The Innovation Hub

for Affordable Heating and Cooling

Design Studio Outcomes Report (100% Milestone)

IDS-09 Lightning Ridge Local Aboriginal Land Council Multi-Purpose Building – Outcome Report

Project IDS09

27 May 2022

University of Wollongong

About i-Hub

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

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

This Project received funding from ARENA as part of ARENA's Advancing Renewables Program.
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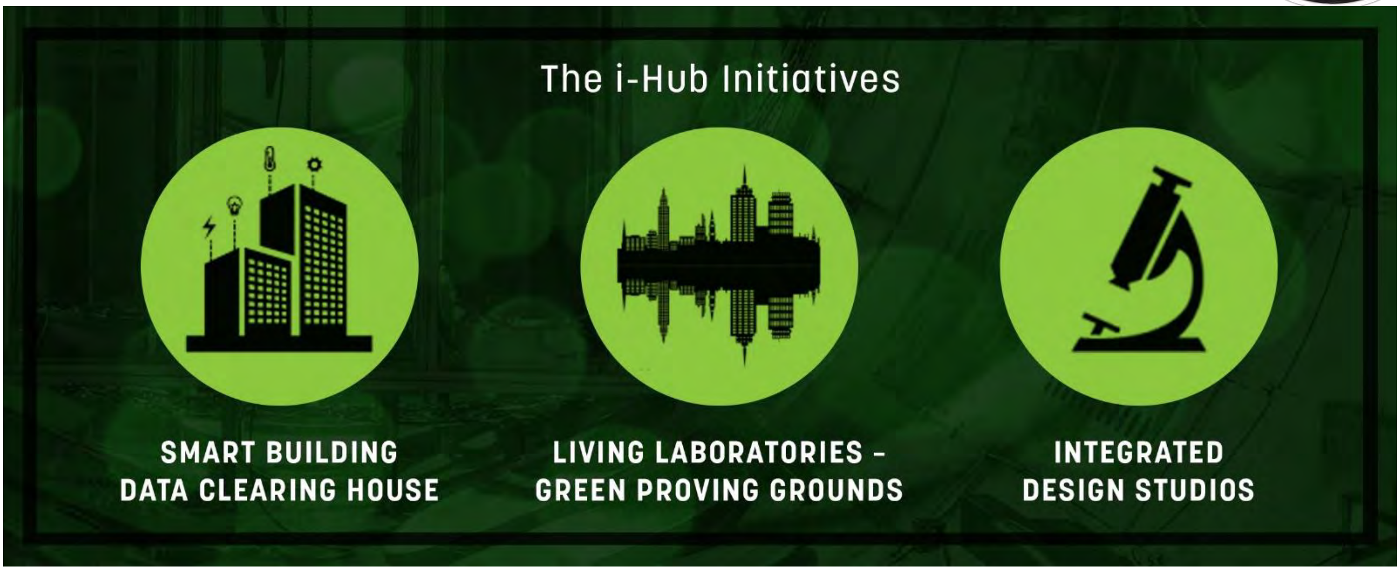
Primary Project Partner



i-Hub Design Studio Outcomes Report (100% Milestone)

The IDS-09 Lightning Ridge Local Aboriginal Land Council (LALC) Multi-Purpose Building Integrated Design Studio investigates design innovation to reduce net energy consumption of a proposed multi-purpose community centre to be constructed in central Lightning Ridge, to be owned and operated by the Lightning Ridge Local Aboriginal Land Council (LRLALC). Over a 13-week period, a group of multidisciplinary students, consultants and academics worked collaboratively to develop several design proposals for the client (The Dr. Steve Burroughs Foundation) who is acting on behalf of the LRLALC. These designs will be conscious of the land councils concern towards environmental impact and energy usage, while also promoting inclusion within the community of Lightning Ridge and incorporating indigenous design principles.

The indigenous community are concerned around the effect of climate change, and the contribution that they may have on the environment now and into the future. Any development involving the land council is required to be conscious of these factors, while also being of benefit to the Lightning Ridge community at large. Lightning Ridge, being a small, rural town in northern NSW, largely relies on income generated through tourism to help sustain the community. The proposed multi-purpose building can assist with this by offering commercial opportunities to generate revenue, while also increasing employment opportunities for those living in the surrounding region.

Based on the brief provided by Dr. Steve Burroughs, studio participants explored novel approaches to address the environmental concerns of the land council with the aim to achieve a net-zero carbon solution through inclusion of renewable energy technologies, efficient building strategies and building materials. Considerations were given to capital versus operation and life cycle costs, while also being mindful of the limited capital available for development, and the limited variety of construction materials in the surrounding region.

Lead organisation	University of Wollongong		
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1 SUMMARY

1.1. Purpose

This report summarises the findings obtained from IDS09 (Lightning Ridge LALC Multi-Purpose Building), marking the 100% completion milestone at the conclusion of the project. The report contains information previously communicated within the 50% milestone report, and is supplemented by the findings highlighted within the consultant vetting report, submitted student assessments, design development conducted by architectural consultants, and participant feedback. The content outlined within this milestone report will assist in developing a 'Lessons Learned' report associated with the key learnings attributed to IDS09, and be further disseminated under the IDS knowledge sharing strategy.

1.2. Executive summary

The IDS09 Lightning Ridge LALC multi-purpose building builds upon lessons learnt from the previous integrated design studios undertaken by the University of Melbourne (UOM) and by the University of Wollongong (UOW). This design studio was initiated in late July 2021, after substantial stakeholder engagement that commenced in Q2 of 2021. In the second week of spring semester, the client (Dr Steve Burroughs Foundation representing Lightning Ridge Local Aboriginal Land Council) provided an introduction to the proposed site location in central Lightning Ridge and provided the project participants with a brief on the multi-purpose building. This brief sets the goals and constraints of the integrated design process.

Outcomes for the design studios have been aligned to focus on producing integrated solutions that target 'Net Zero' design. Due to the impact of COVID-19, the studio lectures and interactive workshops were delivered via a fully online platform (Zoom) where emerging designers had the opportunity to work as a team and interact with peers, studio tutors and participating industry consultants.

The design studios were undertaken by students from multiple specialisations of engineering (Architectural, Civil and Environmental), with all students enrolled in various stages of an undergraduate degree. Following the project's client brief, the multi-disciplinary teams produced a number of return briefs and site-assessments with guidance from industry consultants and studio tutors.

Work progressed with participants developing preliminary designs for the multi-purpose building, with floorplans and 3D visualisations produced to pitch their proposed designs to the client. These preliminary designs included a business-as-usual (BAU) examination and a self-generated evaluation matrix comparing different technologies and strategies to determine which are most suitable for the given client brief. Students presented their preliminary design, receiving feedback from client and consultants, and updated their designs based on these responses. Energy simulations were undertaken to determine which strategies should be implemented to achieve an REF (renewable energy fraction) greater than 1, analysing results on an hourly basis. It was found that, under a number of pre-specified assumptions and constraints, that the majority of baseline designs had an annual average REF between 0.6 and 0.7. The finalised designs and recommendations have been presented to the client, outlining which strategies are most suitable for the requisite brief. An example of simulated modifications showing their impact on hourly REF values is given in Table 1.

Table 1: Student work extract: Simulated REF and no. of hours (8760) for specific technological/strategic inclusions

SOLUTION	REF	REF = 0	0<REF<0.3	0.31<REF <0.95	0.95< REF <1.05	REF > 1.05
WINDOWS						
SINGLE GLAZING WITH NO INTERNAL SHADING	0.596	5	4375	2492	191	1697
SINGLE GLAZING WITH INTERNAL SHADING	0.67	5	4263	2215	184	2093
DOUBLE GLAZING WITH INTERNAL SHADING (BASE CASE)	0.747	5	4234	2131	161	2229
DOUBLE GLAZING WITH INTERNAL SHADING AND ARGON	0.738	5	4258	2154	163	2180
DOUBLE GLAZING WITH INTERNAL SHADING AND LOE	0.784	5	4220	2112	136	2287
DOUBLE GLAZING WITH HIGH REFLECTIVITY BLINDS	0.826	5	4164	2037	131	2423
DOUBLE GLAZING WITH NO INTERNAL SHADING	0.697	5	4248	2364	177	1966
DOUBLE GLAZING ELECTROCHROMIC GLASS	0.876	5	4204	1866	144	2541
TRIPLE GLAZING WITH INTERNAL SHADING	0.753	5	4243	2140	148	2224
TRIPLE GLAZING WITH NO INTERNAL SHADING	0.707	5	4253	2347	175	1980

While reinforcing the findings of prior IDS's, the most relevant findings in relation to the integrated design process were:

- Collaborative design empowers architects and engineers to overcome preconceived perceptions about their capabilities in exploring design solutions.
- Well defined frameworks assist less experienced designers through the integrated design process, assisting in the development of innovative design solutions relevant to the requisite brief.
- Improved and numerous feedback mechanisms directly correlate towards improved project outcomes and student development.
- Designing in isolation inhibits integrated design outcomes and interdisciplinary collaboration
- Studio timeframe and student experience greatly affects design outcomes
- Building typology greatly affects design opportunities, with integrated design solutions having greater potential when considered at project inception

In terms of technical findings suitable for the building type and climate, design strategies anticipated to be most relevant to abating operational carbon were:

- Low-carbon/low-process materials – Prioritising natural and repurposed materials to reduce carbon footprint
- Passive design strategies – Abate operational carbon through lessening the requirements of active solutions
- Operational improvements and solutions – Actively improving occupant comfort while reducing energy demand
- Renewable energy generation – Optimising rooftop orientation to maximise PV output
- End of life planning – Maximise material reuse and recycling opportunities, design for end of life disassembly

Overall, the IDS process has proven valuable for all participants and is now intended to become a permanent approach in the training of students. The IDS has empowered participants to overcome constraints in relation to their field of expertise – architectural design and engineering – to improve technical outcomes and enable architecture rather than compromising it as is often the case.

2 PROJECT CONTEXT AND INCEPTION

2.1. Context to the Lightning Ridge LALC Integrated Design Studio

The Dr. Steve Burroughs Foundation (acting on behalf of the Lightning Ridge Local Aboriginal Land Council (LRLALC) proposed the development of a multi-purpose building in central Lightning Ridge, to design and construct a centre which contributes commercial, career, and social opportunities to the surrounding community. The proposed building will incorporate a commercial restaurant and several, smaller retail stores focusing on selling local indigenous art and artefacts from the surrounding region, such as locally mined opals. These spaces will promote tourism within the town, while also generating additional revenue, and employ local residents.

The multi-purpose building will include several communal spaces available to the public, with one being larger, and several smaller rooms. The large space will be ideal for community gatherings, such as town meetings or festive events, while the smaller spaces will be ideal for community groups, small presentations/meetings, or classes and workshops aimed at training/upskilling individuals within the Lightning Ridge region. The new offices for the land council will be included upstairs, remaining easily accessible to the public while offering additional security/privacy when required. A private carpark will be included at the rear of the structure for staff and land council members.

Figure 1. Street view of design studio development site in Lightning Ridge

In addition to functionality, the Lightning Ridge LALC is also concerned about the ongoing emissions associated with building operation and the corresponding operational expenses. To minimise both, the building is to be designed to be net-zero through implementation of renewable energy generation technology, high efficiency building strategies, and using thermally efficient building materials while being mindful of the limited capital available for development.

2.2. Studio Inception

Prior to the commencement of spring semester 2021, two integrated design studios were conducted by the University of Wollongong project team, where a series of lessons' learned were obtained. These lessons (in addition to those previously obtained from the University of Melbourne project team) were considered to identify potential shortcomings and benefits associated with the design studios. Several lessons remained consistent across all, such as the importance of avoiding unnecessary delays with ethics approvals, while some lessons identified limitations in using existing structures as a case study within a design studio environment. Using these lessons, the team engaged with industry to identify prospective design studio case studies to be investigated, and consultants to support these studios. Two case-studies were selected to run in parallel over the course of spring semester 2021 which commenced 26th July and concluded on 5th November.

The Lightning Ridge LALC Multi-Purpose Building Development was one of these two case studies selected to be investigated within the IDS program. A consultation process followed with the Dr. Steve Burroughs Foundation (who would act as a representative of the Lightning Ridge LALC) which provided a refinement of the brief and problem statements to be provided to the IDS participants at the start of semester. The design studio team went on to develop the subject assignments to align the IDS outcomes with the existing curriculum. A series of collaboration agreements and IP Deeds were generated to manage the expectations of the studios and UOW internal Ethics Approval was sought. In the early weeks of semester, the client presented the brief to studio participants providing an opportunity for students, consultants, and tutors to clarify any expectations of the brief before students produced a return brief for the client.

2.3. Client Engagement

The project was undertaken through collaboration with the Director of the Dr. Steve Burroughs Foundation, who has extensive knowledge of the site and requirements of this type of development, while also having considerable experience working with indigenous communities on a wide variety of indigenous projects. The principles of the IDS align with the ideals of the Lightning Ridge LALC in minimising environmental footprint, with the aim of achieving a net-zero carbon solution. The IDS provides a beneficial testing ground to explore innovative solutions to meet these net-zero aspirations, while examining architectural layouts and aesthetics in keeping with indigenous cultural customs.

Figure 2. Site location in Lightning Ridge

As no current design proposals exist, the Lightning Ridge LALC will use the designs developed by students to inform their design decisions in the future. The recommendations made by the students and the consultants (supported by energy simulations conducted in comparison to a business-as-usual baseline) will highlight the advantages of the strategies, technologies, and materials being investigated. The various strategies investigated by students will also be mindful of capital costs, and the potential return-on-investment offered by these selections.

The clients' representatives (the Dr. Steve Burroughs Foundation) have offered continued support to the project participants, having attended the mid-semester presentations and (most recently) the end-of-semester presentations where the studio teams and individuals presented their work to date and final solutions. The outcomes of this IDS in combination with an engaged client have great potential in providing a lasting impact to the Lightning Ridge LALC, and to the greater Lightning Ridge community.

2.4. Site Visit

The Lightning Ridge LALC Multi-Purpose Building is proposed to be developed at 34 Morilla Street, in central Lightning Ridge. A site visit to this location would have given students the opportunity to interact with the land council and discuss the proposed design with the client, as well as investigating the site and its surrounds. However, the distance to site in addition to the outbreak of Covid-19 restricting movement for the Greater Sydney region (including Wollongong) did not allow for a site visit to occur. Students instead discussed the site with a representative for the Dr. Steve Burroughs Foundation through Zoom, with investigation of the surrounding site being completely virtually.

3 DESIGN STUDIO PROGRESSION

3.1. Setup for Collaborative Design Integration

Prior to the start of spring semester, the subject coordinator and participating project team members designed the course content so that it encourages cross disciplinary collaboration between the participants. The content was designed to equip the participants with the fundamental aspects of design and provides an understanding of building performance and thermal comfort. The content also provides a deeper overview of building simulation models for estimating performance and comfort. This provides the participants with an understanding and the tools required to assess the expected impact of their design concepts.

Lessons learned from previous IDS's (from both the University of Melbourne and University of Wollongong) were considered when developing the content for IDS09. A particular focus was placed on the findings from IDS10 and IDS11, which identified benefit in exploring design for a 'green site', as opposed to using existing structures. *Lessons learned* highlighted that the use of pre-established structural form inhibits integrated design opportunities, with mostly retrofitted solutions being the only avenue available to designers. Similarly, through discussions with consultants and clients (and feedback from studio participants) it was evident that integrated design has more relevance and a greater potential when implemented at project inception. These *lessons learned* influenced the selection of a complete design (as opposed to retrofitting an existing structure), due to its potential to promote a more holistic design exploration and foster a greater sense of integrated design between the building's architecture, operational requirements and thermal performance.

3.2. Schedule for Interdisciplinary Engagement

The studios have been designed around two group reports (return brief/proposal and preliminary business-as-usual (BAU) analysis, and schematic design development with finalised BAU) with a group presentation which facilitates cross disciplinary conversations and collaborations. This is supported through weekly interactions with the studio tutors and industry consultants, with additional periodic consultation/input with the studio client. Additionally, both engineering and architectural consultants have allocated time each week to engage with student groups individually (if sought by the student groups) do further discuss design ideas and receive professional feedback. A final design report and presentation is conducted individually where students are required to undertake a deeper analysis on the selected design and its expected impact. This individual contribution has a requirement that participants address how this solution will interact with their group members selected solutions which encourages ongoing interdisciplinary interactions while still meeting the required subject outcomes at an undergraduate level.

3.3. Weekly interaction between Design Studio Participants

The IDS program consists of a weekly lecture delivering a variety of course content supplemented with additional learning material where required. This is followed by a weekly two-hour studio workshop facilitated by the tutors and in collaboration with the industry consultants. The topics covered in weekly lectures serve to progress student knowledge on sustainable design practices, giving students the necessary tools to undertake a design appropriate to the brief. This is supplemented by expert advice from industry consultants, to assist in design strategies, technical reporting, and building analysis. The industry consultants work together with the student groups to provide detailed advice on their ongoing designs, while also giving high-level advice to the participants at the conclusion the studio. The consultants are available outside of the standard studio hours for group consultations.

Interaction during these lectures and studios is restricted to a 100% virtual learning environment due to an outbreak of Covid-19 across NSW (and greater Australia), though alternate delivery methods and tools were devised in an attempt to maximise student, consultant and tutor interaction and engagement.

Earlier weeks give students an overview of the Integrated Design Studios, while also providing them with fundamental information of building physics (e.g. heat/energy transfer, thermal comfort, passive and active design strategies). Supplementary advice and knowledge is provided by the consultants during this period to assist in outlining preliminary design methodologies, assessing energy consumption for building typology (for a BAU analysis) and establishing a return brief for client review.

More technical information is delivered to students in intermediate weeks on renewable energy generation, ventilation and air quality. Additionally, simulation software is introduced (with a focus on EnergyPlus/OpenStudio) so as to better understand/assess the building envelope, and predict renewable energy systems generation output, energy performance and thermal comfort. Students continue to develop their designs during this period, based on the methodologies established in earlier weeks, while also being mindful of the newly learned technical requirements. These weeks reveal to students the complexities of developing sustainable and comfortable buildings while integrating the requirements outlined by the client. Simulation software offers them a tool to visualise the internal conditions of their designed structure and adjust accordingly. The preliminary designs established by the end of week 8 are presented to a cohort of IDS participants (i.e. students, clients, consultants, studio tutors) and invited guests. These presentations were met with enthusiasm, with both the client and consultants providing valuable feedback and direction on progressing the design.

Later weeks see participants focusing more on technical aspects of the design, with more detailed information of building simulation being provided, in addition to an overview of Australian certification and rating schemes (e.g. BASIX, NatHERS, etc.) and how they impact design. Finally, internal comfort conditions were examined, with an exploration as to how different factors affect internal comfort conditions, and how these are measured/assessed. Students are able to use these assessment strategies to assess the performance of their design for calculating the Renewable Energy Fraction (REF), and if the systems considered are capable of providing a comfortable internal environment in accordance with the design requirements. For this period, students are encouraged to continue undertaking an integrated design as a group, however, due to requirements of the university, the final design report and presentation is undertaken individually. It was also encouraged for students to discuss their design ideas openly within the class, to assist each other with design feedback rather than relying on (ex) group members and consultants. Final designs were again presented to the IDS participant cohort (i.e. students, clients, consultants, studio tutors) and invited guests, who provide feedback on the completed designs.

The earlier component of this studio sees participants learning to communicate across disciplines and convey their respective ideas or disciplinary advice to each other while generating innovative solutions to meet the client's needs. To help facilitate this, the participants were required to produce an evaluation matrix to review and score each design solution across a range of criteria (i.e. capital cost, ongoing cost, benefit, compliance with codes/certification schemes etc.), and conduct a business-as-usual assessment using existing case-studies to ascertain the operational energy requirements of the preliminary design.

3.4. Impact of COVID-19 on IDS Planning, Level of Engagement and Studio Outcomes

The COVID-19 pandemic continues to impact universities across Australia, particularly with international students being unable to enter the country. This has resulted in lower student availability; however, a sufficient number of students were recruited to enable the IDS to proceed (12 students). In addition to lower student numbers, the course content has had to be developed to be delivered via an online platform, with lectures and design studios being conducted virtually via Zoom. This has enabled continued remote participation and enabled additional colleagues of the consultants to also participate at times.

Studio participation remained consistent throughout the semester, with a majority of students attending all studio sessions, with continued involvement from all groups each week. Zoom breakout rooms allowed students to participate in discussion within project team, but also in project specific discussions in conjunction with studio tutors and consultants. Project collaboration was facilitated through programs such as Miro (as seen in Figure 3), giving participants access to visual collaboration tools, and also providing students a manner of interacting with one another and sharing ideas and critical information pertinent to the project. While restrictions limited face-to-face interactions, technology allowed for participants to work collaboratively with one another and progress their designs as a team.

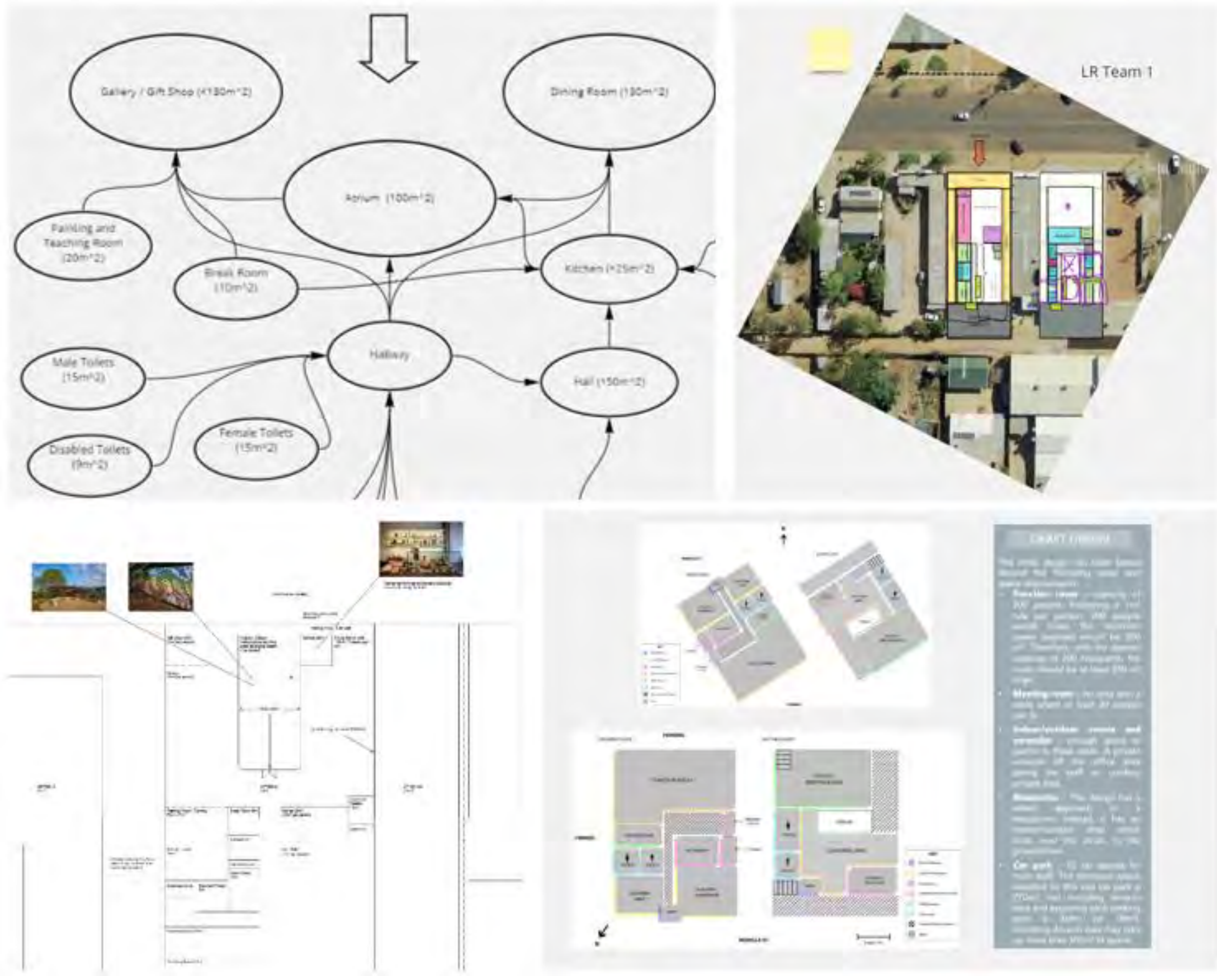


Figure 3. Select examples of preliminary student work from the Miro workspace

4 DESIGN STUDIO PROCESS FINDINGS

The findings from the Integrated Design Studio IDS09 have been separated into three main categories for further examination:

1) Key observations recorded during the studio workshops
2) Feedback from participating industry consultants, studio tutors and the client, and
3) Feedback from participating students

Observations made during the studio workshops give insight into what worked well (or did not work well) in the overall running of the IDS, either in terms of student learning outcomes, or work completed. These observations are primarily from the perspective of the researchers/studio tutors involved in the IDS. To ensure these perspectives are not entirely biased, the notes of an observing researcher are also included, who was not involved with the classroom teaching and had minimal contact with the students for the duration of the 13-week studio. Alternatively, feedback from industry consultants, studio tutors, clients and students give a perspective from those participating in the studio, providing reflection on the studio operations and how things may be altered to improve potential learning outcomes in future studios, or indicating aspects which were found to be greatly beneficial.

4.1. Key observations during the studio

4.1.1. Pre-defined framework leads to improved outcomes

Innovative design solutions require a process where flexibility is given to the students and the consultants to develop all possible thoughts into design options and interrogate them across a range of criteria. Students were provided with a framework that acted as a guide, following generic predefined steps:

i. Site analysis, user requirements and identification of opportunities
ii. Business-as-usual study
iii. Development of a matrix that ranks proposed net zero energy design measures at least in relation to relevant prescribed criteria (e.g. feasibility, capital and operation cost estimates; energy and carbon savings potential, innovation, potential impact on the rating produced by existing green building certifications or standards).
iv. Detailed quantification of the impact of selective design solutions

While the design process is flexible, this framework outlined smaller achievable goals for the students to work towards, progressing them from an initial conceptual design towards a finalised design. This framework was presented to the students in the form of assessments, with each subsequent assessment built on the work completed previously. This progression assuaged the overwhelming nature that design can have, and reinforced the development of constructive design principals, with a design progressing step-by-step with changes being made based on a variety of feedback mechanisms.

The inclusion of a design matrix assisted in students assessing the numerous potential design opportunities available, and provided a means to quantitively compare potential technologies against one another to determine which may be more appropriate for the design. Some technologies stood out as 'better' depending on which criteria the students identified as being most critical from their assessment of the client brief. The primary factors affecting each technology in the matrix were:

- Operational cost– Are the costs beneficial over time?
- Capital cost and feasibility – Is the technology appropriate, viable, and within the budgetary constraints outlined by the client?
- Building Regulations and Certification – Do different certification schemes assess these technologies, and how well do they perform?
- Energy/Carbon Savings – Does the system save on energy/carbon compared to alternative systems?

Table 2: Selected extracts from student work - Evaluation matrix

Net Zero Energy Design Strategy

Design Measures	Business-As-Usual Case	Measure Description	Design Criteria with Weightings (Overall Weightings = 1): Feasibility 0.17	Innovation 0.03	Green Star Impact 0.08	WELL Impact 0.11	Energy Savings Potential 0.22	Carbon Savings Potential 0.19	Capital Cost 0.06	Operational Cost 0.14	Weighted Value (Higher is Better Practice)	Overall Ranking (1 = Best Practice)
Solar Panels	Fossil Fuels (Petroleum, Natural Gas and Coal)	[illegible]	[illegible] Value: 3/3	[illegible] Value: 1/3	Credit 15.0: Greenhouse gas emissions; Credit 16.0: Peak electricity demand reduction. Value: 2 credits	[illegible] Value: 6 points + 0 requirement	[illegible] Value: 3/3	[illegible] Value: 3/3	[illegible] Value: 1/3	[illegible] Value: 3/3	3.07	6
Transpired Solar Collector	Heat Recovery Units (Heat Pump System and Heat Exchanger types)	[illegible]	[illegible] Value: 3/3	[illegible] Value: 1/3	Credit 14.0: Thermal comfort; Credit 15.0: Greenhouse gas emissions. Value: 2 credits	[illegible] Value: 3 points + 2 requirement	[illegible] Value: 3/3	[illegible] Value: 3/3	[illegible] Value: 2/3	[illegible] Value: 3/3	5.02	8
Power Purchase Agreement	No Power Purchase Agreement and Purchase of Electrical Generating Equipment	[illegible]	[illegible] Value: 3/3	[illegible] Value: 2/3	Credit 15.0: Greenhouse gas emissions; Credit 16.0: Peak electricity demand reduction; Credit 21.0: Sustainable products. Value: 3 credits	[illegible] Value: 5 points + 1 requirement	[illegible] Value: 2.5/3	[illegible] Value: 2/3	[illegible] Value: 3/3	[illegible] Value: 2/3	5.5	4

In general, the provision of a predefined framework assisted students in thoroughly assessing how to best meet the specifications outlined by the client, and address conflicts of interest in terms of design.

4.1.2. Importance of feedback mechanisms

The receipt of feedback from the client and consultants was found to be very beneficial for all students participating in the design studio, serving as a primary means to measure design progression and adherence to the design brief. Student designs were iterated based on weekly feedback from consultants, with semi-regular feedback from clients highlighting aspects of the design which align with the brief, and indicating features which have not been considered or which diverge from the provided design specifications.

The interdisciplinary background of the consultants and client led to important discussions/feedback on the suitability of design solutions. For example, the social and cultural impact of using locally sourced materials for the interior façade, the impact that these materials have on the internal environmental quality (IEQ) and thermal performance, and how certain techniques to integrate these materials can assist with supporting the structure. The expertise of the consultants assisted the students with implementing these aspects on a technical level, while the clients' insights enhanced student understanding of how these inclusions are culturally positive and give a greater sense of ownership and belonging to the building owners and occupiers.

The provision of feedback was found to be more difficult given the limitations placed on the studio delivery (discussed further in Section 4.1.4). While feedback was provided to each group on a weekly basis, interactions with the consultants was brief due the class size, and the interactions were to the cohort, rather than an individual group level. The online delivery mode also limited interpersonal discussion between students due to Zoom discussions being limited to a single presenter at any given time. Due to these limitations, students were encouraged to post questions on discussion forums (to engage with studio tutors and peers) and to reach out to consultants outside of the weekly studio sessions, though students appeared hesitant to engage in this manner (discussed further in Section 4.1.5). Students became more familiar with the studio and the consultants as the weeks progressed, reducing their nervous demeanour and improving their engagement, though by this point feedback is of lesser importance as the design is closer to a finalised state and changes are more difficult to implement.

Prior IDS's undertaken at UOW revealed that larger working groups (approx. 10 students, two consultants and one studio tutor) achieve more positive feedback amongst students, consultants and studio tutors compared to smaller working groups. Similar principles were implemented for this design studio, with slight alterations due to the variation in delivery mode (i.e. online). From observation, a greater degree of detail can be achieved (via online delivery) when engaging with smaller working groups (i.e. approx. 4 students and one consultant), though other student groups are left in isolation without supervision/guidance for a time (e.g. 20 minutes). Though a lesser level of detail is reached, similar weekly feedback can be provided to each group when a larger working group is maintained, in addition to students gaining insights on other groups designs and strategies, which they may choose to use or adapt for their own design.

While many factors appear to impact the student outcomes, feedback is of key importance. It has been seen that outcomes are maximised when students engage to a greater extent with clients, consultants, studio tutors and their peers, and while some are more comfortable engaging in earlier weeks, most students tend to engage to a greater extent when they become more familiar with the design studio format.

4.1.3. **Interdisciplinary communication**

Though there were divides between the specialisation of different students, there were no evident communication issues observed between the student participants. It should be noted that the design studio was run as a second-year elective subject, with students only beginning to specialise in their chosen disciplines in their second year (i.e. the first year of engineering is common across all engineering disciplines at The University of Wollongong). Though the students were undertaking integrated design practices, their education within their chosen discipline had (likely) not yet biased their design processes and focuses. These biases were more prevalent in the older students who are further along in their education (e.g. third and fourth year), though the older students amalgamated within groups did not appear to bias the design practices of the team as a whole.

Additionally, the students focussing on architectural studies are undertaking a Bachelor of Architectural Engineering, and as previously mentioned, still complete the common engineering first year. These students, though having a greater focus on architectural design, have a technical background to better assist them with communicating with engineers of other specialisations (e.g. civil, structural, mechanical, etc.).

A greater level of interdisciplinary communication was witnessed between the students and the consultants. When students interacted with the consultants, it was observed that the greatest difficulty occurred when conversing with the architectural consultants, though these obstacles were not significant, and were overcome with further elaboration. This is likely due to the architectural consultants not necessarily having a technical background or training in engineering, though their previous experiences working with engineers assisted in conveying information to the students. These misinterpretations were not apparent during regular conversations, only when architectural practices, concepts and techniques were discussed. Such difficulties were not witnessed between the engineering consultants and students. This interaction indicates that, while engineering and architectural terminology and practice may differ, these barriers can be easily overcome with patience and a desire to collaborate.

4.1.4. **Studio delivery methods**

Due to the outbreak of Covid-19, lockdowns were imposed over the greater Sydney area (including Wollongong), resulting in a transition to online learning for the totality of the design studio. Students were still able to participate in the studios in a virtual environment, with consultants and clients also participating in the virtual classroom. While remote deliver offered some advantages, there were also apparent limitations in this method of delivery.

