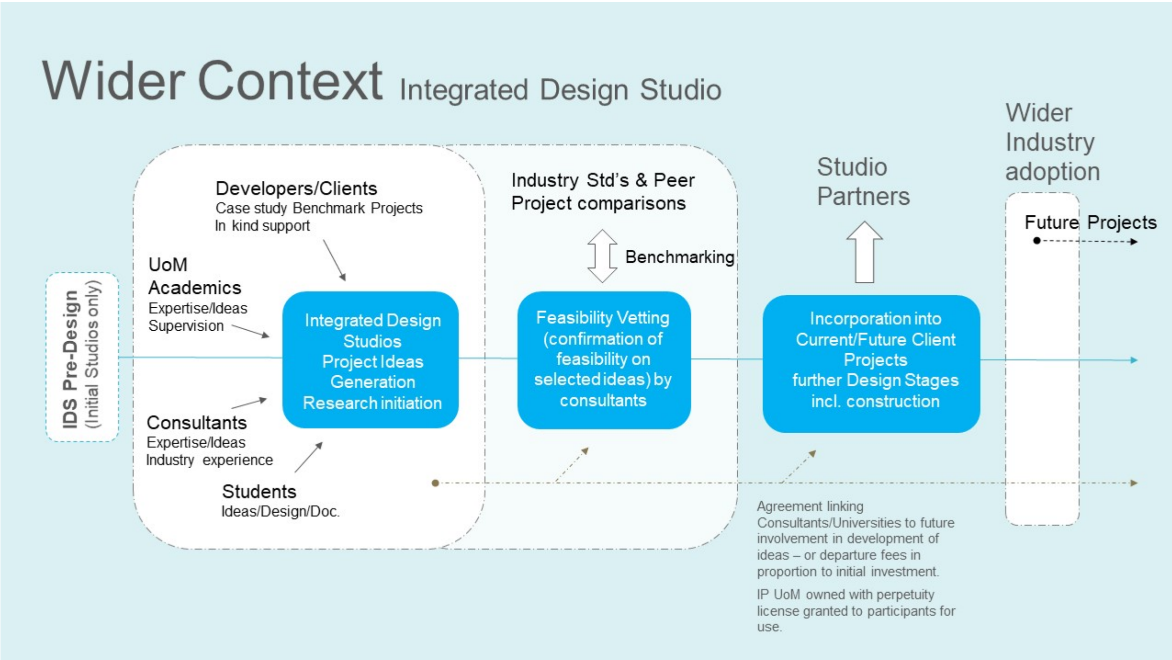

Figure 2--4 Describing the wider context of the IDS studio setup

3. OUTCOMES PART 1: INTEGRATED DESIGN LEARNINGS

The broad array of Integrated Design Studios delivered an array of insights over the duration of two and a half years. With the key findings related to Zero Carbon design addressed in the Carbon Catalogue section of this report, this discussion centres on the learnings from the studios in relation to implementing Integrated Design. It addresses practical takeaways and specific recommendations for Architect/Engineer collaboration in practice.

All parties participating in individual IDS studios were asked to reflect on their experience at the end of the studio experience. The resulting feedback offered in-depth insights on the co-design process experienced by the students (via a questionnaire), the tutors, the client, and the industry consultants (via individual interviews conducted online). Several key themes were identified by the participants in relation to factors that support integrated design processes. Some of these are studio specific, but others are common to both the studio setting and the industry context. Many of the interviewees identified the importance of selecting the right people as part of the integrated design team.

3.1. The client plays a major role in allowing Integrated Design to unfold

Client impact on Integrated design starts with project procurement and the generation of the brief, it also extends to the way tasks by individual contributors are assessed.

Interviews with project participants point towards the benefits for clients to understand the intricacies of developing a brief that allows their project participants to maximise the benefits of collaboration. This is not always a given. Stakeholder feedback suggests that on some IDS, the nature of the client brief changed, depending on the intended audience; goals often get divided into profession-specific deliverables, with a lack of common goals defined that cut across disciplines. Some studio leaders experienced challenges in getting students to focus on activities outside of their immediate deliverable scope (i.e. assessment scope). This finding translates equally to practice, where tight project budgets and time-constraints pushes professionals to only work to immediate deliverables.

In contrast to the above scenario, the flexibility provided in the IDS, aimed to allow students 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 who received additional education (even at a basic level) of other disciplines could participate actively in interdisciplinary discussions, having a less siloed focus on design. In this context, it proved to be beneficial for experienced IDS practitioners to develop and implement staged training/emersion for less experienced colleagues.

It was observed on several IDS how feedback mechanisms and interactions between clients, consultants, academics, and students throughout decision points during semester formed an important for the success of the project.

3.2. Balancing/integrating architectural and engineering input

When considering the key aspects of balancing architectural and engineering output, IDS participants were unified in their identification that central to critical decision-making in a studio about sustainable built outcomes was the need for all students to have a good understanding of fundamental climate analysis and passive design. As one of the consultants noted, ‘everything leads from there…’. This was a challenge, as initially, many of the architectural designs did not provide substantial evidence of a knowledge of building science, in particular the properties of materials, and how the selection of materials influences internal heat gains and hence the cooling required to be met by a HVAC system.

In this context, a commonly identified aspect was the need to help the architecture students to reach a point where they were able to use the engineering information as a toolkit for thinking differently about the design, rather than becoming fixated on overtly applying particular engineering ideas to a pre-considered design. The IDS investigations unveiled that it helps to tailor the Integrated Design approach and the associated strategy for collaboration in consideration of the different project stages.

The process of integrated design was described by the various consultants and studio leaders as one in which the participants work in a coordinated and complementary manner towards common goals, with an inherent understanding of the roles and responsibilities of other disciplines. Acknowledging that integrated design is iterative and ensuring that the consultants and the client understand that and are willing to go on the slightly unknown journey, was identified as important for the success of integrated design projects. The articulation of a 'whole of project' vision and engaging participants in this vision is a key to successful integrated design. Reframing projects as design elements to be integrated enabled the 'whole of project vision' to be articulated and intelligible at varying levels by students and with varying degrees of success

That said, several studios also explored the benefits of 'extreme design' where project participants would first seek solutions only related to their own domain, which afforded designers an opportunity to see the impact of optimising engineering aspects over the architecture and vice versa. The need for balance was readily taken on board by some students together with the need to prioritise key design elements as part of the integrated process; however, several students struggled to bring multiple aspects into play. Students were encouraged to find creative ways of 'connecting' these elements to produce inspired integrated responses. Not all students grasped integration at this elemental level although some students responded with notable clarity in arriving at a design proposition.

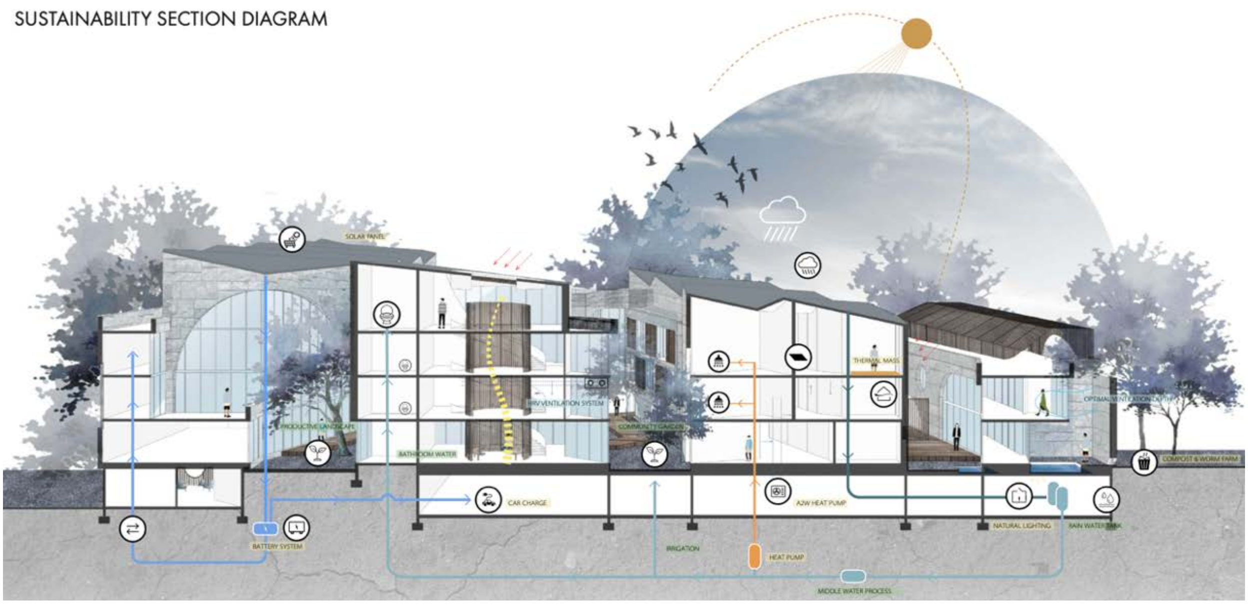

Figure 3--1 Exemplar Sustainability Section Diagram

3.3. Performance Benchmarking, Decision-making and measurements of success

The design process plays out differently for each project. Some IDS studios participants suggested staging the IDS with milestones and firm expectations; however, this may sway the goal toward defined deliverables and a conventional process. Ideally integrated design will evolve naturally. Triggers could be inserted at different points to re-focus designers. Suggestions included 'proposition' and 'response' games that can engage participants in collaborative and responsive behaviours. Other triggers relate to the introduction of specific qualitative and quantitative benchmarks to allow students to understand the impact of their design decision on the overall carbon performance of their projects. One such trigger was the introduction of computational tools to help quantify environmental design solutions (Passive Haus or otherwise) via parametric means. Another approach was the use of a decision matrix to establish rankings of different environmental solutions against predefined benchmarks.

It emerged during the studios, that some Architecture students (or those in closely related fields) perceived certain tasks involving energy-related considerations exceedingly difficult to tackle. The above triggers helped them to establish a different mindset on how to pursue Zero Carbon strategies.

