The i-Hub Blue Book of Zero Carbon.

February 2023

The University of Melbourne

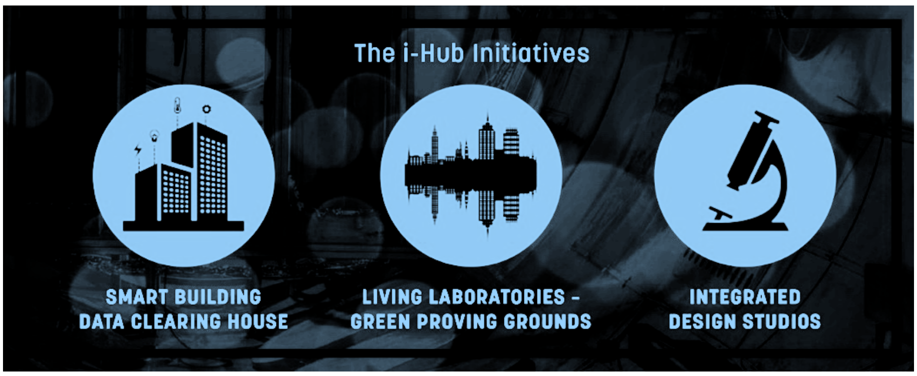
About i-Hub

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



The i-Hub Blue Book of Zero Carbon

This book presents 'Integrated Design' research on zero carbon. It comes from work carried out under 'i-Hub', a research hub initiated by AIRAH (the Australian Institute for Refrigeration and Air Handling), and funded by ARENA (Australia's renewable energy authority). The work was led by The University of Melbourne in collaboration with Queensland University of Technology, and the University of Wollongong.

This book serves as a summary document of findings, further more detailed information can be found in the detailed research reports produced as a part of the 'Integrated Design Studios' or IDS stream at www.i-hub.org.au

Lead Institutions	The University of Melbourne		
Partner Institutions	Queensland University of Technology, The University of Wollongong.		
I-Hub Sub-Project number	IDS-KS		
Sub-Project commencement date	21st July 2021	Completion date	27th May 2022

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2. ZERO CARBON THROUGH INTEGRATED DESIGN

This book surmises approaches designers can take to move towards zero carbon across various building typologies. The findings come from research carried out in 'Integrated Design' studios at The University of Melbourne, QUT, and The University of Wollongong.

Integrated design is a design approach that aims to better integrate stakeholder drivers (in particular architectural and engineering), into projects. It aims to produce outcomes where the 'whole that is greater than the sum of the parts', the architectural and engineering outcomes surpass what each discipline could have achieved on its own, costs to build and maintain are reduced, and environmental and climate impacts are reduced.

This book serves as a summary document of findings, further more detailed information can be found in the detailed research reports produced as a part of the 'Integrated Design Studios' or IDS stream at www.i-hub.org.au

2.1. Framework

This work in the research studios compared the potential to achieve net zero for a select range of building typologies 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.

What is 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."[1] 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.

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

Building Typologies Examined

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.