A fully face-to-face learning environment allows students to communicate in person with consultants, studio tutors and peers, increasing their ability to participate in discussions. Alternately, remote delivery does not support this same level of engagement, though certain tools were implemented to try and improve this impairment. Zoom, the communication medium for online delivery, facilitates classroom discussion and instruction, but limits conversation to one individual at a time. Zoom offers breakout rooms to assist with facilitating smaller discussions (i.e. for student groups, for one-on-one conversation between students and studio tutors, etc.), though participating in these conversations excludes the participant from other breakout rooms. This limits the engagement of consultants to one particular group at a time, hinders class-wide discussion, inhibits potential group development opportunities, and restricts the degree of observation for studio tutors over groups to gauge potential issues or delays with design progression.

Miro (a digital workspace) was suggested by a consultant as a tool for students to work together and share ideas. This resource (especially during earlier design stages) was very beneficial in allowing students to work collaboratively on their preliminary return brief and initial building footprint. Collaboration became a more difficult prospect when transitioning to modelling, energy simulations and detailed design, with students tending to work in isolation and share results. While this is what was necessary to complete the work, it does not adhere to the integrated design philosophy. While integrated design may be possible when working remotely, observations appear to support that isolation from project partners and team members restricts the potential for integrated design outcomes.

4.1.5. **Communication outside the studio environment**

Access to the consultants was possible outside of the design studios, however students showed little-to-no initiative in engaging the consultants outside of scheduled class times. This behaviour has been witnessed in previous design studios, and therefore does not appear to be an effect of remote learning. What is interesting to note is the interest the students displayed in requesting (during studio sessions) more interactions with the client, which the client was happy to accommodate. To ensure the client was not overwhelmed by student questions outside of the studio, the cohort was asked to use the Moodle discussion forum to direct questions to the client out of class time, so the studio tutors could facilitate this interaction. This was infrequently used, again indicating a lack of initiative. The students appeared to be completely capable of developing their design as a team, though they were not fully utilising their greatest resources, the expert consultants and client. The specific reasoning for this is unknown, though it could be due to several factors:

- Working professionals – Students may have considered the consultants to be busy individuals and hesitated in contacting them as they did not wish to interrupt their work.
- Open forum communication – The Moodle forum on which the students were asked to post questions was open to the whole class. Students may not have asked questions due to embarrassment or shyness, similar to the hesitation in asking questions seen in some students in a face-to-face classroom setting.
- Classroom dynamic – The IDS is a classroom dynamic unfamiliar to the students, and though information was provided to the students, they may have remained unaware that they were able to discuss designs and ask questions of the consultants outside of the classroom setting.
- Lack of initiative – Students may not have the initiative to seek out additional support, believing that they are capable of completing the design as a team.
- Lack of motivation – Completing learning in a fully online learning environment can be difficult for educators and students alike. While students were diligent in undertaking their designs, they may have had reduced motivation to undertake additional work.
- Other commitments – While remaining attentive and participating in classroom studios, this is not the only subject being undertaken by students. Priorities shift as deadlines loom, meaning students may not have sufficient time to reach out to consultants and clients. This factor could be compounded by other factors, such as work.

Numerous factors could be responsible for the lack of communication seen throughout the studio between students and consultants/client. The reasoning behind this may not be completely due to the actions (or inactions) of the students but may also (in part) be due to the actions of the researchers/studio tutors. Previous experiences in integrated design studios indicated that the clients, while thinking the IDS was beneficial to students, were not as involved in developing student designs. It was presumed by the research team that a similar attitude would be seen in the client for this design studio, though this is not necessarily true. The client may have wished to be more involved, though this was not conveyed or misunderstood during preliminary meetings with the client. The relationship with the client throughout any design is of great importance, and their involvement and feedback paramount. While students should be further encouraged to reach out to their client in the future, it is advised that the educators running a design studio also continue to engage with the studio client and ascertain the desired involvement of the client at studio inception.

4.1.6. **Expectations vs. Reality**

The Integrated Designed Studios have been developed in such a way as to give students the opportunity to work on a project with a sincere client, an authentic client brief, and experienced professional consultants to offer advice and guidance. While the design studio resembles a legitimate project and offers students the opportunity to undertake a credible design, the reality is that it is students undertaking the design in a classroom setting.

To mitigate the potentially overwhelming expectations that the students may envision, the design studio has been prepared in a manner that assists in guiding students through the design, with assignments set as key milestone deliverables (i.e. return brief, preliminary design, finalised design). This undertaking is also to provide a structured process for the students to complete the necessary work in a fixed 13-week university semester.

The involvement of the researchers/studio tutors in developing the studio curriculum and assessable materials may result in unanticipated and inadvertent conflict with the desires of the client and the specifications of the client brief. An example of this may be that students present the technical aspects of their design in accordance with a marking rubric to maximise their marks, whereas the presentation style and information is not what is desired from the client. Without significant input from the client in the developing stages of the curriculum, this will often lead to a disconnect between the expectations of the client, the desires of the researchers, and the necessary learning outcomes of the educational institution.

4.1.7. **Design complexity and timeframe**

As described in Section 4.1.6, the studio is structured in a manner to guide students from one aspect of the design to another, assisting with design progression throughout each week. This assistance is necessary so that a successful design is achieved. It should be noted that not only are the majority of the participating students completing their second year of tertiary education, but that most have little-to-no experience in the area of design and construction, are being educated on various building physics principles as they undertake the design, are attempting to consider alternate design perspectives in addition to their own, and are integrating cultural and social aspects within the design while being mindful of financial costs, the multi-faceted use of the building, all within a 13-week period. These compounding aspects increase the difficulty of the design studio, and while it is evidently possible to complete an integrated design, the studio outcomes could potentially be improved if certain complexities are mitigated or eliminated, for example:

- Requiring an older/more experienced student cohort (e.g. final year students)
- Longer timeframe to complete the integrated design (e.g. annual subject)
- Pre-requisite knowledge on building design/building physics principles (e.g. developing a precursor subject to establish a fundamental knowledge base to extract pertinent design information from)

4.1.8. **Relevence of disciplne at differing stages**

Consultants were in attendance within the studio environment for 12-weeks, with the first week being an introduction to the IDS, where consultant advice was not necessary. The following 12-weeks saw students undertaking their designs in a step-by-step process with advice and guidance being offered by the consultants but allowing students to complete their respective designs without significant oversight. Differing stages of the design saw the input of certain consultants being more prominent than others, with a shift occurring as the designs developed. What was observed was greater consultation with architectural consultants during preliminary design stages, with structural and ESD consultants being more consequential during mid-to-late design stages. All consultants remained involved in conversations at all stages of the design, though the relevance of some consultants was greater depending on the design stage.

Architectural guidance and advice would be of greater relevance at project inception when considering the surrounding environment, spatial assessment of the design, preliminary footprint and façade. With the exception of some involvement with the footprint and façade, Structural and ESD involvement during this period is limited, though not irrelevant. Opposingly, when progressing the design further, the involvement of the structural and ESD consultant becomes more beneficial as the structure is further developed and the technical functionality of the building is assessed. During this period, the architectural input lessens, but again, is not ineffectual. For effective integrated design to occur, all consultants should be involved in the design process throughout the projects duration, however it is still rational that the involvement of certain specialisations is more imperative at certain stages of the design.

4.1.9. **Building typology**

A previous design studio (IDS11) identified that a pre-existing structural form inhibits potential integrated design opportunity. IDS09 was opportune to examine this further, due to the site being greenfield (i.e undeveloped location) with no pre-existing structure impacting design opportunities. It was observed that students were capable of achieving integrated design proposals, though the preliminary stages of the design progressed slowly. While a pre-existing structure was seen to impede design flexibility, a greenfield site afforded too much flexibility, with students appearing to be overwhelmed by number of opportunities available for exploration. Consultants assisted greatly in refocussing students before they became too overwhelmed by choice, providing strategies (such as bubble diagrams) to examine internal spatial interactions before skipping too far ahead with their designs and missing key design criteria. The complexity of the building typology should possibly be considered in concert with the recommendations highlighted in Section 4.1.7, especially regarding project timeframe and pre-requisite knowledge.

4.1.10. **Observing researcher notes**

In addition to the general observations of researchers, observations were conducted throughout the design studios by an observing researcher who did not take an active role in the running of the studio, keeping interactions between themselves and studio participants to a minimum. The observing researcher took unbiased notes, to highlight important positive and negative aspects, to identify any additional learning outcomes relevant to the studio. These notes have been evaluated, with key findings being extracted and discussed further in this section. The complete set of notes can be found in Appendix D.

The observing researcher identified the difficulties associated with the IDS being conducted in a virtual learning environment. This posed problems for all involved parties, including the observing researcher, who was able to observe and note interactions in previous design studios (IDS10 and IDS11) due to them running in parallel, though this was functionally impossible in an online environment where (once again) two design studios were run in parallel (IDS09 and IDS12). This separation was aimed at better facilitating discussion amongst students undertaking identical projects, though this also limited the observational capacity of the observing researcher. What was noted by the observing researcher was the limited discussion in the working groups, with this likely being linked to video conferencing only being able to facilitate one speaker at a given time. This restricts tangential discussions from spontaneously occurring in parallel (as would normally be observed in a classroom or workshop). However, a greater level of sharing was witnessed from participating students (seeking feedback on their design development) and from consultants (offering guidance and leading questions).

Earlier weeks of the studio were seen to focus primarily on the requirements of the project, with students being provided with a design brief to dissect and given the opportunity to consult the client to ascertain further information. These discussions appeared to favour the challenges associated with renewable energy (given the finite budget of the construction) and methods of evaluating design solutions. Consultants were quick to emphasise the *dangers of getting caught in 3D modelling* in the early stages of design due to its potential to cause designers undue attachment to a preliminary design, impeding further design development/iterations. Due to their limited understanding of space, consultants also suggested that students use furniture to better ascertain the scale and functionality of the designed spaces. The observing researcher noted that many students/student groups did not heed this advice, opting rather to use modelling software to better visualise their designs, with internal spaces simply labelled to denote function.

As the studio progressed and students gained a firm grasp on the design requirements, questions became more technical, with focus shifting to the technologies suitable to be integrated within the design. During these weeks, it was observed that students were more interested in the advice of the consultants, utilising their expertise and knowledge to determine the suitability of researched solutions. Consultants were free with their recommendations of design tools and suitable codes which would assist students in their undertaken designs. It was also noted that conversation amongst the consultants' (or between consultants and students) became more frequent, with consultants asking leading questions to maintain conversations and *keep the discussion in the classes going*. These discussions were a continual source of knowledge for students, and while not always relevant, entertained a vast array of topics, including design of stairways, and determination of energy consumption. These discussions appeared to be aimed at provoking student interest and thought, to consider ideas or design aspects which had not previously been considered.

While it took time, by the end of the design studios the observing researcher witnessed an *openness between groups*, with students tending to be more collaborative than was seen in prior weeks. The intermediate weeks of continual discussion and sharing of knowledge made students more receptive to collaborative design opportunities, seeing them recommending ideas to one another and providing opinions. While this shift in behaviour was common, it was also common to see groups being more reliant on their models and design detailing, aiming to present a finalised design as opposed to assessing alternate solutions. Their lack of consideration of the advice offered by the consultants at the earlier stages of design were seen to limit *their ability to fully explore integrated design*.

4.2. **Feedback from participating industry consultants, studio tutors and the client**

Feedback from participating industry consultants, studio tutors and the client were obtained through conducting short interviews. The scope of the interview was to allow interviewees the opportunity to reflect on the design studios and discuss any factors which either facilitate or impede the integrated design process in either the environment of the design workshop, or in industry itself. Throughout this questioning, the importance of integrated design was explored in a tertiary setting, examining the benefits that this may provide to students and industry in the future. The interviewees were asked to reflect on the principals which worked or did not work in the design studio setting, and what changes may be beneficial to include to maximise the potential opportunities afforded to all participants in any further IDS's. A full set of transcribed interviews can be found in Appendix B.

4.2.1. **Integrated design drivers**

The interviewees offered a diverse view on what they believed to be the key factors influencing the integrated design process. Some of these views related specifically to the design studio, while other views related to factors affecting integrated design in a general sense. While some may be considered more relevant than others, all are important factors worthy of consideration. The primary factors identified were the client brief, diversity of experience and expertise, finances, and engagement//communication. While this list of factors is not conclusive and each item alone is not imperative to the success of integrated design, all are considered primary factors by the clients and consultants relating to a positive integrated design outcome. While the importance of the client brief was emphasised as being a key factor, this will be discussed in greater detail in Section 4.2.2.

A diversity of experienced experts was expressed as the most critical component necessary to undertake integrated design. While integrated design may be undertaken by one specialisation in isolation (i.e. engineers or architects), it would be seemingly impossible to comprehensively grasp the necessities of the project from the perspective of other experienced consultants from relevant professions. A diverse team is required so that experts have the opportunity to *champion their own agenda* while additionally gaining the opportunity to *consider other people's views*. This ultimately results in a balance between professions, ideally resulting in a successful design

[This] is always one of the challenges that we find in the real world, someone will… do what they want, and it won't consider anyone else's needs – Consultant 3 (ESD Consultant)

Multiple consultants identified that in the studio setting, engagement is key. This was identified as being difficult, given the online learning environment, so identifying methods to maximise student engagement and interaction is critical to successfully undertake an integrated design. Miro was identified as being a very important tool to facilitate these interactions, allowing students to share ideas and discuss designs with each other, but also to talk through the preliminary design and share ideas with the clients/consultants. Developing a method of effectively engaging with students was described as being a *hard nut to crack.* Whether the studio was undertaken online or face-to-face, engagement appears to be one of the primary metrics in determining integrated design studio success.

The successful studio thing was finding those platforms or those spaces for people to open up and share, that's true across all the studios. – Consultant 2 (Structural Consultant)

The client believed that *the number one thing is communications*, both in regard to communicating information to the designers and between the designers, but also in regard to conveying information back to the client. While integrated design between the building architecture and engineered performance is important, the client and their desires should be of primary importance throughout the design. It is necessary that communication is clear between designers to facilitate effective integrated design, though this design should not be conducted in complete isolation to the client.

I think communications is important and I think there was a lack of including me in things. – Client (Dr. Steve Burroughs Foundation)

Both the client and a consultant identified that financial constraints are also an issue impacting integrated design success, not just in industry, but also in the classroom. The client identified that, while they approved of the studios, it was recognised that *it all comes down to money, and the ratio of students to staff.* Limitations on this aspect result in limitations on student engagement and interaction, and ultimately final outcomes. This is a parallel to industry, where financial constraints influence the degree of success on integrated design outcomes.

4.2.2. **The client brief**

Client briefs can be varied in what is provided, ranging from vague and flexible, to restrictive and detailed. Interviewees appeared to disagree on the level of detail included within the client brief, with opinions ranging from the briefs being sufficiently detailed through to inadequately detailing the necessary information to complete a successful design.

One architectural consultant found the client brief to be an improvement over the brief provided by the IDS running in parallel (IDS12), while the other architectural consultant believed the opposite was true. Though there is no definitive way to say which is true, it was still found that the client brief was lacking in detail, with a consultant expressing that *clarity in the brief is critical.* This was further emphasised, due to the limited time in which the students had available to work on their designs. An architectural consultant highlighted the follow-on effects of an unclear client brief. The lack of clarity in the brief affected student's ability to *hit the ground running in terms of what they're trying to achieve*, which impacted their ability to perform a comprehensive site analysis, and when compounded with a short time frame, affected the quality of the preliminary design.

There was a lot of toing and froing because the brief wasn't clear – Consultant 1 (Architectural Consultant)

…in the real world, you don't get briefs that are so vague – Consultant 4 (Architectural Consultant)

A similar assessment was provided by an ESD consultant, though described this as a *good experience for the students.* To elaborate, the consultant explained that in practice, the desires of the client or what they ask for are not necessarily what they mean, with part of the challenge being to *understand what it is that you are really looking to do.* Another consultant described the brief as *vague* and *ill-defined*, but in a good way. These open-ended briefings can be beneficial, as they reflect the reality of industry, where you are not necessarily provided with a detailed overview. Client briefs typically require further investigation and interrogation (echoing the statement of the ESD consultant), which is what the students endeavoured to undertake within the studio when the client delivered the brief. Similar sentiment was shared by the architectural consultant, where they described the assembling of a client brief as a *whole skill set in itself*. If the client brief is highly detailed, then this does not necessarily reflect what is typically provided in industry. If the brief is less detailed, then your design outcomes may be limited due to the limited studio time. These mentalities around the ‘level of sufficient detail’ are mutually exclusive, and bias opinions surrounding the quality of the brief. The consensus in interviewees’ opinions is that briefs need to be developed through engagement between the designer and the client, with a sheet outlining the brief being nothing more than a starting point in the design process.

I think [the client brief] is necessarily messy in that way. And the [architects], they did a really good job with students, helping them to work through that – Consultant 2 (Structural Consultant)

The opinion of the client was also of interest, as they were unsure if the brief had been directly provided to the students, or if the researchers/studio tutors had refined or altered the original brief provided. These questions were raised by the client due to their belief being that students were unable to meet the provided brief, in addition to not addressing certain aspects of the client brief. These concerns were warranted given the information delivered via the final student presentations, though the students ability to meet (or fail to meet) the client brief should not be judged on this factor alone.

“*I know that I wrote a basic brief... Did they take my words and rewrite them into a different type of brief? I don't know” – Client (Dr. Steve Burroughs Foundation)*

As discussed in Sections 4.1.5 and 4.1.6, interactions occurred between the client and students on a semi-regular basis, but not as frequently as would be expected in industry. The infrequency of these interactions likely resulted in students deviating from the client brief, or believing key factors had been addressed, and focused more on complying with the assessment outcomes rather than the client brief itself. This lack of engagement and the size of the project resulted in students being required to interpret what factors were most important in a short period of time. This ultimately resulted in students following the assessment as closely as possible to maximise their potential subject marks. While the client brief should be at the core of the design process, this document alone is not sufficient, requiring a greater level of interaction with the client to ascertain whether the core design principles are being achieved.

The client and consultants did not have a unanimous consensus on the client brief, with some finding it good, while others found it poor. What was agreed was that further consultation with the client is necessary to determine the essential details to include within the design throughout the entirety of the design process, with a key focus on this in earlier stages of the design. Given the time constraints of the IDS, this may need to be undertaken by the subject tutors/research team prior to the IDS to give students a more comprehensive design guideline so as to not waste limited time on determining these key details before design commences.

4.2.3. **Consultants and studio tutor contibutions**

Both architectural consultants found the greatest assistance they were able to offer the students was in understanding and utilising space. The client brief required a multi-purpose building, capable of facilitating numerous practices in a finite space. The consultants’ ability to assist students in evaluating the functionality of and interconnectedness of these spaces was invaluable in determining a layout that was functionally, culturally, and socially appropriate. However, it was also remarked that the push to use technology to visualise and present the building impeded design development.

While some consultants found their technical knowledge and skills to be their greatest asset, others found their ’soft skills’ to be a greater contributing factor. Multiple consultants found their greater contributions were in discussions with the students, whether these discussions were directly related to the project or not. Being able to relate questions back to solutions implemented in industry gave students insight into how industry operates while also seeing how technologies worked (or failed to work) depending on the requirements of the design, the functionality of the space, or the location in which it was designed. Students can obtain a single answer if a client gives them a direct response, though they gain greater insights and understanding if a conversation occurs outlining *how it works, why it works, what climate it would/wouldn’t work in*. Alternately, consultants can also ask questions of the students, to generate further thought on their designs and answer why they believed their design would/wouldn’t work. In justifying their own design, students could find flaws and make the conscious decision (largely on their own) to adjust the design or overhaul it completely.

I think my value was in guiding the group, getting all the students to talk, and also the consultants – Consultant 4 (Architectural Consultant)

…being a part of the conversation is a valuable contribution of a consultant – Consultant 2 (Structural Consultant)

One consultant added that it is very important to have these conversations, as many people recognise that the process of design is not natural to anyone. Design is further described in this case as an *intangible thing that you just sort of learn by watching people*. Every project is unique, with the team being comprised of different people, the locations changing, the functionality varying and the developer outlining unique requirements and constraints. While there may exist a rough outline regarding the key steps that must be undertaken, there is no rigorous set of guidelines which you can follow. Design is *s a learned process*, and is improved by *sitting with people and interacting*. Through having consultants facilitating discussions with students and with one another, it exposes students to the types of discussions which occur through a typical design process.

While the client found that the involvement of the consultants was beneficial for student learning and understanding, it was also iterated that the methods that were imparted on the students don't *really hold true in remote Australia*. This was not necessarily to state that what the consultants were explaining or what the students were accomplishing was wrong, rather that remote Australia is a different place with different rules and customs, and the expectations of the typical building industry differ from more metropolitan areas. This statement reinforces the comments of some consultants, in that design is intangible, with the process differing with respect to location and client requirements and constraints.

4.2.4. **Critical decision making**

Interviewees offered a variety of opinions regarding what was critical in the decision-making process. One consultant offered that a key question needed to be answered before further progress could be made: *"What are we doing with this space?"*. Students, who were not necessarily familiar with the process of design, needed to truly understand the answer to this question before meaningful design could take place. *Once you've answered that question, all the options for environmental design solutions just flow from it.* In this sense, the involvement of the architectural consultants was very beneficial, assisting the students with an understanding of interior spatial interrelationships as well as assessing the site and its surrounds.

A similar thought was expressed by an architectural consultant, as the students did not have a full appreciation of the functionality of the spaces they had designed. Many of the student designs had a space with a label outlining the 'function' of that space, with little understanding about how the occupants use it, how they *move around* it, what actually made the space functional. The consultant found this process of *learning on the run* beneficial, as it gives the students a greater appreciation/sensitivity to the space, though further elaborated on this being a skill developed over time, where an understanding is developed of *effective use of space* and how the space works.

…we've got these vacuous spaces, where they've got no idea of how those spaces are being used, for the simple task of actually putting furniture on the plan. – Consultant 1 (Architectural consultant)

Time needs to be invested in understanding the *analysis of space, ergonomics, movement* to fully appreciate this process, something the architectural consultants specialise in, offering valuable guidance for students. As commented by the structural consultant, *the architects contributed a lot in that studio… when you have these blank canvas projects where you do need to invent a lot of architecture, then, it was really great to have them there.*

It was also commented that it was very beneficial for students to have fundamental understanding of the cultural and social requirements when designing for an indigenous client (or in this instance, a client representing an indigenous group). The client was found to be greatly beneficial in instilling this critical knowledge within the students, discussing the *specific cultural things that [the design] needed to address.* This is especially important *particularly when there is an indigenous overlay, documenting all the nuances.* Integrating these cultural aspects within the design provides a sense of meaning and ownership to the community, rather than another structure designed (and built) by *a white fella back here on the east coast*. It is important that students take the time, particularly during the preliminary design, to understand the people and the community, what is important to them, and integrating those aspects within the buildings design. This critical process was praised by the client, who believed that the students successfully *looked at their values and looked at their totems. They looked at their cultural aspects… I think that was done very well.*

Consultants found difficulty in not *spoon feeding [the students]*, rather letting them make the decisions themselves, though this was made difficult when students were unsure how to proceed or were struggling to create their own designs. In these instances, consultants asked leading questions to stimulate thought, with this occasionally being done with the intention of leading them down an incorrect path so students could learn for themselves why that idea would not work.

…when they were drawing blanks, what we try to do is ask directed questions, or suggestive questions. Sometimes down the wrong path deliberately, to send them on the trip to work out that that's not a real solution, but also to spark their interests and get them excited about what's going on. – Consultant 3 (ESD Consultant)

Students were often found to be splitting work for assessments (which is typical) to complete everything on time. One consultant thought this was excellent, an efficient *division of labour*. While this was recognised as being less than advantageous in previous IDS's (IDS10 and IDS11), the earlier level of education common among the students (e.g. being in 2nd or 3rd year) seen in this IDS often meant that even though a small level of specialisation had already occurred, students were still being pushed into unfamiliar areas. This allowed students to specialise in this project and report back to their team, to develop the design with fact driven discussion with feedback from the consultants to confirm if their understanding was correct.

The students were also provided with an evaluation matrix, so they were better able to compare technologies. A general outline was provided, with the students having to develop the details of the matrix and determine what they believed to be an appropriate weighting system. Again, the consultants were a great benefit in this regard, as more detailed explanations of different industry metrics could be described (i.e. NABERS, Greenstar, etc.) which could be incorporated within this framework. These metrics gave tangible values for direct comparison of strategies or technologies which may not usually be comparable, providing students with a tool to justify their decisions.

4.2.5. **Aesthetic and functional compromises**

When as asked about the balance witnessed between the aesthetic and functional aspects of the design process, the responses were varied between interviewees. Interestingly, those with an architectural background were of a consensus, that they didn't necessarily witness the balance between these aspects of the design, while those with an engineering background agreed that the students had successfully balanced these elements.

An architectural consultant found that, while there was collaboration between engineering and architecture, there was not necessarily aesthetic compromise to the structural form. *Calculating PV areas… that then dictated roof form* was the only example of balancing architectural and engineered design, otherwise the consultant failed to recall a single *engineering solution modified by an architectural imbibe or visa verse*. One opinion as to why this occurred was due to the lack of diversity in the student cohort. *They were all engineers of a certain type… there weren't even any service engineers and there weren't any architects.* It was also noted that in this design studio, a greater focus was placed on functional outcomes due to the assessments, with a lesser importance placed on the building aesthetic. An alternate opinion is that a lack of aesthetic and functional compromise was witnessed due to the lack of an *iterative process* typically seen in a design workshop, due to the nature of the online teaching format. Where students could normally work on a design, receive feedback, and iterate (in a typical design setting), students received larger chunks of feedback within the studio, and further developed the design outside of class, somewhat excluding the consultants from witnessing any type of design iteration or development.

To be honest, I didn't see the impact of either of engineering or architecture… - Consultant 1 (Architectural Consultant)

Agreeing with the observations of the architectural consultant, other consultants found that there was not necessarily an observed collaboration within the classroom setting, though this did not appear to impact the consultants' conclusions that students were able to successfully integrate aesthetic and functional aspects with their designs. Designs considered a plethora of conditions, ranging from size, location and orientation of site, cultural nuances, climatic conditions, prevailing winds, etc., with students incorporating this information into the architecture and engineered design. Many of these aspects are typically considered from an architectural perspective, with an engineered solution later being adapted based on aesthetic. In this instance, students were able to consider how these aspects will affect indoor environment quality, thermal comfort and interior functionality, utilising them to their best effect, rather than adapting an existing aesthetic solution to address these concerns.

They weren't setting the architecture and then putting the engineering in on top, which is what happens 99% of the time in the real world of design – Consultant 3 (ESD Consultant)

Examples were provided by the consultants to support this, primarily focussing on the use of light on interior spaces and how this could be maximised while also considering the impact of heating loads and how this may be balanced. While this may not show significant innovations, it does exemplify the student's consideration of aesthetic and interior functionality while also being mindful of energy usage and occupant comfort. Additionally, an engineering consult was complementary of the student work regarding the use of software, and how this was applied to visualise the designed aesthetic. While the architectural consultants were critical of the use of this software, being described as detrimental to the design process, this still shows the advantages to its use in developing the exterior façade and incorporating cultural principles outlined in the design brief.

…I think what they came up with is pretty good. Sympathetic, as they say, to the brief. – Consultant 2 (Structural Consultant)

4.2.6. **Integrated design definitions**

The understanding of integrated design was fairly uniform from the perspective of the consultants and studio tutors, however the client's opinion differed. The client's comprehension of integrated design was combining technical design aspects and cultural symbolism, developing a greater meaning and sense of ownership between the design and members of the community. For the IDS, this was not the desired definition for 'integrated design', however it can be understood how this perception was achieved. This understanding led to the client stressing the importance of *listening more than you talk* when interacting with members of the community, to truly understand what they want and how they want it accomplished.

Similar principles were repeated by the architectural consultant, in listening to and understanding the behaviours, desires, and aspirations of the client, and how those key factors drive the design. These were found to be ideal traits for design generally, but for integrated design specifically, the architectural consultant specified that not only should collaboration be an important aspect early on, but the design would be considered a successful integrated design when an optimal outcome is achieved *both in terms of architecture and engineering*.

So, starts early, obviously collaborative, there's respect, and that all parties at the end feel that they've achieved the optimum outcome – Consultant 1 (Architectural Consultant)

These sentiments were echoed by all other consultants, being described as where everyone is *invested in doing a good job and working holistically*. It was specified that not only does a client need to be willing to undertake the process (which can be a challenging task in and of itself), but the consultants also need to be capable and willing to make the *extra effort to collaborate, rather than keeping [their] head down and doing the minimum that you need to do.* Additional to working in a collaborative and holistic manner, it is important that all individuals invested in the project have *the opportunity to come in and challenge the design*, meaning that all voices participating in the design process are equal, with all design decisions being debatable and requiring justification. Interestingly, the ESD consultant described that a successful integrated design has been achieved when all parties are *equally unhappy about the final design*. While this sounds counterintuitive, the elaborated explanation outlines that all parties have desired outcomes, but compromise in the design is a necessity. Architects, engineers and the client alike need to compromise equally, fighting for design aspects they require, while relenting on items less necessary to their vision. *Integrated design is where everybody is suitably compromised to a point where sustainability has been balanced, everyone's pure drivers have been negotiated and met to a level that works for everyone*. In offering a different viewpoint, if all of the invested parties are equally unhappy, then they are all also equally happy with the final outcome

…its about having the appreciation for the bigger picture – Consultant 2 (Structural consultant)

4.2.7. **Constraints impacting integrated design engagement and colaboration**

A number of consultants and the client commented on how a virtual environment increases the difficulty of undertaking effective integrated design. There are difficulties in communicating design aspirations and critical features (from a client perspective), in collaborating, and discussing design possibilities within a team setting. While the client has engaged in remote learning previously (with students in the Czech Republic), this was expressed as being incomparable to teaching a class where every student is separated, with limited engagement opportunities. *[Remote learning] must be extremely difficult for all of you (i.e. researchers and teachers). It is from me. I think if I could be in front of them, I would certainly have given them a lot more.* Similar sentiments were echoed by the consultants, in that *the current context that we're working in made that more difficult than it usually would be.* Where normally, a design or concepts would be able to be workshopped in person, iterated, and developed in a much more productive environment, the studio became more of *an hour or two's conversation, and then away for a week, and then whatever direction that had taken*. This was found to be a less fluid and dynamic process, due to students becoming attached to their designs, with feedback from clients/consultants being more critical due to their needing to respond to a weeks' worth of work as opposed to a shorter design window with numerous iterations.

Face-to-face engagement allows students (and clients/consultants) the opportunity to point at certain design aspects, to interact with drawings, and to further elaborate in separate discussions with individual students/student groups. These types of collaborations are greatly hindered in a virtual environment. *Meeting in person and physically drawing and having workshops in person, I think there's just something there that you don't get online*. A consultant recommended the use of Miro, a virtual interactive workspace, which assisted in the collaborative design process, but only on a preliminary basis. When comparing to the design studios previously undertaken at UOW (IDS10 and IDS11), a virtual/remote learning environment does not appear to prevent integrated design from occurring, but is a detriment to the overall process.

Similar parallels can be made to industry, in that virtual collaboration is a hindrance to integrated design. *Having the luxury of being able to do video conferencing and video workshops is a barrier to that kind of collaboration.* Face-to-face engagement between clients and consultants or between teams of consultants allows for ideas to be workshopped and adjusted, drawings to be shown and discussions to develop and progress in fluid manner. Video conferencing is very rigid in its inability to show and share ideas and allowing only one party to talk at any given moment without discussions becoming confusing. In this sense, technology is a hindrance to the design progress. While offering employees the flexibility to work remotely, it becomes a *barrier of convenience*.

The topic of technology (in the teaching environment) was also raised as being a hindrance to design development. While this was raised by the architectural consultant, a similar concern was also raised by the client. Both were of a similar opinion that students began developing a digital model before the design had been fully refined and developed. This approach, while seemingly giving you a better visualisation of your design, also results in a feeling of investment, in being locked into the chosen design, where thinking becomes more limited.

I'm seeing architectural students just jumping in there, getting into CAD and whipping up a model before we sort of refined it. – Client (Dr. Steve Burroughs Foundation)

I do think technology in the early stages is a limiting rather than enabling factor… – Consultant 1 (Architectural Consultant)

Similarly, a consultant found that the modelling was *very impressive*, but this can also be a limiting factor for some students. For some, modelling came naturally, with some of the final models being very detailed, but some found this process difficult. *Modelling stuff and analysing it is just hard, especially if you're trying to learn it by yourself.* In this regard, the students were again limited by their online learning. While resources existed to assist the students in their learning of the software, they were largely undertaking this study on their own which can be a difficult exercise, and can limit design development as crucial time is spent learning software that may or may not assist the students with their final designs.

[Modelling] is something that takes years and years of making mistakes to get any sort of confidence in – Consultant 2 (Structural Consultant)

A misunderstanding of sustainability has also resulted in technologies inhibiting integrated design. While integrated design encourages engineers and architects to work collaboratively to achieve more holistic design outcomes, it has been stated that students tend to examine potential technologies as the primary solution to their problem *rather than use sustainable design philosophy*. The reasoning for this is likely time, in that students do not necessarily have an adequate period in which to develop a holistic design. Instead, they approach the problem with a *checklist*, and tick off items that are typically found in more sustainable buildings rather than considering the building as a whole. This may also be due to the design brief and assignment outcomes, where students make these inclusions to accommodate the requirements that they have been provided, rather than truly understanding building. While the technologies imbedded within the design encompass passive and active strategies, these tend to focus on active technological solutions and neglect more passive design potential.