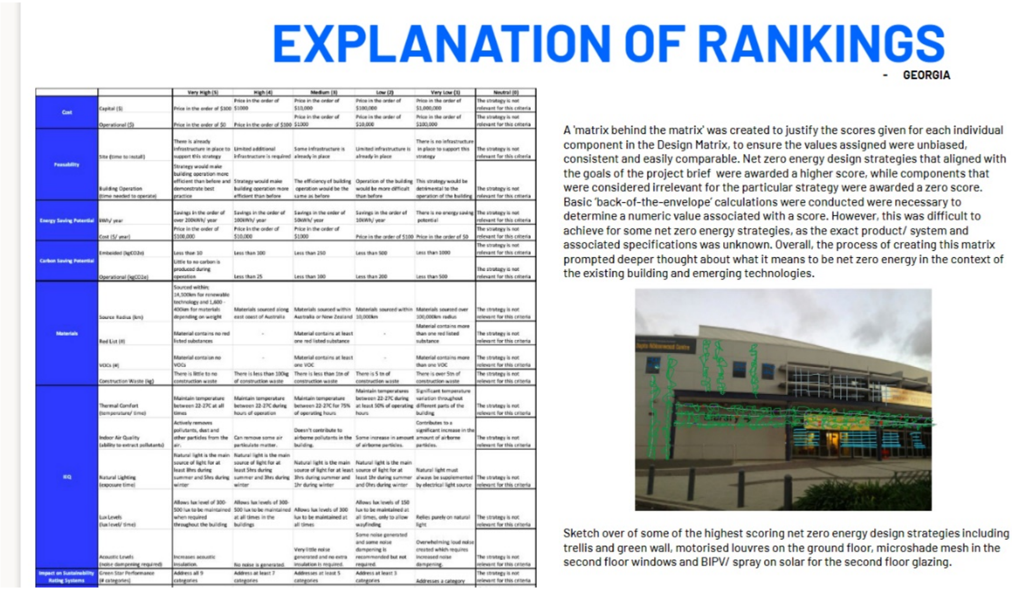

Figure 3-2 Exemplar Sustainability Matrix for a Community Centre (UoW)

3.4. Challenging existing attitudes towards design authorship

It was observed that Cross-disciplinary engagement cannot be forced upon participants. It needs to be facilitated and curated, to then occur intuitively/unconsciously within the same cohort. Engineer/architect co-ownership can readily arise from recently shared challenges that re-emerge; and engineering/architecture discussion is more illuminating when accompanied by sketches, illustrations, and joint benchmarks that cross all boundaries. Projects can comprise grand gestures as well as many small moments that can be capitalised on, and trigger opportunities for co-ownership that may seed co-authorship. Experiencing this aspect of the integrated design process may be more important than the outcomes

Current design paradigms often place engineering as following architecture in the design process. This encourages a consulting type approach to the engineering where engineers are asked to comment on preformed ideas. Design integration can occur in this model, however to a reduced potential with the initial ideation missing ideas founded in engineering aspects of the project. Early studios found this consulting model difficult to break free from. Close attention was paid in this studio to create a mindset of 'design co-authorship' in all participants (engineers and architects alike).

At times students struggled to move away from early architectural ideas unless the right questions got asked; however, the state of 'flux' of many proposals hindered questions and critiquing. This "chicken and egg' scenario was noted by several participants and is an important point to keep in mind for design co-authorship and integrated design overall.

3.5. Integrated Design needs active curation

The presence of a ‘third party’ studio leader in the integrated design studios highlighted the benefits such a role has to offer integrated design as a process. Designers (students and consultants alike), tended to let the focus of the design task at hand dominate their problem-solving perspectives. The role of the studio leader was able to maintain a big picture dispassionate view of the design direction and degree of success in meeting the established high-level goals. In this capacity the studio leader (or integrated design facilitator), was able to curate the process towards the desired ends.

As a result, there was agreement that the integrated design process benefits greatly from third party curation. In the absence of such a role this task typically falls to members of the design team which is not ideal as it is difficult to pull back and appreciate overall directions, design balance, and outcome success.

From an engineering viewpoint opportunity was identified for participating more actively in the curation of the integrated design process by fostering multidisciplinary thinking within teams and to establish processes that empower anyone from any discipline to ask the client why, to question the brief and to challenge the vision to come to a more widely considered final design.

The constraints to integrated design were seen as largely relating to traditional professional fee allocation and available time budgets for consultants to undertake their scopes of work. Design thinking is often built into architectural processes, whereas engineering processes revolve around assessing a provided design, so the processes and time allocation are not adequately aligned.

Conservative, low risk models of insurance for engineers was also identified as a constraint, with overdesign for safety factors potentially hindering the ability to design something more adventurous.

One of the clients noted that budgets do not necessarily match an integrated design view. Construction budgets are set to get the design built. They do not allow the timeframe, nor the budgetary consideration for those things that reduce long-term costs.

3.6. Proposing the role of ‘Design Integrators’ on projects

As highlighted in the previous section, active curation of the collaborative process among project stakeholders is an essential factor for success. At the start of a project collaborators at times do not yet fully understand how to engage with others via an integrated design process; they tend to focus on their immediate individual deliverables. Some collaborators feel pushed to revert to the workflow they were used to from prior projects, in particular if tight deadlines and financial risk pressures them to generate output in a short amount of time. With bespoke delivery targets and contractual obligations, joint goals can easily be side-lined. The IDS experience highlights the benefits of third-party curation via an agent who actively promotes integrated design approaches. This agent helps to liaise and balance between individuals and their targets, to establish a collective understanding of overarching goals that promote zero carbon outcomes. It is relevant for those in that role to be able to understand the key deliverables of others involved, and to be able to tie them to the bigger picture for co-design.

The role of the ‘Design Integrator’ could become an essential agent on medium-to-large-scale projects with a high level of complexity and input required from various stakeholders. Those holding these roles could work alongside the project manager with the task to assist in introducing decarbonisation targets as part of the briefing and tendering process, to then assist in guiding and monitoring supply-chain input during design and construction. The role could be tied to the role of Sustainability Manager with good oversight over zero carbon targets both for design (e.g. Green Star), or operation (such as ASHRAE), and expand from a sustainability focus into other areas benefitting design integration.

3.7. Digital Technology as an enabler for Integrated Design

Prioritising the key aspects of the design that can define a unique outcome remained a challenge for some IDS participants. The use of digital environmental analysis tools such as PHPP –Passive House Planning Package energy modelling software, allowed some students to enhance, and underpin their understanding of how buildings interact with their environment at multiple levels. In addition, there exists a demonstrated capability for computational analysis and parametric design to inform material selections that impact on the energy performance goals on a number of project types investigated. These digital tools allowed students to quickly compare several options of their design hand in hand with the associated environmental impact.

Optioneering via parametric means as an approach to optimise building performance allowed designers to better understand the relationship between good design and performance, inform their understanding of building systems and the environment, and broaden their own perspective in a way that will support better integration of design inputs.

3.8. Contract Procurement methods have a major impact on ID to unfold

Investigations on several IDS highlight that there is a strong argument for including construction (together with architecture and engineering) at the concept and feasibility stage (e.g. through alternative procurement methods such as very early contractor involvement). 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. The overall goal is to ensure cost-effective value that aligns the design to achieving the best possible outcome for the client. Collaborative contracting facilitates integrated whole-life delivery solutions, and it is suitable for contracts extending into the operational phase of projects. One of the most distinguishing features of the above collaborative contract models is that they prioritise values shared performance over individual performance.

The Integrated Design approach, incorporating client, architecture, engineering and construction management, can best be supported in industry through an Integrated Project Delivery procurement model. This procurement model also addresses some of the issues raised by participants in several IDS, perhaps suggesting that future IDS activities involving universities, clients and consultants could mimic such an alliance contract.

Clients will possibly perceive collaborative contracting approaches as a potential risk. Conventional competitive tendering might initially promise to offer ‘the best bang for your buck’ when it comes to their capital expenditure on projects. This is where government regulations and incentives are required to benefit those who can demonstrate better carbon performance of their projects in operation (ultimately reducing Total Cost of Ownership via lower energy bills. In order to move towards a Zero Carbon future, more education is needed to help make co-design become the mainstream approach embraced by all.

3.9. Making Integrated Design a mainstream approach

In a contemporary project setting in practice, targets for individual contributors are frequently clearly defined with tight project deadlines and submission protocols governing project progression throughout various project stages. Conventional contractual obligations introduce risks to project participants who explore new pathways for collaboration and the mindset of most collaborators therefore typically relates to focusing on their immediate individual deliverables first. In a linear workflow where one party develops an idea for the other party to then continue working on to resolve any issues, this approach has worked more or less over the past few decades. This workflow is not sufficient for addressing Zero Carbon goals, where frequent iterative design processes require expert input from various professionals in short intervals, connecting different datasets for rapid evaluation. Built environment professionals need to embrace a new paradigm for collaboration that prioritises common, overarching goals over individual deliverables and change their behaviour to facilitate design integration.

Willingness and positive attitude of professionals is not enough though. As described in this report, changes to contractual frameworks need to be enacted where co-design gets incentivised and actively curated by the client. This change towards collaborative contracting (or Integrated Project Delivery) needs to go hand in hand with the re-articulation of goals in the brief, as well as a change in how collaborators get procured in the first place.

3.10. Communicating the benefits of early stage integrated design

Responses from all IDS participants (both academic and industry) point towards the benefits of design integration early on. One of the key problems identified within the activity stream was a tendency towards a 'linear design' mentality among collaborators. In other words: the expectation of architects to develop their ideal in isolation to then pass on their designs to the engineers. Those would then verify and advance the design proposal via empathetic engineering that simply served to confirm or reject the architects' ideas.