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

Table 4-1 Summary of typologies in study scope

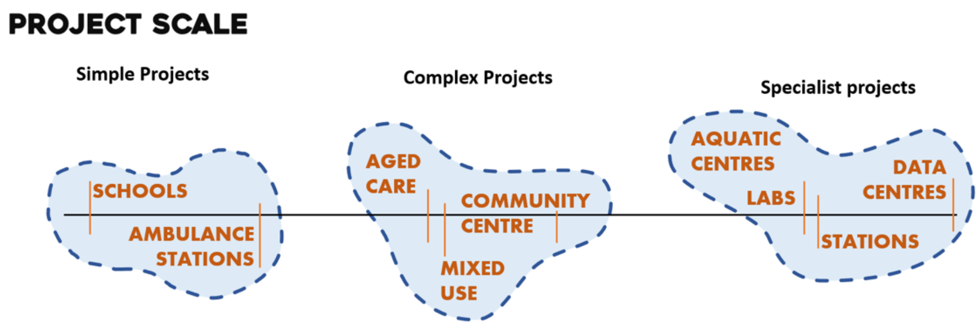

Figure 2-2 Project scale spectrum

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>
<tr><th>Building Footprint</th><th>Intervention</th><th>Scope of Assessment</th></tr>
<tr><td rowspan="3">Energy use</td><td>Building fabric</td><td rowspan="5">Quantified for
Net Zero (Energy)</td></tr>
<tr><td>Passive design</td></tr>
<tr><td>Active design (HVAC performance)</td></tr>
<tr><td rowspan="2">Energy source</td><td>On-site energy generation</td></tr>
<tr><td>On-site energy storage</td></tr>
<tr><td rowspan="2">Embodied carbon</td><td>Materials</td><td rowspan="2">Consideration only
Net Zero (Carbon)</td></tr>
<tr><td>Construction methods</td></tr>
<tr><td rowspan="4">Holistic sustainability</td><td>Water</td><td rowspan="3">Consideration only
Environmental impact</td></tr>
<tr><td>Waste</td></tr>
<tr><td>Nature</td></tr>
<tr><td>Health</td><td>Consideration only
Occupant impact</td></tr>
</table>

Table 4-2 Summary of design interventions in study scope

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

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 CO2-e)
- Energy consumption and generation are measured in kilowatt-hours per year (kWh/year)

- Occupied building area is measured in Gross Floor Area (GFA) (m2)
- Annual operational energy consumption as EUI is measured in kilowatt-hours per GFA per year (kWh/m2/year)

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.

2.2. Results

2.2.1. 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.

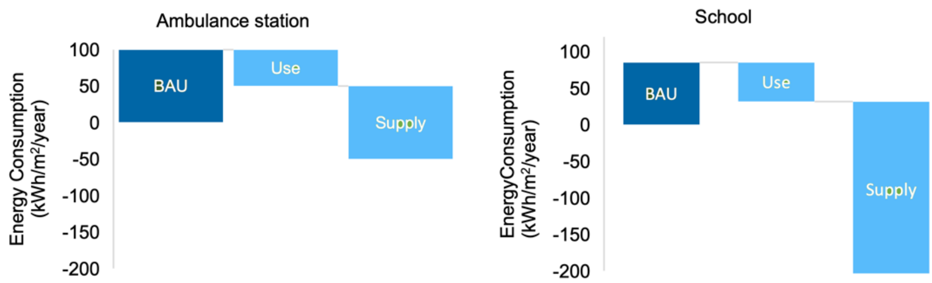

Figure 4--2 Summary of simple typology energy consumption and net zero pathways for (a) Ambulance Station and (b) School

	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		

Table 4-3 Summary of simple Typology design interventions

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 300m2, 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[2] 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/m2/year, 100 kWh/m2/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.

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 50-65m2. 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 separately3 in the two studios completed. Based on research of industry benchmarks, the range of EUI was determined to be 75-95kWh/m2/year. This benchmark is averaged to 85kWh/m2/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.

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.

2.2.2. 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.