They're considering each element discreetly, but not necessarily holistically about the overall building – Consultant 3 (ESD Consultant)

Students also appeared to focus on embedding as much technology as possible to achieve a greater renewable energy fraction (REF), including more photovoltaics and batteries, and more efficient HVAC and lighting systems, though they did not stop to *consider the flow-on effects to design considerations*. It was assumed (by a consultant) that this was likely due to a lack of experience on the student's behalf. While in keeping with the design brief to be 'sustainable', this did not balance with the monetary constraints of the client and neglected to acknowledge the continual maintenance costs of these sophisticated systems. This is also likely due to disunity which existed between the client brief and the assessments provided by the studio tutors, which had a greater focus on REF and active systems, shifting focus away from the brief.

Finally, multiple consultants added that money is a large barrier to the process, where often, a client isn't interested in investing additional money into a project unless it's necessary. Additional costs associated with integrated design quickly add up, especially with the additional meetings that are occurring. Consultant's time can be quite costly, so the cost of the numerous meetings required to achieve integrated design is *really expensive*. Another consultant added that if a client is cost driven, then the language used to talk with them is different, explaining how *sustainable design will save them money, or increase the value of their asset, or de-risk their asset*. While this may result in the necessary funds to undertake an integrated design, *just throwing more money at it* does not guarantee a successful integrated design. While money offers a very tangible barrier for people to not undertake integrated design, it also requires motivation and drive which many professionals are not willing to invest. *Everyone's pressed for time, and they don't have the money. It not always that you have the conditions were you can fully invest lots of emotional energy in making something really good.* While integrated design is an idea for many, it can also be very difficult, requiring substantial effort. It can happen when the conditions are right and a team is motivated, but the difficulty comes in identifying when the opportunity exists, when the team has sufficient drive, when funding is not an issue, and when it can be undertaken from design conception.

Sometimes you get a project where everyone is on their A game and wants to do a really good job and keen to collaborate. That's when it goes well – Consultant 2 (Structural Consultant)

think in this case, product of time, product of the technology, limitations of only meeting over zoom … and probably partly too that you've got engineers struggling in a different realm in terms of the architectural planning – Consultant 1 (Architectural Consultant)

4.2.8. **Value of integrated design experience at university**

While many of the consultants and client offered conflicting sentiments regarding many aspects of the studio (e.g. the client brief, student outcomes, constraints, etc.), all of the interviewees offered unanimous agreement that the integrated design experience was overwhelmingly positive for students undertaking higher degree education.

I think that if I was provided the opportunity to do more of this stuff it would've been a great benefit to the way that I work. – Consultant 4 (Architectural Consultant)

The IDS gives [students] the opportunity to… appreciate someone else's perspective, someone else's philosophy, which gives everyone a leg up – Consultant 3 (ESD Consultant)

While the consultants praised the design studios, many reflected that the studio was not perfect, and that further development was required to improve the outcomes for students and the value for invested clients.

I think [the studios] can really be developed. I think it's going to take a while, but I believe that it could come to the point that students are absolutely going to be queued up to get into that studio – Client (Dr. Steve Burroughs Foundation)

…but in a short timeframe, what the learning objectives are and how you make the most of that in the time, probably that's where it needs further thought – Consultant 1 (Architectural Consultant)

Though additional work may be required in further refining the content of the studios, all consultants (and the client) recognised the many values offered to the students through such a program. While the intent of the studio was to expose students to integrated design practices, consultants also identified that these practical subjects give students the opportunity to decide if this is what they want to pursue following the completion of their studies, while also providing students a competitive edge over their peers when applying for graduate positions.

I'd definitely continue to look to hire from the students through this degree – Consultant 3 (ESD Consultant)

…those studios are a chance for me to find some young spark and see if they take an interest. Then it's a chance for me personally to give them some guidance and to get them on their way if they're keen on that type of thing – Client (Dr. Steve Burroughs Foundation)

4.3. **Feedback from participating students**

Feedback from consenting students was obtained through conducting anonymised surveys which students could voluntarily complete. The students were asked in a series of question to rank their various experiences within the IDS and give written feedback in response to the following criteria:

- Understanding and experiences of environmental and sustainable design
- Factors impacting integrated design
- Information provided via the client brief
- Personal assessment of consultant involvement
- Balancing engineering and architectural priorities

Through evaluating the responses of the students, these factors can be assessed to determine if the student participants found the IDS's beneficial overall, what experiences were most beneficial, and if any aspects of the IDS should be adjusted to improve student interaction and engagement in the future. For a full breakdown of student responses, please see the Appendix C.

4.3.1. **Environmental and sustainable design**

The following responses relate to Questions 1, 2, 6 and 12 from the student survey found in the Appendix C

Of the students who participated in the survey, 17% had never (prior to the IDS) participated or experienced involvement in either environmental or sustainable design practices, with the opposing 83% stating that their familiarity ranged from *Somewhat* to *Moderately familiar*. Due to the anonymization of the survey, it cannot be determined if there are any commonalities between these participants (i.e. studying the same major, prior experience, etc.). It is also unknown to what extent these students have previously engaged in *Environmental Design*, with this being a self-assessed response.

Based on the experience gained within the IDS, students were asked to select which options they believed were key design-drivers affecting the success of environmental design, specifically relating to renewables and zero-carbon. The responses to each of these factors is broken down in Figure 4. Of the five options available, *"Imagination and creativity"* was selected by 100% of respondents, highlighting the believed importance that these factors definitively play an integral role in successfully achieving renewable/zero carbon design goals. Alternatively, 83% of respondents also found *"Software skills to simulate and analyse building performance"* to be of great importance. While the other three options were only recognised by 67% of respondents, this does not infer that they are any less important in successfully undertaking environmental design. While 33% of students may not consider these factors (*Existing expertise, Technology knowledge,* and *Time*) to be as essential, most students still found these aspects to be crucial.

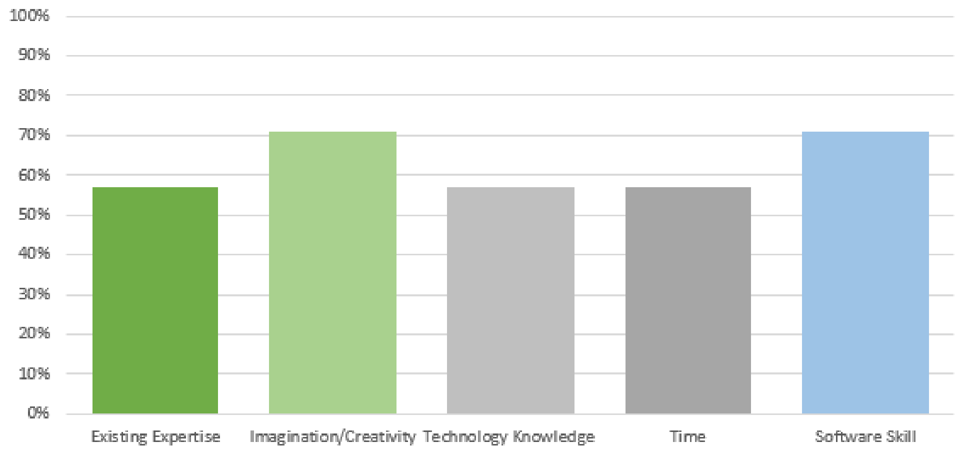


Figure 4: Simplified breakdown of student responses (Student Survey - Question 2)

It was of interest to gain further insights into the mindset of the participating students, to better understand where they drew their design inspiration from. When asked, many sources were offered which all provided some form of inspiration, with many of these being resources directly provided directly to the students through the IDS (client brief, assignments, example return briefs, etc.). Through their own initiative, students discovered case studies of *designs used in similar regional and climatic settings* drawing on technologies, materials and strategies that have a proven performance history within these regions. Some of these case studies were also for indigenous clients or groups, and while the cultural practices of these groups may differ from those at Lightning Ridge, these case studies provided insight into how indigenous culture can be addressed and incorporated within sustainable buildings. Students also examined innovative design trends and current practices *around the world* to gain greater insight into the current state of sustainable design.

Following on where inspiration was drawn from, the question was asked to ascertain where students had the greatest struggle in advancing their sustainable designs. Responses were limited, though the most distinctive response related to imposing net-zero energy solutions on a pre-existing design. It appears as though students were initially unaware of the net-zero energy requirement at the preliminary stages of the design and needed to alter their design to accommodate for this constraint at a later stage. This resulted in a *huge struggle* for student designers, who believed that there design could have been more accommodating of this design constraint had it been discussed/outlined at an earlier date, rather than being allowed to develop a preliminary design which required adaptation to meet the supplementary requirements.

4.3.2. **Factors impacting integrated design**

The following responses relate to Questions 13, 14 and 15 from the student survey found in the Appendix C

In examining the collaboration between architects and engineers, students were asked which factors they found to be the biggest barriers or constraints which existed between the two disciplines outside of the design process. Interestingly, most students found that *Inability to define joint goals* and *Knowledge gaps* were the least likely to be barriers impacting integrated design, likely believing that these aspects were able to be overcome. Only 33% of student respondents selected these factors as being seen as a barrier. Students likely saw these factors as being surmountable, as they were able to overcome their own knowledge gaps and define joint goals within their own design, and expect that these factors will not be a great impedance to more experienced consultants. 66% of respondents found *Education in isolation* and *Contractual/fee barriers* as significant barriers. As these were recognised as collaboration barriers *outside* the design process, it is understandable that *contractual/fee barriers* can impact any collaborative process, and *Education in isolation* is also understood, as design is a major area of overlap between engineers and architects. The one factor with no variation in opinions was *Time constraints on projects*, where 100% of respondents were found to agree that this is a factor significantly affecting collaboration. The unanimity witnessed in this response is likely due to the time restraints placed on the students throughout the design studio, with students likening this experience to what would be expected in industry. A breakdown of these results is shown in Figure 5.

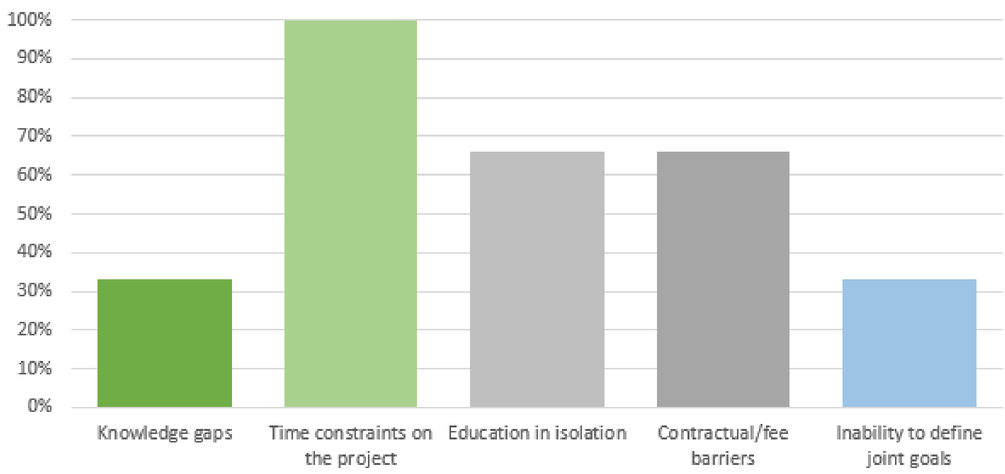


Figure 5: Simplified breakdown of student responses (Student Survey - Question 13)

Descriptions of integrated design found students having a sound understanding of this being collaborative a process requiring the input many experts to *achieve a design that incorporates ideas from all parties involved*. Further, students astutely identified the importance of continual consultation between the involved parties throughout the design process, emphasising that the client *needs to be regularly consulted to ensure no design considerations are compromised*. This is likely an observation made from limited contact with the client throughout their own design experience. This was highlighted as being of particular importance, especially when cultural aspects are to be incorporated within the design. When asked if there was benefit in learning about integrated design process' within a university environment, the response was overwhelmingly positive, with 66% of respondents claiming the experience was *Extremely useful*, with the other 33% claimed it was *Very useful*. While the learnings of the students may have varied, overall, the experience appears to have been received very well by all students involved within the IDS.

4.3.3. **The client brief**

The following responses relate to Questions 3 and 4 from the student survey found in the Appendix C

In response to the client brief, students were split in their belief of how conducive the information truly was and how well it supported their ability to achieve a balanced engineering/architectural design. 50% of respondents found that the client brief was only *slightly supportive,* indicating that approximately half of the cohort likely found that it did not contain a sufficient level of detail necessary to undertake the design. Alternately, 17% of students found that the brief was *very supportive*, with the final 33% stating that the brief was *moderately supportive*. More detailed feedback was varied, with some responses being positive and some being negative, but the unanimous consensus was that the brief was not perfect and did not address all the necessary information required to undertake the design.

Respondents found that the brief lacked an adequate level of detail, particularly around *space uses and requirements*. This can be difficult when students have little-to-no prior experience in design and will likely find difficulty in determining how large (or small) a space should be to address its required function. It was also outlined that feedback was provided on certain smaller aspects, with little commentary being offered on the *overall design*. Though this is speculative, this may be a shortcoming of the studio tutors/consultants/clients, in highlighting shortcomings of the undertaken design rather than offering praise on aspects that had been completed well.

One respondent noted that *the client brief needed to match with the client values*. The client discussed the importance of integrating indigenous culture within the design of the multi-purpose building, however the brief was very specific about the function of the building but noticeable devoid of aspects regarded as important to the indigenous population. This likely made the design difficult for the students, as they were likely making assumptions regarding the importance of certain cultural aspects while being certain of what spaces were required within the building. Further clarification of cultural priorities would be beneficial to future design undertakings. While in general the responses were not overly negative nor critical of the brief, the undertone of the responses indicates that a greater level of detail was necessary, particularly regarding spatial requirements

4.3.4. **Personal assessment of consultant involvement**

The following responses relate to Questions 7, 8 and 9 from the student survey found in the Appendix C

The consultants involved in the IDS were there to support and guide the students in their design process, being able to give industry expertise relevant to the project. The guidance offered by the consultants varied, with the students being able to ask any questions throughout the IDS. When asked about which advice was most beneficial, the responses varied, covering many aspects of the project, including (but not limited to):

- Relevant sustainable initiatives
- Feasibility of design
- Understanding of relevant codes and standards
- Sharing useful collaboration tools
- Relatable past experiences
- Insightful questions to ask the client
- Standard practice and methods

It is clear from the responses listed that the students received beneficial advice across many different areas, indicating the vast amount of knowledge and experience gained from their time spent with the consultants. This demonstrates the value of involving consultants in an educational setting. The respondents were asked to expand on this, to determine (in their opinion) how interactions with the consultants could be altered to improve potential learning outcomes. All responses specified that one-on-one consultation would be desirable, to obtain feedback more relevant to the groups' design. This was difficult to facilitate due to the digital learning environment, though is worth considering in future design studios. The other noticeable response referred to interactions with the consultants not being utilised to their full extent due to a *fear of asking the wrong questions*. The design studio is a new and unfamiliar environment for students, who have likely had little interaction with consultants previously. To maximise the potential contribution of the consultants in the future, it should be clearly outlined to the students the consultants are there to assist them not only with completing their designs, but to assist in their education.

A poll was provided to the respondents, to gauge the effect of the consultants on student learning, determining if an increase in understanding was noticed for environmental issues and associated solutions. A majority of responses were found to be positive, with 80% of respondents finding the consultants to be *moderately supportive,* with 20% of these finding the consultants to be *extremely supportive*. It is worth remembering that the consultants mostly offered experiential knowledge and were not directly teaching. If students misunderstood the involvement of the consultants, then this may have resulted in a more critical response within the poll, though more critical responses could have also been due to an unfortunate of unfavourable interaction with a consultant within the studio environment. When examining student responses to questions 7, 8 and 9 holistically, it appears that interactions with the consultants were viewed positively, with their involvement being an overall beneficial experience for student participants.

4.3.5. **Balancing engineering and architectural priorities**

The following responses relate to Questions 5, 10 and 11 from the student survey found in the Appendix C

Environmental and sustainable design solutions are imperative in the design process for both engineers and architects. Students were asked to elaborate on this, expressing what they believed to be the most critical decision-making points/questions when balancing engineering and architectural solutions. A variety of responses were provided by students, with material selection being seen to be a high priority in achieving this balance. Options such as *efficient glazing, locally sourced* materials and *environmentally friendly materials* were all considered as both aesthetic and functional aspects needing consideration in balancing architectural and engineered solutions. Identifying the importance of these selections was critical to students, with material selection impacting the operational capabilities of the structure and the aesthetic appearance.

Students also identified through this material selection that financial constraints limited their ability to undertake and achieve integrated and net-zero energy design. An approximate budget had been outlined by the client, which limited more efficient material and technology acquisitions. Students queried the limits to which the budget could be pushed, as they identified an increase in capital cost would be offset by longer term operational cost savings, and ultimately reduce the business-as-usual energy expenditures of the designed structure. Students also specified that *it was necessary to follow codes and standards* for achieving net-zero energy design, while simultaneously being sympathetic of cultural and functional aspects, and considering the structures impact on the immediate and surrounding community.

It was found through polling that 60% of respondents believed that either aesthetic or functional design aspects were *moderately compromised* through the design process when a balance was being achieved between architectural and engineering solutions. Though this response was not unanimous, it is clear that a higher number of respondents found that it was impossible to isolate aesthetic or functional compromises from architectural or engineered solutions. Interestingly, 40% believed that the design was *not at all compromised*, meaning that these respondents found that all aesthetic and functional considerations were completely decoupled when attempting to balance architecture and engineering. It may be that respondents misunderstood the question (*Were aesthetic and functional design aspects compromised when balancing architectural and engineering concerns?)* though this is only speculative.

Additional feedback indicates that respondents are of the belief that compromises can be lessened or avoided by *not designing for a detailed solution early on*. Through collaboratively undertaking design strategies such as *bubble diagrams* and *design specification sheets*, the respondent believed that more integrated solutions between different specialisations could be achieved with fewer compromises being necessary. What may be inferred from this feedback is that haste in completing a preliminary design was a primary factor necessitating compromise between designers. If additional time were allocated to completing a comprehensive design plan before a more detailed design is undertaken, many compromising issues may be mitigated.

4.4. Summary

Qualitative data obtained through observations (studio tutors), interviews (client and consultants) and surveys (studio participants) reveal that all parties view the studios as being successful across a number of qualitative factors. Generally, responses were positive, either with regard to student outcomes or the approach undertaken throughout the studio. While some of the responses were critical, these opinions highlight shortcomings which may be addressed, and were often accompanied by suggestions on how to rectify the issues encountered. The client and consultants identified a number of areas which may be improved through future iterations of the design studios, but generally agreed that practical design projects (such as those provided through the integrated design studios) were greatly beneficial to students, affording them the opportunity to improve their technical knowledge and communication in a realistic design setting.

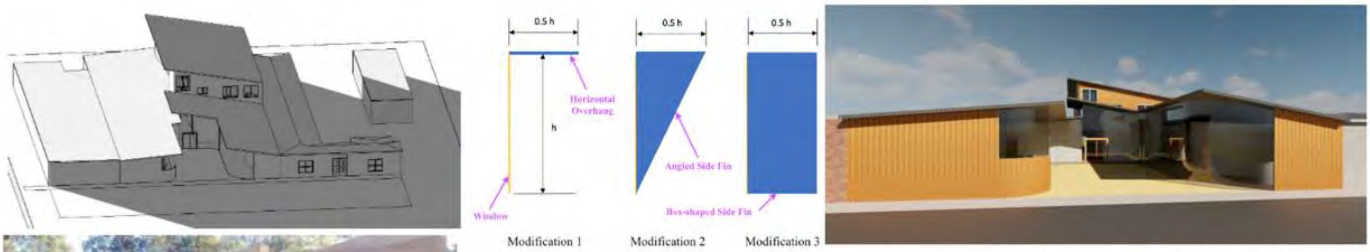
Student survey responses were generally positive for the design studios, with the most beneficial aspect of the studio being the involvement of industry professionals. The student respondents agree that the design studios overall were beneficial to their studies.

5 STUDIO OUTPUTS – SAMPLE OF TECHNICAL FINDINGS

The following section summarises the design solutions identified by participants in the design studios, though does not reflect the entirety of solutions examined by the participants throughout the design studio. For a summary of all reports assessed for this project, please see Appendix A.

5.1. Passive Design Measures

While not a primary focus specified in the client brief, participants were encouraged to investigate passive design strategies to implement within the Lightning Ridge Multi-Purpose Building. It was suggested that these passive strategies be mindful of the social and cultural requirements of the owners/occupiers, while also addressing the requirements of the assessment, and keep embodied energy, CO_2, energy saving potential, financial outlay and feasibility in mind. The passive measures investigated encompass a wide range of strategies, examining many different aspects associated with the building envelope, the connection with the land, and the values of the surrounding community.



SOLUTION	REF	REF = 0	0<REF<0.3	0.31<REF <0.95	0.95< REF <1.05	REF > 1.05
WINDOWS						
SINGLE GLAZING WITH NO INTERNAL SHADING	0.596	5	4375	2492	191	1697
SINGLE GLAZING WITH INTERNAL SHADING	0.67	5	4263	2215	184	2093
DOUBLE GLAZING WITH INTERNAL SHADING (BASE CASE)	0.747	5	4234	2131	161	2229

Figure 6: Passive design strategies - Extracts from student work

The following examples were proposed across the student reports, with some examples being highlighted in Figure 6. **Note:** Not all of these initiatives were investigated in detail, though all were considered at least on a preliminary basis via the selection matrix.

- Sustainably sourced and reclaimed materials (e.g. local cypress timber, rammed earth walls, etc.)
- Internal/external green wall and green roof
- Solar irradiance and thermal mass (e.g. Trombe wall)
- Improved glazing solutions (e.g. window films, double/triple glazing, etc.)
- Exterior and interior shading
- Geothermal heating/cooling
- Natural and mixed-mode ventilation strategies (e.g. malqaf, solar chimneys, etc.)

5.2. Active Design Measures

The client brief and student assessments outlined a greater focus on active strategies, predominantly focusing on the use of HVAC to maintain comfort conditions, and renewable energy generation/storage to provide a higher energy fraction throughout the year. Many students were unfamiliar with these topics, with most having only a fundamental understanding of building services and energy generation. This resulted in students being more favourable of passive strategies, though due to the requirements of the client brief/assignment, participants endeavoured to examine numerous active strategies, with all final building designs including at least one (if not multiple) active design measures.

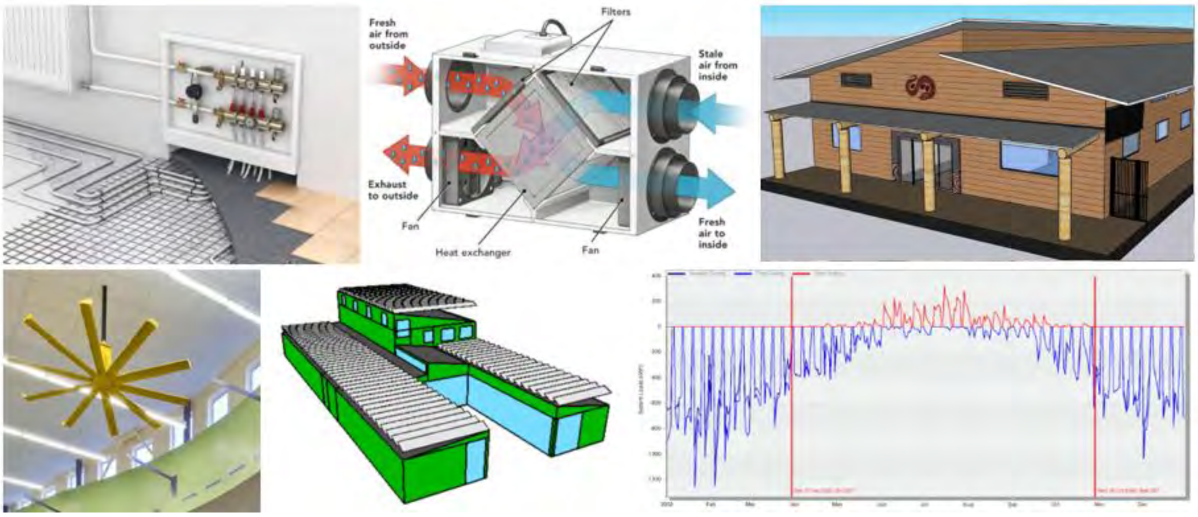


Figure 7: Active design strategies - Extracts from student work

The following examples were proposed, with some examples being highlighted in Figure 7. **Note:** Not all of these initiatives were investigated in detail, though all were considered at least on a preliminary basis via the design selection matrix.

- Building Management System (BMS)
- Efficient HVAC systems paired with Energy/Heat Recovery Ventilation (ERV/HRV)
- Photovoltaic systems and energy storage (e.g. battery storage, phase change material)
- Efficient appliances and lighting strategies
- Low-cost air circulation (i.e. ceiling fans)

5.3. Other Design Measures

While the passive and active strategies implemented affect the operation and comfort conditions within the building, a larger focus of the client brief related to the functionality of the building, its links to indigenous culture, how it facilitates social nuances, and its greater impacts to the community. Some of these design considerations include (but are not limited to):

- Proximity of gendered bathrooms
- Functionality of commercial spaces
- Façades which recognise indigenous artistry, history and culture
- Separation of commercial and office spaces and their security

Though these considerations do not necessarily align with the aims of the IDS in addressing environmental impact and net-zero energy consumption, the functional purpose of the design is the primary focus for the client, and therefore must remain a core principle in driving the final project outcomes. The desires of the client may (at times) conflict with the vision of the designer, however it is necessary for the designer to work within the constraints provided to achieve an integrated design outcome which is not only efficient, but satisfactorily meets the clients' wishes.

6 SUMMARY OF CONSULTANT VETTING

Consultants participating in the design studios further assessed the individual designs submitted by consenting students, where a number of key design parameters (e.g. practicality, feasibility, innovation, implementation, operation, cost, etc.) were used to differentiate designs so that they may be evaluated, with the overall design being compared against a business-as-usual baseline to determine the success of the final concept and of the individual strategies incorporated. Design solutions can be categorised as either passive or active, with a variety of strategies having been compared within the vetting report. The following two sections outline summarised information from the vetting report, highlighting key strategies which were examined by both students and consultants. The complete vetting report can be found as an appendix to this document (Appendix E).

6.1. Existing Opportunities

As the design undertaken through the design studio utilised a *greensite*, many possibilities were available to be explored, with the primary limiting factors being the isolated nature of the site and the overall capital expenditure. This resulted in participants exploring many different potential technologies and strategies. After evaluating many of these strategies, the list of feasible possibilities diminished once they were evaluated with cost limitations and logistics in mind.

The consultants identified the key opportunities explored by the students, before identifying their own additional strategies which students may not have considered. The strategies identified by both parties can be seen (below) in Figure 8.

Student Ideas
(O) High efficiency HVAC systems
(O) Energy Recovery Ventilator
(P) Natural ventilation and mixed mode ventilation
(R) PV systems
(I) Power Purchase Agreement
(O) High efficiency appliances and systems
(P) Double or triple glazed windows
(O) Data management and Advanced BMS
(P) Use of phase change materials (PCM)
(O) Thermal zoning (thermostat control)
(O) Indoor Breathing Wall
(O) Battery Storage for excess PV production
(O) Use of Biogas plant
(P) Shading
(P) Rammed Earth Walls
(P) Thermal mass
(P) Trombe Wall
(P) Solar Chimney w/ Earth Tube

Additional Ideas Explored
(O) Automated blinds
(O) Occupancy detection
(O) Daylight Dimming
(O) Relaxed setpoints
(O) Adaptive comfort through ceiling fans
(O) EC Plug fans
(O) Centralised, efficient heating/cooling plant
(P) Improve quality of window/door seals beyond business as usual

Feature categorisation
(P) – Passive design
(O) – Operational efficiency
(R) – On-site renewables
(I) – Innovation/other

Figure 8: Student and consultant design solutions – Excerpt from vetting report

Between the solutions investigated by students and those additionally suggested by consultants, a considerable number of potential strategies were highlighted within the vetting report. Of these potential strategies, the consultants have featured five strategies which would likely be of the greatest benefit to the associated project, having been tested commercially on existing structures with a proven performance history. These strategies are further detailed in Section 6.2, and have been classified under the headings of:

- Embodied carbon
- Passive design solutions
- Operational improvements
- Renewable energy generation
- Designed for end of life considerations

6.2. **Improvements vs. Business as Usual (BAU)**

Based on the building typology (i.e. multi-purpose building) a BAU baseline was developed, incorporating case studies for buildings existing within a similar climatic zones. This BAU baseline was developed to establish a benchmark for energy requirements, to which different strategies could be directly compared to measure their success. These strategies (outlined in Section 6.1) are generalised and encompass many potential solutions (as evidenced by Figure 8). For instance, passive design solutions may relate to a variety of materials/architectural concepts relating to the building envelope (e.g. insulation, shading elements, improved glazing, etc.). The following is a more detailed overview of the solutions investigated by the consultants.

<u>Embodied carbon (locally sourced culturally significant materials)</u>

The client (and end user) has a focus on their environmental impact, with a desire to minimise their overall impact on the surrounding region. To achieve this, it is desirable to utilise *low-process and low carbon materials* such as timber, muds/clays, and repurposed/recycled/upcycled products. It is recommended that the design utilise materials that are locally sourced, minimising transportation requirements. Locally sourced timbers would not only achieve this low-processed desire, but are culturally significant to the local indigenous population, meaning that their implementation would achieve multiple design outcomes. Additionally, the incorporation of local mining tailings (a waste stream) could be used to create mudbricks or rammed earth walls, offering both structural and massing solutions for the building.

<u>Passive design solutions</u>

Passive systems such as thermal mass, building layout and orientation, and materials with good thermal properties were highly recommended to assist in regulating the internal thermal environment, which also assists in reducing the requirements of active systems. Thermal chimneys could also be included within the design to assist in ventilating the building's interior and maintain comfort conditions. Air infiltration also needs to be considered, to minimise undesired air changes when comfort conditions have been achieved.

<u>Operational improvements</u>

Consultants outlined a series of operational improvements which could be implemented. These included (but are not limited to):

- HVLS (High-Volume Low-Speed) fans to offset air conditioning
- Daylight dimming to reduce artificial lighting demands
- Occupancy sensors for lighting management
- Installation of Energy Recovery Ventilators (ERV's)
- Relaxation of temperature set point control
- Energy Management Systems

<u>Renewable energy generation</u>

Maximisation of PV systems should be considered due to their high return on investment and low payback periods. Due to this being a *greensite*, roof orientation can be designed to maximise solar gains, with building integrated PV systems highly suggested due to the simplification of their installation during construction, rather than being later retrofitted.

<u>End of life</u>

No building is expected to last forever, so the best time to plan for its eventual deconstruction is during the design phase. Design for end of life can maximise the potential reuse/recycling opportunities for materials once the end of life phase has been reached, especially given the remoteness of Lightning Ridge. Designing for disassembly is one method of maximising the potential reuse of materials, while modular assembly is also recommended. Modular design will simplify the assembly process, while also minimising potential waste during assembly/construction.

6.3. Key Findings

The strategies outlined by the consultants show that through implementation of commercially available solutions, a reduction of over 25% of operational carbon is possible given the various strategies being implemented. Depending on the design improvements implemented in addition to the onsite/offsite renewables, the consultants suggest that net-zero operational carbon is possible for the Lightning Ridge multi-purpose building.

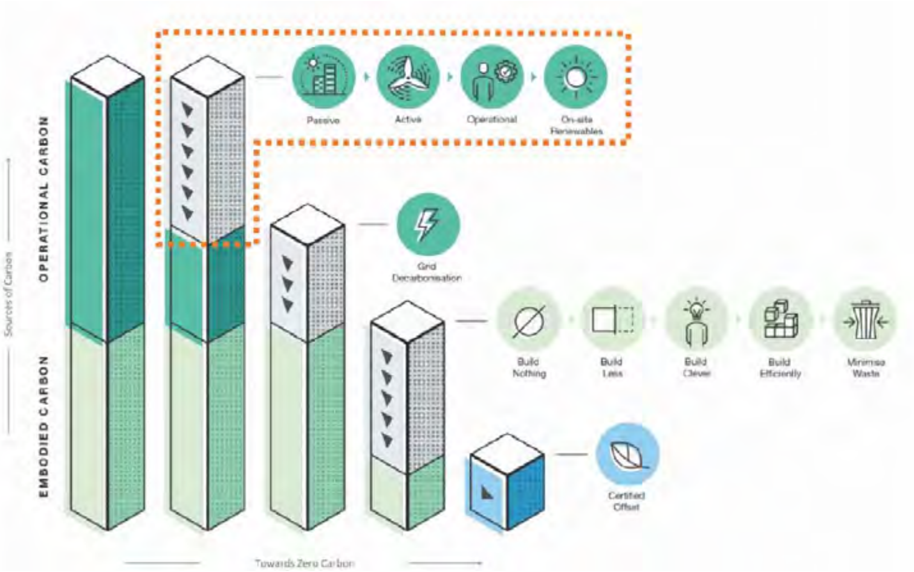


Figure 9: Net zero carbon buildings: Three steps to take now (ARUP 2020)

While students have aimed to achieve a renewable energy fraction of 1.0, most student designs found that a REF of 0.6-0.7 is a distinct possibility, aligning with the remarks of the client as well as with the characteristics of the considerably cooling-dominated climate at Lightning Ridge. These values suggest that up to 70% of the sites operational carbon can be abated given the strategies implemented by the students alone. Given the insights and experience of the consultants, a net zero operational carbon strategy appears to be a viable possibility.

7 CONCLUSIONS

7.1. Conclusions

Considering that the entirety of the project was conducted in a virtual environment due to the advent of Covid 19, the IDS was still considered to be a major success from many of participants involved.