When it comes to tackling Zero Carbon design, this approach is nonsensical. Many fundamental decisions early on have major impact on the performance of the final design. In a quest for carbon reduction involving embodied energy and operational energy, different options need to be evaluated by balancing functional, aesthetic and environmental considerations when the project's geometry is not yet locked in.

Such an endeavour cannot be realised via a linear, sequential design process. It requires co-design among collaborators, where the quest for solutions is iterative, particularly in the early stages. Only by stating key joint goals that include environmental targets and by allowing designers to jointly explore decisions that have a major influence on achieving these targets can the potential for integrated solutions be maximised. In that sense, project procurement and adequate briefing lay the foundations for Integrated Design to unfold, and the client plays an important role as facilitator.

Communicating the benefits of early stage integrated design isn't enough. Clients need to actively address the reasons why individual project parties tend to focus on individual, rather than joint goals, by introducing qualitative targets to be met as a team (rather than simply focusing on individual outputs per discipline). Project participants then require incentives to stray from their 'Business as Usual' approach to balance out the risks associated with greater dependency on others to meet certain targets.

3.11. Improving developer and building owner decision making capabilities

The investigation of collaborative design settings on multiple studios run under the IDS activity stream clearly point towards substantial benefits of early adoption of Integrated Design principles for all project participants. Co-design processes not only strengthen the information flow across supply chain members, but the resulting joint effort also equally benefits clients and developers who receive a higher quality asset where sustainability and zero Net Carbon outcomes can intrinsically get tied to a project's design. The investigation of novel technologies undertaken by the aspiring graduates (and supported by industry experts), highlight in great detail the mechanisms for carbon reduction on projects, hand in hand with a reduction of energy needs. Both active and passive measures demonstrated clear energy demand reduction achieved embedded and operational energy of different project types. For most of the project types investigated, the savings range somewhere from 30-40% all the way to excess energy supply via renewables (with PV rooftop solutions being the most common example). The only instance where the proposed measures had no major impact on the energy needs of a type were data centres which have a disproportionally high energy demand due to their particular function. Results showcased in the IDS Carbon Catalogue illustrated different pathways for carbon reduction on 8 different building types. As much as some examples are highly context dependent, they nevertheless offer a great reference for decision making by owners and developers when it comes to zero carbon approaches.

Workflows that include the introduction of a 'decision matrix' or computational analysis in close-to real time, offer greater certainty about project outcomes. The earlier such feedback can be provided, the greater the opportunity for clients and developers to take necessary steps to adjust their project brief.

In addition, the data stemming from the exemplar projects forming part of the carbon catalogue offer high-level insights into the carbon-reduction possibilities and measures to be considered by designers and contractors. This informs owner decision-making either directly in case their project typology aligns with one of those presented here, or in for instances where the IDS methodology for analysis can get applied to derive benchmark data on project types that differ from those included in this summary document.

3.12. Updating Integrated Design Principles based on IDS feedback

Going through the process of delivering 14 Integrated Design Studios within the IDS activity stream has offered the participating academic institutions valuable insights of how the collaborative work environment needs to be set up to maximise the potential for Net Zero Energy design. Next to informing the Carbon Catalogue published as a separate document, the findings also reinforce points made by a prior study undertaken at the Rocky Mountain Institute. Their '*Factor 10 Engineering Design Principles'* were initially designed to help change engineering design to achieve radical energy efficiency (in the order of a factor of 10). Here they get reinterpreted in the light of the findings from the IDS activity stream.

Table 3-1 Integrated Design Principles per Design Phase

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.
	Aim to include specific goals and targets that cut across disciplinary boundaries as part of your project briefing. Ensure these are clearly communicated as part of the project tender. 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. The US IPD strategy calls this phase 'Criteria Design' where ideas often emerge jointly in workshops or another co-design setting.

	Implement an Integrated Project Delivery contract that rewards teams for meeting KPIs and providing savings, rather than producing documents. The earlier stakeholders get to work together, the higher the chances for NZE goals to get addressed holistically.
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? Give collaborators the time to understand the issues and explore alternatives instead of having to chase from one submission deadline to the other. Once individuals are in 'production mode' they will not likely engage in co-design or harness the feedback offered by others. Consider the use of technology to evaluate options digitally in close to real time, and/or develop a decision support matrix to channel the efforts of the collaborative team.
	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). Ensure that the whole-of-life approach is understood by all collaborators. This will also require for each participant to emphasise with the goals and concerns of other collaborators.
	Establish BAU benchmarks for the KPIs, and whole-system, lifecycle value of savings (e.g. in kWh, kW, CO2e, HVAC kVa, PV kWp etc). Set these benchmarks up in a tabular/matrix form for ease of comparison of different options. This will give designers who may not necessarily understand the full depth of performance data at least an understanding of general trends and consequence of choices.
	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 in isolation, basing ideas on a familiar or previous design, conventional assumptions, or methods. Start afresh with no preconceptions and allow others to influence your thinking.
	Question all rules of thumb and assumptions. Dare tackling a design problem, even if it is not yet 100% defined. Don't revert to a sympathetic engineering process where engineering is merely used to 'make the architects' design happen'. 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. Seek involvement from a third party (e.g. a Design Integration specialist) to help with prioritising your approach and to streamline the Integrated Design process.
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.

4. OUTCOMES PART 2: THE CARBON CATALOGUE

This catalogue compares the potential to achieve net zero for a select range of building typologies explored in the IDS studios in various locations/climates. The typologies are neither exhaustive, nor are the results representative sector-wide for all climate zones. The results nevertheless offer relevant insights on how active and passive interventions allowed designers to impact energy use intensity (EUI) on the projects investigated.

4.1. Framework Scope and Methodology

This assessment summarises the potential to achieve net zero for a select range of building typologies drawn from the studio experimentation and exploration across three universities in various locations and climates. All 14 building designs have been investigated in detail in vetting reports[1] specific to the design brief explored in the studio. Although the typologies explored in these studios is not exhaustive, analysis of the studio prototypes results provides an opportunity to explore patterns and themes for future technology development.

4.1.1. Net Zero

In this analysis, net zero is defined in alignment with the International Living Future Institute's (ILFI) Zero Energy Standard where, "One hundred percent of the building's energy needs on a net annual basis must be supplied by on-site renewable energy. No combustion is allowed."[2] In the assessment of building typologies, this is captured in 'net zero energy' analysis of the design schemes' passive and active interventions. Further, consideration of embodied global warming potential, as measured in carbon dioxide equivalent emissions, and holistic sustainability outcomes is also discussed as non-monetary benefits of sustainable design interventions.

4.1.2. Categories

The range of building typologies considered in this study is determined based on the i-Hub IDS program schedule of studios. Fourteen studios were undertaken across nine building typologies. The building typology prototypes have then been categorised for this net zero energy analysis by the scale and function of their construction and operation into three groupings:

- **Simple** typologies include those that have a simple construction and function requirements, i.e. minimal function-specific plant or equipment that consumes a significant quantity of energy on an annual basis.
- **Complex** typologies include those that have a complex functional requirement on building construction and high demand for operational function. This category may also consider buildings that are 3 or more stories high such that the roof area available for solar PV systems compared to the total gross floor area is limited.
- **Specialist construction and function** typologies include those that have very high energy demand from equipment specific to the building's function and may have a complex-built form requirement.

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[1] All vetting reports www.ihub.org.au/the-knowledge-hub/

[2] https://living-future.org/zero-energy/certification/

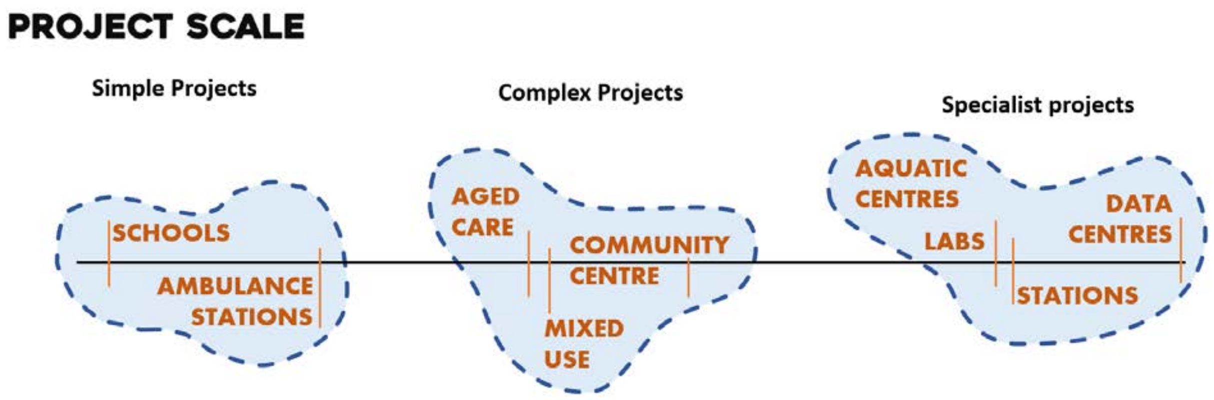

Figure 4-1 Project scale spectrum

4.1.3.Typologies

Table 4-1 Summary of typologies in study scope

Category	Typology	# Studios completed
Simple	School	2
	Ambulance Station	1
Complex	Aged Care	2
	Mixed-use	4
	Community Centre (Retrofit)	1
Specialist	Data Centre	1
	Aquatic Centre	1
	Transport Building	1
	Laboratory	1

4.1.4.Design Interventions

The design interventions and elements integrated by the studio participants have been categorised under the following categories for the purpose of comparison of the prototype typologies net zero potential:

Table 4-2 Summary of design interventions in study scope

Building Footprint	Intervention	Scope of Assessment
Energy use	Building fabric	Quantified for Net Zero (Energy)
	Passive design	
	Active design (HVAC performance)	
Energy source	On-site energy generation	
	On-site energy storage	
Embodied carbon	Materials	Consideration only Net Zero (Carbon)
	Construction methods	
Holistic sustainability	Water	Consideration only Environmental impact
	Waste	
	Nature	
	Health	Consideration only Occupant impact

4.2. Pathway to net zero

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

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

4.3. Functional unit and performance parameters

The comparison of net zero potential for different typologies is enabled by clear functional unit and performance parameters:

- Global warming potential is measured in kilograms of carbon dioxide equivalent (kg CO_2-e)
- Energy consumption and generation are measured in kilowatt-hours per year (kWh/year)
- Occupied building area is measured in Gross Floor Area (GFA) (m^2)
- Annual operational energy consumption as EUI is measured in kilowatt-hours per GFA per year ($kWh/m^2/year$)

4.4. Limitations

The scope of this study has been set to best utilize the value of the prototype data created in the i-Hub integrated design studios. The explorations of the studios have value as a microcosm of free and experimental prototype design however it is important to understand the context and associated constraints of this program. The interpretation of net zero potential for the various prototypes acknowledges this.