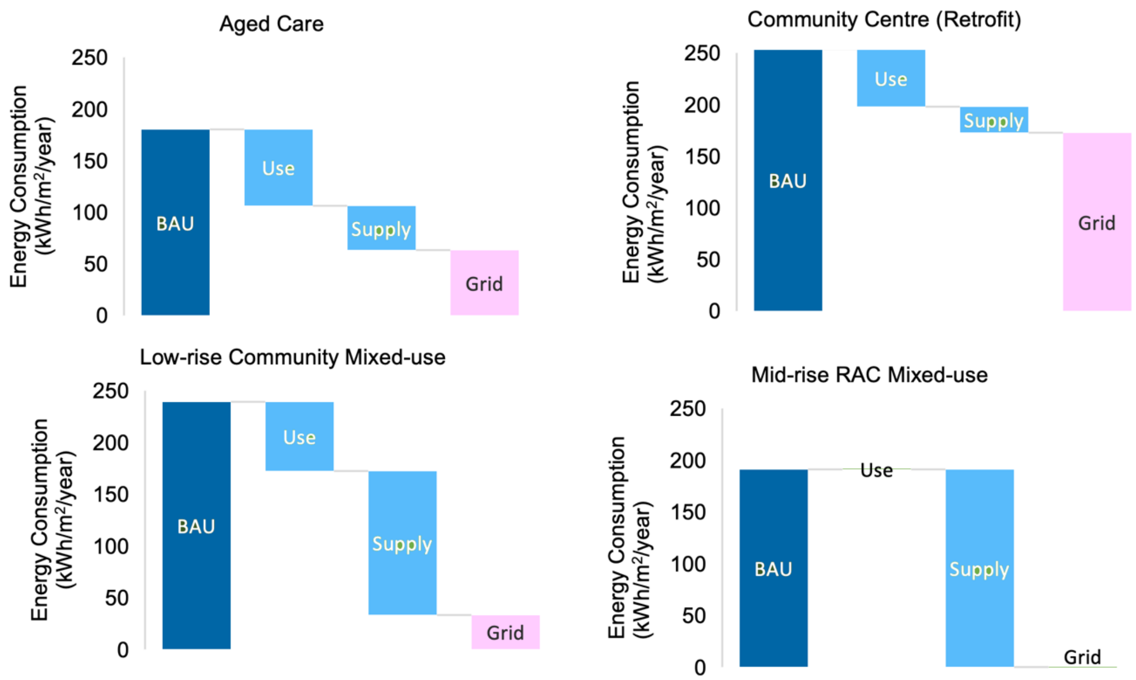

Figure 4--5 Summary of complex construction and function typology annual energy consumption and net zero pathways for (a) Aged Care and (b) Community Centre (Retrofit), (c) Low-rise Community Mixed-use, (d) Mid-rise RAC Mixed-use

	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

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

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 50m2 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 separately4 in the two studios completed. Based on research of industry benchmarks, the range of EUI was determined to be 100-230kWh/m2/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. 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.

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 determined5 to be approximately 250kWh/m2/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 BAU of 32% was achieved. This protype design is limited

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

by the constraints of the existing building envelope and services as well as the client priorities for realistic implementation under financial constraints.

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.

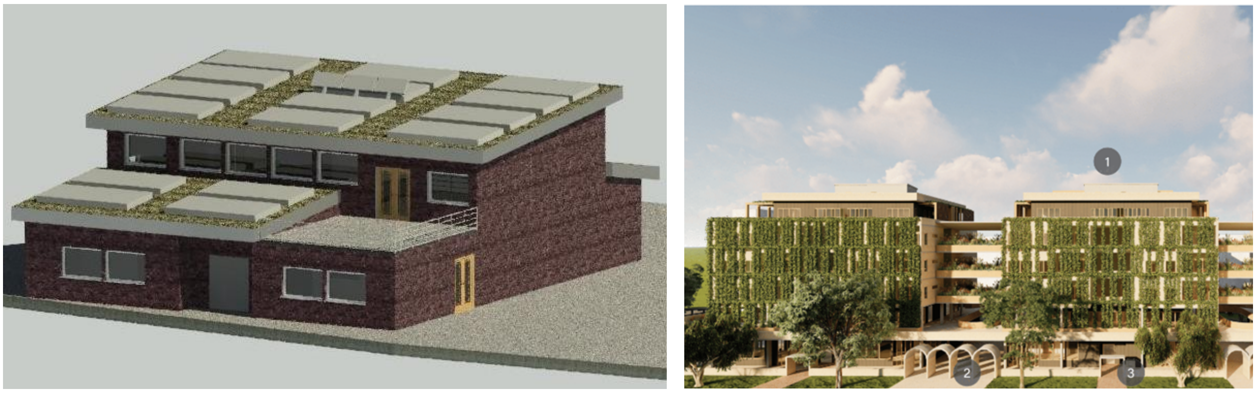

Figure 4--8 Example of student design for mixed-use typology (a) southern NSW, (b) QLD.

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[6] 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[7] 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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[6] Stantec, MIEngineers www.ihub.org.au/the-knowledge-hub/

[7] 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.

2.2.3. 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.