The nature of the online environment resulted in many limitations to the project, but also yielded some benefits. The manner of working in isolation mimics the expected way in which architects and engineers would typically interact, working individually in isolation before sharing ideas and designs. These isolated working environments were found to limit creative design, inhibiting the integrated design process. It is expected that working in person would greatly improve the outcomes of the integrated design process. It was also found that online tools (such as Miro) provide an effective environment for designers to interact and share ideas, which lends support to the possibility of integrated design being possible in isolation. While integrated design is feasible online, feedback from the participants suggested that this limits design iteration, which ultimately impedes the idealised outcomes of the integrated design studios.

Compounding factors (building typology, designer inexperience, online environment, etc.) directly impact the potential outcomes for the project. When examined individually, it is difficult to measure the level to which each factor detrimentally affects the design outcomes, however when examining these factors holistically, it is evident that shorter timeframes are insufficient at delivering high-quality finalised designs. While it is not impossible to deliver a finalised design (as proven by the IDS), it can be argued that more technical and thorough designs are achievable in larger timeframes.

While there are advantages to using a greenfield site (i.e. few restrictions on potential strategies and technologies), this can also be overwhelming for younger or inexperienced designers and can result in a time consuming exercise of attempting to include too many strategies, or assessing the many possibilities available. To improve outcomes and aid students in their design progression, a well-defined framework of the integrated design process is essential.

The studios highlight the importance of feedback mechanisms, particularly in the earlier stages of the design studio. Due to the relative inexperience of the students, early feedback promotes growth in student abilities and positive development of the emerging design while also facilitating an understanding of other specialisations involved within the project, which ultimately results in a superior design. The experiential and technical expertise of the experienced consultants benefits the younger participants in the studios greatly, offering them a source of knowledge that is otherwise (typically) unavailable to them. Their interactions with the consultants provided them with a confidence in their own design choices. Participation within the design studio will ultimately give emerging practitioners a greater appreciation for other specialisations requirements, and how they can tailor their own future designs to be more accommodating of the needs of other strategies and technologies.

In terms of technical findings, apart from including renewable energy generation, the suggested design solutions focused on three main areas: 1) use of materials with low embodied energy/carbon; 2) optimisation of passive design features; and 3) operational improvements using energy efficient active systems and controls. The metric used to assess the impact of design solutions was the Renewable Energy Fraction on hourly basis. Hourly REF of 1 implies that the simulated energy demand on site is perfectly matched by the generated renewable energy on site at that specific hour of the year. The development of the Business As Usual cases took into account constraints for the available roof area to install PV panels as well as other modelling assumptions that were necessary to generate a baseline design. The majority of the resulted baseline designs had an annual average REF between 0.6 and 0.7 which was then improved with suggested design solutions from the above listed 3 areas to reach an annual average REF of approximately 0.9. Significant emphasis was put on extracting hourly results that demonstrated the difficulties for reaching zero energy on hourly basis without the use of electric storage systems (e.g. batteries).

Feedback from consultants and the client indicate that they strongly support future integrated design endeavours, recognizing the benefits that it offers, providing participants with knowledge, experiences, and connections within industry which will benefit them in their future careers.

APPENDIX A – SELECTED STUDENT WORK

UNIVERSITY OF WOLLONGONG

ENGG210 - TASK 3

BUILDING PHYSICS AND BUILDING SERVICES

Faculty of Engineering and Information Sciences
School of Civil, Mining and Environmental Engineering

Executive Summary

This report stems from a project proposal from clients of the Lightning Ridge Aboriginal Lands Council (LALC) to design a multi-purposed community cultural centre in Morilla Street. Building off a detailed design matrix and interim report which detailed a breakdown of net zero energy strategies, general feasibility, cost comparisons, energy saving potentials, carbon saving potentials and innovation within the market, the base case model for the following assessment was determined. Following client requirements and net zero energy principles, this report will detail step through improvements made to the base case design using Design Builder, an energy simulation tool, in order to satisfy the thermal comfort requirements of the building occupants.

Through sustainable practices and occupant considerations, the following goals are hoped to be achieved:

- To design a building that services both the public and private sectors of the community and utilize open plan, free flowing spaces to promote connectivity.
- To celebrate, facilitate and educate on the surrounding cultural traditions and heritage of the area.
- To design a building that compliments its environment through passive principles and sustainable practices.
- To design a building that is resilient to its environmental and socio-economic surroundings.
- To explore forward thinking and innovation to promote new incentives.

Within the baseline model it was found that within the building majority of the consumption could be attributed to the cooling spaces this is due to the high heating loads created from sunlight, occupancy and lighting. In the baseline model it can also be seen that within the hotter months there is more

From the energy study it was found that solutions which reduce the sunlight into the space are the best solutions for use in the site. These included shading both internal and external as well as increasing the glazing. These solutions provided the best REF values of all conducted simulations and were able to sufficiently meet the client brief as well as the assessable constraints. In addition to this it was found that recommendations in previous tasks were not suitable for implementation on this site proven through energy models conducted.

The solution that Vision Artisans recommends for the implementation on the site (based on simulations completed) are using external shading of 0.5m, double glazing windows with internal shading, split system HVAC unit and reductions on natural ventilation in the design. This will be both cost effective as well as energy efficient.

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Introduction

The Lightning Ridge Local Aboriginal Land Council is a multi-use space, designed as a community hub for Lightning Ridge it intends to serve as a gallery, restaurant and café, function hall, and a meeting place for influential members of the aboriginal community.

The intended plot is 34 Morilla Street, Lightning Ridge, the site has two access points one from Morilla street and a back access via a back street. The site is relatively flat and bordered by a Vinnies Store and Bluey's motel either side of the intended plot.

To best design the facility, Vision Artisans have created an energy model of the design in order to test the best solutions to allow the site to achieve the high renewable energy fraction (REF). Renewable Energy Fraction is the ability of the site to generate renewable energy to meet its consumption. To complete this process Design Builder was used. Design Builder is an energy modelling software used to simulate buildings against a variety of real-life factors. For this design energy generation and consumption were focused on using Design Builder even though other features such as water could have been investigated.

Schematic Floor Plans

The Schematic floor plans available in Appendix C, are a revision from the previous concept plans. These plans have a reduced floor level on the first floor as well as simplification made to the curvature of the rammed earth wall. These changes have been made through conversations with consultants on the project and are intent on reducing the loads required to heat and cool empty space. The below figures show a 3d renders of the revisions completed on the floor plans and give some evidence of the material choices.

Figure 1. Render completed from street view of the site.

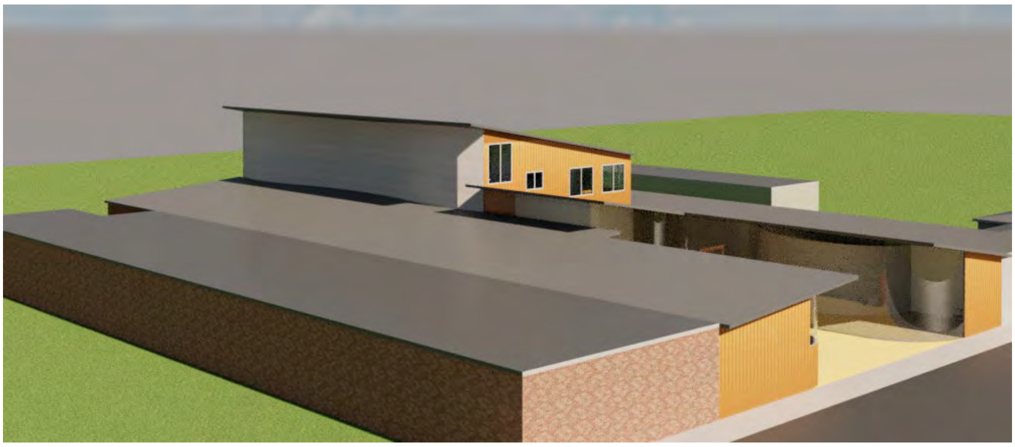


Figure 2. Axonometric render of the site.

Base Line Model

In using design builder there are some limiting factors with the software. As a result of this it was required that there were some amendments made to the model so that simulations will run smoother, these are:

- Curvature is limited: Modelling rounded glass in design builder can be very difficult and due to time pressure, it has chosen to be reduced to simple geometry.
- Curtain walls differ in size: Glass Curtain walls at the front streetscape of the building are slightly smaller than the schematic plans. This is due to limitations caused by the software not allowing the whole wall to be covered by glazing.
- Not all spaces are accounted for: Some spaces such as the barista area as well as the gallery are not included within the spaces analysed in the energy model. This is due to zoning being similar to the spaces they are in as well as there being no geometry that separates the two zones.

Model Zones

In completing the energy model spaces had to be defined. These are the spaces that were included in our model

- Ground Floor
  - Art Rooms
  - Commercial Kitchen
  - Corridor 1
  - Disabled Toilet
  - Elevator
  - Entertainment Hall
  - Female Toilet
  - Fridge and Freezer
  - Gallery
  - Male Toilet
  - Pantry
  - Restaurant
  - Staff Room
  - Store Room
  - Teaching Room 1

    - Teaching Room 2
- First Floor
    - Office (CEO)
    - Office (CFO)
    - Common Area
    - Office (COO)
    - Corridor 2
    - Lift
    - Meeting Room
    - Store Room
    - Uni-Sex Toilets

Each of these spaces have unique assumptions which will be touched on within the following paragraph.

Assumptions

To create the base case a variety of assumptions were made using both brief requirements legislative requirements specifically NCC Volume 1 Section and assignment constraints. These assumptions made for each space are outlined below:

Activity:

ZONE	TEMPLATE	OCCUPANCY (USING NCC SECTION J)	HEATING AND SETBACK	COOLING AND SETBACK	OFFICE EQUIPMENT AND COMPUTER
ART ROOM	Generic Office Block	Table 2f	18.0, 16.0	25.0, 28.0	Off and off
COMMERCIAL KITCHEN	Food Preparation Area	Table 2f	18.0, 16.0	25.0, 28.0	On and off
CORRIDOR	Circulation Area	Unchanged from 8am-8pm in template	18.0, 16.0	25.0, 28.0	Off and off
DISABLED TOILET	Toilet	Unchanged from 8am-8pm in template	21.0, 19.0	25.0, 28.0	Off and off
ELEVATOR	Circulation Area	Unchanged from 8am-8pm in template	18.0, 16.0	25.0, 28.0	Off and off
ENTERTAINMENT HALL	Hall/Lecture theatre/assembly Area	Table 2h	21.0, 19.0	25.0, 28.0	Off and off
FEMALE TOILETS	Toilet	Unchanged from 8am-8pm in template	21.0, 19.0	25.0, 28.0	Off and off
FRIDGE AND FREEZER	Light plant room	Unchanged from 8am-	0.00, 0.00	0.00, 0.00	Off and off

		8pm in template			
GALLERY	Gallery	Unchanged from 8am-8pm in template	21.0, 19.0	25.0, 28.0	Off and off
MALE TOILETS	Toilet	Unchanged from 8am-8pm in template	21.0, 19.0	25.0, 28.0	Off and off
PANTRY	Store Room	Unchanged from 8am-8pm in template	18.0, 16.0	25.0, 28.0	Off and off
RESTAURANT	Eating and Drinking Area	Table 2f	18.0, 16.0	25.0, 28.0	Off and off
STAFF ROOM	Generic Office Area	Unchanged from 8am-8pm in template	18.0, 16.0	25.0, 28.0	Off and off
STORE ROOM	Store Room	Unchanged from 8am-8pm in template	18.0, 16.0	25.0, 28.0	Off and off
TEACHING ROOM 1	Teaching Areas	Unchanged from 8am-8pm in template	21.0, 19.0	25.0, 28.0	Off and off
TEACHING ROOM 2	Teaching Areas	Unchanged from 8am-8pm in template	21.0, 19.0	25.0, 28.0	Off and off
CEO OFFICE	Generic Office Block	Table 2c	21.0, 19.0	25.0, 28.0	On and on
CFO OFFICE	Generic Office Area	Table 2c	21.0, 19.0	25.0, 28.0	On and on
COMMON AREA	Reception	Unchanged from 8am-8pm in template	18.0, 16.0	25.0, 28.0	Off and off
COO OFFICE	Generic Office Area	Table 2c	21.0, 19.0	25.0, 28.0	On and on
CORRIDOR 2	Circulation Area	Unchanged from 8am-8pm in template	18.0, 16.0	25.0, 28.0	Off and off
LIFT	Circulation Area	Unchanged from 8am-8pm in template	18.0, 16.0	25.0, 28.0	Off and off

MEETING ROOM	Generic Office Area	Table 2c	21.0, 19.0	25.0, 28.0	On and on
STORE ROOM	Store Room	Unchanged from 8am-8pm in template	18.0, 16.0	25.0, 28.0	Off and off
UNI-SEX TOILETS	Changing Facilities with showers	Unchanged from 8am-8pm in template	21.0, 19.0	25.0, 28.0	Off and off

Table 1. Activity Assumptions

Construction:

For the construction assumptions a "best practise medium weight" template was used. This was checked to meet the minimum NCC requirements especially statements made in J1.3, Table J1.5a and Table J1.6.

Openings:

For the openings a Double-glazed window with internal shading is used. This meets requirements set by J1.5 however the current design does not meet Table J1.5b. Future iterations of this design will look at meeting these requirements.

Lighting:

For Lighting assumptions LED with linear controls were used. To determine the Power density in each area Table J6.2a was used. In addition to this these were checked against the assignment constraints and were feasible to assume.

HVAC:

For the HVAC as specified in the brief a split system air conditioning unit with mechanical ventilation was used. This had a heating and cooling COP of 4. In addition to this air flow and ventilation were checked especially the fresh air supply into each zone using the methods outlined in the assignment constraints against the design builder schedules and all proved to be valid.

Results

Completing a simulation using the before mentioned assumptions, it was able to be extracted that the site used:

CATERGORY	ENERGY (MJ)
Cooling	256387.404
Heating	13883.544
Water System Heating	47929.392
Interior Lighting	36424.584
Interior Equipment	9239.796
Total	363864.72

Table 2. Baseline Simulation Results

The validity of this results comes from the comparison of the business as usual. The business as usual (found in the previous assessment) was generated from a NABERS energy calculator assuming a 6 Star rating for the site. This calculator determined the annual energy requirements for the location, floor area and the desired star rating. This resulted in an annual energy requirement of 367642 MJ, once compared to the results from the baseline study it can be seen that there is a 98.9% similarity between results. This validates the base line model for the site.

Annual Heating and Cooling Loads

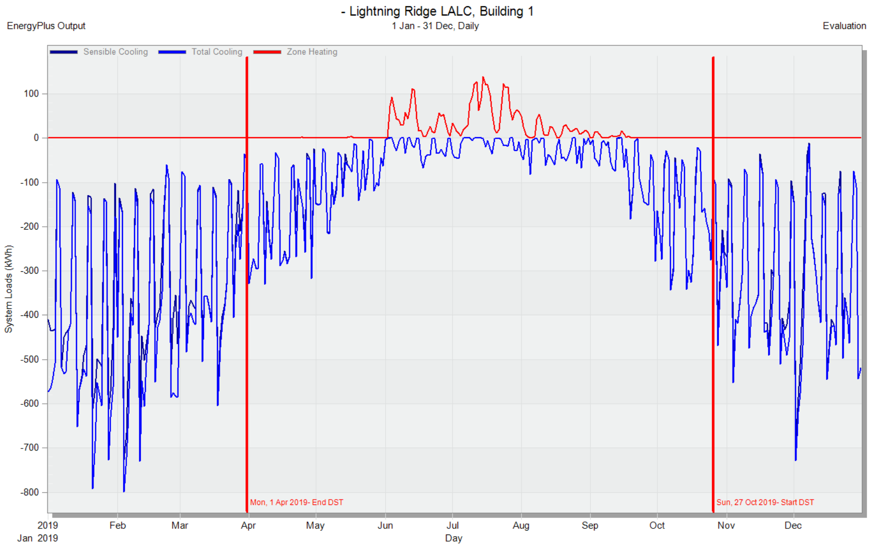


Figure 3. Annual Heating and Cooling Loads

Observed in the above graph it can be seen that simulations conducted on the design shows a high cooling load throughout the year with a minimal heating load. As a result of this the solutions tested in the simulations are going to be tailored to reducing the cooling load. It can be noted that the high heating loads and low cooling loads can be attributed to internal gains on the site specifically from lighting, occupant activity, equipment gains and solar gains evident in figures 6 and 7. This dramatically increase the temperature in the space, lowers the heating load and increase the cooling load.

Peak Heating and Cooling

From the completed simulations it can be observed that the peak loads for heating and cooling occur on the 14th of July and the 4th of February. A 24 hour period was simulated to observe when these peak loads occurred and how much they consumed at that time, evident in the figures below.

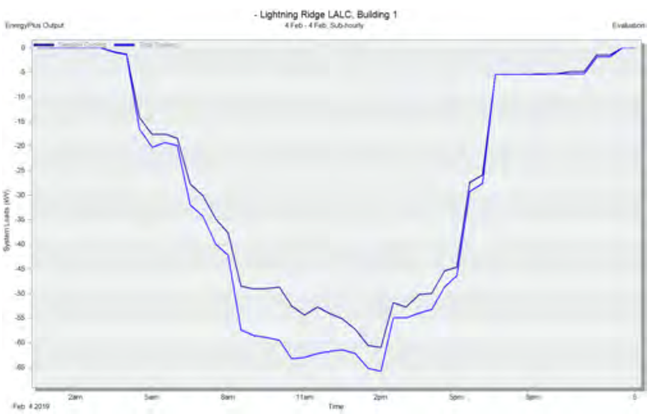


Figure 4. 4^{th} of February peak Cooling load

Figure 5. 14th of July peak Heating load

Apparent from these figures 4 and 5 it can be seen that the peak cooling load will be at 2:00pm while the peak heating load will be at 7:30am on each respective day.

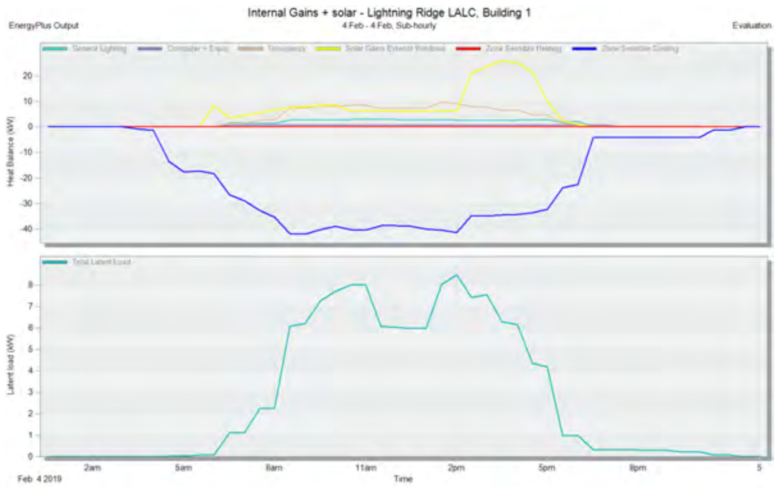


Figure 6. Internal gains and solar on the 4th of February

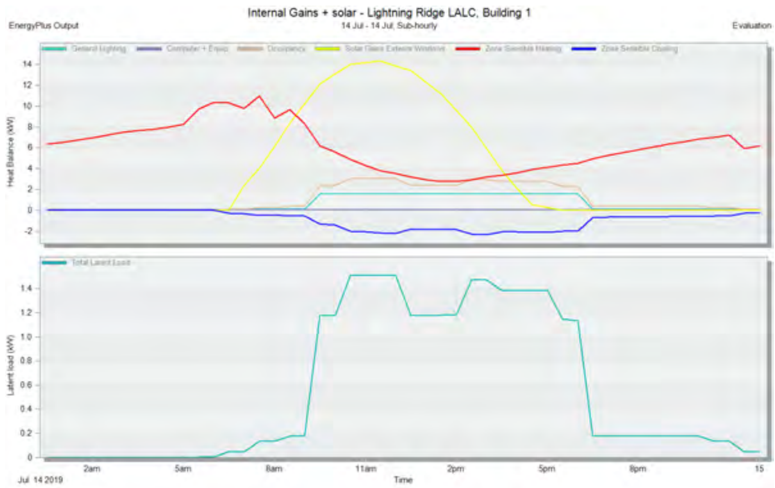
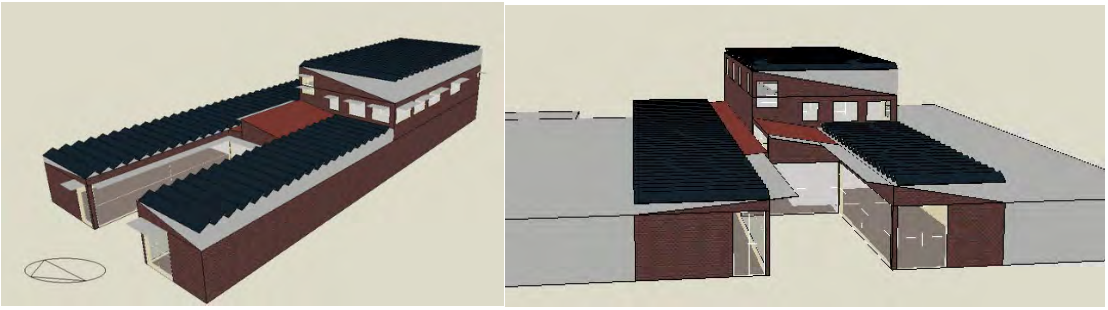


Figure 7. Internal gains and solar on the 14th of July

Investigating the peak heating and cooling days in more detail it can be observed that there is a high load contributed by solar gains as well as more minimal gains occurring from occupancy and general lighting evident by figures 6 and 7.

Design Modifications

Visuals and Generation on Site Using Photovoltaics



Figures 8 and 9 Solar panel arrangements within design builder

Once the base line model data had been extracted the method of onsite generation needed to be considered. It was decided that the design would use photovoltaics exemplified in figures 8, 9 and 10. These solar panels will account for 60% of the roof space(calculations in Appendix B) and slanted 23 degrees while being flush with the 5 degree slant of the roof. The arrangement in figures 8, 9 and 10 are not apparent of this design but due to software limitations this design was not able to be completed. Completing a simulation with the addition of the photovoltaics, the site was able to generate a total of 243755 MJ annually, based on 2019 weather data

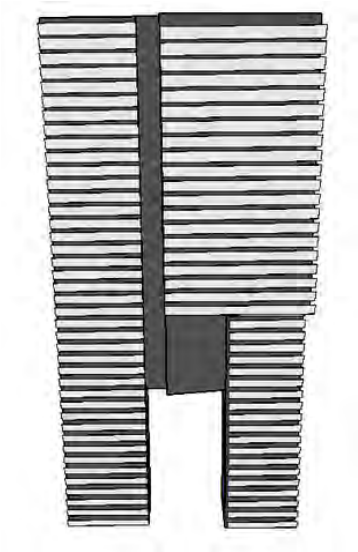


Figure 10. Solar Panel Arrangements

From the analysis completed on the generation of the photovoltaics it can be observed from the figures 11 and 12 that the generation provided by the photovoltaics can account for the heating load in winter, resulting in a positive REF value. However, it cannot account for generation within summer days due to the high cooling load. These figures also illustrate that within summer months, there is a higher generation than winter due to differences in sun angle and daylight hours being less.

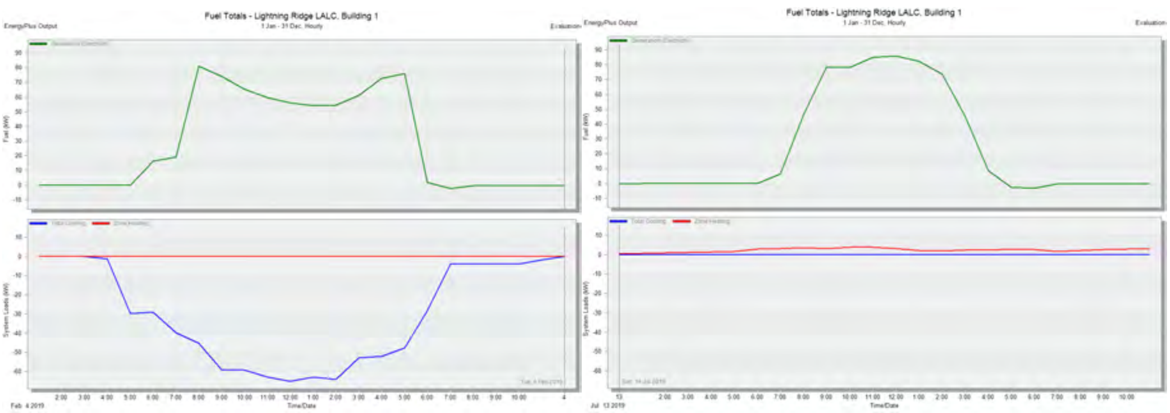


Figure 11 and 12. 4th of February cooling load and 14th of July heating load vs generation

Solutions Proposed.

Based on the base line simulations it has been decided that the investigation of lighting, glazing, shading and HVAC would be the best solutions to be tested for the design. Each simulation completed is outlined below:

Windows

- Single glazing with no internal shading (Air Filled)
- Single glazing with internal shading (Air Filled) (medium reflectivity shading)
- Double glazing with no internal shading (Air Filled)
- Double glazing with internal shading (Base Case) (Air filled) (medium reflectivity shading)
- Double glazing with electrochromic glass (Air Filled) (medium reflectivity shading)
- Double glazing with internal shading (Argon filled) (medium reflectivity shading)
- Double glazing with internal shading (Low emissivity coatings) (Air Filled) (medium reflectivity shading)
- Double glazing with internal shading (high reflectivity shading) (Air Filled)
- Triple glazing with no internal shading (air filled)
- Triple glazing with internal Shading (medium reflectivity shading) (Air Filled)

Exterior Shading

- None (Base Case)
- 0.5 m

HVAC

- Split Air Systems (Base Case)
- Heat Pump

These solutions will be investigated to determine their impact to the renewable energy fraction (REF) value against the baseline model and their feasibility for implementation.

Results

In completing the simulations Vision Artisans were attempting to achieve a REF values of 1. An REF value is the generation of the site divided by the consumption of the site. This REF value was calculated across every hour of the year and then averaged across each hour of the year to get the average REF value. Each REF value was then sorted into categories, scoring 1 or 0 if the REF was in or not in the category. This allowed investigation into how many hours of the year each REF value was being generated and attempt to improve it.

*note: The REF= 0 category only equals 0 for the warm up of the software which takes 5 hours hence the 5 values across all the data.

*note: The base case for the site is the Double Glazing with Internal Shading. This is used to conduct all other simulations on the HVAC, Shading and natural ventilation categories.

SOLUTION	REF	REF = 0	0<REF<0.3	0.31<REF <0.95	0.95< REF <1.05	REF > 1.05
WINDOWS						
SINGLE GLAZING WITH NO INTERNAL SHADING	0.596	5	4375	2492	191	1697
SINGLE GLAZING WITH INTERNAL SHADING	0.67	5	4263	2215	184	2093
DOUBLE GLAZING WITH INTERNAL SHADING (BASE CASE)	0.747	5	4234	2131	161	2229
DOUBLE GLAZING WITH INTERNAL SHADING AND ARGON	0.738	5	4258	2154	163	2180
DOUBLE GLAZING WITH INTERNAL SHADING AND LOE	0.784	5	4220	2112	136	2287
DOUBLE GLAZING WITH HIGH REFLECTIVITY BLINDS	0.826	5	4164	2037	131	2423
DOUBLE GLAZING WITH NO INTERNAL SHADING	0.697	5	4248	2364	177	1966
DOUBLE GLAZING ELECTROCHROMIC GLASS	0.876	5	4204	1866	144	2541
TRIPLE GLAZING WITH INTERNAL SHADING	0.753	5	4243	2140	148	2224
TRIPLE GLAZING WITH NO INTERNAL SHADING	0.707	5	4253	2347	175	1980
SHADING						
NONE	0.747	5	4234	2131	161	2229
0.5M SHADING	1	5	4137	1974	105	2539
HVAC						
SPLIT AIR SYSTEM	0.747	5	4234	2131	161	2229
HVAC HEAT PUMP	0.724	5	4287	2199	162	2107
HVAC HEAT PUMP WITH HEAT RECOVERY	0.724	5	4287	2199	162	2107
NATURAL VENTILATION						
OFF	0.747	5	4234	2131	161	2229
ON	0.969	5	4191	2002	86	2476

Table 3. Results from proposed solutions.

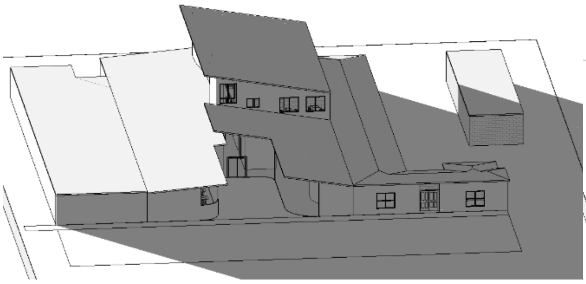
Findings:

It can be found that from the data, solutions that mitigate sunlight into the spaces produce the best REF values. This is due to their ability to reduce the overall cooling load within the site. This is relevant when observing the impact of introducing exterior shading as well as internal shading vs no internal shading on to the site which have dramatic changes to the REF value.

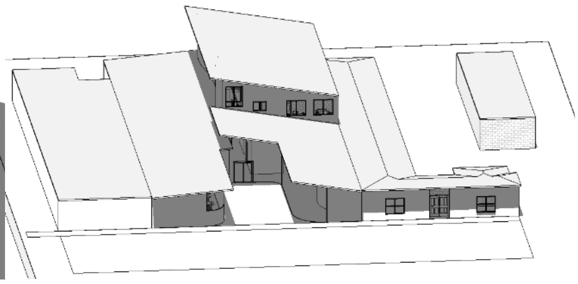
Shading Diagrams

Within the design Vision Artisans put emphasis on allowing sun to enter spaces, both acting as heating and lighting source. As such it was imperative to complete shading diagrams on the site to design for year-round solar infiltration into these spaces. These can be seen below:

Summer Solstice 20/12/2021



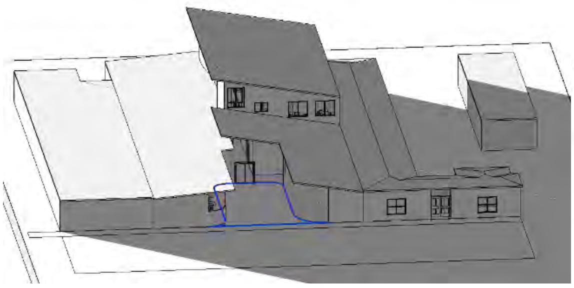
5:05 am



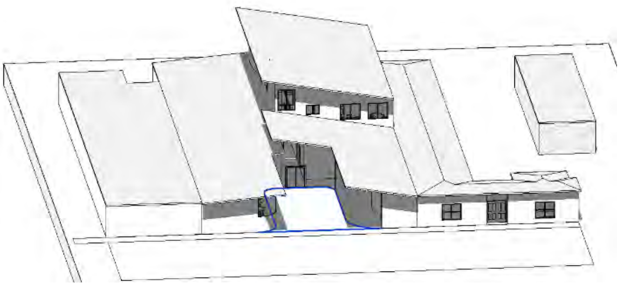
12:00 pm

7:05 pm

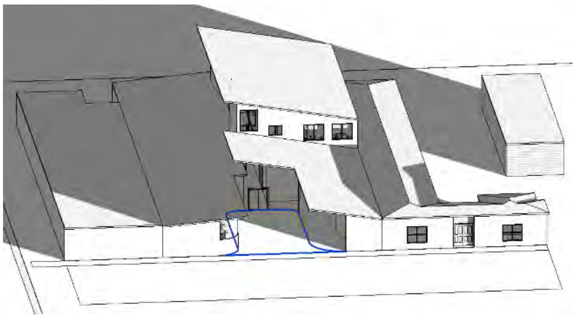
Winter Solstice 20/06/2021



7:02 am



12:00 pm



5:16 pm

As you can see from both these diagrams sun will be able to enter these spaces within all stages of the year. It is also apparent that morning sun will fill the gallery while afternoon sun will fill the café.

*note: The design revision now allows for more sun to enter the central hallway allowing for better lighting and reducing the use of artificial lighting.

Discussion

From the results it can be seen that the best-case scenario for the site is to implement external shading of 0.5m, double glazing windows with internal shading, split system HVAC unit and no natural ventilation. This was able to give us a REF value of 1 which means that the on-site generation by the solar panels can meet the consumption of the site. This solution is relatively cost effective and easy to source as windows, HVAC and shading options are already established on the market and relatively available to source. The justification why this solution is so impactful is due to its ability to reduce the high cooling load in the spaces. The implementation of these options can reduce the sunlight into the space, however this does limit the natural lighting in the space. This is a slight reduction in natural lighting and is an acceptable compromise to achieve better energy efficiency.

Another potential solution which provides a relatively high REF value is using natural ventilation, double glazed windows with internal shading, split system HVAC unit and no shading. This results in an REF of 0.969 which means that there will still be some requirement of the site to be connected to the grid for electricity. However, this will not limit the natural lighting into the space as the beforementioned option does but however will impact on the air quality allowing for more breathable air to enter the space. This will reduce the cooling load required by HVAC units as a result of natural breezes cooling spaces. This does reduce the temperature control in the area which can lead to occupant discomfort.

In previous assessments heat pumps were validated as the best option for the site. Upon the simulation of the site this however has been proven incorrect, the internal gains and design of the site minimise the heating loads. Once a simulation was conducted using a heat pump it proved to have a reduction in REF value which showed it wasn't as beneficial as a Split air system. In addition to this when a heat recovery unit was simulated in conjuncture to the heat pump the same results were recorded. This shows that a heat pump or heat recovery unit are not suitable for the site.