The building designs were primarily developed by university students at the undergraduate and master's level, undertaking architecture or engineering degrees. As a result, the extent, refinement, and innovation of the technologies explored are limited by the level of knowledge students entered the studios with.

The vetting reports collated and compared in this study were undertaken by a range of industry professionals, across engineering, environmentally sustainable design (ESD) and architecture. Therefore, there is variation in the scope and detail included in the reports for different buildings.

The typologies presented in this comparison are not exhaustive and the number of studios and schemes developed for each typology varies based on the IDS program schedule. Further, each studio focused on a specific location and associated climate. Therefore, the conclusions of the technology potential are limited in application to the location in Australia where the studio brief was established.

4.5. Results

4.5.1. Simple

The net zero study for simple typologies, ambulance stations and schools, is summarised below, demonstrating the typical BAU EUI, the impact of energy use reduction through passive strategies and active technologies and the potential energy generation on-site. This summary demonstrates that both simple typologies can achieve significant energy use reduction and energy generation in excess of demand, therefore achieving net zero energy. This is implemented through the interventions listed which are consistently readily available and market established.

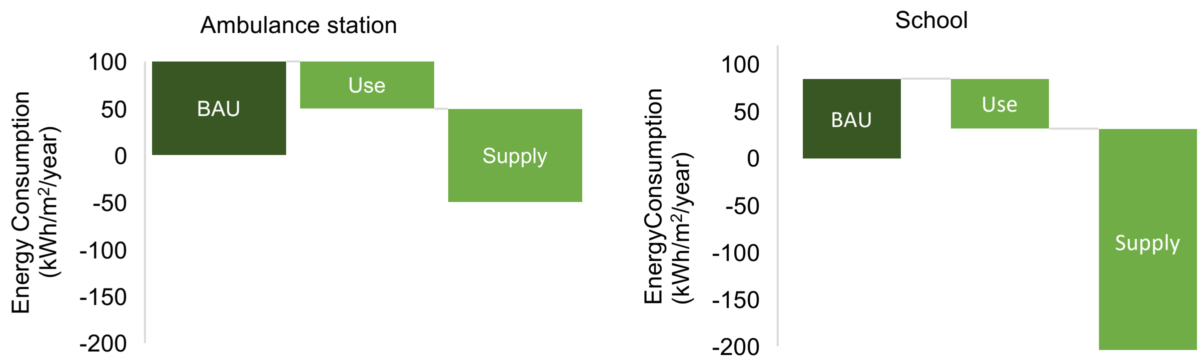

Figure 4--2 Summary of simple typology energy consumption and net zero pathways for (a) Ambulance Station and (b) School

Table 4-3 Summary of simple Typology design interventions

	Intervention		Ambulance Station		School
Energy use	Building fabric	√	Passive House standards for detailing and air-tightness	√	Increase insulation performance and airtightness
	Passive design	√	Optimized building orientation and façade Cross-ventilation Good daylight	√	Shading devices
	HVAC performance	√	Ground source heat-pump Heat recovery ventilation	√	Heat recovery ventilation
Energy supply	On-site energy generation	√	Rooftop solar photovoltaic system	√	Rooftop solar photovoltaic system
	On-site energy storage	√	Battery		

4.5.1.1. Ambulance Stations

The ambulance station typology was investigated in one studio, where designers explored architectural precedent, engineering technologies, Rhino modelling, the Passive House Planning Package (PHPP) and eTool LCD software to develop net zero buildings for Ambulance Victoria. The typology brief was characterized by the functional requirements of an ambulance station in Melbourne, Victoria, assuming an average GFA of 300m^2, providing functions similar to a residential home with additional medical cold storage and vehicle storage space. Further, the brief promoted designs prioritising occupant health and well-being and maximising life-cycle savings.

Figure 4--3 Example of student design for Ambulance Station typology (UoM)

BAU ENERGY CONSUMPTION

The base case established for ambulance station typology[3] determined the range for BAU energy consumption based on client specific data inputted into a PHPP model. The BAU energy consumption was determined to be in the range of 40-120kWh/m^2/year, 100 kWh/m^2/year will be used as the conservative baseline for comparison in this study.

INITIATIVES

The initiatives implemented in the proposed ambulance station designs were generally market-available established technologies and strategies with a focus on passive strategies before active systems and services. The most significant initiatives were high performing building fabric, enhanced airtightness and passive solar design, as well as maximising rooftop solar PV system size.

NET ZERO POTENTIAL

Based on the design and modelling undertaken, there is net zero energy potential for ambulance stations. The implementation of passive strategies and active technologies achieved a 50% reduction in energy use. The modelled generation potential was 100% of the BAU EUI. A total reduction from BAU of 150% was achieved. This is a result of the operational function and construction scale of the typology such that net zero could be achieved through passive strategies and a PassiveHouse approach to building envelope detailing, without large investments or experimental technologies.

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[3] Atelier Ten www.ihub.org.au/the-knowledge-hub/

4.5.1.2. Schools

The school typology was investigated in two studios, where designers used architectural precedent, site visits, engineering technologies, Rhino modelling and the Sefaira analysis platform to develop net zero buildings for the ACT Government. The typology brief was characterized by the functional requirements of school buildings, considering primary and secondary (high) schools in Canberra, ACT with daytime function only and assuming an GFA for a classroom as 50-65m^2. There was specific interest from the client in indoor environmental quality and occupant productivity and well-being. Further, adaptive re-use and refurbishment was explored as well as demolition/construction.

Figure 4--4 Example of student design for school typology

BAU ENERGY CONSUMPTION

The base case established for the school typology was established separately[4] in the two studios completed. Based on research of industry benchmarks, the range of EUI was determined to be 75-95kWh/m^2/year. This benchmark is averaged to 85kWh/m^2/year for all school buildings, understanding that the EUI of primary and high school buildings with different functions, e.g. libraries, science labs and conventional classrooms, would vary.

INITIATIVES

The initiatives implemented in the proposed school designs were generally market-available established passive strategies and active technologies. This is a result of the operational function, the government client, and the scale of building construction where the site area is relatively large, and buildings are single or double story. Therefore, net zero could be achieved without large investments or experimental technologies. The most significant initiatives were efficient lighting, heat recovery ventilation and PassiveHouse-standard airtightness, as well as maximising roof-top solar PV system size.

[4] Arup www.ihub.org.au/the-knowledge-hub/
Jacobs www.ihub.org.au/the-knowledge-hub/

NET ZERO POTENTIAL

Based on the design and modelling undertaken, there is net zero energy potential for schools. The strategies and technologies explored achieved a 60% reduction in energy use. The modelled generation provided 280% of BAU EUI. A total reduction from BAU of 320% was achieved.

4.5.2.Complex construction and function

The net zero study for complex construction and function typologies, aged care, community centres (retrofit) and mixed use (low-rise community and mid-rise RAC), is summarised below. This summary demonstrates that although net zero energy was not achieved for most studios completed, significant reductions in grid energy consumption are possible. This was achieved through a range of interventions focused on passive design where possible and energy efficient systems and services in both new builds and retrofits with some on-site energy generation.

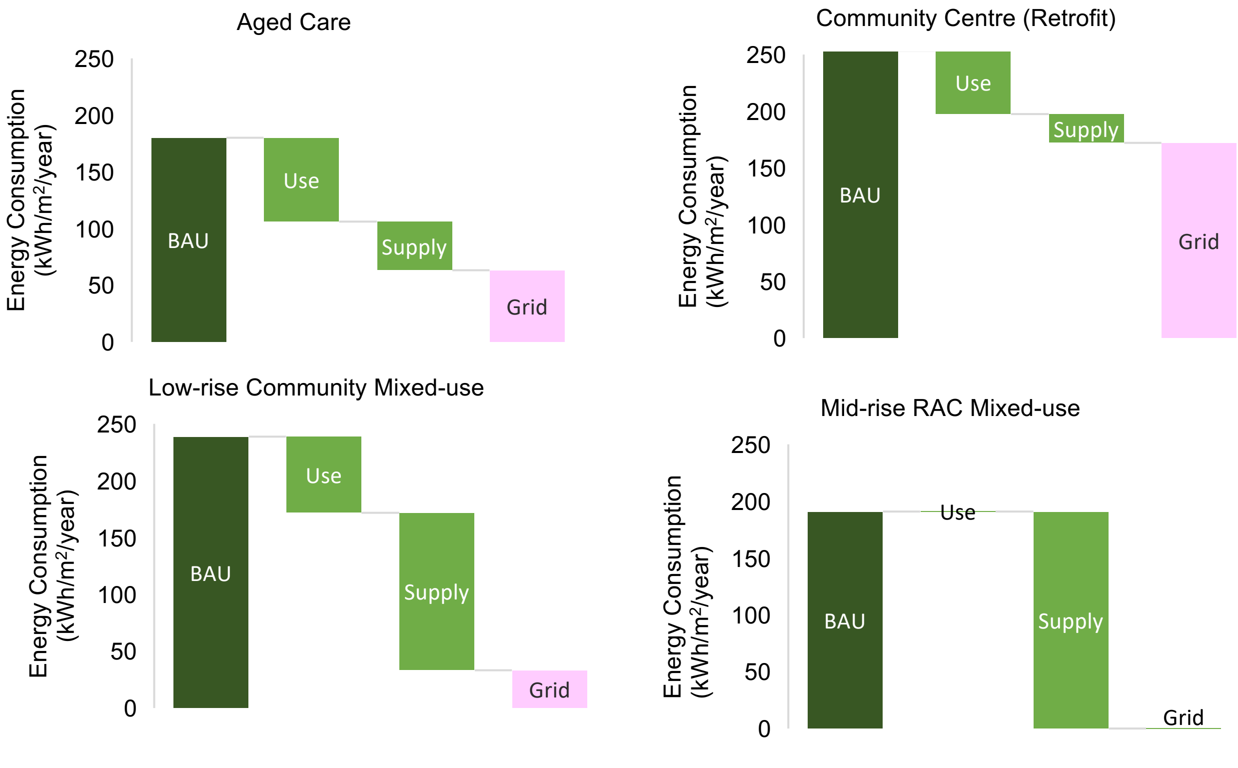

Figure 4--5 Summary of complex construction and function typology annual energy consumption and net zero pathways for (a) Aged Care and (b) Community Centre (Retrofit), (c) Low-rise Community Mixed-use, (d) Mid-rise RAC Mixed-use