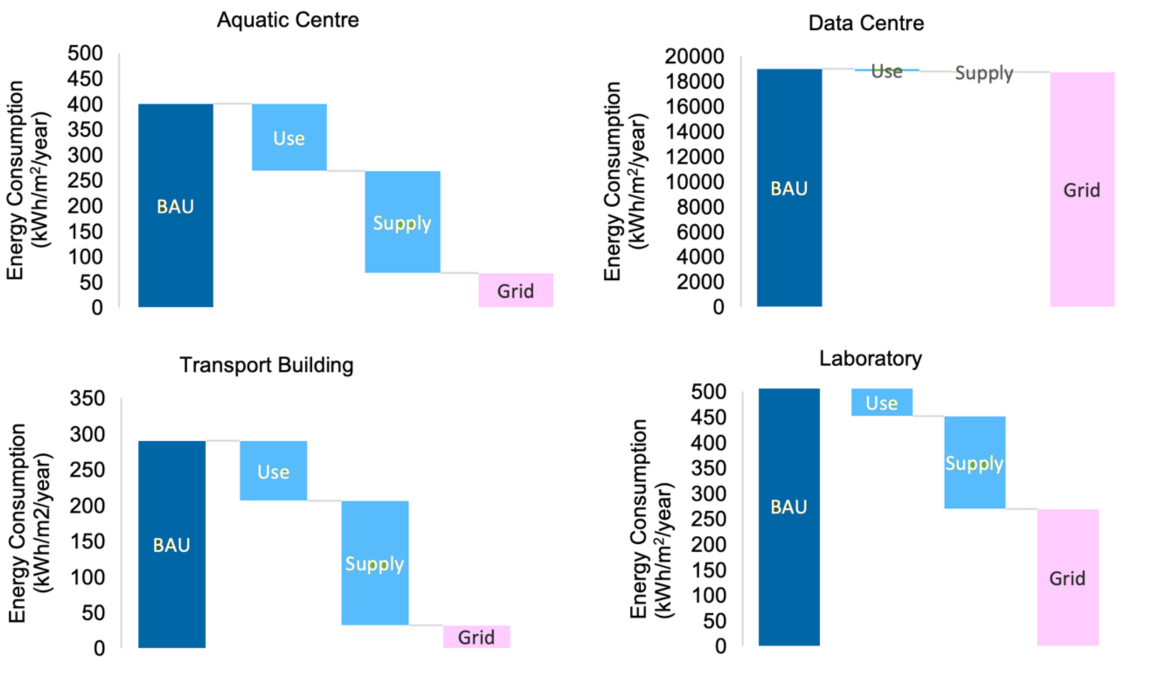

Figure 4--9 Summary of specialist construction and function typology annual energy consumption and net zero pathways for (a) Aquatic Centre, (b) Data Centre, (c) Transport Building and (d) Laboratory.

	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		

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

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 determined8 in the one studio completed. Based on industry benchmarks, the range of EUI for this typology is 300-500kWh/m2/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 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.

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.