Future tasks

If there was more time permitted to the design Vision Artisans would investigate the front curtains walls. Heat gain through solar were a massive contributor to the cooling loads on the site and reducing the window size could have had potential at reducing the load as a result. In addition, it would have been interesting to observe the impact of introducing windows on the rammed earth wall as to further light level one and the ground floor corridor. Finally, an extensive investigation of materials and their potential to be used as thermal mass would have been useful for the client.

Conclusion

In conclusion, Vision Artisans recommends use of external shading of 0.5m, double glazing windows with internal shading, split system HVAC unit and reductions on natural ventilation in the design, this coupled with solar panels covering 60% of the roof will allow renewable energy generation on site. This option best aligns with the set brief requirements, legislative requirements and assignment constraints as well as allows the site to be sustainable while providing a comfortable environment for the occupants.

References

[1] New.gbca.org.au. 2021. Green Star – Performance | Green Building Council of Australia. [online]

APPENDIX A – Sustainability Rating System

For the design, Greenstar was used as a rating system. Greenstar is a sustainability rating system used for buildings, fit-outs and communities [1]. Greenstar is split into 9 categories observed in the figure below.

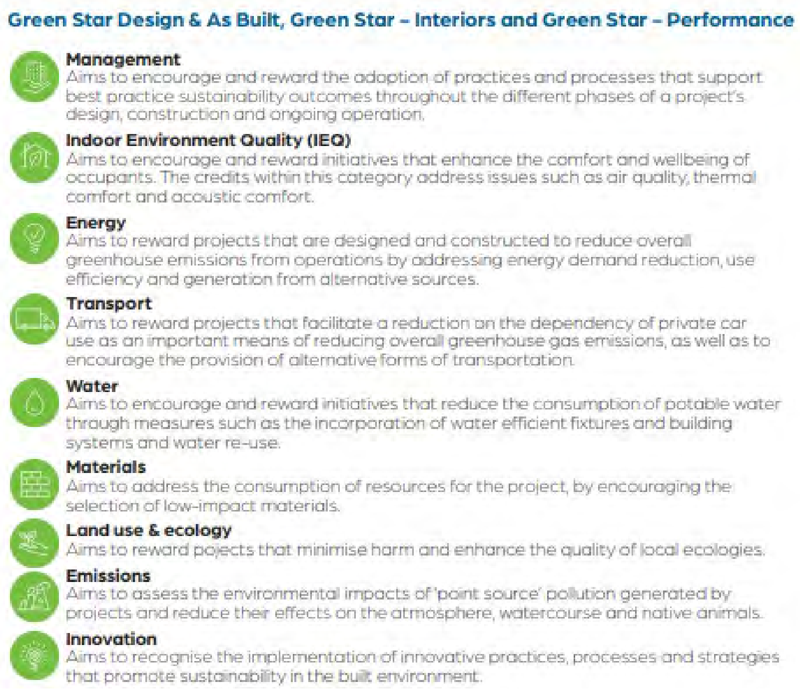


Figure Design As Built categories.

For the design our site was intending to meet a 5-star Greenstar rating as a minimum while striving to meet a 6-star Greenstar rating. Based on the design and the solutions generated it can be seen that the site can meet 7 out of the 9 categories. The categories that these solutions and design miss are the innovation and the transport.

Within our design there are less conventional ideas proposed, however they aren't revolutionary to the industry. If some of the more unique solutions such as the heat pumps with heat recovery were proposed then the innovation may have been able to be met, however due to the assessment of the brief these solutions wouldn't be suitable and hence the innovation category isn't able to be achieved. Due to the relatively remote location of lighting ridge transport can be costly, especially with some of these more unique design ideas. If some of these solutions were more readily available to remote locations in Australia then the transport category could be achieved easier. This does bring up the point that if a solution is readily available and commercially viable is the idea still innovative?

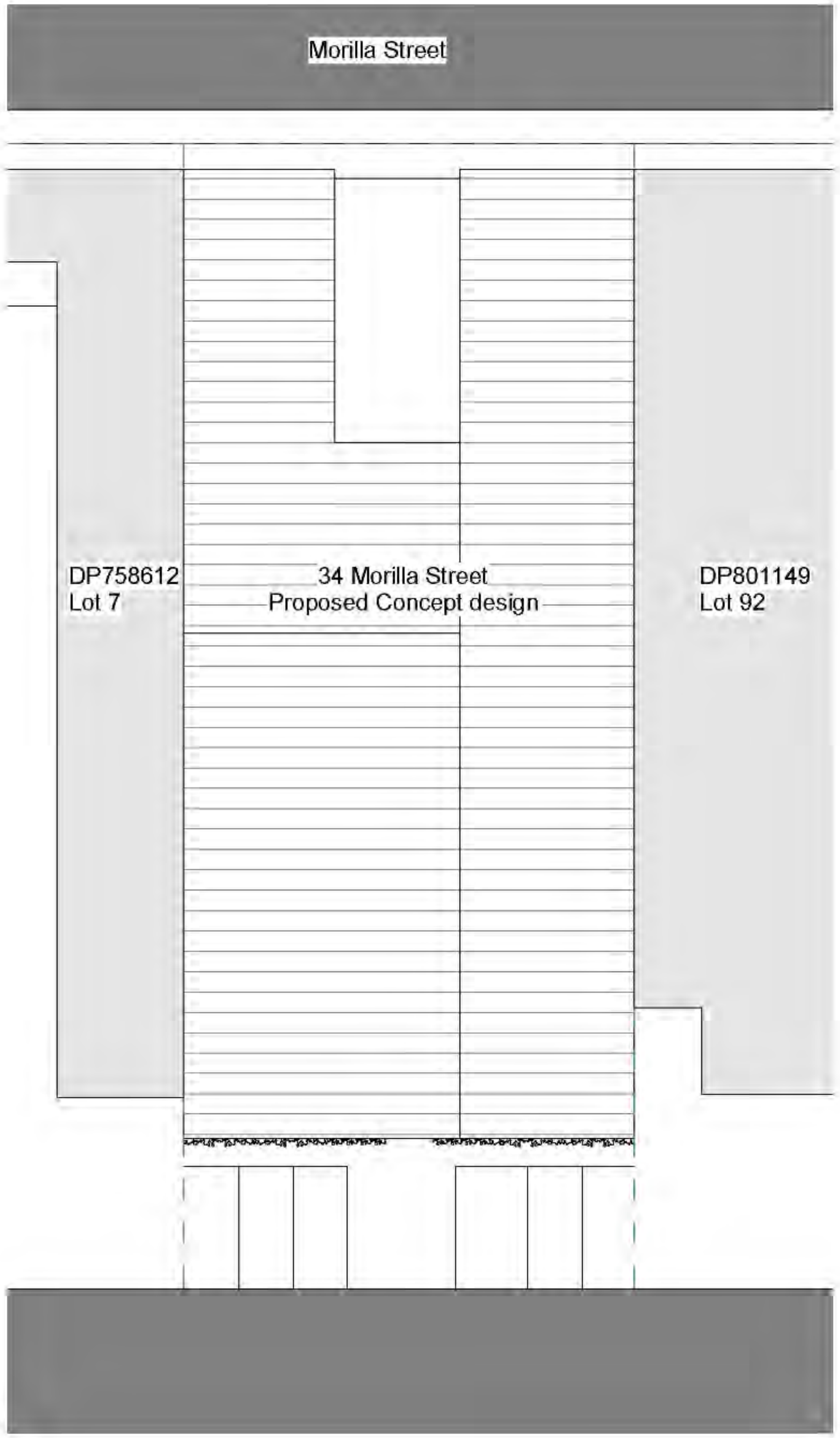
In addition to Greenstar, NABERS was used to generate the base case energy for the site which has been referenced within this report. NABERS is another sustainability measurement system which has places more emphasis on the operation of the site. For the design a 6-star NABERS rating was adopted which was used to validate our baseline energy model.

APPENDIX B – Solar Panel Calculations

CALCULATIONS

TOTAL ROOF AREA	845.1088	m^2
SOLAR AREA	507.06528	m^2
SOLAR SIZE	1651 x 990	mm
OP. TILT ANGLE	29.4	deg
SOLAR ANGLE FOR BUILDING	23.7	
SOLAR TRIANGLE HEIGHT	397.9283	mm
SOLAR WIDTH HEIGHT	819.51802	mm
TOP ROOF W SPACING	180.4	m^2
EAST ROOF W SPACING	235.34	m^2
WEST ROOF W SPACING	98.4	m^2
TOTAL	514.14	m^2

APPENDIX C– Revised Floor Plans



Site

1 — 1 : 300

Vision Artisans

No.	Description	Date

Vision Artisan's

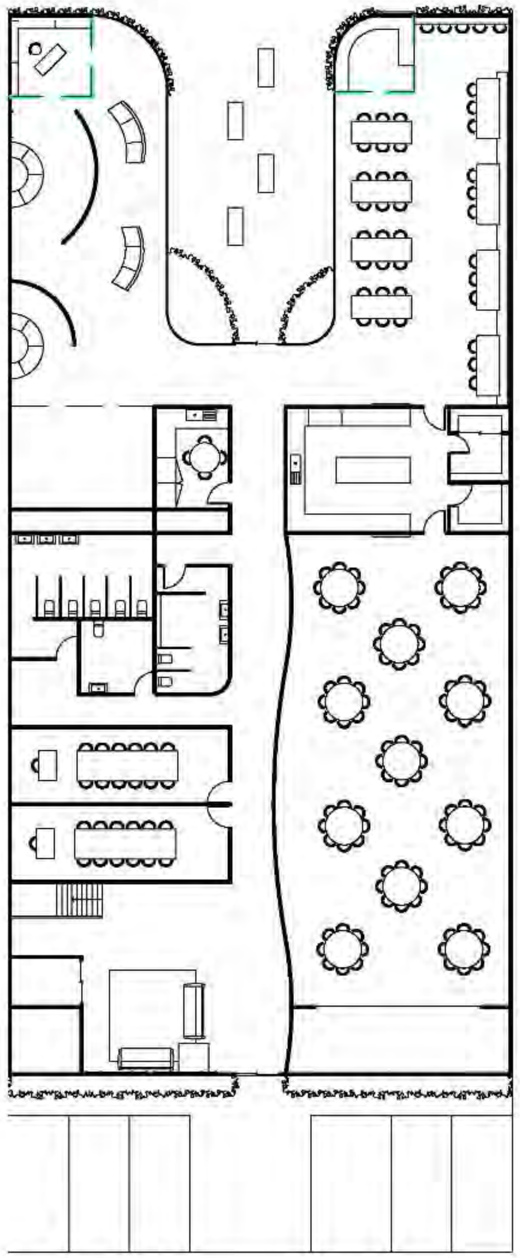
Lightning Ridge LALC

Site Plan

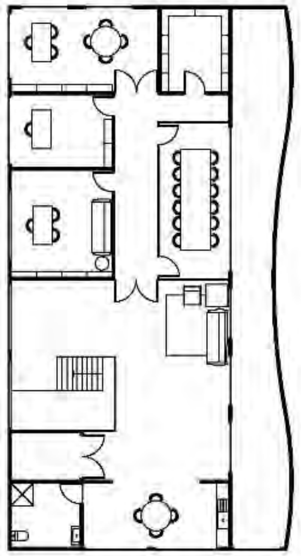
Project number	210922
Date	22/09/21
Drawn by	Vision Artisans

A102

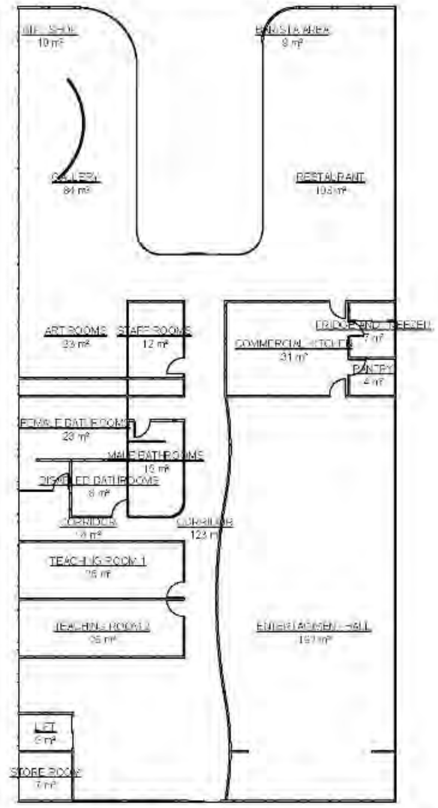
2021 10:33:16 AM



1 Ground Floor
1 : 300



2 Floor 1
1 : 300



3 Ground Floor
1 : 400

4 Floor 1
1 : 400

Vision Artisans

No.	Description	Date

Vision Artisan's

Lightning Ridge LALC

Floor and Area Plans

Project number	210922
Date	22/09/21
Drawn by	Vision Artisans

A103

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LIGHTNING RIDGE LALC

Net zero energy design against business as usual case

UOW AUSTRALIA

1 Executive Summary

This report explores the energy modelling and design specifications of the proposed Lightning Ridge Local Aboriginal Land Council. The mixed-use building has high energy consumption rates that were not abe to be offset by 60% solar photovoltaic (PV) panel coverage. Several modifications were undertaken to the baseline model to attempt to achieve net zero. These were geared towards a Renewable Energy Fraction (REF) target of 1, in order to not waste additional energy generated. The primary modifications were the improvement of the building glazing, the insulation, introducing shading along the western windows and increasing the ventilation.

When comparing energy loads for the building, the cooling load made up 49% of the energy consumption. This was followed by the electrical and hot water requirements of the spaces, in particular the kitchen and offices with all their equipment and hot water demand.

When introducing solar panels, the new roof angle, adjust from the last design brief, assistend in capturing lots of north eastern sunlight. Unfortunately, the energy usage-generation ratio was 3.6, with the solar not even covering a third of the building's annual energy consumption. It was no surprise that the REF value for the baseline was 0.65.

Several modifications were made to the baseline to improve this REF value, but every single modification actually lessened the value. This was due to several outliers in the hourly data, throwing the value off. In terms of the modifications, the shading was the most effective, with increased ventilation and optimisation of the solar array also having a positive impact on reducing the energy consumption of the building. The challenge that was faced with the improved insulation and glazing was, that they trapped heat inside the building and with the hot dry climate, this increased the very high cooling energy load.

Further exploration of options and methods to achieve net zero is still required, as the target was not achieved in this simulation. However, when being assessed against other building energy standards, such as GreenStar, other more holistic factors of the building are looked upon favourably, and the design still meets all the Client's original brief requirements.

2 Introduction

The focus of this report is on the proposed building's capacity to achieve net zero energy consumption annually. That is, the energy used by the building is to be offset with renewable energy generation, so that there will be a net zero energy requirement, or even a positive energy production. Through the use of solar panels and various other measures, the energy requirements of this LALC building were explored.
This report discusses challenges with renewable energy net zero design and proposes some effective measures to reduce energy demand, without increasing a solar photovoltaic (PV) system size.

3 Benchmark Model

The benchmark model assumes no renewable energy on site and models the building with all the passive design elements, available including cross ventilation with the prominent wind direction, and taking advantage of the north eastern morning sun with the large glass wall for the restaurant/entertaining space.

The client gave clear feedback for the previously proposed building, outlining the need for the front of the structure to fit into the street-scape more and also for the roof to primarily be facing North East. The double height café entrance was lowered to be a high ceiling sign height area and the front balcony was moved from the western side of the building to the north-east corner. This significantly reduced the hot western light into that space and softened the feel of the front of the building, as you approach from the street.

Figure 3.0.1: The original Building design – Isometric View

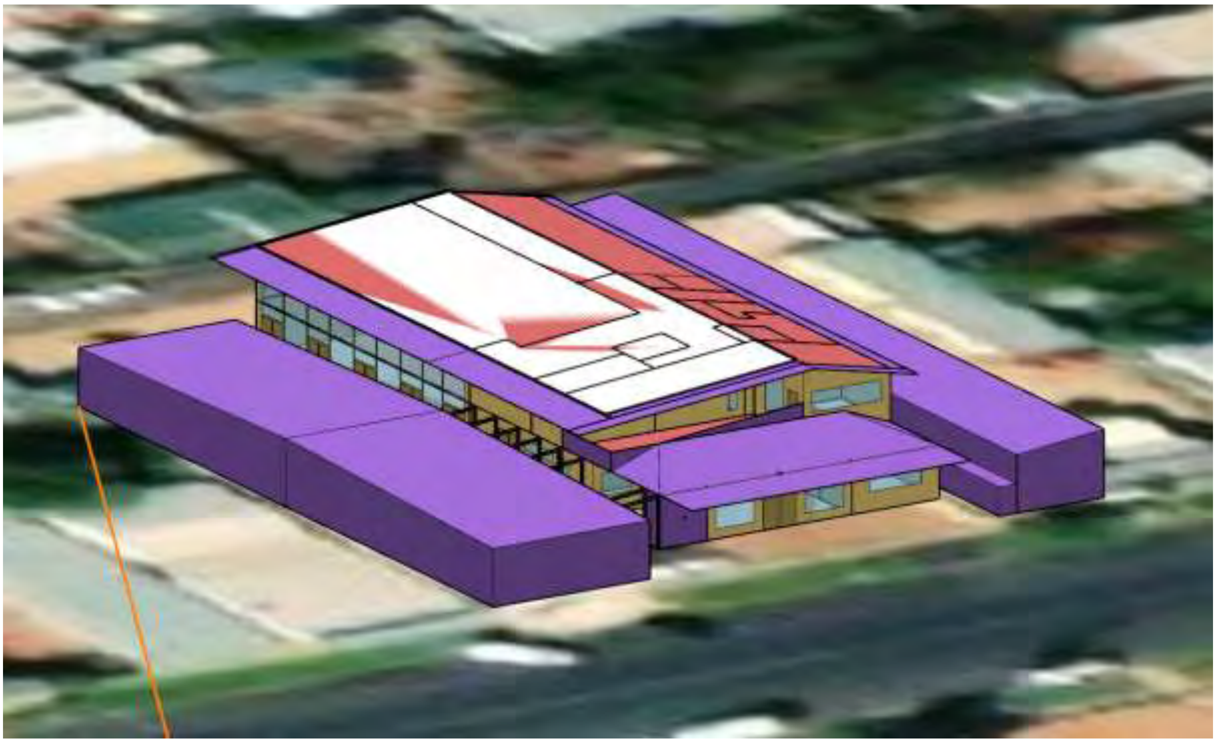


Figure 3.0.2: The new energy model building design – Isometric View

The client also wanted more articulation of the side of the building, which has been achieved through the use of a vine support structure, which will guide vegetation over the café seating area.

Figure 3.1.1: Isometric View of Energy Model from Street

Figure 3.1.1: Isometric View of Energy Model from rear of property

3.1 Main Assumptions

The 'Moree' Weather File was used as the closest weather data to Lightning Ridge.

Thermal Zones (see Appendix B)

The rooms in the building were simplified when outlining the thermal zones.

- The Bathroom transition/entrance spaces have been included in the bathrooms
- Small storage areas have been included into their larger rooms. They are considered to have the same thermal properties and are negligible due to their size.

- The offices and boardroom are all one space, as these all have the same heating and cooling requirements. Also, culturally, this encourages the doors to be left open which is the preferred collaborative work option.

Spaces

The spaces in the building were further simplified and are outlined in Appendix B.

Model Assumptions

- All doors have been modelled as solid, not glass, due to software limitations
- Internal components have not been modelled, these include the stairs and permanent kitchen fixtures like benches.
- The internal wall partition was not modelled because it did not prevent air flow through that space and was a visual/aesthetic component to the design, not an energy or structural one.
- The curved walls have been modelled as straight and the downstairs curved spaces have been simplified.
- Furniture was not modelled

Load Assumptions

Hot water

Hot water demand has been modelled as an electrical demand of 2 kW between 8am and 8pm for the entire year.

Lighting

See Appendix B for the maximum illumination power density (W/m2) in each thermal zone and combined space. These were taken from the NCC Vol 1 – Table J6.2a.

Equipment

The kitchen, office spaces and elevator all had electricity loads from equipment modelled. Other communal spaces and meeting rooms did not have equipment modelled, because it was considered negligible. This is the case for many rooms that do not have high occupancy usage.

Heating and Cooling

The cooling temperature was set to 24 degrees as a maximum value and the heating temperature set point was 21 degrees as a minimum comfort level. This gave the building a comfortable range, in line with NCC and health requirements for patrons and employees to comfortably enjoy the building.

The heating and cooling air conditioning is only on when occupants are in the building and it has been tailored to each thermal zone and building occupant requirement.

Occupancy

Each thermal zone has been assigned occupancy configurations and loads, with hours of occupation. These were based on the NCC but tailored for the Business Case of this LALC. Opening hours for the Council are set from 9-5, with lighting and heating on from 8am to 6pm. The café/restaurant also has earlier start hours to operate 8am to 4pm Monday - Thursday and 8am to 11pm on Friday and Saturday. The café/restaurant is only open from 8am to 2pm on Sundays.

Air flow and ventilation

As per the specifications, outdoor air flow was set for 0.35L/s per m^2 at all times. The required fresh air ventilation for a person in an occupied space was assumed to be 10 L/s per person. See Appendix 8 for calculations of these flow rates depending on occupancy and floor area.

Materials

For Climate Zone 4, NCC (Section J1.5) minimum material requirements were met. The wall material has a minimum R-value of 1.4 and my proposed external wall materials were greater than this.

The minimum R-value of the ceiling, in NCC Specification J1.2, is 3.7 and with a standard OpenStudio roof insulation, this was achieved.

The minimum R-value for a floor in Climate region 4 is 2.0. This was achieved through the use of insulation boards over the concrete slab and a timber floor as the internal finish.

The maximum U-value specified for glazing was 2. This was achieved with a template glazing material in OpenStudio.

3.2 Results

Table 3.3.1: Annual Energy Requirements

Description	Heating	Cooling	Equipment + Hot Water	Lighting	Total Energy Requirements
Baseline (GJ)	22.51	720.73	590.18	132.45	1,465.88
Baseline (kWh)	6,253	200,203	163,939	36,792	407,189

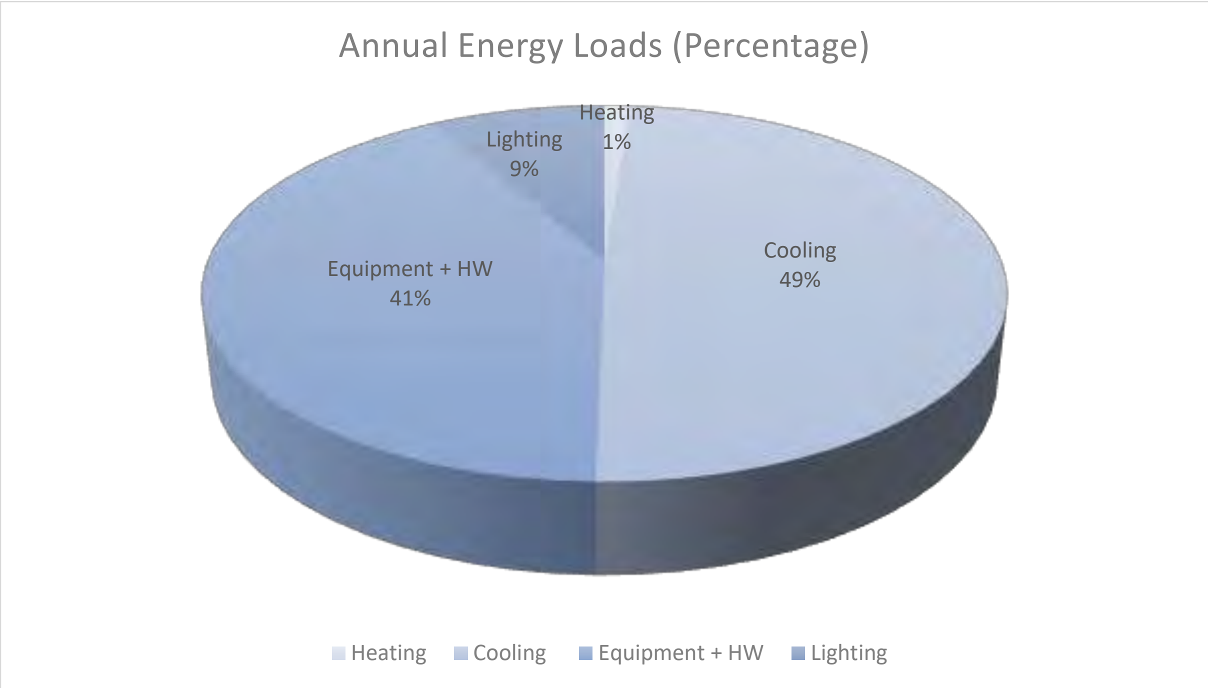


Figure 3.3.1: Annual Energy Loads – percentage of total building energy requirements

Table 3.3.2: Peak Energy Demand for Heating and Cooling

Description	Peak Energy Demand (kWh)	Time of Occurrence
Summer – Cooling	94.67	9am on the 3rd of Feb
Winter - Heating	58.62	6am on the 27th of July
All Loads Combined	149.27	9am on the 3rd of Feb

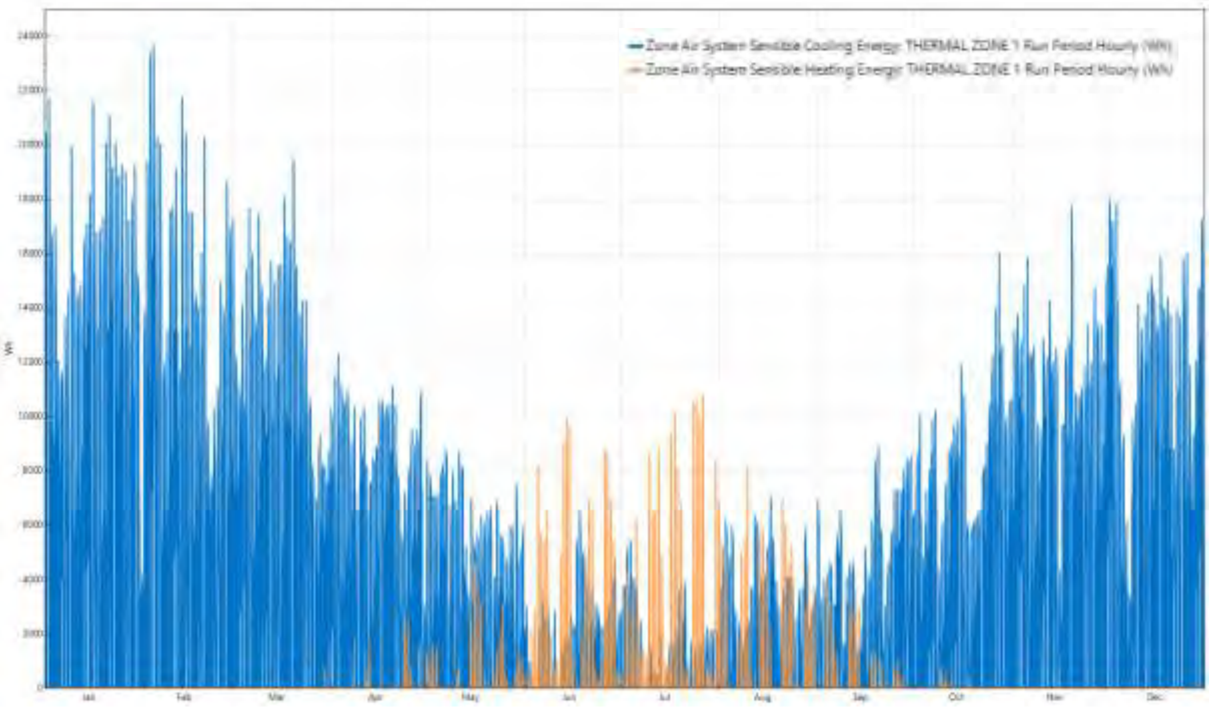


Figure 3.3.2: Annual Heating and Cooling Energy Usage

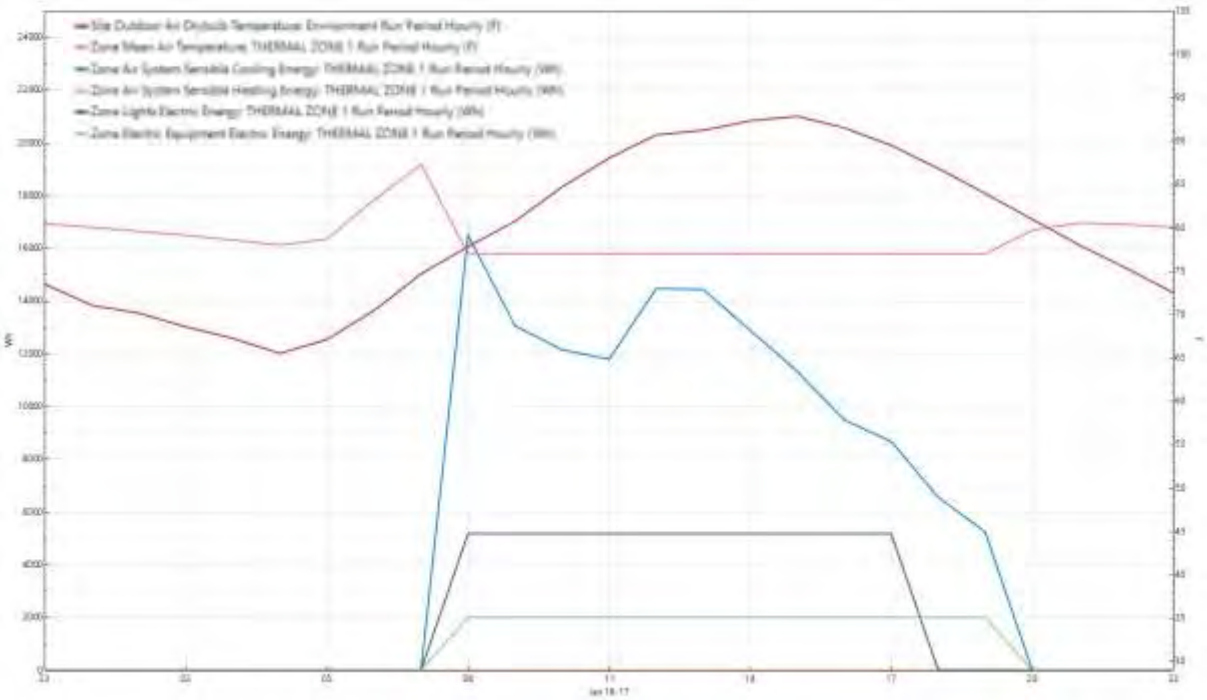


Figure 3.3.3: Typical Daily Energy Use Profile – Summer

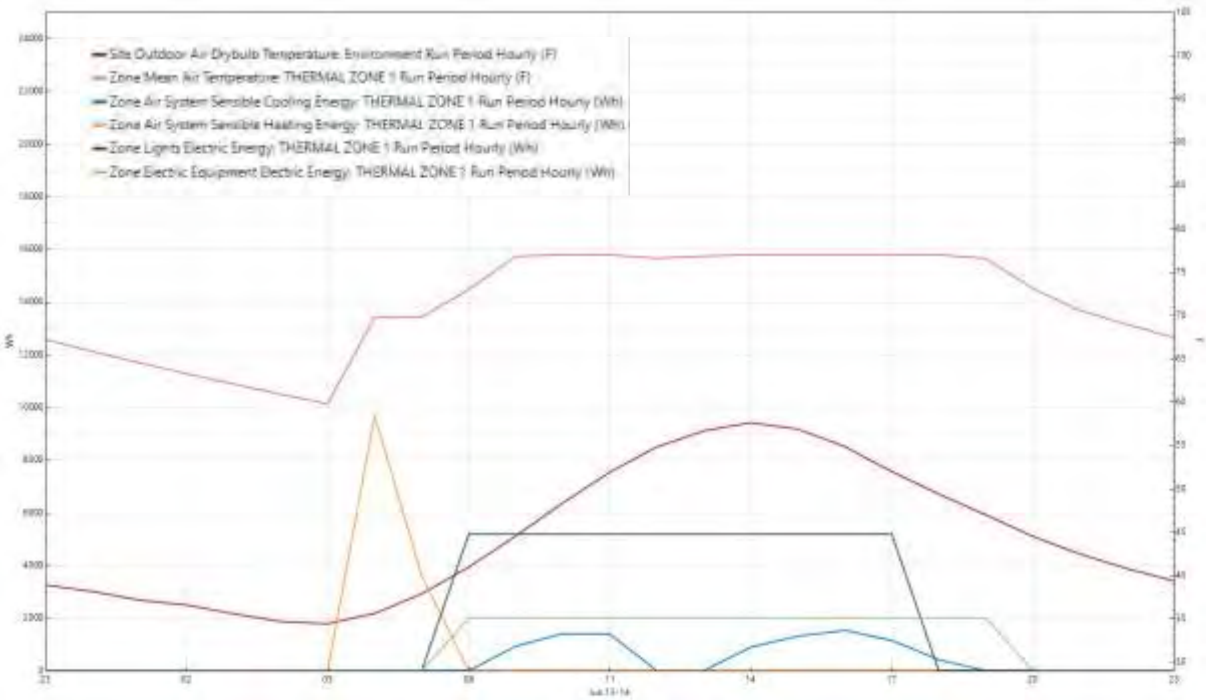


Figure 3.3.4: Typical Daily Energy Use Profile – Winter

3.3 Discussion

The cooling load is far greater than the heating load and this was to be expected due to the climate and daily average temperatures in Lightning Ridge. An interesting note is that the cooling system is activated most days in winter too to maintain the thermal comfort level of between 21 and 24 °Celsius.

The peak energy load for the year is on one of the hottest days in summer. As the cooling energy requirement make up 49% of the building energy consumption, it is logical that the peak energy use would be on a day with the highest demand for cooling.