Table 4-4 Summary of complex construction and function typology design interventions

	Intervention		Aged Care		Community Centre (Retrofit)		Mixed Use
Energy use	Building fabric	√	Passive House standards for detailing and air-tightness	√	Increase insulation performance and airtightness	√	Increase insulation and glazing performance Secondary roof for tropical climate
	Passive design	√	Optimized building orientation, massing and façade Cross-ventilation and stack ventilation Good daylight	√	Shading devices	√	Optimized building orientation, massing and façade Cross-ventilation and stack ventilation Good daylight
	HVAC performance	√	Ground source heat-pump Heat recovery ventilation Energy management	√	Heat recovery ventilation	√	Ground source heat-pump Heat recovery ventilation Energy management
Energy supply	On-site energy generation	√	Rooftop solar photovoltaic system	√	Rooftop solar photovoltaic system	√	Rooftop solar photovoltaic system Green roof enhanced solar
	On-site energy storage	√	Battery			√	Battery

4.5.2.1. Aged Care

The aged care typology was investigated in two studios, where designers used architectural precedent, site visit engineering technologies, Rhino modelling and Passive House Planning Package (PHPP) modelling to develop low energy buildings following their client briefs. The typology brief was characterized by the functional requirements of medium-rise aged care facilities, assuming 50m^2 GFA allocated per person for both private and public spaces. Further, there was a strong focus on occupant health and well-being. The two studios were based on southern coastal NSW and southern Victoria respectively.

Figure 4--6 Example of student design for aged care typology

BAU ENERGY CONSUMPTION

The base case established for the aged care typology was determined separately[5] in the two studios completed. Based on research of industry benchmarks, the range of EUI was determined to be 100-230kWh/m^2/year. The large range in EUI for this typology is a result of the variance in hospital equipment and plant potentially required for different aged care facilities.

INITIATIVES

The initiatives implemented in the proposed aged care designs were generally market-available established technologies and strategies. The most significant initiatives were passive design features, biophilic or architectural shading, heat recovery ventilation and maximising solar PV area.

NET ZERO POTENTIAL

Significant energy reductions are possible for this typology, however net zero is not achieved. The strategies and technologies explored achieved a 40% reduction in energy use. The solar PV generation offset a further 25% of the BAU energy consumption. A total reduction from BAU of 65% was achieved.

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[5] Arup, Stantec MIE Engineers and COX Architects www.ihub.org.au/the-knowledge-hub/
Atelier Ten www.ihub.org.au/the-knowledge-hub/

The full-time occupation and hospital level equipment and plant, as well as the multi-story building type, limit the potential for net zero energy to be achieved for this typology.

4.5.2.2. Community Centre (Retrofit)

The community centre (retrofit) typology was investigated in one studio, where designers used architectural precedent, engineering technologies, site visits, Sketchup modelling and analysis including SAM and OpenStudio to develop a retrofit strategy to support a low energy community centre for Wollongong City Council. The typology brief was characterized by a retrofit, rather than a new building, and specified reductions in operational energy and embodied carbon while fostering community wellbeing and comfort.

Figure 4--7 Example of student design for community centre (retrofit) typology

BAU ENERGY CONSUMPTION

The base case was established for the community centre typology in one studio based on site-specific historical metered data. The EUI was determined[6] to be approximately 250kWh/m^2/year. Note, this EUI is based on existing building performance rather than current industry benchmarks and influences the outcome of net zero comparison with other typologies.

INITIATIVES

The initiatives implemented in the proposed community centre retrofit designs were generally market-available established technologies and strategies. The most significant interventions were improvements to building envelope, passive cooling through biophilic shading, installation of mechanical ventilation with heat recovery and solar PV arrays.

NET ZERO POTENTIAL

Based on the design and modelling undertaken, the studio demonstrated up to 22% energy use reduction and a further 10% energy offset from on-site renewable (PV solar) energy generation. A total reduction from

[6] Arup, Stantec, MIE Engineers and COX Architects www.ihub.org.au/the-knowledge-hub/

BAU of 32% was achieved. This protype design is limited by the constraints of the existing building envelope and services as well as the client priorities for realistic implementation under financial constraints.

4.5.2.3. Mixed-use and/or Multi Purpose

The mixed-use and/or multi-purpose typology was investigated in four studios, two in Southern New South Wales (NSW) and two in Queensland (QLD), where designers used architectural precedent, engineering technologies, Rhino or Sketchup modelling and OpenStudio or EnergyPlus analysis to develop a scheme incorporating multiple building classes within one site. The typology briefs ranged between the studios but were generally characterized by the inclusion of multiple functions including commercial, retail, aged care and residential. The southern NSW studios focused on low-rise multi-purpose/mixed use with community function, where one studio used a brief for hybrid greenfield/refurbishment development, and the QLD studios focused on mid-rise mixed use with residential aged care (RAC) function. The briefs all specified reductions in operational energy and embodied carbon while fostering community wellbeing and comfort. There was some additional consideration for efficient and cost-effective construction management and contracting.

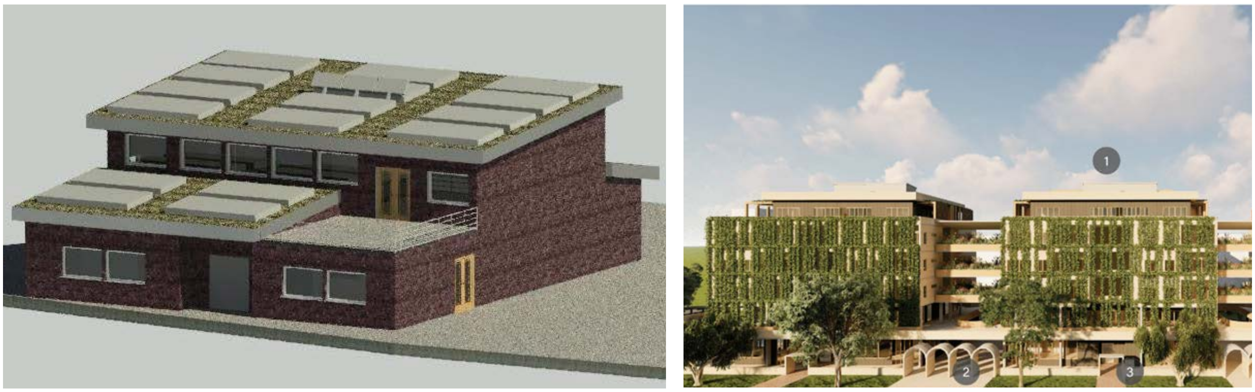

Figure 4--8 Example of student design for mixed-use typology (a) southern NSW, (b) QLD.

Because of the variation in brief for the mixed-use/multi-purpose typology, the summary of vetting analysis has been separated into (a) low-rise community and (b) mid-rise RAC.

BAU ENERGY CONSUMPTION

(a) The base case was established for the low-rise community mixed-use typology using industry data. The EUI was determined[7] to be approximately 240kWh/m^2/year.
(b) The base case was established for the mid-rise RAC mixed-use typology using industry data for aged care buildings. The EUI was determined[8] to be approximately 190kWh/m^2/year.

INITIATIVES

The initiatives implemented in the mixed-use building designs were a combination of market-available technologies and strategies and some exploration into ambitious and innovative solutions.

(a) The most significant interventions for the low-rise community mixed-use/multi-purpose typology were improvements to building envelope, natural ventilation, and solar PV arrays with some use of batteries.

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[7] Stantec, MIEngineers www.ihub.org.au/the-knowledge-hub/

[8] Stantec, JHA Engineers, Norman Disney Young/Tetra Tech, Hansen Yunken, The Built Environment Collective (BEC) www.ihub.org.au/the-knowledge-hub/

(b) The most significant interventions for the mid-rise RAC mixed-use/multi-purpose typology were improvements to building envelope including an innovative secondary roof, large amounts of biophilic shading, and solar PV arrays with some use of batteries.

NET ZERO POTENTIAL

Based on the design exploration and modelling undertaken, the studios demonstrated significant savings in energy use and generation. Due to the variability of this typology, it was challenging to quantify these savings in a comprehensive way.

(a) The low-rise community mixed-use/multi-purpose typology demonstrated more than 25%% energy use reduction and potential for up to 75% energy offset from on-site renewable (PV solar) energy generation. This accounts for the green field and the hybrid refurbishment/green field prototypes. A total reduction from BAU averaged at approximately 85%.
(b) The mid-rise RAC mixed-use/multi-purpose typology was unable to comprehensively quantify energy use reduction due to the highly variable loads of aged care and retail building classes. The studios assessed the potential for thermal load reductions based on the design interventions to be 15-30% but the total energy of the building could not be considered due to the potential for specialist equipment. The inclusion of significant on-site renewable (PV solar) energy generation offered the potential for 100% energy offset based on the BAU energy use assumptions. A total reduction from BAU of 100% was demonstrated.