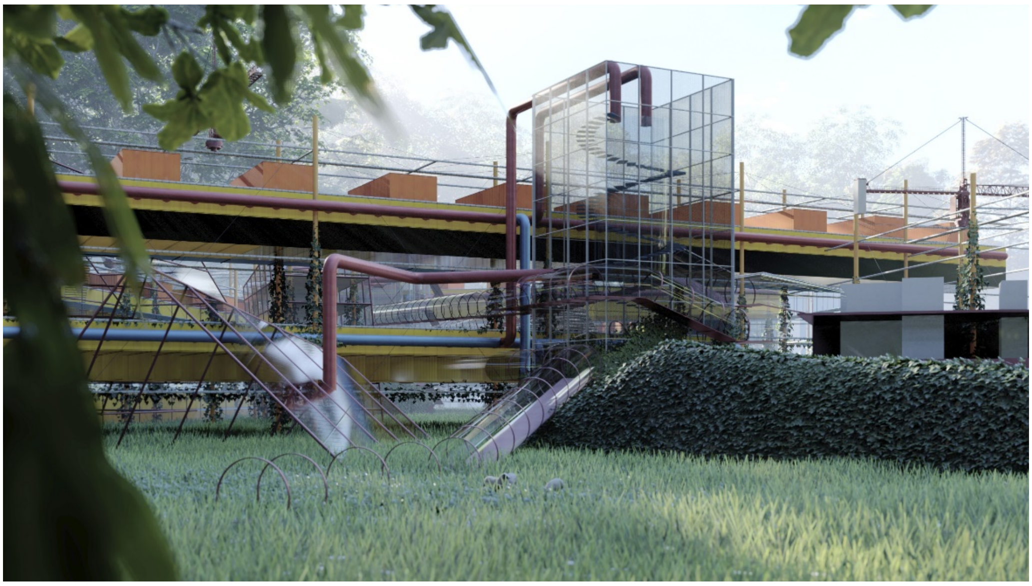

Figure 4--11 Example of student design for data centre typology

BAU ENERGY CONSUMPTION

The base case established for the data centre typology was determined9 in the one studio completed. Based on the client brief, the EUI for this typology is 19,000 kWh/m2/year. This BAU is representative of a multi-story 80MW data centre normalised for the average student design GFA of 48,000 m2. 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.

[9] 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.

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--22 Example of student design for transport building typology

BAU ENERGY CONSUMPTION

The base case established for the transport building typology was determined[10] in the one studio completed. Based on the station size, the EUI for this typology is 290kWh/m2/year. This BAU is representative of a train station with trenched platform level with a total GFA of 1,400 m2. 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

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

[10] 100% Outcomes Report www.ihub.org.au/the-knowledge-hub/

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.

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--33 Example of student design for laboratory typology

BAU ENERGY CONSUMPTION
The base case established for the laboratory typology was determined[11] in the one studio completed. Based on industry precedent, the range of EUI for this typology is 270-830

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

kWh/m2/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.

2.3. 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.

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.

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.

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.

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.

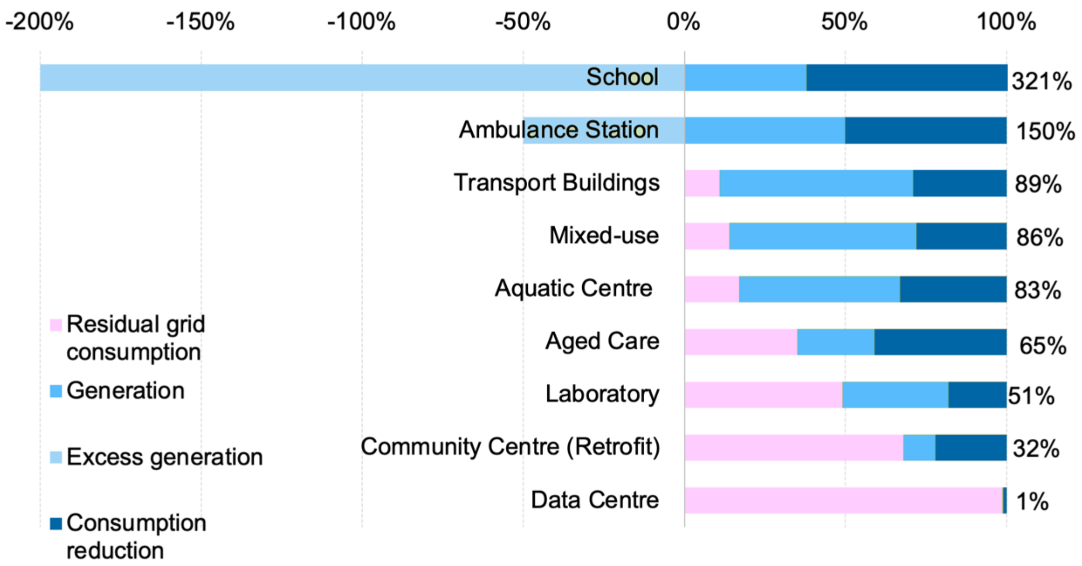

Figure 4--44 Summary of typology prototypes' energy grid consumption after implementing the net zero pathway interventions where (-) indicates more energy is generated than consumed by the typology.

2.3.1.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.

2.3.2.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.

2.3.3.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.

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’).