5 Design Modifications/Improvements

The benchmark model was then modified to include solar photovoltaic panels on 60% of the roof area, at 15% efficiency.

The total area for solar panels is:

$$A_{main} = 11048\text{mm} * 33400\text{mm} \ + \ 5105\text{mm} * 33400\text{mm} = 539.51\text{m}^2$$

$$A_{front} = 4707mm * \frac{16000mm + 10600mm}{2} = 62.60\text{m}^2$$

$$A_{total} = A_{main} + A_{front} = 539.51\text{m}^2 + 62.60\text{m}^2 = 602.11m^2$$

$$A_{solar} = 60\% * A_{total} = 0.6 * 602.11\text{m}^2 = 361.27m^2$$

361m^2 of solar PV panels fit comfortably on the North Eastern main roof area of the building. This does not include the awnings, but it does include the shading over the outdoor eating area upstairs. See Figure 4.0.1 for an illustration of the location.

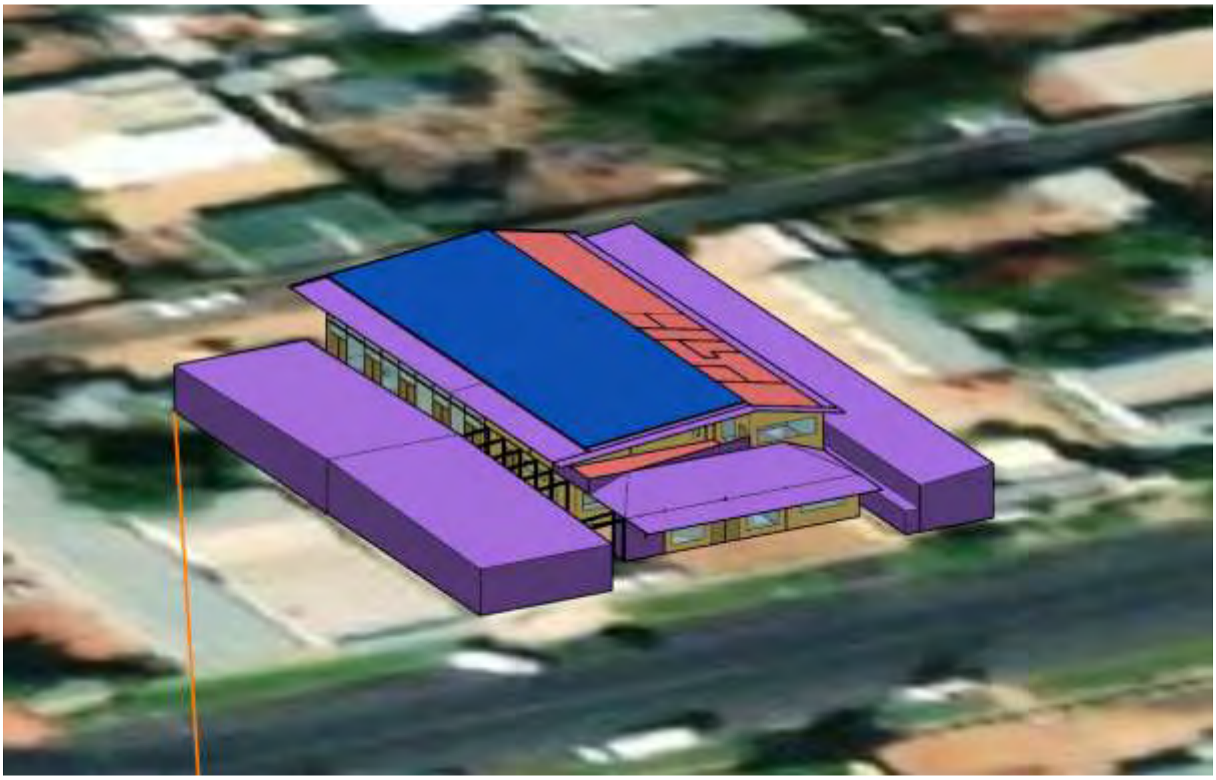


Figure 5.0.1: Solar Array on Main Roof

5.1 Results

Table 5.3.1: Annual Net Energy Requirements

Description	Total Annual Energy Requirements	Total Annual Energy Generation (Photovoltaic)	Total Net Energy
Baseline with PV (GJ)	1,465.88	405.17	1,060.71
Baseline with PV (kWh)	407,189	112,547	294,642

$$Energy\ Usage\ to\ Genration\ Ratio = 407{,}189 : 112{,}547 = \ 3.6$$

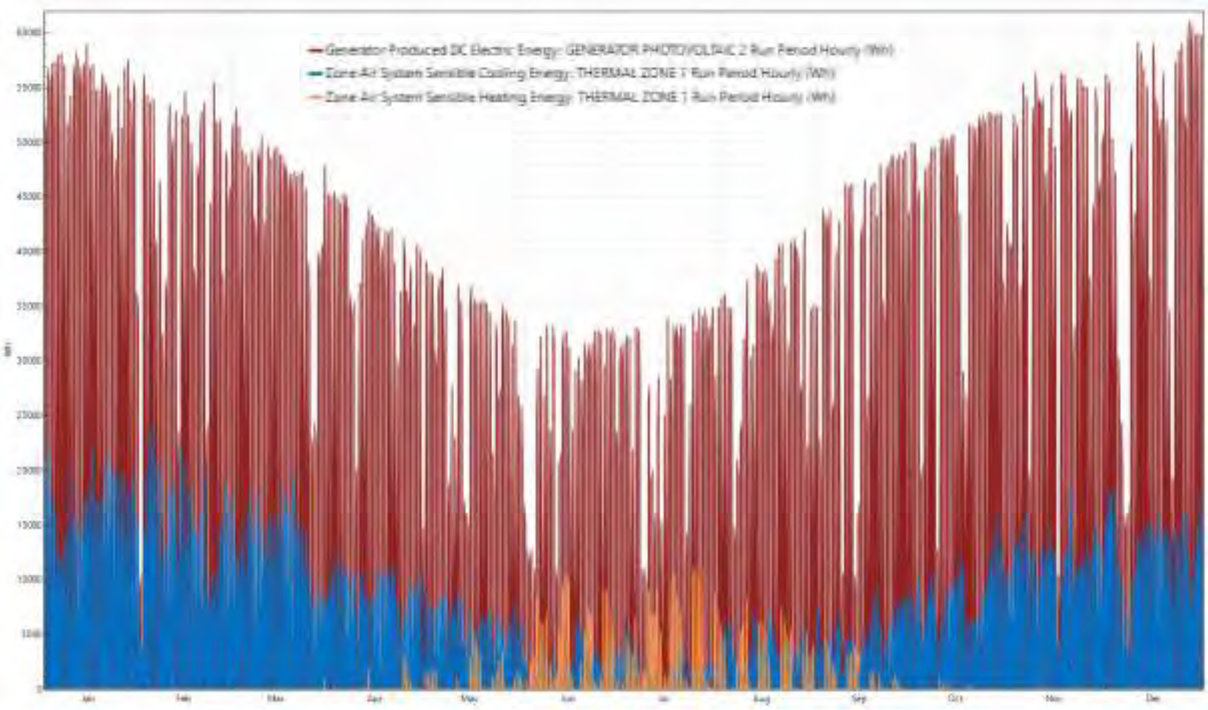


Figure 4.3.2: Annual Heating and Cooling Energy Usage compared to PV Energy Generation

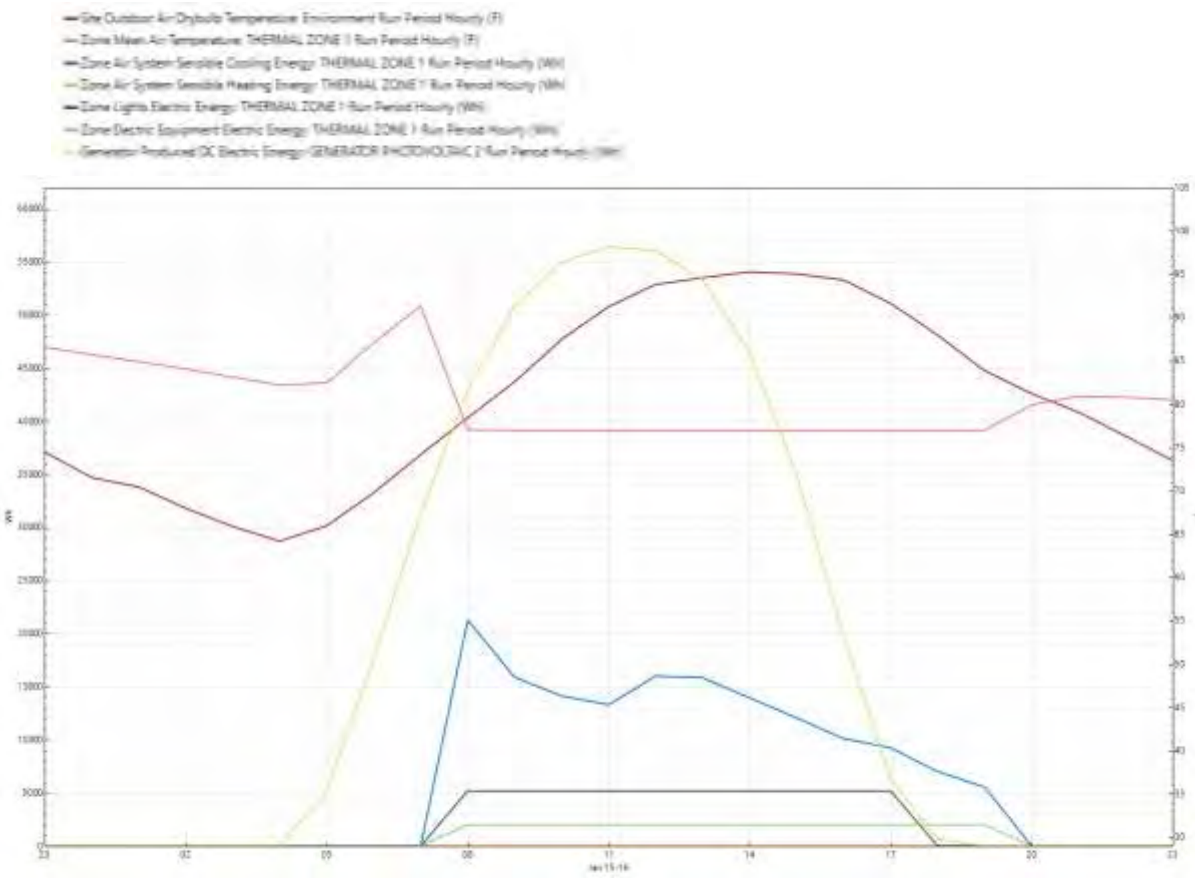


Figure 4.3.2: Typical Daily Energy Use and Generation Profile with PV – Summer

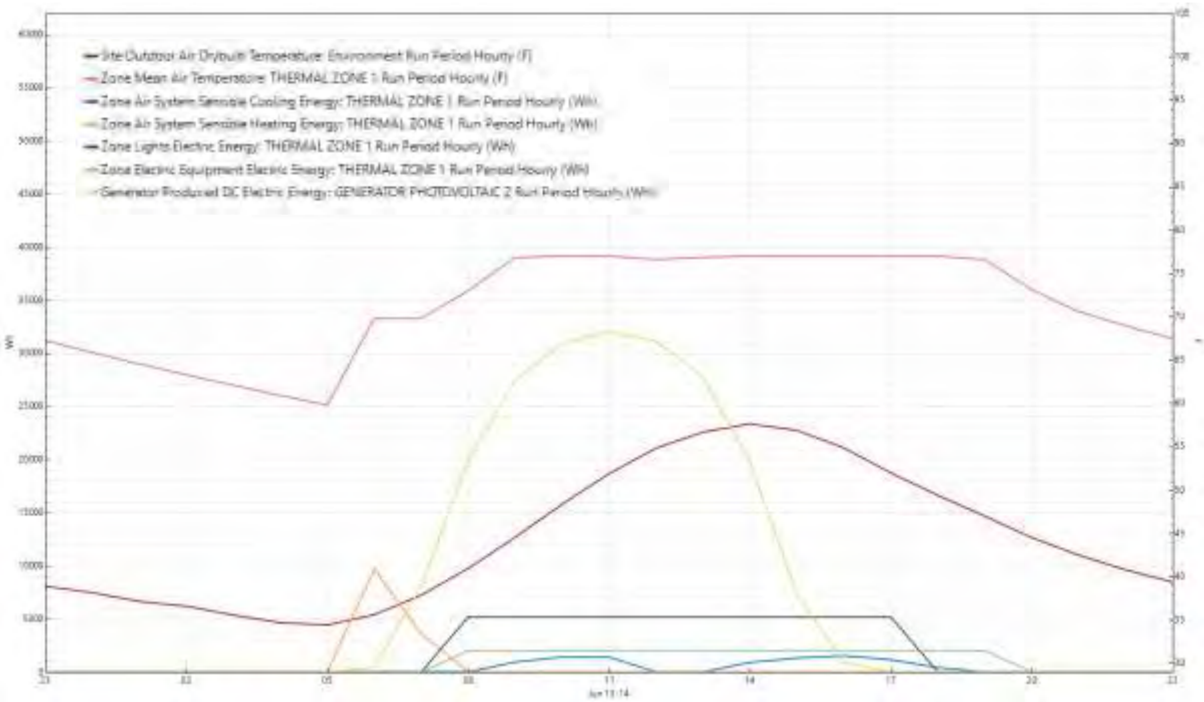


Figure 4.3.3: Typical Daily Energy Use and Generation Profile with PV - Winter

5.2 Discussion of Solar PV

The energy generated by the PV system looks to be significantly greater than the heating and cooling loads on the graph shown in Figure 4.3.2, however, this is just the heating and cooling loads for Zone 1, the first of the 18 thermal zones in the building. When combined with the total electrical equipment and lighting energy demands, the consumption of the building outweighs the energy generation by more than 3 times, as shown by the Energy Usage-Generation ratio of 3.6.

Validation of results: a typical solar panel is 1.7m^2 , there are 24 panels in a 6.6kW system. In Sydney, a 6.6kw system generates approximately 9636kWh per year.

24*1.7m^2 = 40.8m^2 generates 9636kWh per year.
361m^2/40.8m^2 = 8.84
8.84*9636kWh = 85,259kWh per year.

The baseline results show that the building generates 112,547kWh annually. Which is in the same order of magnitude as the simplified calculations and not unreasonable, given that Lightning Ridge is in a region with high solar radiance and no shading on the panels from other buildings or trees.

Renewable Energy Fraction (REF)

The renewable energy fraction was calculated for each of the 8760 hours of the simulation and the on-site renewable was divided by the energy requirement.

The hours that these values fell into certain ranges were then analysied.

Table 4.3.3: Renewable Energy Fraction Sectioning

	Number of Hours
REF = 0	1144
0<REF<0.3	1747
0.31<REF<0.95	2176
0.95<REF<1.05	13
1.05<REF	327
REF = infinity	3353
Total	8760

$$Sum\ of\ all\ REF\ values\ \text{(excluding 1 outlier)} =\ 5664.47$$

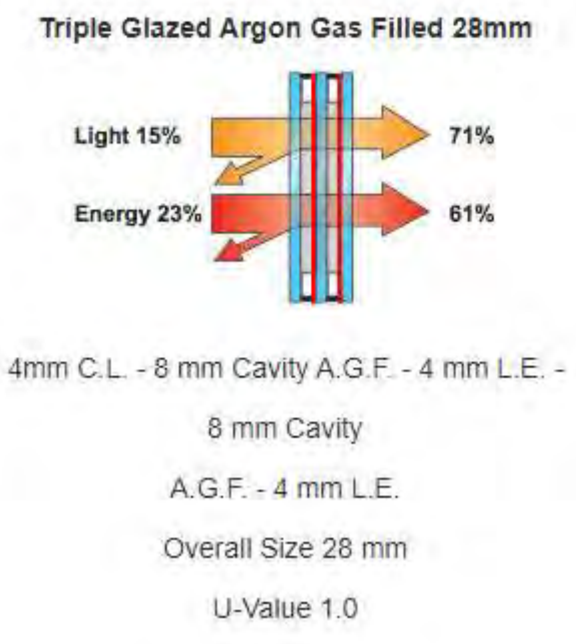
$$\text{Average REF annually} = \frac{5664.47}{8760} = 0.65$$

5.3 Discussion

The outlier was an REF value of 5299.48 Wh that occurred when a very small energy load appeared during the early hours of the morning. This type of exponential number can occur when there is a very small (nearly zero) load being offset by solar energy generations – in this case 3.4 Wh. With this outlier included in the calculations, the average annual REF would have been 1.25.

Improved Window Glazing

The building has large areas of glass windows, which are responsible for significant heat conductivity and thermal gain in Summer. The U-value of the glass was taken from the maximum value of 2 as specified by the NCC and lowered to 1.0 to simulate a triple glazed argon filled window; bst practice in the industry.



Triple Glazed Argon Gas Filled 28mm Window with a U-Value of 1.0
(https://asgardwindows.ie/windows/glazing-options)

Table 5.3.1: Annual Energy Requirements – Comparing the baseline to improved glazing

Description	Heating	Cooling	Equipment + Hot Water	Lighting	Total Energy Requirements
Baseline (kWh)	6,253	200,203	163,939	36,792	407,189
Improved Glazing	5,867	203,733	162,481	36,792	408,873

The improved glazing actually increased the total energy consumption of the building. This may be because a large amount of light was emitted through the Eastern windows but the heat might have been unable to escape quickly enough to balance this.

The average annual REF = 0.53, was obtained after removing 4 outliers greater than 1000 from the system. All outliers occurred in the early morning hours due to a very small energy demand load. The reason that this average REF is lower than the baseline case, is that it had more outliers removed than the original

.

Improved Thermal Properties of Materials - Additional Insulation

The wall insulation was increased to R2.7 and the ceiling was increased to R7.0.

Table 5.3.2: Annual Energy Requirements – Comparing the baseline to improved insulation

Description	Heating	Cooling	Equipment + Hot Water	Lighting	Total Energy Requirements
Baseline (kWh)	6,253	200,203	163,939	36,792	407,189
Insulation	6,047	201,295	162,481	36,792	406,614

Improving the building insulation lowered the total energy consumption slightly and whilst it increased the cooling demand, it did decrease the heating demand. This suggests that it trapping the warm air inside the building during summer.

The average annual REF = 0.45 (after 5 outliers greater than 1000 were removed). All outliers occurred in the early morning due to a very small energy demand load. The reason that this REF is lower may be due to the removal of additional outliers, compared to the baseline and window glazing.

External Window Shading – Louvres

External shading was added to the western windows as louvres to shield the windows from excess sunlight in the Summer. Again, the focus of the modification is to reduce the demand for cooling energy during the day and afternoon, thus increasing the number of hours the REF value is between 0.95 and 1.05.

Table 5.3.3: Annual Energy Requirements – Comparing the baseline to improved shading

Description	Heating	Cooling	Equipment + Hot Water	Lighting	Total Energy Requirements
Baseline (kWh)	6,253	200,203	163,939	36,792	407,189
Shading	9,650	193,389	162,481	36,792	402,311

The decrease in energy consumption is very minimal. It can be seen that the heating load increased while the cooling load decreased. Decreasing the cooling load would be a successful way to align the panel energy and the building energy us.

The REF value dropped to 0.42, after 5 outliers greater than 1000kWh were removed.

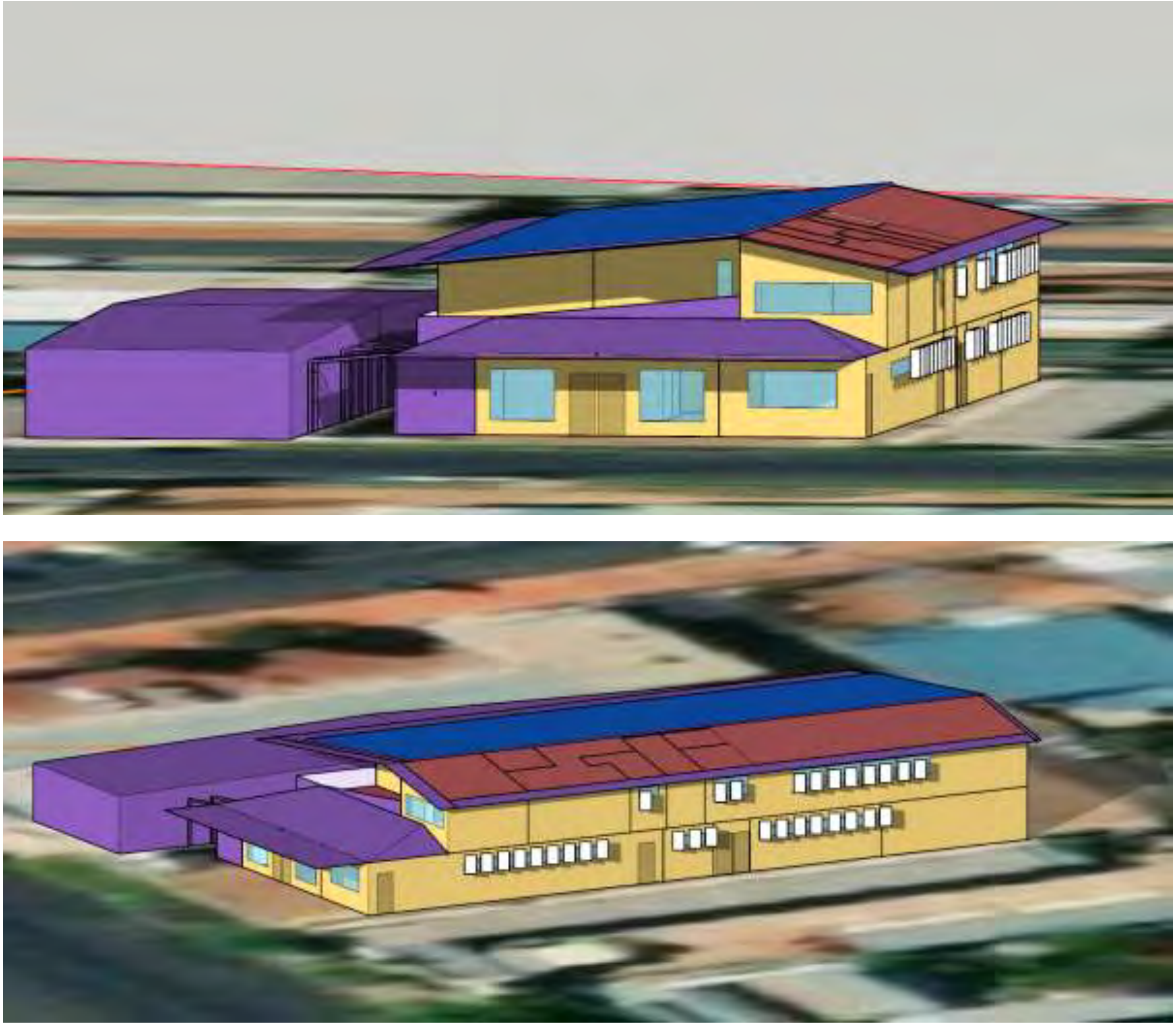


Figure 5.3.2: Louvres on the Western Wall of the Building

Increased Natural Ventilation

The outside air intake was increased from 0.35 L/s to 0.45 L/s.

Table 5.3.4: Annual Energy Requirements – Comparing the baseline to improved ventilation

Description	Heating	Cooling	Equipment + Hot Water	Lighting	Total Energy Requirements
Baseline (kWh)	6,253	200,203	163,939	36,792	407,189
Ventilation	9,644	193,864	162,481	36,792	402,781

This lowered the overall total energy consumption annually by decreasing the cooling demand in summer, however, it did increase the heating demand slightly in winter; not as much as the shading did.

The average annual REF = 0.43 (after 4 outliers greater than 1000 were removed). All outliers occurred in the early morning due to a very small energy demand load. The reason that this REF is lower may be due to the removal of the outliers, compared to the baseline.

Optimised location of Solar PV to North-west facing front roof

The last modification was to locate some of the solar panels on the lower north-western face of the building. This space was fully utilised, with all flat surface, not awnings, covered.

Figure 5.3.2: Proposed Secondary solar location on LALC building

Table 5.3.5: Annual Energy Requirements – Comparing the baseline to improved insulation

Description	Heating	Cooling	Equipment + Hot Water	Lighting	Total Energy Requirements
Baseline (kWh)	6,253	200,203	163,939	36,792	407,189
Solar	9644	193847	162481	36792	402767

The REF value is at a 0.46 with 4 outliers above 1000 excluded.

Figure 5.3.3: Energy generation from Both Solar PV Arrays.

Summary

Despite the modifications undertaken, the REF values did not show a significant change. The only exception to this is the solar panel reorientation, with an additional 200 hours from the 0 to 0.3 RE range, now in the 0.3 to 0.95 REF range.

Table 5.3.8: REF Values comparison between all modifications

	Number of Hours					
	Baseline	Glazing	Insulation	Louvres	Ventilation	Solar moved
REF = 0	1144	1139	1134	1229	1228	1228
0<REF<0.3	1747	1743	1732	1733	1734	1510
0.31<REF<0.95	2176	2176	2189	2209	2207	2417
0.95<REF<1.05	13	13	15	14	15	15
1.05<REF	327	331	331	324	323	337
REF = infinity	3353	3358	3359	3251	3253	3253
Annual Average REF	0.65	0.53	0.45	0.42	0.43	0.46

Table 5.3.9: Energy Requirement Summary Table and Comparison between Modifications

Description	Heating	Cooling	Equipment + Hot Water	Lighting	Total Energy Requirements
Baseline (kWh)	6,253	200,203	163,939	36,792	407,189
Improved Glazing	5,867	203,733	162,481	36,792	408,873
Insulation	6,047	201,295	162,481	36,792	406,614
Shading	9,650	193,389	162,481	36,792	402,311
Ventilation	9,644	193,864	162,481	36,792	402,781
Solar	9,644	193,847	162,481	36,792	402,767

6 Overall Discussion and Conclusions

The findings seem to indicate that is very challenging to achieve a net zero building for a scale this large. With 60% roof coverage for Solar Panels, the system was not large enough to support the energy demands generated by the LALC. From the REF comparison, it areas that the building model has air spaces that are too tightly sealed to maximise the use of better insulation.

Additional measures should be explored, such as reorienting the space internally, to maximise air flow and a more detailed model design undertaken to verify this. The potential for all the solar panels to be positioned on frames to optimise solar generation is another innovative idea.

The target of achieving an average REF value of 1 could not be achieved when ignoring outlier numbers. The REF system is helpful to analyse how energy demand through the day compared to the usage, but it does not give a full picture, especially when there is low or no energy consumption.

6.1 Constraints from original brief

All the original brief criteria was met and nothing was compromised in the redesign. In fact, whilst not affecting the building energy performance too much, the louvres definitely will positively impact the users of the boardroom.

7 Appendix A

The proposed solution can feed into Government Certification Schemes like NABERS, GreenStar and WELL by meeting the criteria and ranking highly. In this proposed design, certain features will be look upon favourably, such as the solar panel energy generation and local materials, but there are also some limitations to these standards.

For this building design to rank highly with NABERS Energy Green Power Stars, (https://www.nabers.gov.au/), it would need 100% of the electricity on site to be renewable.

The GreenStar Ranks are a little more holistic in their consideration of 8 different categories of building assessment: Responsible, Healthy, Resilient, Positive, Places, Nature, Leadership and People. Our building definitely meets several of those to a high extent with the way t has been designed. GreenStar rankings do take into consideration technical requirements as well, but theyr are part of a bigger picture (https://gbca-web.s3.amazonaws.com/media/documents/introducing-green-star.pdf).

Barriers that should be removed are the energy tarrifs that make it not as profitable to sell excess electricity back into the grid. The government should be doing more to encourage renewable solutions. Also, the high expense of batteries, limits the ability of the LALC to store excess electricity.

8 Appendix 8

Appendix *Space Types and Schedules*

Lighting and heating Schedules (Hours of Occupation)						Occupancy	Occupancy Schedule	Activity (W/person)	Maximum illumination power density (W/m2)
		Mon-Thu	Fri	Sat	Sun				
Space Type 1	Café/Restaurant/Souvenir Shop	8am to 6pm	8am - 11pm	8am - 11pm	8am to 2pm	100	Varied	210	14
Space Type 2	Bathrooms	8am to 6pm	8am - 11pm	8am - 11pm	8am to 2pm	7	Varied	130	3
Space Type 3	Kitchen	7am to 5pm	7am to 12am	7am to 12am	7am to 3pm	8	Varied	300	4
Space Type 4	Storage	-	-	-	-	2	1 hour	210	1.5
Space Type 5	Boardroom, offices and classroom	8am to 6pm	8am to 6pm	-	-	10	Varied	120	4.5
Space Type 6	Elevator (lift)	8am to 6pm	8am to 6pm	-	-	4	Varied	130	3
Space Type 7	Atrium	8am to 6pm	8am - 11pm	8am - 11pm	8am to 2pm	0	Varied	0	8
Space Type 8	Kitchenette/lunch room					6	Varied	210	4

NCC Building Class	Description	Space Type Name	Building Story	Occupancy
9b	Open Area (Cafe, restaurant, entertainment)	Space Type 1 - open area	Building Story 1	20 people, varied
6	Male Bathroom	Space Type 2 - restrooms	Building Story 1	5 people, 3 hours a day
6	Female Bathroom	Space Type 2 - restrooms	Building Story 1	5 people, 3 hours a day
6	Disabled Bathroom	Space Type 2 - restrooms	Building Story 1	1 person, 3 hours a day
6	Kitchen	Space Type 3 - kitchen	Building Story 1	6 people
6	Storage (under stairs and stair landing)	Space Type 4 - storage	Building Story 1	-
6	Classroom	Space Type 5 - class/office	Building Story 1	5 people, 3 hours a day
6	Lift	Space Type 6 - lift	Building Story 1	1 person, 1 hours a day
9b	Main upper floor / Atrium / above restaurant	Space Type 7 - upper area	Building Story 2	-
5	Boardroom + 3 offices	Space Type 5 - class/office	Building Story 2	3 people
5	Storeroom (outside boardroom)	Space Type 4 - storage	Building Story 2	-
5	Female bathroom	Space Type 2 - restrooms	Building Story 2	2 people , 2 hours a day
5	Male Bathroom	Space Type 2 - restrooms	Building Story 2	2 people, 2 hours a day
5	Upper landing and corridors	Space Type 1 - open area	Building Story 2	1 people, 3 hours a day
5	Lift	Space Type 6 - lift	Building Story 2	1 person , 1 hour a day
5	Disabled bathroom	Space Type 2 - restrooms	Building Story 2	1 person, 1 hours a day
5	Meeting room	Space Type 5 - class/office	Building Story 2	4 people, 3 hours a day
5	Lunchroom	Space Type 8 - eating	Building Story 2	3 people, 3 hours a day

Thermal Zone Schedules and Specifications

			Hours of occupation				
Thermal Zone Name		Mon-Thu	Friday	Sat	Sun		Maximum illumination power density (W/m2)
Thermal Zone 1	Space Type 1 - open area	8am to 6pm	8am - 11pm	8am - 11pm	8am to 2pm	Open Area (Cafe, restaurant, entertainment)	14
Thermal Zone 2	Space Type 2 - restrooms	8am to 6pm	8am - 11pm	8am - 11pm	8am to 2pm	Male Bathroom	3
Thermal Zone 3	Space Type 2 - restrooms	8am to 6pm	8am - 11pm	8am - 11pm	8am to 2pm	Female Bathroom	3
Thermal Zone 4	Space Type 2 - restrooms	8am to 6pm	8am - 11pm	8am - 11pm	8am to 2pm	Disabled Bathroom	3
Thermal Zone 5	Space Type 3 - kitchen	7am to 5pm	7am to 12am	6am to 12am	7am to 3pm	Kitchen	4
Thermal Zone 6	Space Type 4 - storage	-	-	-	-	Storage (under stairs and stair landing)	1.5
Thermal Zone 7	Space Type 5 - class/office	8am to 5pm	8am to 5pm	-	-	Classroom	4.5
Thermal Zone 8	Space Type 6 - lift	8am to 6pm	8am to 6pm	-	-	Lift	3
Thermal Zone 9	Space Type 7 - upper area	8am to 6pm	8am - 11pm	8am - 11pm	8am to 2pm	Main upper floor / Atrium / above restaurant	8

		Mon - Fri	Weekends				
Thermal Zone 10	Space Type 5 - class/office	8am to 6pm	-			Boardroom + 3 offices	5
Thermal Zone 11	Space Type 4 - storage	8am to 6pm	-			Storeroom (outside boardroom)	1.5
Thermal Zone 12	Space Type 2 - restrooms	8am to 6pm	-			Female bathroom	3
Thermal Zone 13	Space Type 2 - restrooms	8am to 6pm	-			Male Bathroom	3
Thermal Zone 14	Space Type 1 - open area	8am to 6pm	-			Upper landing and corridors	4.5
Thermal Zone 15	Space Type 6 - lift	8am to 6pm	-			Lift	3
Thermal Zone 16	Space Type 2 - restrooms	8am to 6pm	-			Disabled bathroom	3
Thermal Zone 17	Space Type 5 - class/office	8am to 6pm	-			Meeting room	4.5
Thermal Zone 18	Space Type 8 - eating	8am to 6pm	-			Lunchroom/Kitchenette	4