4.5.3.Specialist Construction and Function

The net zero study for specialist typologies, aquatic centre, laboratory, data centre and transport building, is summarised below. This summary demonstrates that net zero energy is consistently not possible based on the operational function of large, specialised equipment. Although net zero was not achieved, significant reductions were demonstrated through the programs, when considering the high BAU EUI magnitude, this would have a significant impact on main grid consumption for a region.

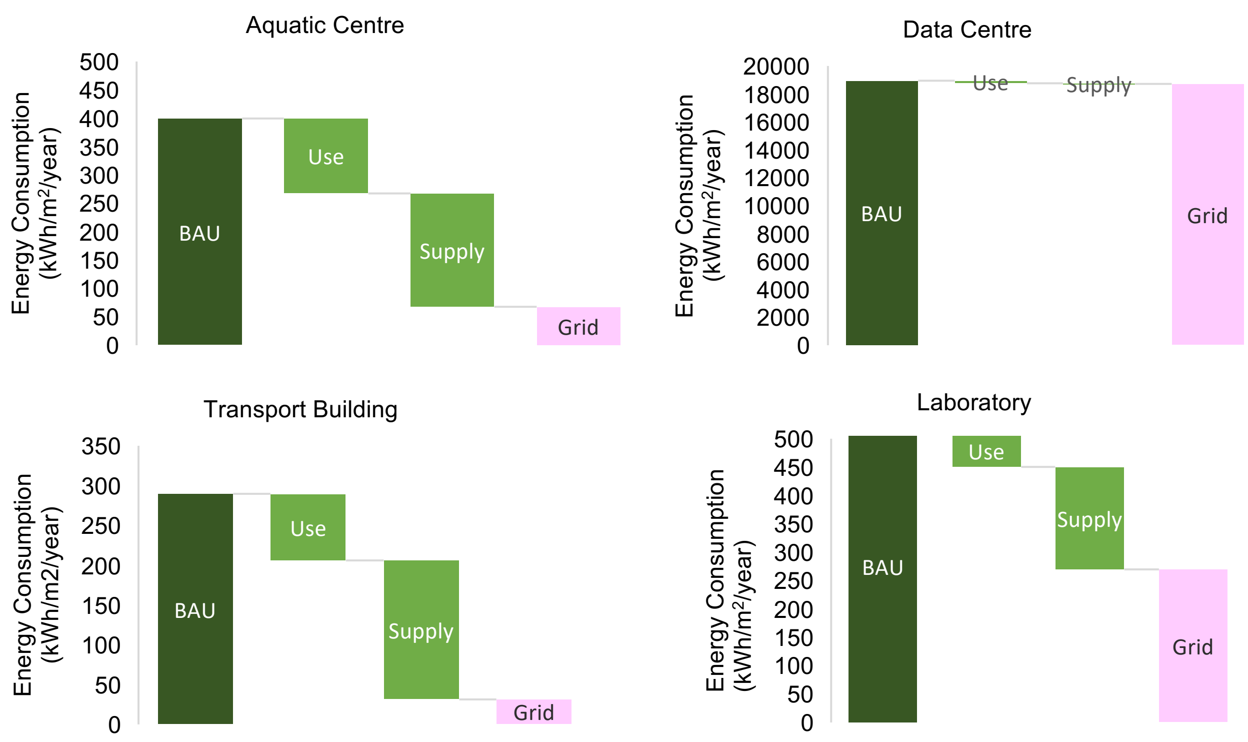

Figure 4--9 Summary of specialist construction and function typology annual energy consumption and net zero pathways for (a) Aquatic Centre, (b) Data Centre, (c) Transport Building and (d) Laboratory.

Table 4-5 Summary of specialist construction and function typology design interventions

	Intervention	Aquatic Centre	Data Centre	Transport Building	Laboratory
Energy use	Building fabric	√ Polycarbonate facade		√ Increase insulation and glazing performance	√ Increase insulation performance and airtightness
	Passive design	√ Optimized building orientation, massing and shading Cross-ventilation Good daylight	Energy monitoring and management	√ Optimized building orientation, massing and façade Cross-ventilation and Good daylight	√ Optimized building orientation, massing and façade Cross-ventilation and stack ventilation Good daylight
	HVAC performance	√ Passive solar water Ground source heat pump	√ (Efficient server equipment specification)	√ Ground source heat-pump Relaxed temperature set-points	√ Ground source heat-pump
Energy supply	On-site energy generation	√ Rooftop solar photovoltaic system Piezometric pads	√ Rooftop solar photovoltaic system Solar road system Omni-processor	√ Rooftop solar photovoltaic system Piezometric pads	√ Rooftop solar photovoltaic system
	On-site energy storage		√ Thermal energy (used off-site)	√ Battery	

4.5.3.1. Aquatic Centre

The aquatic centre typology was investigated in one studio, where designers used architectural precedent, engineering technologies and Rhino modelling and analysis to pursue a net zero aquatic centre building design in Melbourne, Victoria. The typology brief was characterised by the high operational requirements of an aquatic centre focussed on indoor air quality and thermal comfort with consideration for water-sensitive design.

Figure 4--10 Example of student design for aquatic centre typology (UoM)

BAU ENERGY CONSUMPTION

The base case established for the aquatic centre typology was determined[9] in the one studio completed. Based on industry benchmarks, the range of EUI for this typology is 300-500kWh/m^2/year. This BAU range accounts for significant variations in equipment efficiency and building envelope performance for different aquatic centre precedents. Therefore, an average was taken for this study.

INITIATIVES

The initiatives implemented in the proposed aquatic centre designs were a mix of market-available strategies and innovative technologies and materials. The most significant interventions were passive daylight and ventilation, solar heating of water and significant on-site energy generation including solar PV and innovative technologies, for example, piezometric energy generation.

NET ZERO POTENTIAL

Based on the analysis undertaken, there is potential to achieve significant energy reductions for aquatic centres based on energy use reductions and on-site energy generation, up to approximately 30% reduction in energy use from BAU and 50% of BAU energy consumption can be generated through on-site renewables. A total reduction from BAU of 80% was achieved. Although this typology has high energy demands, based on thermal comfort and indoor environmental quality, the characteristic built form, single

[9] WSP www.ihub.org.au/the-knowledge-hub/

story with a large roof area, provided the opportunity for significant solar PV arrays. Further, operational function is limited to daytime occupation, supporting good utilisation of passive design for daylight and ventilation.

4.5.3.2. Data Centre

The data centre typology was investigated in one studio, where designers used architectural precedent, engineering technologies and Rhino modelling and analysis to pursue a theoretical net zero 80MW data centre building design in Melbourne, Victoria, for the client, NEXT DC. The typology brief was characterised by the extremely high operational energy requirements of an 80MW data centre and the production of significant waste heat.

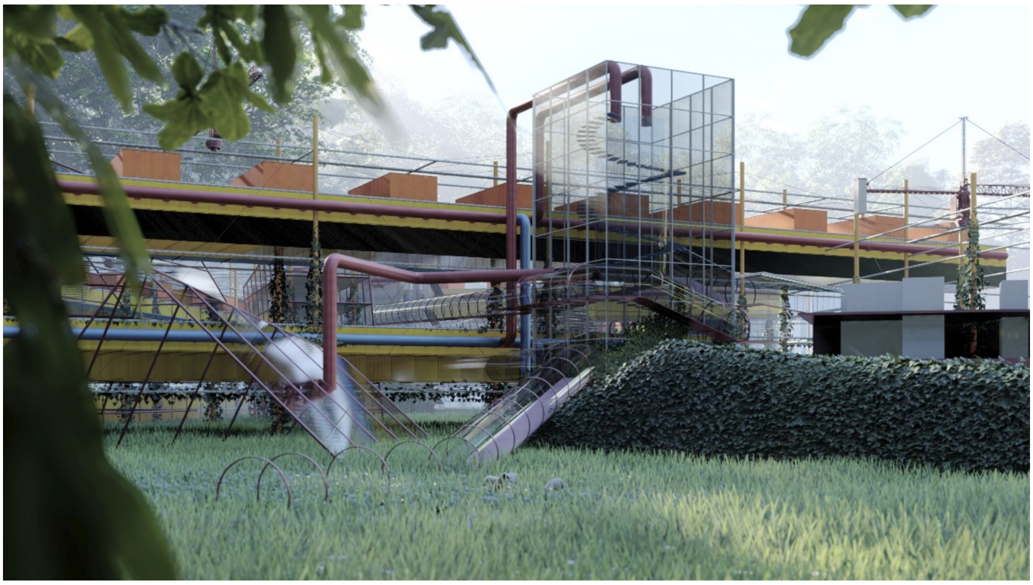

Figure 4--21 Example of student design for data centre typology

BAU ENERGY CONSUMPTION

The base case established for the data centre typology was determined[10] in the one studio completed. Based on the client brief, the EUI for this typology is 19,000 kWh/m^2/year. This BAU is representative of a multi-story 80MW data centre normalised for the average student design GFA of 48,000 m^2. This GFA includes space that is not specific to the functional brief, therefore, the EUI is not representative of all data centres.

INITIATIVES

The initiatives implemented in the proposed data centre designs were generally ambitious. using innovative energy generation technologies. This is a result of the typology function requiring high energy demand. The most significant initiatives are rooftop solar PV, a solar road, a waste to energy 'omniprocessor' and significant waste heat transfer off-site for the wider community. Improving the efficiency of server equipment is included but this technology was not explored in detail in the studio.

[10] Aurecon, www.ihub.org.au/the-knowledge-hub/

NET ZERO POTENTIAL

Based on the research and modelling undertaken, it is not possible to achieve net zero within the site boundary based on the extremely high energy demand of the typology. The schemes achieved less than 1% reduction in BAU energy demand from energy use and generation interventions. However, when the scope of the project is broadened to the wider community, there is a significant opportunity to transfer the waste heat from a data centre to other buildings, for example to a green house or aquatic centre, which could result in a significant reduction in energy use for the community.

4.5.3.3. Transport building

The transport building typology was investigated in one studio, where designers used architectural precedent, engineering technologies and analysis tools including eQuest and SAM to develop a net zero train station at a level crossing removal project (LXRP) in Melbourne, Victoria. The typology brief was characterised by the specialised functional requirements of a train station, with a focus on community value and social sustainability. The energy requirements for train operation and signalling are not included in the scope of the design.

Figure 4--32 Example of student design for transport building typology

BAU ENERGY CONSUMPTION

The base case established for the transport building typology was determined[11] in the one studio completed. Based on the station size, the EUI for this typology is 290kWh/m^2/year. This BAU is representative of a train station with trenched platform level with a total GFA of 1,400 m^2. The design GFA includes space that is not specific to the functional brief, including significant retail, therefore, the EUI is not representative of all transport buildings. Note, the scope of this study excludes rail operation and signalling.

INITIATIVES

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[11] 100% Outcomes Report www.ihub.org.au/the-knowledge-hub/

The initiatives implemented in the proposed transport building designs included some innovative energy generation technologies to respond to the 24/7 energy demand including the challenge of maintaining thermal comfort in unsealed spaces. The most significant initiatives for energy use reduction were industry-standard building envelope improvements and passive strategies such as good daylight, as well as efficient lighting and HVAC, including a heat pump. Energy can be generated on-site using significant rooftop solar PV across the large roof. Piezometric energy generation was assessed but had a <1% contribution in offsetting BAU energy use.

NET ZERO POTENTIAL

Based on the design and modelling undertaken, it is not possible to achieve net zero within the site boundary based on high energy demand of the additional retail and large station size and the designer focus on community and social sustainability rather than energy efficiency. Based on the analysis undertaken, there is potential to achieve approximately 28% reduction in energy use from BAU and 60% of BAU energy consumption can be generated through on-site renewables. A total reduction from BAU of approximately 88% was achieved. The 24/7 occupation and unsealed building envelope contribute to the high energy demand. If the scope of energy generation was broadened to the broader transport system, including the trains, there is potential to harness additional kinetic energy to power the station. This would require significant innovations in future technologies.

4.5.3.4. Laboratory

The data centre typology was investigated in one studio, where designers used architectural precedent, engineering technologies and Rhino modelling and analysis to pursue a theoretical net zero laboratory building design in Melbourne, Victoria for the client, CSIRO. The typology brief was characterised by the operational function of a laboratory, split into office-type spaces and PC2 ‘wet-lab’ spaces with specialised equipment.

Figure 4--43 Example of student design for laboratory typology

BAU ENERGY CONSUMPTION

The base case established for the laboratory typology was determined[12] in the one studio completed. Based on industry precedent, the range of EUI for this typology is 270-830 kWh/m^2/year. The large range for this baseline is due to the variation in specialised equipment used in laboratories, therefore, the average value of this range has been used in the net zero pathway.

INITIATIVES

The initiatives implemented in the proposed laboratory designs included both market-ready strategies and innovative technologies. This is a result of the characteristic challenges of the specialised equipment and function requirements, including limits of vibration, lighting and ventilation, as set out in the design brief. The most significant initiatives are passive design strategies for office areas, natural ventilation or ground source heat pumps and rooftop solar PV. The energy use reduction strategies were not applied to the laboratory zones of the development due to the demanding functional requirements. Hybrid mass timber and concrete structures were explored to reduce the embodied carbon of the development within the functional constraints of the typology.

NET ZERO POTENTIAL

Based on the analysis undertaken, it is not possible to achieve net zero within the site boundary based on the high energy load from laboratory specific equipment. A 18% reduction in EUI was achieved through the strategies and technologies and a further 33% of the BAU energy use was offset by on-site solar PV energy generation. A total reduction from BAU of 50% was achieved. This reduction is significant in the context of the energy loads of a typical lab. Future exploration in the efficiency of laboratory-specific equipment could demonstrate greater net-zero potential.

[12] Atelier Ten, www.ihub.org.au/the-knowledge-hub/

4.6. Summary Observations

This investigation has produced strong preliminary results for the potential of the net zero energy for the select building typologies explored in the IDS program. Most prototype buildings explored in this program would be able to achieve net zero operational carbon emissions through green power purchasing agreements, the data centre building may be an exemption for this scenario due to its extremely high energy consumption. A broad range of typologies and climates could be analysed for net zero potential based on future NABERS metered data and full envelope and system energy modelling, there is precedent for such work in the global market, such as the ASHRAE (2012),1651-RP Development of Maximum Technically Achievable Energy Targets for Commercial Buildings. Further, a detailed exploration into function-specific equipment and technologies could provide greater net zero energy potential for specialist typologies and exploration of community master planning for net zero energy are all valuable future ventures.

4.6.1.Simple

As the simple typologies have been demonstrated to have the potential to achieve net zero energy, future technology exploration could be focused on the refinement of energy efficient equipment, including specialised equipment and solar panel sizing, to optimize net zero buildings for cost. Alternatively, rather than optimizing for cost, exploration into district wide energy demand could allow schools to offset the energy demand of nearby buildings or infrastructure that cannot supply their own energy through on-site generation only.

It should be noted, for the school typology, the estimate of the BAU baseline EUI is based on conventional classrooms and does not consider high school trade, computer and science facilities that would have specialised loads for function-specific equipment. A deeper investigation into this equipment and potential efficiency and use management interventions would support all schools achieving net zero energy. Further, the IDS program was limited to climates specified in the studios, an exhaustive range of Australian climates could be investigated to understand the shift in impact of both energy use reduction interventions and solar PV generation potential. Both the school and ambulance station designs demonstrated the high impact of PassiveHouse design approach, particularly for simple buildings on the scale of domestic residential buildings, this could be explored further.

4.6.2.Complex

The complex typologies have been demonstrated as having potential for significant energy use reductions but, in some cases, not achieving net zero energy. Future technology exploration into the efficiency and control of specialist equipment such as hospital equipment for aged care buildings, could further the energy use reductions possible for these buildings. It is not cost effective to scale up on-site energy further for these typologies, but green power purchase agreements could provide a net zero operational carbon emissions pathway through off-site renewable energy generation.

Although the community centre (retrofit) typology did not demonstrate significant energy reductions when compared to new builds, this is partly due to the establishment of BAU EUI. For this exploration, a EUI was used based on the existing building, constructed based on old building code compliance. In contrast, other studios used current industry benchmarks for BAU EUI. Further, the quantification of avoided whole of life embodied carbon emissions could be undertaken to demonstrate the life cycle cost savings of adaptive re-use and retrofits.

Mix-use typologies presented a challenge in quantifying energy use reductions due to the variability of energy loads. Where specialist equipment is required for multiple tenancies, including aged care, retail and food preparation, the breakdown of energy consumption is difficult to quantify. The thermal loads for space heating/cooling can be targeted for energy use reduction but it is difficult to adjust the reductions for total building energy use. This cannot be generalised, particularly across climate zones, and needs to be undertaken on a project-by-project basis.

The BAU baseline EUI estimates used in these prototype designs can vary widely based on building age, climate, function, and scale. A survey of metered data from across multiple climate zones could support more accurate estimates for BAU energy consumption.

4.6.3.Specialist

The specialist typologies have been explored to some extent, but further exploration is required to achieve greater net zero potential for most typology prototypes. Because the EUI is generally higher, when compared to the simple and complex typologies, with a large component from specialist equipment, detailed mechanical and electrical engineering technologies need to be explored in industry to reduce the energy consumption and subsequent carbon emissions of these buildings. The assumption that these typologies have reduced potential may be reconsidered as the generation potential for some specialist typologies is greater than the simple and complex typologies based on the building form. Rather, it can be concluded that specialist typologies cannot have generalised net zero potential but require refined exploration and testing.

The aquatic centre demonstrated very significant reductions, the built form of this typology had a large role to play in this and provides a significant opportunity for aquatic centres to achieve net zero and look to ambitious sustainability outcomes. Future technology exploration could focus on on-site water recycling and the energy consumption of such systems. The transport building performed similarly, achieving significant reductions due to a large roof canopy with significant solar PV. The program of a transport building would have a major impact on its net zero potential where food retail and mixed-use spaces increase the BAU energy load in exchange for greater community utility.

Data centres could not achieve significant reductions however, through re-scoping the design scale, there are opportunities for ambitious energy savings on a district scale. Studies could explore the technology needed to harness the waste heat of data centres on a community scale.

The laboratory typology posed an interesting challenge, the strict functional requirements of the typology limit interventions in some cases. Further exploration of laboratory equipment, as well as the embodied carbon of laboratory buildings, is needed to support a net zero pathway.

The BAU baseline EUI estimates used in these prototype designs could vary widely between locations/climates. Detailed energy modelling or metered data surveys could refine these estimates in future studies for a comprehensive survey of net zero potential of typologies across Australia.

4.7. Cross comparison of reductions in onsite energy use by building typology

The typologies explored in this study demonstrate a range of capacity to reduce energy use and generate energy on-site. The scale of construction and function impact the potential to achieve net zero however climate and extent of designer experience and ambition also impact the net zero pathway. Many of the solutions presented relied on market-ready technologies that got implemented for specific contexts – depending on building typology, functional constraints, spatial characteristics, and holistic environmental principles. In most instances, passive design measures resulted in major benefits in Zero Carbon performance, energy need reduction achieved could then get complimented by onsite renewable energy generation.

One of the key goals of this Carbon Catalogue is to offer an exemplar summary of Net Zero performance associated to the different building typologies investigated. Some results are clearly more representative for the specific building typology than others (e.g. schools, ambulance stations, aquatic centres, transport buildings, or data centres). Here variations mainly relate to different size and locations (in terms of climate zones). Carbon performance for other building typologies (e.g. Mixed-use facilities or Community Centres) frequently have a greater inherent variation in energy needs. They are therefore difficult to 'benchmark' due to great variation in functional requirements and specialist equipment (in particular Laboratories and Aged Care facilities).