Air Flow Calculations for Ventilation

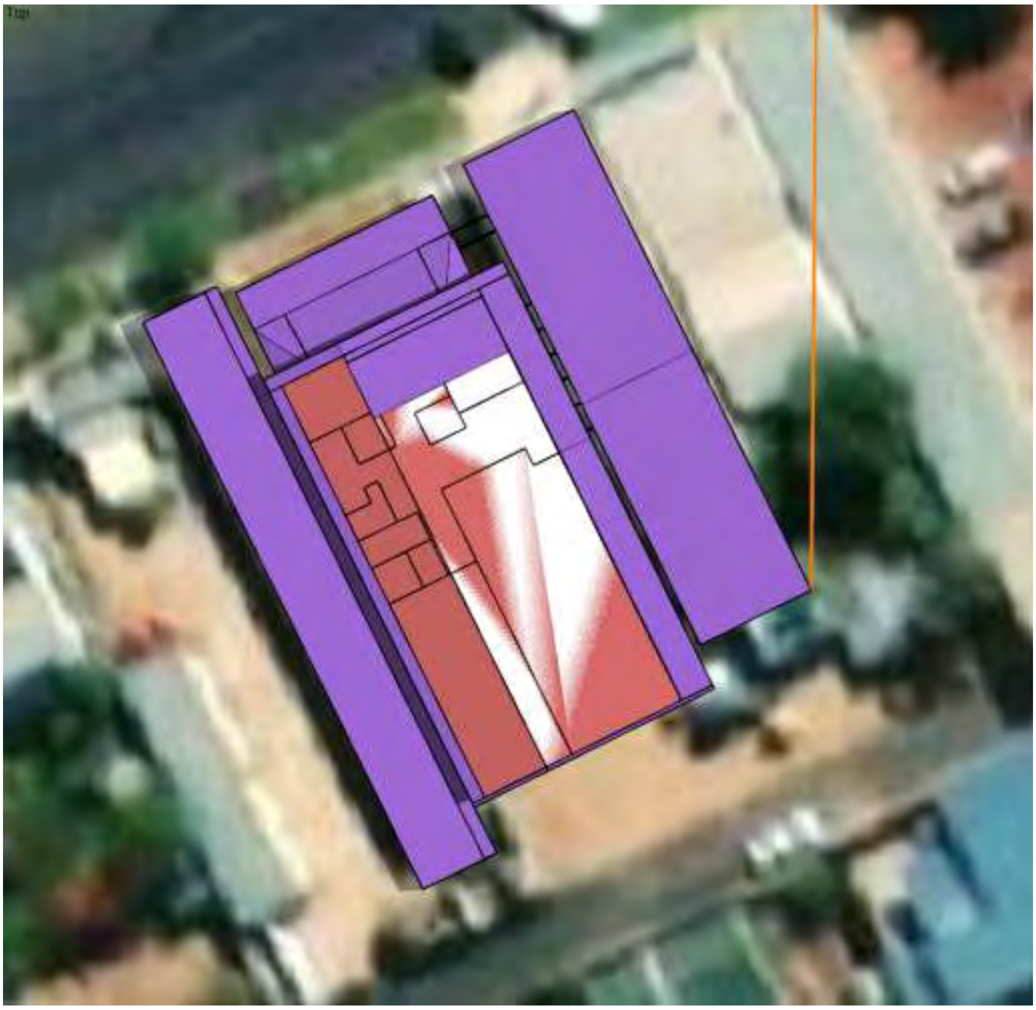
Thermal Zone Name	Outdoor Air Flow per floor area (m3/s)	m3/s fresh air supply per m^2	L/s (fresh air supply) per m^2	Area (m^2)
Thermal Zone 1	47.85027	0.129413	129.4125	369.75
Thermal Zone 2	0.276757	0.009842	9.842	28.12
Thermal Zone 3	0.5054	0.0133	13.3	38
Thermal Zone 4	0.030141	0.003248	3.248	9.28
Thermal Zone 5	2.308841	0.028427	28.427	81.22
Thermal Zone 6	0.064927	0.004767	4.767	13.62
Thermal Zone 7	0.6174	0.0147	14.7	42
Thermal Zone 8	0.02835	0.00315	3.15	9
Thermal Zone 9	12.42441	0.065944	65.9435	188.41
Thermal Zone 10				
Thermal Zone 11	5.005619	0.041857	41.8565	119.59
Thermal Zone 12	0.011774	0.00203	2.03	5.8
Thermal Zone 13	0.03903	0.003696	3.696	10.56
Thermal Zone 14	0.023305	0.002856	2.856	8.16
Thermal Zone 15	3.250512	0.03373	33.7295	96.37
Thermal Zone 16	0.02835	0.00315	3.15	9
Thermal Zone 17	0.019898	0.002639	2.639	7.54
Thermal Zone 18	0.082683	0.00538	5.3795	15.37

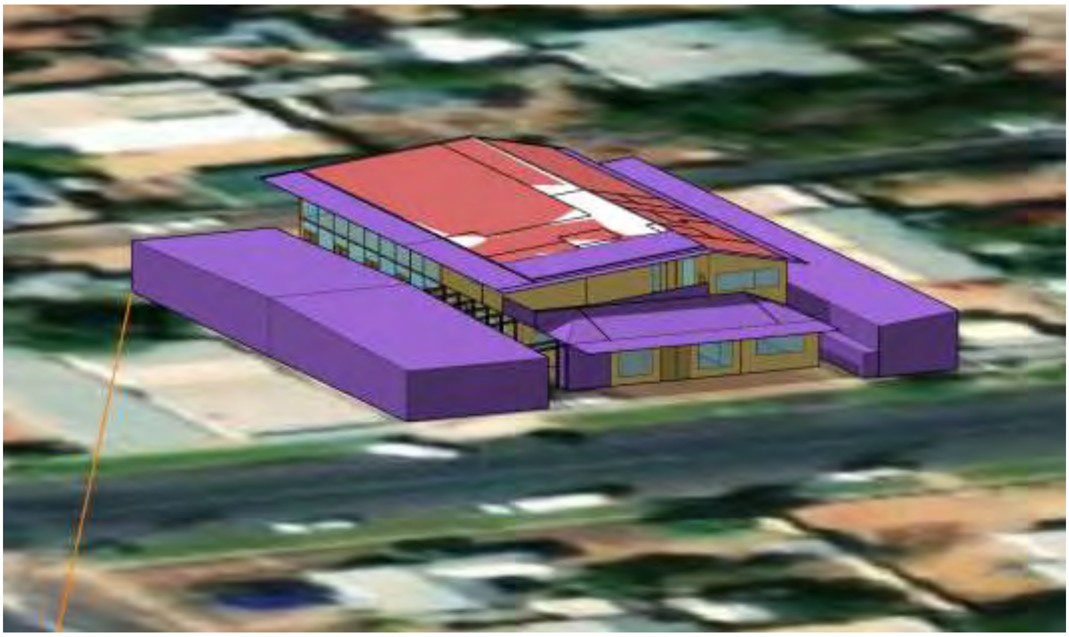
Electrical Equipment and Hot Water Loads

Maximum illumination power density (W/m2) - NCC Vol 1 - Table J6.2a			Electrical Equipment	Energy requirement of electrical equipment (W)	Hot Water Energy Requirement (W)
Space Type 1	14	Café/Restaurant/Souvenir Shop			2000
Space Type 2	3	Bathrooms			2000
Space Type 3	4	Kitchen	Kitchen Appliances	7500	2000
Space Type 4	1.5	Storage			
Space Type 5	4.5	Boardroom, offices and classroom	Office equipment/computers	1000	2000
Space Type 6	3	Elevator (lift)	Lift mechanisms	1000	
Space Type 7	8	Atrium			2000
Space Type 8	4	Kitchenette/lunch room			2000

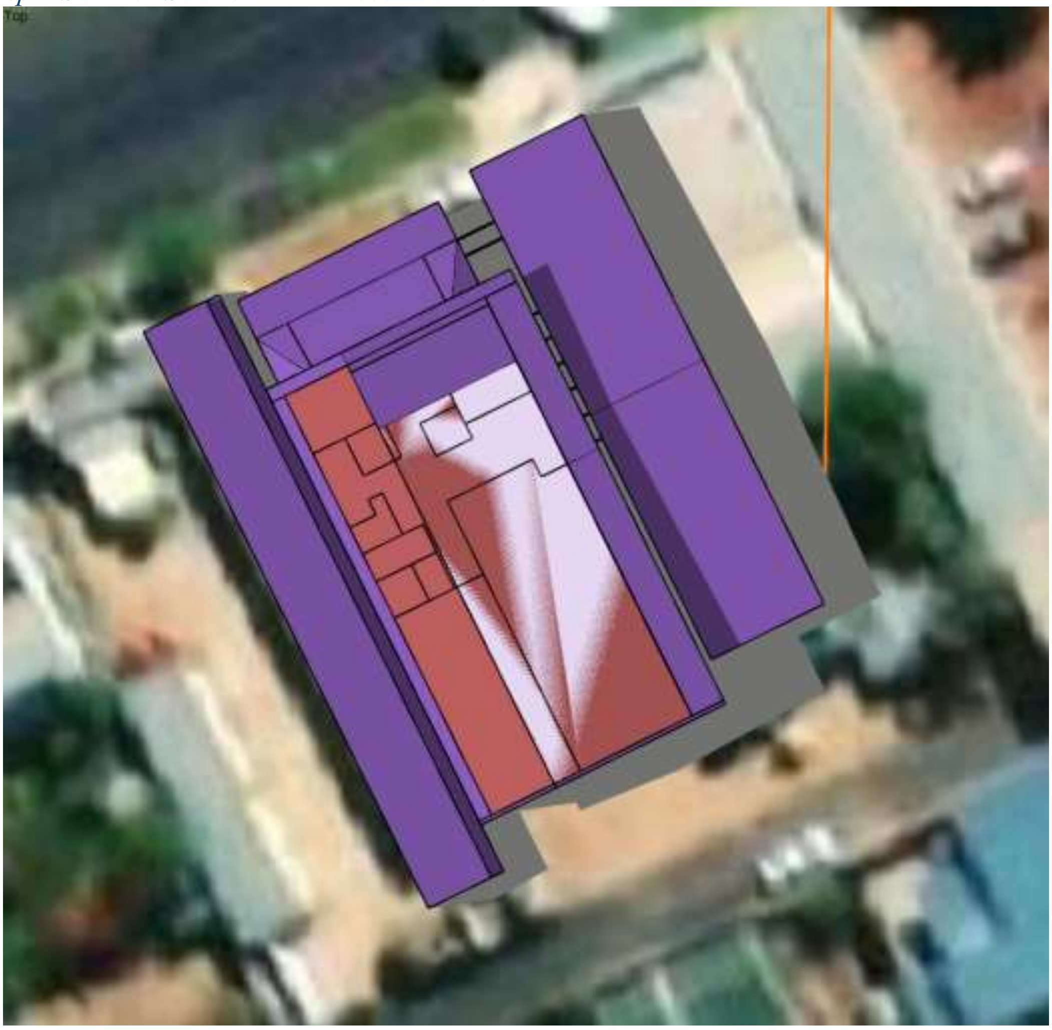
9 Appendix C

10am Summer Solstice – 21st December 2021

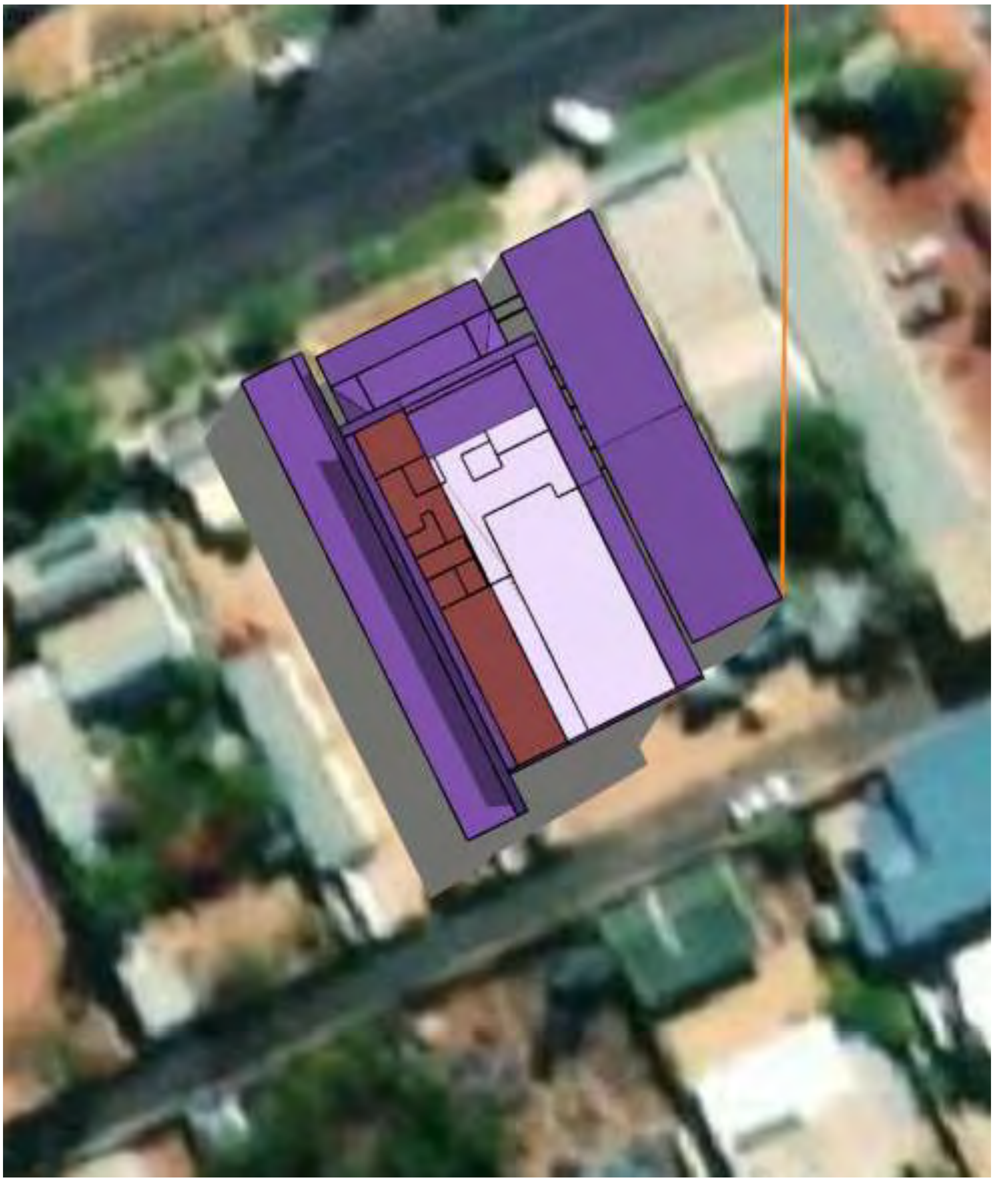


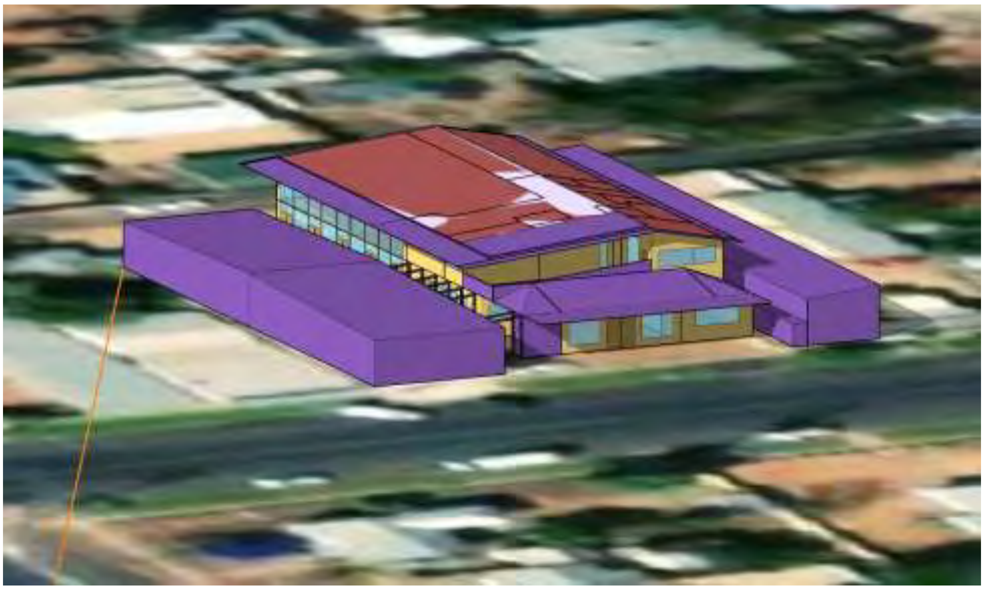


4pm Summer Solstice – 21st December 2021

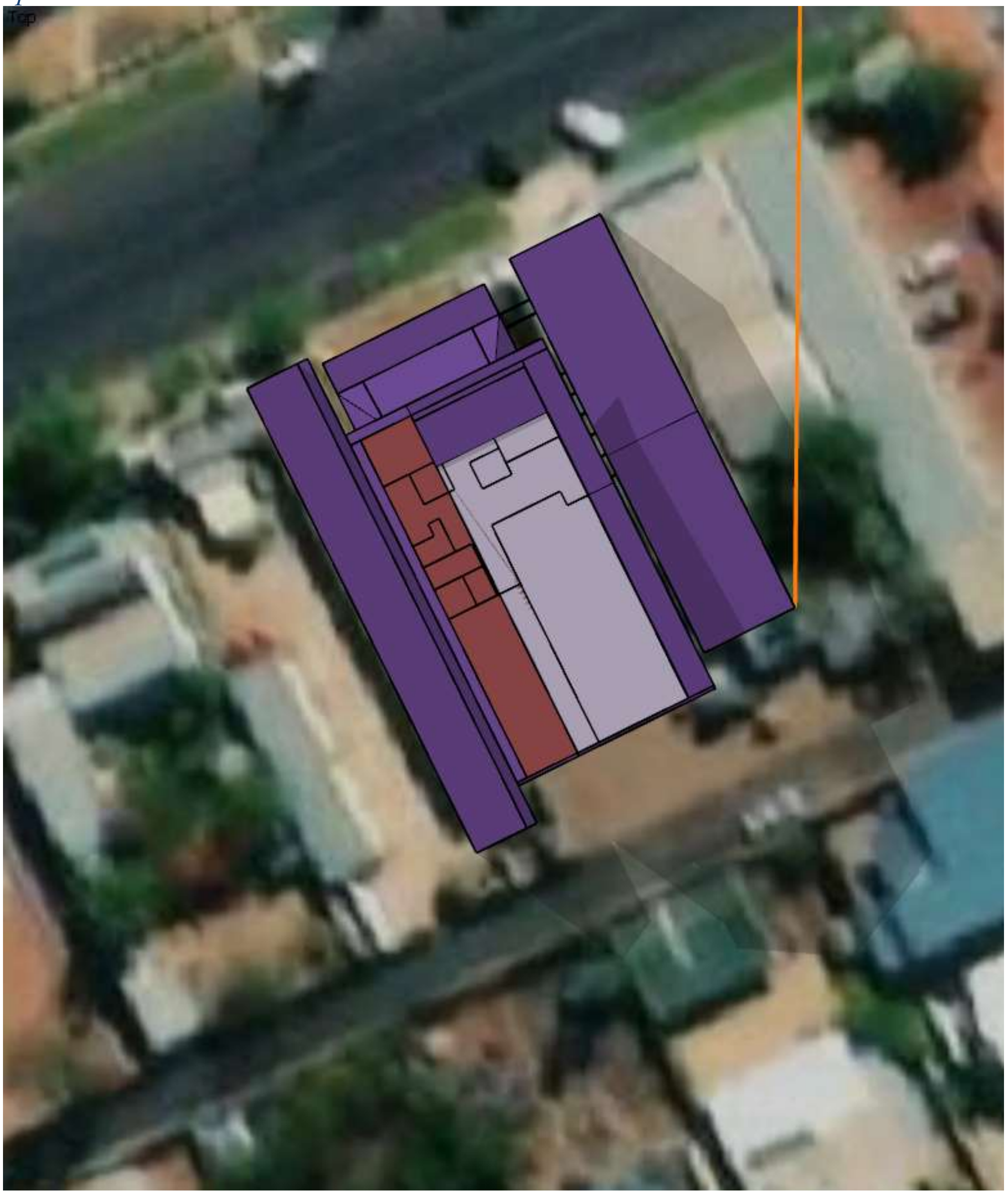


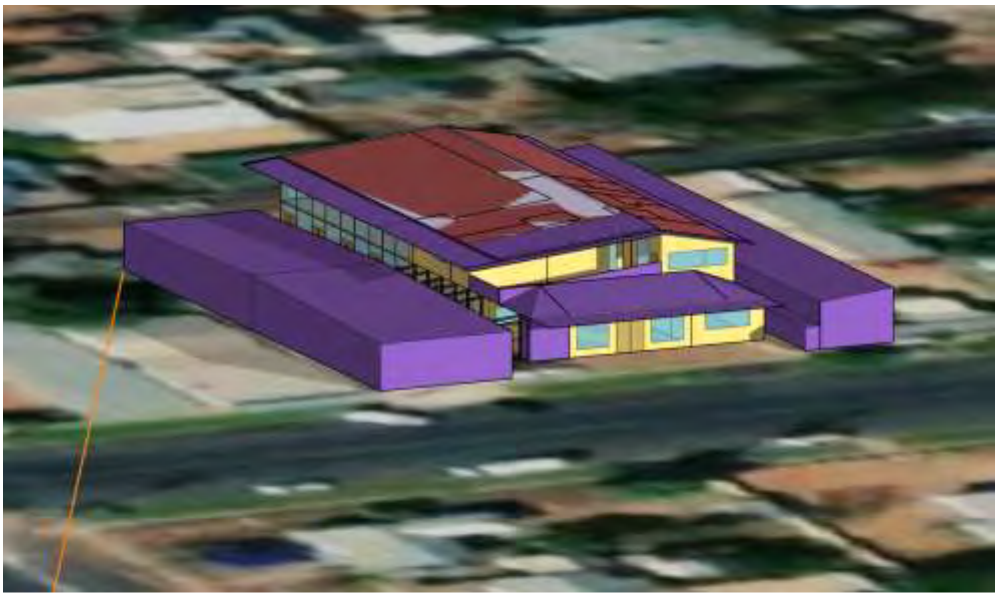
10am Winter Solstice – 21st December 2021





4pm Winter Solstice – 21st June 2021





LIGHTNING RIDGE ABORIGINAL LANDS COUNCIL

NET ZERO ENERGY DESIGN

ASSESSMENT TASK 3

EXECUTIVE SUMMARY

This report documents' the findings of an in-depth study into the energy consumption and design modifications of the proposed Local Aboriginal Lands Council building based in Lightning Ridge. The structure has previously been designed as a group to suit the client's brief and requirements. Now, the design is being modified and simulated to ensure it is as sustainable as possible, being a net-zero building, whilst also sustaining a high level of thermal comfort for the occupants and meeting the clients' expectations.

The simulation model is constructed using SketchUp and OpenStudio. The various rooms, spaces, thermal zones, windows and building materials are input into the software and a simulation is undertaken in respect to the weather file of the location. First the initial Base-model A is simulated and analysed, this model has no photovoltaic panels, and no additional modifications. The model is assumed to have the same value for net site energy and total site energy as there is no renewable energy source in play. This is proven correct, the results of the simulation being net and total site energy as 1090GJ, the peak cooling day being in summer, the 20th January, and the peak heating day in winter, 24th July.

The Base-model B was then produced, the only change being the addition of photovoltaic (PV) panels. After close assessment of shadow diagrams and how much of the roof receives direct solar, panels were added to both sides of the roof. 240x 250W individual 1700x1000mm panels were added to the roof, making up roughly an 80kW system, giving the design a NABERS rating of 5.5. The addition of the PV panels to the OpenStudio simulation model reduced the buildings net energy by 40%, thus significantly reducing its carbon footprint. The total site energy of the design changed to 1082GJ, total source energy 1938.98GJ, the net site energy came out to be 645.8GJ, and net source energy 556.88GJ. The renewable energy production for the Base-model B is 445GJ due to the PV panel production. The Renewable Energy Factor for the simulation was 0.50, which is aimed to be improved with further modifications made for the final model.

For the final model numerous structural modifications were made to try to bring the total site energy value down. Due to the high temperatures Lightning Ridge experiences, some of the windows were made smaller to reduce the thermal transfer from the sun heating the rooms and thus more cooling energy would be needed. The front glass entrance doors and the large external atrium window were also reduced in size for the same reasons. Overhangs were added to the windows, these help to block direct solar and heat from reaching the glass windows. All the modification were added in steps and the simulation was run each time to ensure all modifications had a positive effect in reducing the buildings energy consumption. The final simulation model resulted in the total site energy being reduced to 1062GJ, total source energy 1897GJ, the net site energy lowered to 625.6GJ, and the net source energy 515.1GJ.

The net energy of the final model was significantly lowered due design modifications and the addition of PV panels as a renewable energy source.

TABLE OF CONTENTS

INTRODUCTION

In previous weeks a structure for the Lightning Ridge Local Aboriginal Lands Council (LRLALC) building has been designed as a group, with operational requirements and clients' expectations at the core of the design. This task involves developing this base case model, and advancing it into a net zero energy design, using Open Studio as a simulation tool to verify the design. With the aim now centred about the model being energy efficient whilst also providing thermal comfort to occupants, the design must be modified to improve its overall net energy and utilise renewable on-site energy.

Net zero energy buildings are ones that function from renewable energy consumption, with "net-zero" being achieved when the amount of energy used by the building is equal to the amount of renewable energy produced on the site. The three main characteristics to achieve a net-zero building are: developing an efficient design, targeting energy conservation, and producing renewable energy on the site (Younis, Jourdan, 2020).

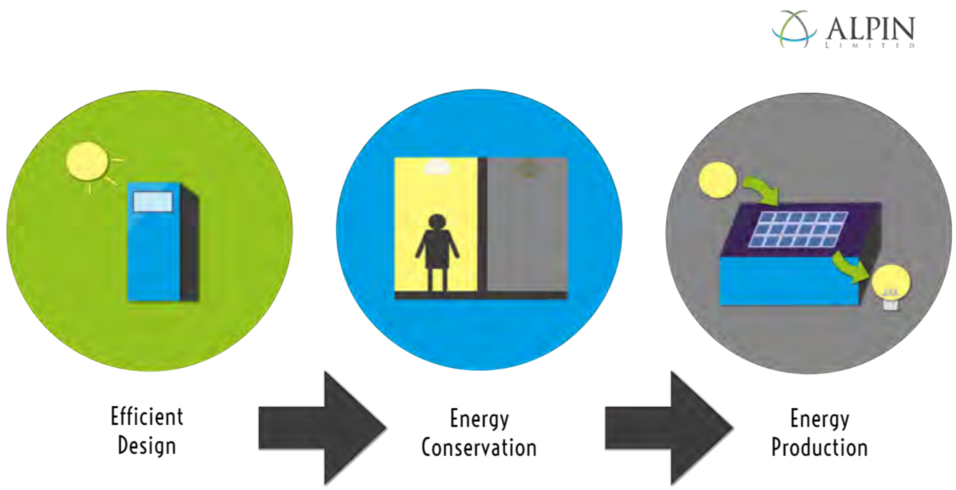


Figure 1: Main Elements for Net Zero Designs (Alpinme.com, 2020)

The building has been structurally designed to be an efficient as possible, including with large eves to block direct sunlight to areas of the building, minimal windows to conserve energy as the building is located in a hot climate but enough to ensure natural ventilation, and covered outdoor areas with fans to have shaded gathering areas outside. Energy conservation has been established with the introduction of double-glazing windows, interior blocking blinds and sustainable materials for the walls. Finally, PV panels are added to the roof of the building a renewable energy production source, making the greatest difference to the carbon footprint of the building, and reducing greenhouse gas emissions.

FINAL DESIGN

After feedback from the Client, Engineers and Architectural consultants the LRLALC design has been altered to better reflect the expectations and requirements of the building. In doing this the second-floor layout has slightly been altered by removing the computer room and making the CEO and CFO offices larger. Further the Second-floor height has been lifted by 0.6m, making the overall appearance of the building also being larger in height.

FLOOR PLANS

Changes to the floor plan have been highlighted in figures 2 and 3 below:

Ground Floor:

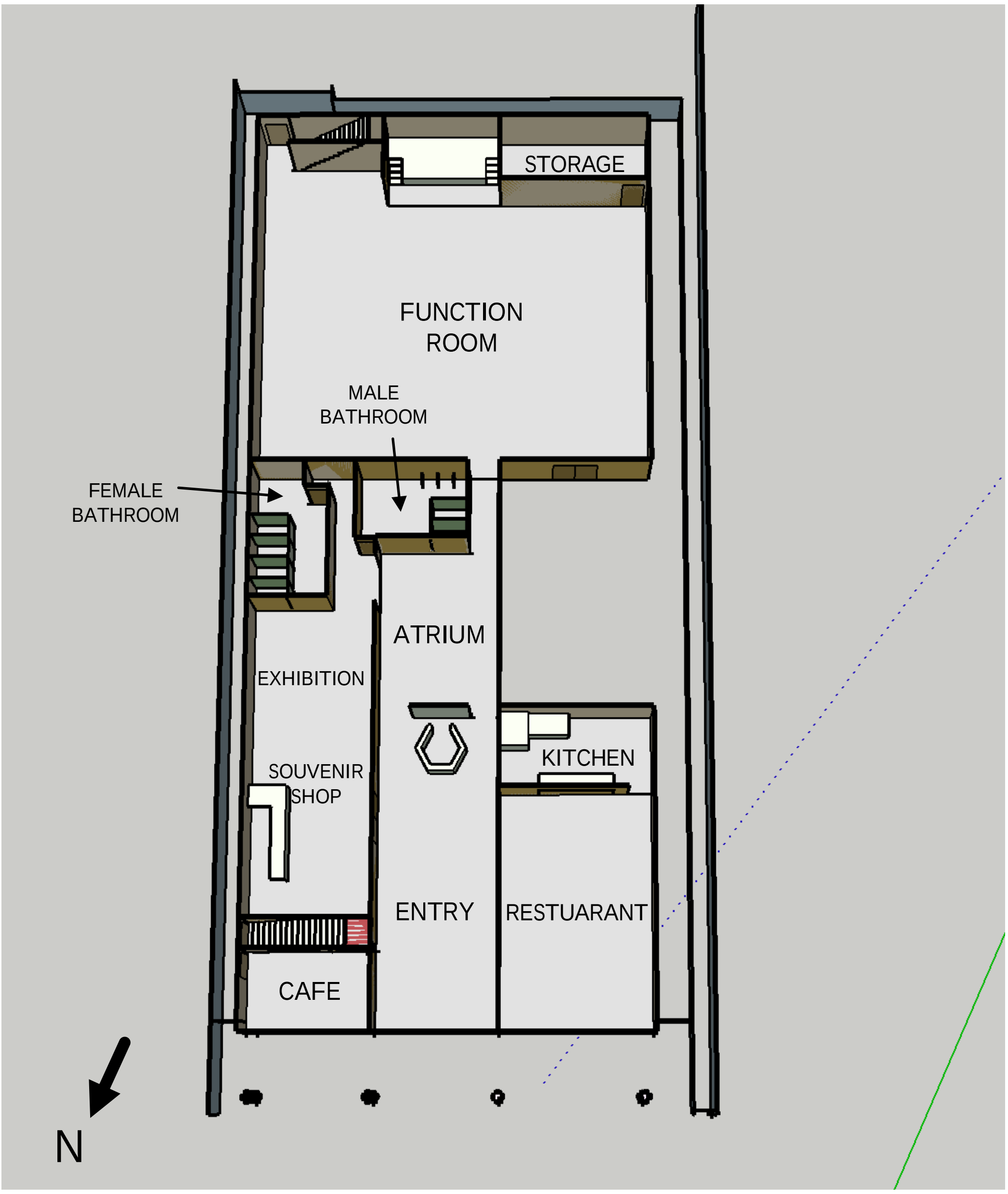


Figure 2: Ground Floor LRLALC Building

Top Floor:

Figure 3: Second Floor LRLALC Building

A noticeable difference to the roof height can be viewed in figures 4 and 5 below.