It is important to read the percentage reduction in energy use presented in this summary in the context of the qualitative explanation provided in the Carbon Catalogue. These explanations offer crucial context that will allow readers to gain a solid understanding about the carbon performance for each building typology and the effectiveness of different interventions selected.

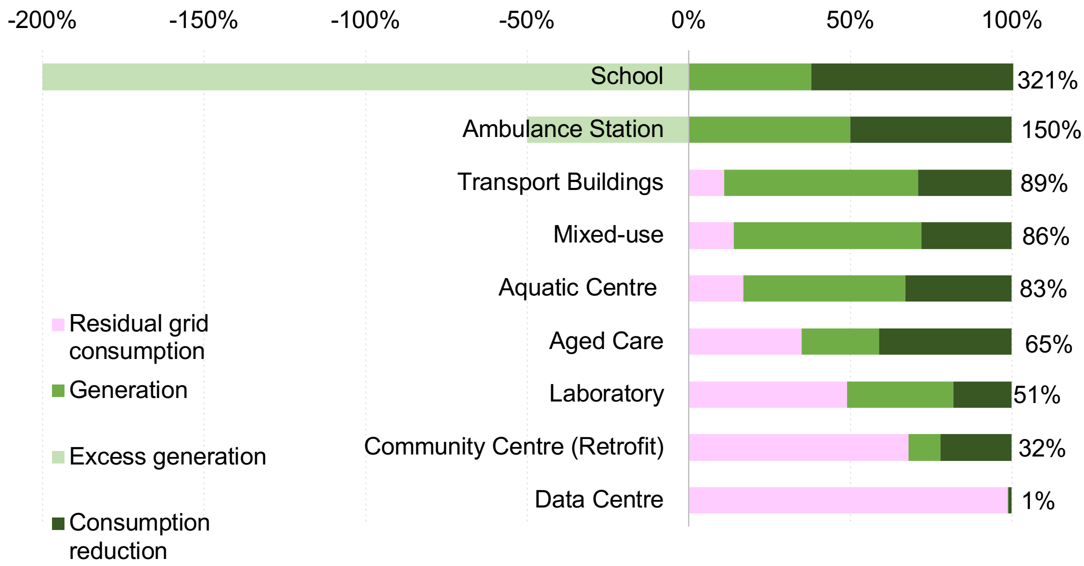

Figure 4--54 Summary of typology prototypes' energy grid consumption after implementing the net zero pathway interventions where (-) indicates more energy is generated than consumed by the typology.

4.7.1.Simple

Energy use reductions of 50-60% are possible for simple typologies through implementation of passive strategies, such as natural ventilation and daylight, then the implementation of active technologies, including high performing HVAC or heat recovery ventilation, and enhanced energy management/ control. The significant reduction potential is possible because most energy consumption is for general building services rather than specialised equipment. For school buildings, operation characterised by daytime-only occupation enhances the potential for on-site generation fulfilling the energy demand. For ambulance stations, the BAU EUI is very similar to a domestic residential typology, lower than other typologies explored in this study, such that significant energy use reduction is possible through passive strategies and market ready technologies. Both typologies were appropriate for PassiveHouse design interventions due to their construction and operation scale.

Both typologies are generally one or two story and therefore the roof area available for solar PV systems can generate more energy than the energy demand. In terms of generation technology, these typologies, in the climates specified in the studios, can achieve 'net negative' energy with market-available solar PV systems, in the range of 150-320% BAU EUI.

4.7.2.Complex

Energy use reduction varies from 25% to 40% for complex typologies dependent on climate and specialist equipment loads. Additionally, the comparison of new buildings and retrofits demonstrated greater potential for energy reduction for new builds that can utilise high performing building envelopes, potential implementing Passive House standards. Further investigation is required to refine these results for the range of differing complex typologies, particularly for mixed-use buildings where it is difficult to comprehensively determine generalised equipment loads. This typology category requires greater refinement to best quantify net zero potential.

All the prototypes investigated had potential for significant rooftop solar PV energy generation due to the Australian climate, achieving 10-50% BAU energy offset. The number of stories of a complex building typology can govern the impact of rooftop generation: Roof to GFA ratio limits the ability to generate all energy demand on-site. Additionally, the scale of freedom of designers to implement large PV arrays affects the scale of impact. For the studios that focused on cost-effective implementation, the on-site generation potential was less. Market availability and cost generally limit the implementation of other renewable energy technologies such as wind power or other innovative energy sources.

4.7.3.Specialist

Energy use reduction varies widely for this category based on the range of typologies with specialist high energy load functions, from 1%-30%. These typologies require a detailed exploration site-specific requirement rather than generalised broad rules of thumb.

Aquatic centres and transport building have large site and roof areas that allow large amounts of renewable energy to be generated onsite, 50-60% using both market-ready and innovative technologies. Laboratories could achieve 30% BAU offset from on-site energy generation, demonstrating that greater energy use reduction is needed, namely a refined exploration of laboratory equipment efficiencies. For data centres, an unconventional approach toward net zero energy is required, by scaling up the scope and harnessing the heat created by the building, it is possible to power buildings in the wider community. A similar strategy may support better energy efficiency for transport buildings, by developing technologies to harness the excess kinetic energy of a braking train, the rail transport network could move towards large energy reductions for the larger transport system. This demonstrates the value of master-planning with an integrated design team to plan for a low emission future.

5. CONCLUSIONS

The IDS program has wide-ranging implications for both industry and the academe. A significant volume of material and knowledge was produced across the fourteen integrated design studios that were undertaken. Valuable lessons in how to facilitate integrated design theory in practice in industry were gained as well as detailed technical learnings on how to approach net zero design.

Integrated Design

The challenge of implementing integrated design principles in practice was explored in depth. The existing theory on integrated design garnered from literature was found to be useful as a design process mechanism, however was found to be lacking in it's ability to be incorporated into the complexity of real world projects as a stand-alone concept.

Project wide framework factors were found to be paramount. The need for a different emphasis during project procurement and project initiation by the client, process change enacted by the architectural and engineering designers, and a different attitude towards collaboration was evident throughout all the studios run under the program. This did not only relate to the way architectural and engineering designers interact, but also to the way clients formulate their brief, plus the way integrated design actively gets curated via expert input. The actual kernel of the integrated design process itself was also interrogated with a number of useful observations made in how to gain traction in design teams.

The work on how to successfully implement integrated design on projects is encapsulated in Section 3 of this report, and in the 'Catalyst for Integrated Design' document.

Net Zero Design

An array of net zero technical design learnings were amassed across the building typologies (nine in total), used as case studies. These were then distilled to practical best practice guidance across three larger typology groupings (simple buildings, complex buildings, and specialist buildings). These have articulated in the 'Carbon Catalogue' produced as a part of the 'Report on Combined Outcomes').

Outcomes

The IDSs largely achieved what they set out to do. While they cannot claim to have instigated the current ground swell of discussion and activity being observed around integrated design and its related fields, in industry, they definitely gave it a large push and have also contributed significantly to the amount of guidance material available on the subject.

A more thorough analysis of the Integrated design Studios activity outcomes against the original i-Hub KPI's and objectives set is contained in the 'i-Hub IDS-KS Final Sub-Project Knowledge Sharing Report'.

5.1. Relevance for Academic Curriculum Development

All participants agreed that experiencing integrated design processes as a part of a higher degree education is beneficial for students. It prepares them for working in multi-disciplinary teams in practice and exposes them to the specific vocabulary and processes used by various other disciplines.

The IDS model shows promise for future application in academia. The frequent design tutorials with the studio tutor and industry consultants offered fertile ground for multiple perspectives to be considered with each design iteration in some groups. In these same groups peer-to-peer critiquing was also observed and with the support of the studio appeared to give rise to more integrated development of designs that enabled key architectural and engineering priorities to be upheld through each iteration. It was observed however, that in at least one group students struggled to uphold some early project aspirations through design development, at the same time as they faced struggles to balance the workload.

The various technologies investigated often needed careful introduction both by the studio leaders, as well as the participating industry consultants. Students frequently needed to get 'sensitised' towards their use and learn how any specific technology could impact on environmental performance of their design, then approach optimised solutions iteratively in conjunction with other relevant design factors.

5.2. What Comes Next for the IDS

A strong degree of knowledge sharing also occurred as a part of the IDS activities. The three institutions are keen to see the work produced continue to be disseminated amongst industry, and for the knowledge gained to be employed in assisting integrated design to gain traction. In this light the IDS proponents will:

- Continue to publicise the 'Catalyst for Integrated Design' document encouraging building owners and industry groups to adopt principles of integrated design in the procurement of projects.

- Further articulate and publicise the 'Carbon Catalogue'. This document has the potential to be a stand-alone document providing guidance on where to start with net zero design.

- Continue to take part in industry discussion around integrated design and its related areas (regenerative design etc). As a part of this further integrated design symposiums have been mooted perhaps on a biennial basis in Melbourne.

- Continue to support the development of an 'inner circle' of integrated design interested people in Melbourne and potentially nationally. Interest in being a part of this industry group has already been shown by Swinburne, Monash, Victoria and Deakin universities as well as by several passionate integrated design individuals from various architectural and engineering consultants. The ultimate realisation of this may be the formation of an integrated design industry body.

- All three institutions involved in i-Hub (The University of Melbourne, The University of Wollongong, and Queensland University of Technology), have indicated forward plans to continue the integrated design studios in a self-funded form.

- Further dissemination through involvement in IEA Annex 80, an international energy research programme in the buildings and communities field with the objective of providing resilient cooling of building.

It is envisaged that opportunities for further work in the net zero field to be carried out will continue to arise as government and private industry grapple with meeting zero carbon targets. The work produced in the integrated design studios places those involved in it in a strong position to partake in these opportunities to further the net zero cause.