Figure 4: Original Design

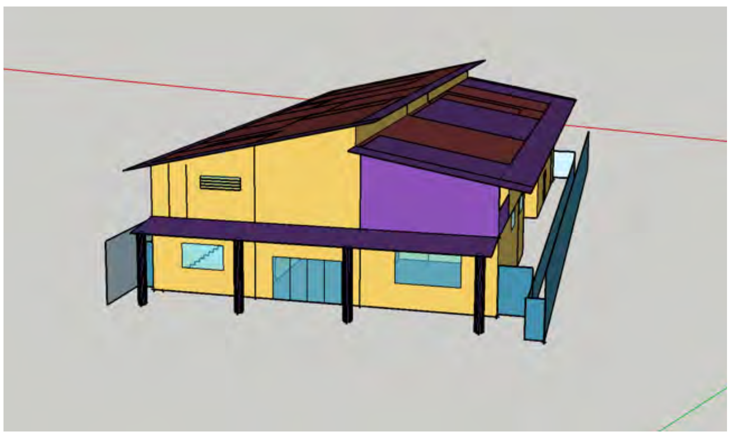


Figure 5: Final Design on OpenStudio

SHADOW DIAGRAMS

<u>January (summer):</u>

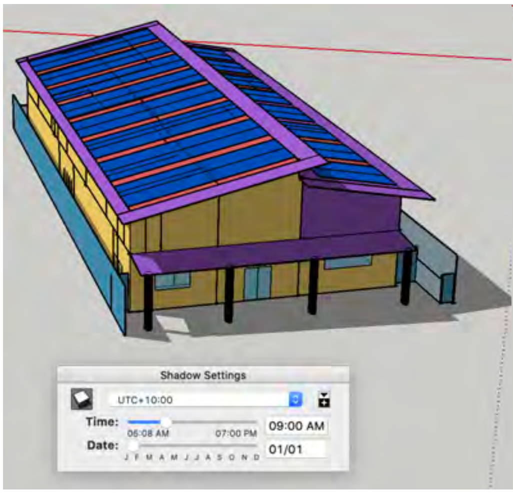


Figure 6: Shadows: 9am, Jan 1

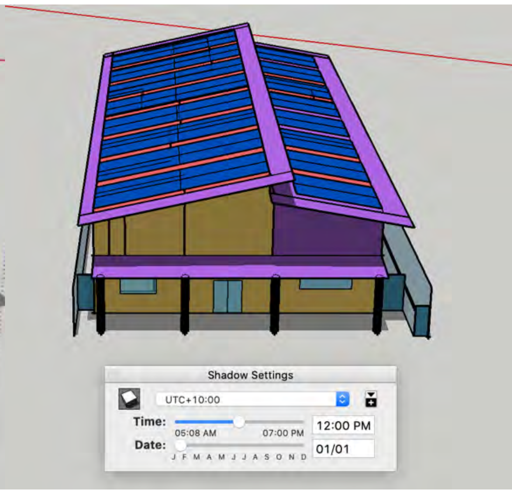


Figure 7: Shadows: 12pm, Jan 1

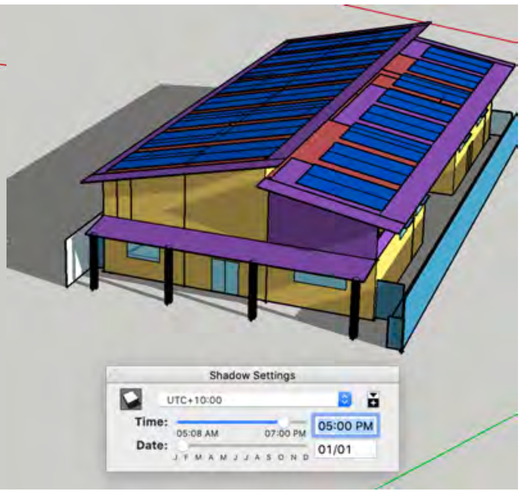


Figure 8: Shadows: 5pm, Jan 1

<u>June (winter):</u>

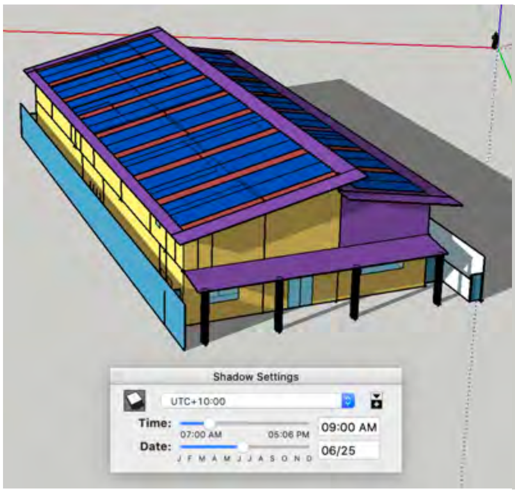


Figure 9: Shadows: 9am, June 25

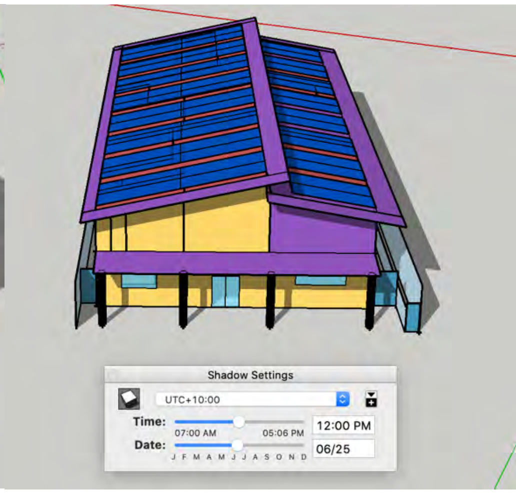


Figure 10: Shadows: 12pm, June 25

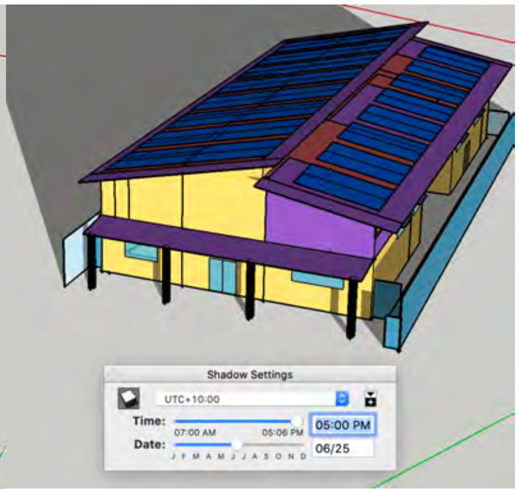


Figure 11: Shadows: 5pm, June 25

After close observation and comparisons of the shadow diagrams from a day in summer and a day in winter at the times 9am, 12pm and 5pm, the following observations can be taken:

- The left side of the building (north-east) experiences a lot more direct sun on winter mornings (9am) rather than summer. Whereas the right side of the building (south-west) experiences more direct solar on summer evenings (5pm) then winter.
- The front of the building receives more direct sunlight during winter than summer, with the windows and doors not receiving any direct solar during summer. This is very good as it reduces the solar heat transfer on the glass during the hottest part of the year.
- The PV panels are subject to a lot of direct sunlight throughout the entire day in winter and summer months, which is very positive.

BENCHMARK MODEL

BENCHMARK MODEL A)

The design has been modelled in sketch up and then a thermal simulation model has been created through the OpenStudio program. This is the base case model with no photovoltaic panels, and no additional energy saving modifications.

The base design has a few structural characteristics which reduce the energy consumption of the building, including:

- Large eves to reduce the amount of direct sunlight hitting the windows and heating the building.
- Cover at the front of the building also blocking direct sunlight to the large glass doors and windows at the front of the building.
- Under cover outdoor areas with large fans to circulate air.
- Minimal windows on the ground level as there is more direct solar to these areas

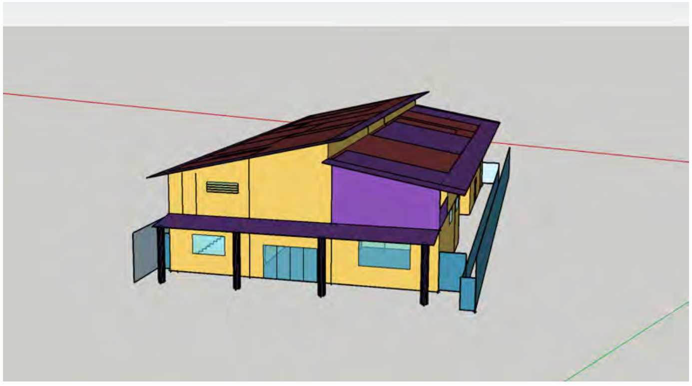


Figure 12: Benchmark model on OpenStudio

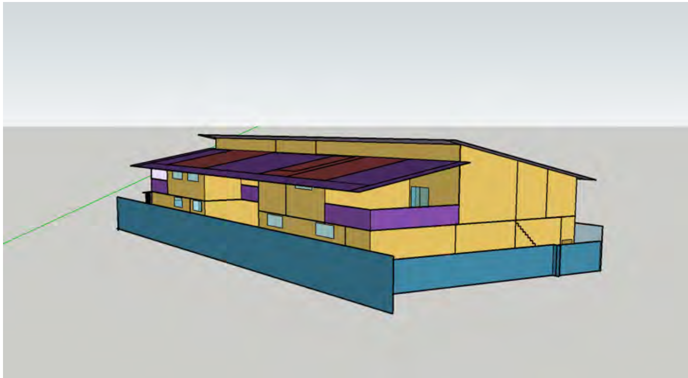


Figure 13: Benchmark model on OpenStudio

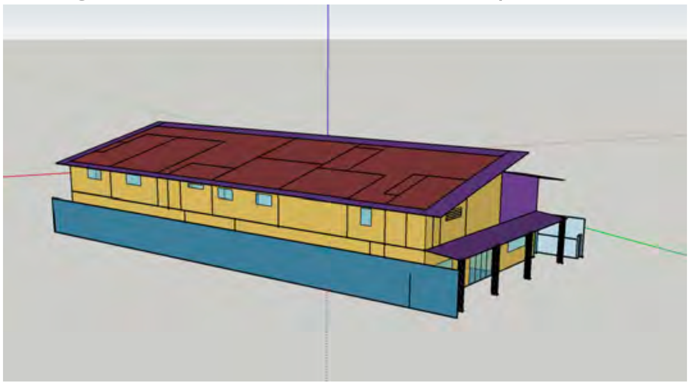


Figure 14: Benchmark model on OpenStudio

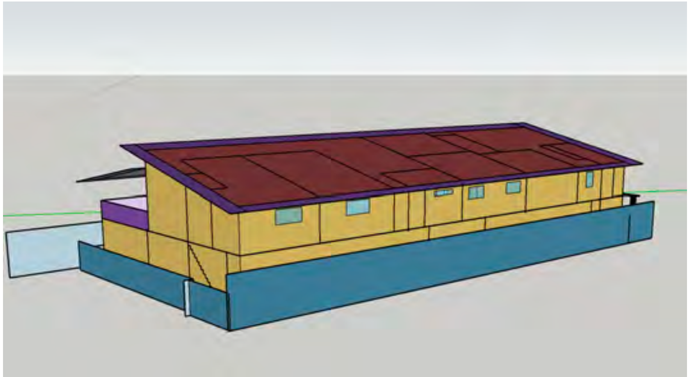


Figure 15: Benchmark model on OpenStudio

Assumptions and a more detailed description of the operation and design of the simulation model can be viewed in the appendix.

SIMULATION RESULTS

Site and Source Energy:

Table I: Simulation Results Benchmark Model A

	Total Energy [GJ]	Total Energy [kWh]	Energy / Conditioned Building Area [MJ/m^2]	Energy / Conditioned Building Area [kWh/m^2]
Total Site Energy	1090.14	302816.6	1248.88	346.9
Net Site Energy	1090.14	302816.6	1248.88	346.9
Total Source Energy	1945.85	540513.9	2229.18	619.2
Net Source Energy	1945.85	540513.9	2229.18	619.2

From Table I it can be taken that the net site energy is the same as the total site energy, this is due to no renewable energy source.

Peak Energy Demand of the Heating and Cooling:

Table II: Peak Energy Results Benchmark Model A

Load	Minimum Value [kW]	Time of Minimum	Maximum Value [kW]	Time of Maximum
Heating	0.00	01-JAN-00:10	47.33	24-JUL-08:10
Cooling	0.00	23-FEB-01:10	135.03	20-JAN-16:00
Electrical Equipment	4.84	01-JAN-00:10	23.47	02-JAN-13:10
Interior Lightning	1.02	01-JAN-00:10	9.82	02-JAN-11:10
Natural Gas	0.33	01-JAN-00:10	4.91	01-JAN-18:10

BENCHMARK MODEL B)

Everything in this model is the same as the benchmark model (A) however, it now includes photovoltaic panels (PV) as a renewable energy source. The assumption for this simulation is that the net site and source energy will go down due to the PV panels producing energy to the site.

The PV panels mostly cover the North-West side of the building as it receives the most direct sun during the day, this side of the roof was purposely designed to be larger so the panels can benefit from plenty of sun, being angled also in favour of the sun. The panels cover 53.5% of the roof and have a nominal efficiency of 15%.

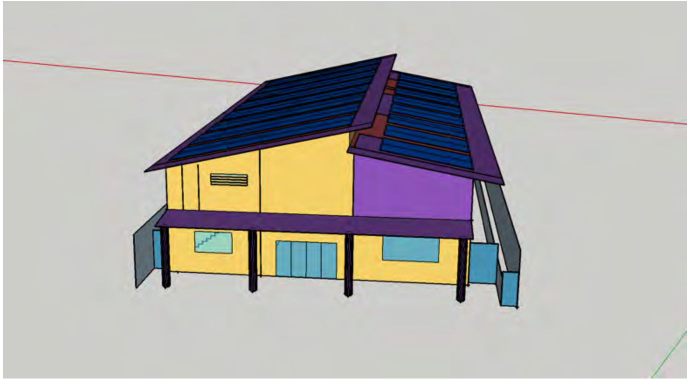


Figure 16: Benchmark model B on OpenStudio

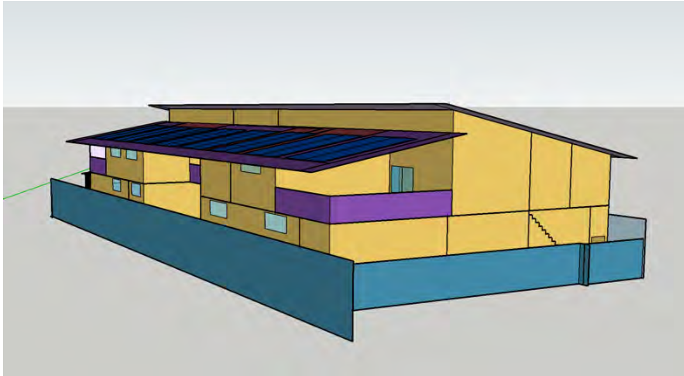


Figure 17: Benchmark model B on OpenStudio

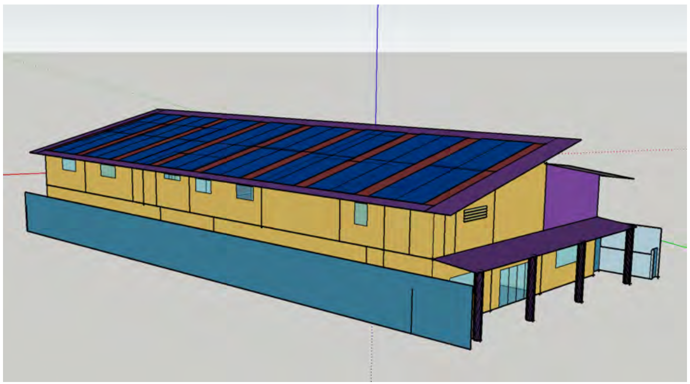


Figure 18: Benchmark model B on OpenStudio

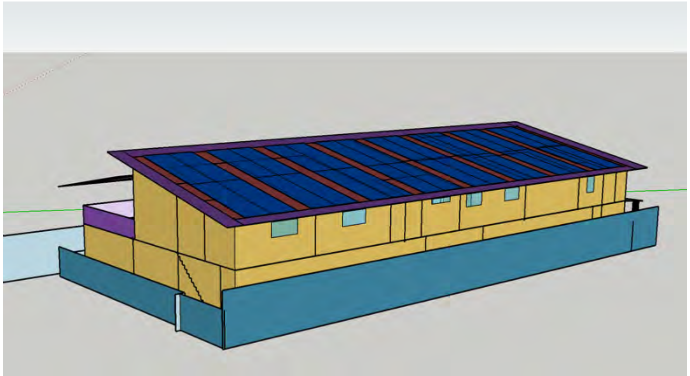


Figure 19: Benchmark model B on OpenStudio

The roof has specifically been designed to have the largest side of the roof facing northeast side and angled to receive the most amount of direct solar, allowing the whole side of the roof to be covered in solar panels. There are 240 panels, 1700x1000mm, close to a 80KW system, and the panels are not positioned on any overhangs and have 1m between them for servicing reasons.

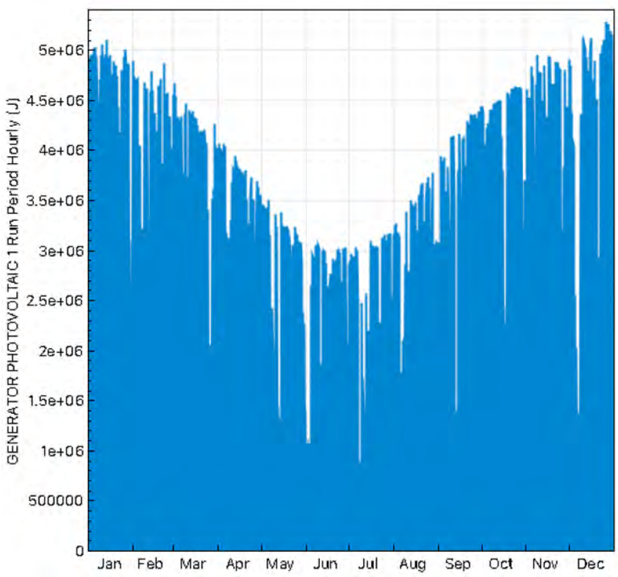


Figure 20: Annual Photovoltaic Generation

Figure 20 is a visual representation of the generation of the Photovoltaic panels from January through December. The graph shows the generation reducing in the winter months, however significant generation is still upheld.

SIMULATION RESULTS

Site and Source Energy:

Table III: Simulation Results Benchmark Model B

	Total Energy [GJ]	Total Energy [kWh]	Energy / Conditioned Building Area [MJ/m^2]	Energy / Conditioned Building Area [kWh/m^2]
Total Site Energy	1082.26	300627.8	1239.85	344.4
Net Site Energy	645.85	179402.7	739.89	205.5
Total Source Energy	1938.98	538605.6	2222.01	617.2
Net Source Energy	556.88	154688.8	637.96	177.2

From this table it can be taken that the total site and source energy is like the value of that in base model (A) however, the net site and source energy is now lower due to the addition of the PV panels. The PV panels have reduced the energy by an annual average of about 40%, with the renewable energy generation being 445.32GJ.

Peak Energy Demand of the Heating and Cooling:

Table IV: Peak Energy Results Benchmark Model B

Load	Minimum Value [kW]	Time of Minimum	Maximum Value [kW]	Time of Maximum
Heating	0.00	01-JAN-00:10	47.01	24-JUL-08:10
Cooling	0.00	06-JAN-04:10	134.27	20-JAN-16:00
Electrical Equipment	4.84	01-JAN-00:10	23.47	02-JAN-13:10
Interior Lightning	1.02	01-JAN-00:10	9.82	02-JAN-11:10
Natural Gas	0.327	01-JAN-00:10	4.91	01-JAN-18:10

RENEWABLE ENERGY FRACTION (REF)

The REF values can be found by dividing the generated on-site renewable energy by the total energy requirements of the site for the specific hour. The renewable energy resulted by the simulating is 445.32GJ.

Overall REF value for Base model B is: 0.41

Table V: REF Values

REF Value	Number of Hours (hrs)
0	4163
0 < REF < 0.3	1129
0.31 < REF < 0.95	1769
0.95 < REF < 1.05	216
1.05 < REF	1483

Note, roughly 4086 hours of the year it is night-time and thus, the REF value will be 0 for this period, hence why the number of hours for a 0 REF value is so large in table V. Using this fact, then the hours of the year must average an REF of above 1.8 to give an annual average REF value of 1.

LIGHTING

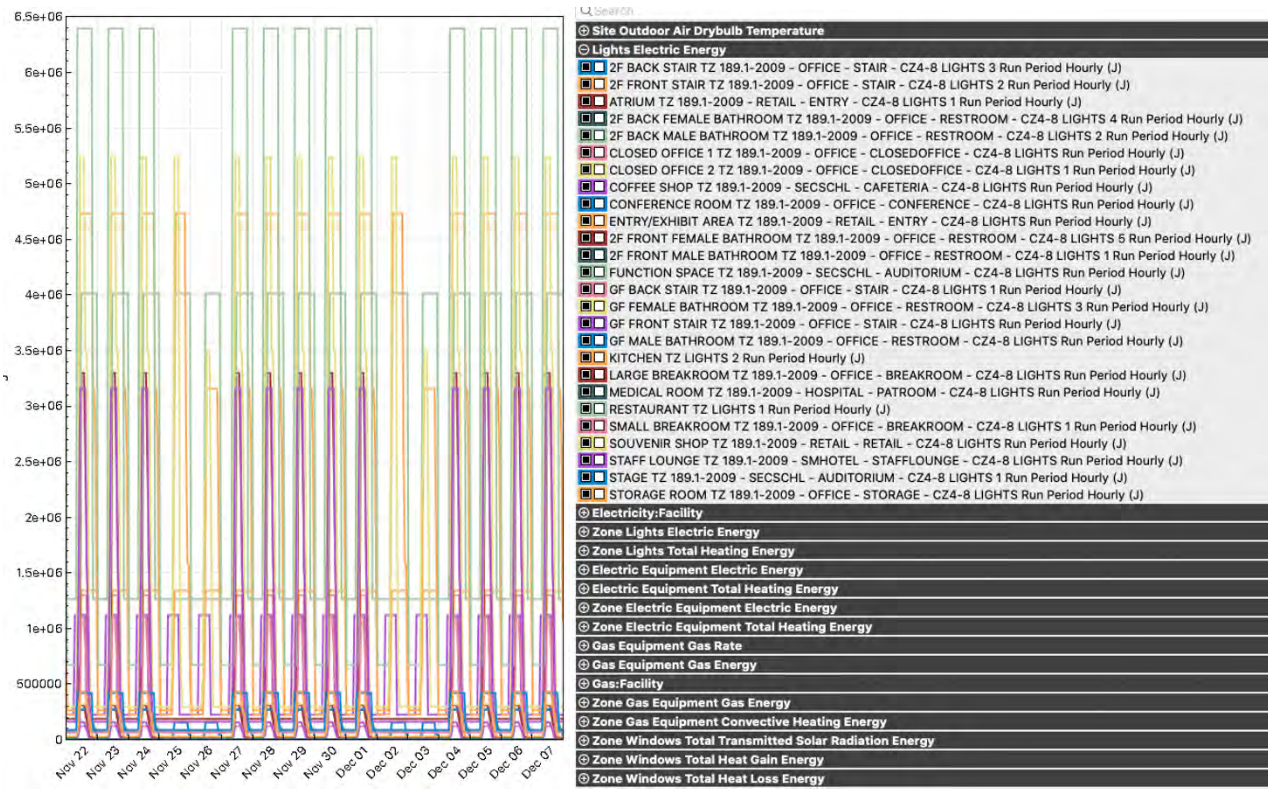


Figure 21: Lights Electric Energy Graph Nov/Dec

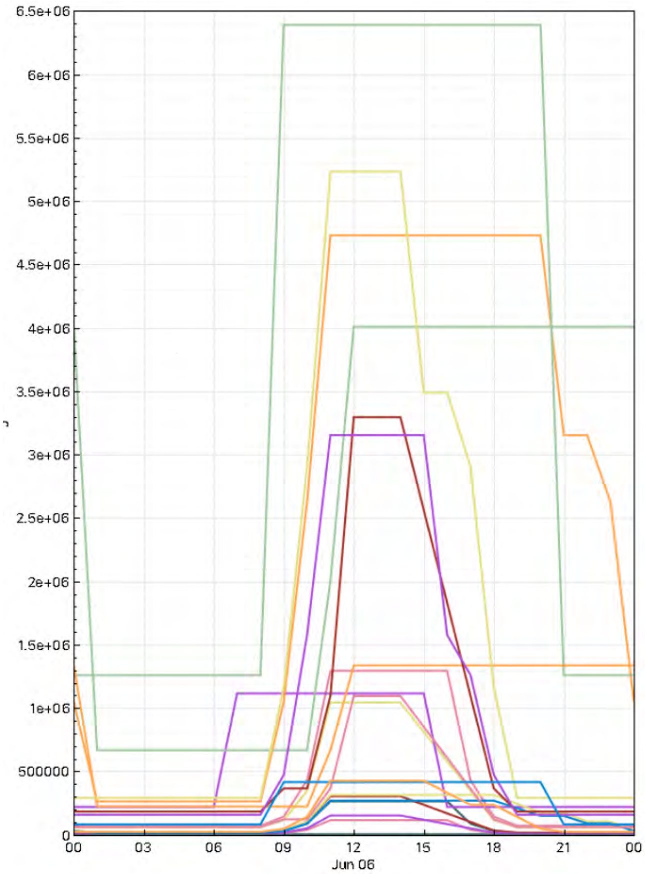


Figure 21: June 6 Lights Electric Energy

Figure 21 demonstrates the large difference in the energy consumption from lighting in the different spaces due to the vast difference in quantity of lights in different sized spaces and the different wattages needed in the different rooms.

The graph shows that the lighting follows a consistent path through the whole year with less light electric energy used on weekends and maximum values through the week.

Figure 22 shows the lighting electric energy usage on peak day. The function room is the maximum value, due to the large size of the room (2123m^2), however, this room will probably not be used every day, and thus this energy and cost will be significantly reduced.

HEATING

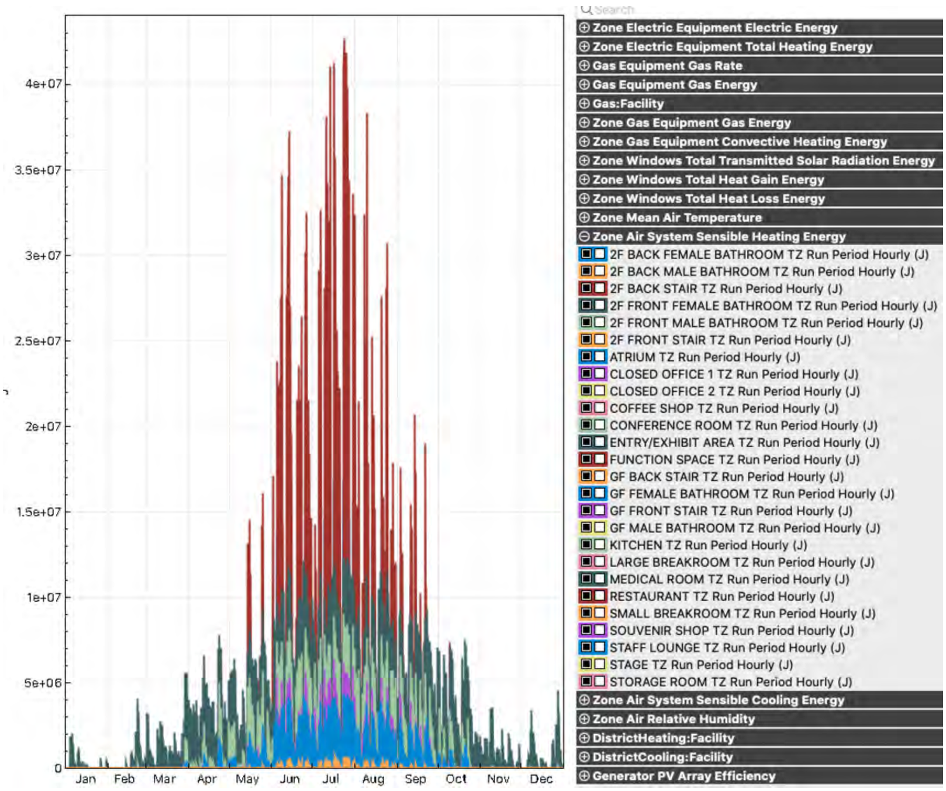


Figure 22: Annual Zone Heating Energy Graph

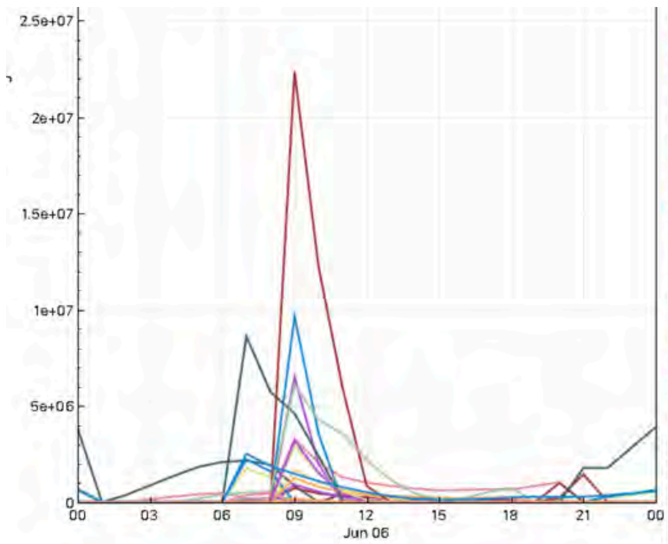


Figure 23: June 6 Heating Energy

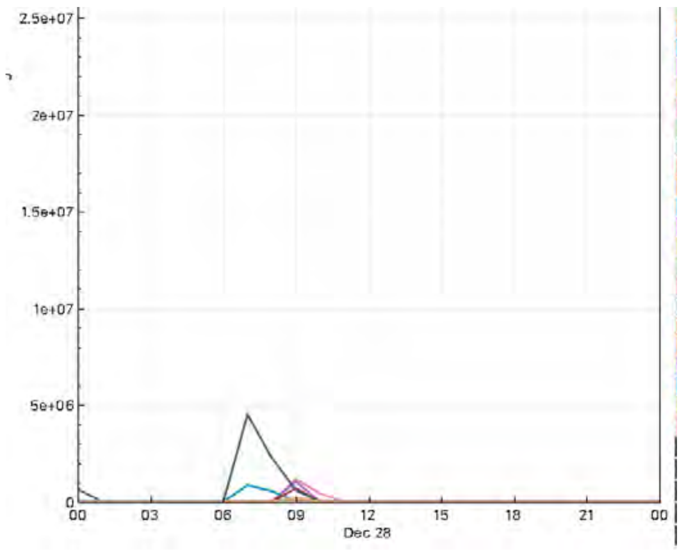


Figure 24: December 28 Heating Energy

From these graphs it is made clear that heating can be visually represented that the heating energy is maximum in winter, and minimum in summer. This could have been expected due to temperatures in winter being much lower and thus, heating having to be used much more.

Figure 22 shows the function room uses much more heating energy than any other spaces, this is due to the space being so large and needing more energy to heat the area. It should be noted this simulation is based on an estimated schedule, and thus the function area may not necessarily be in use as often as was accounted for.

COOLING

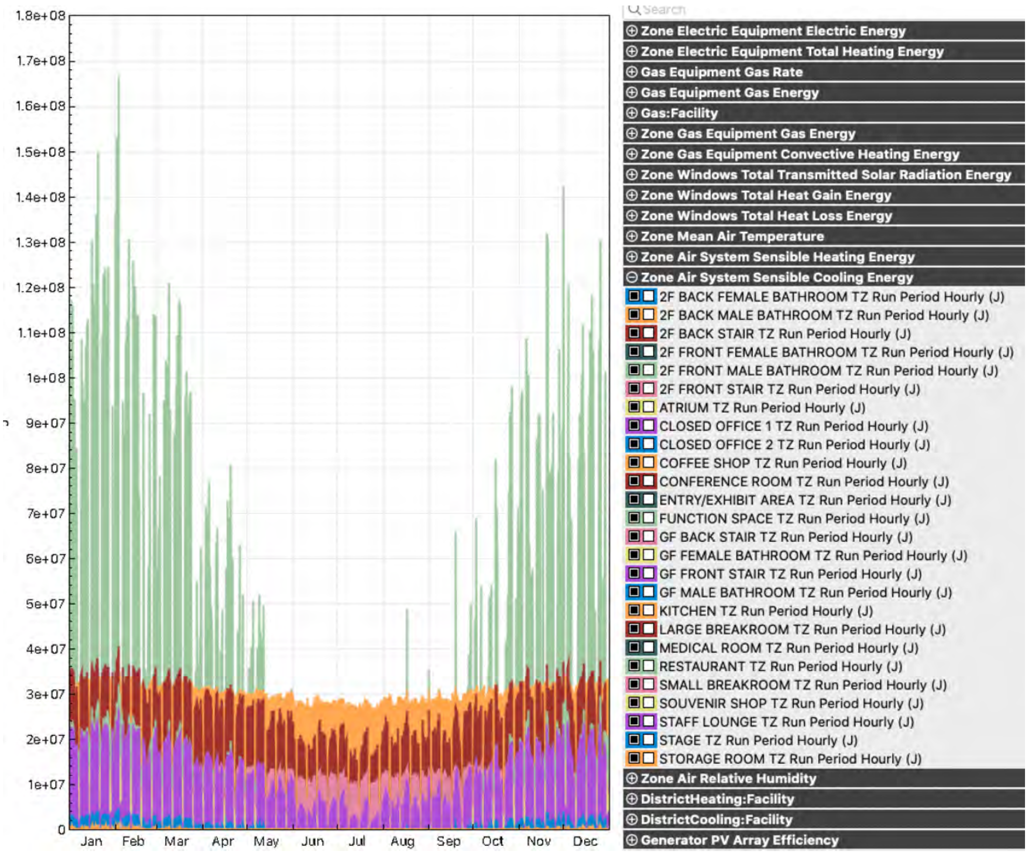


Figure 25: Annual Cooling Energy Graph

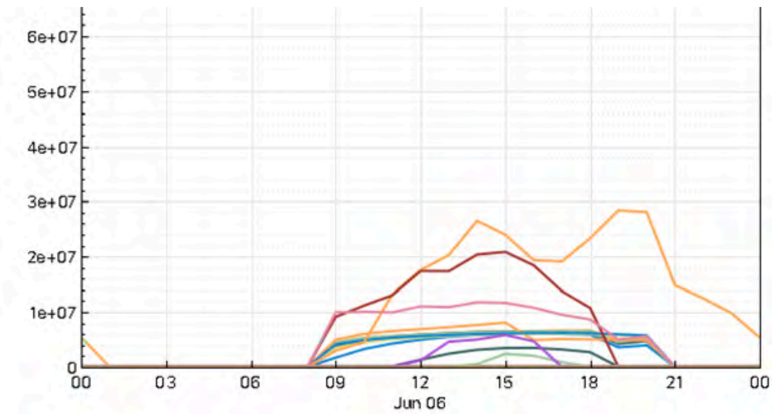


Figure 26: June 6 Cooling Energy

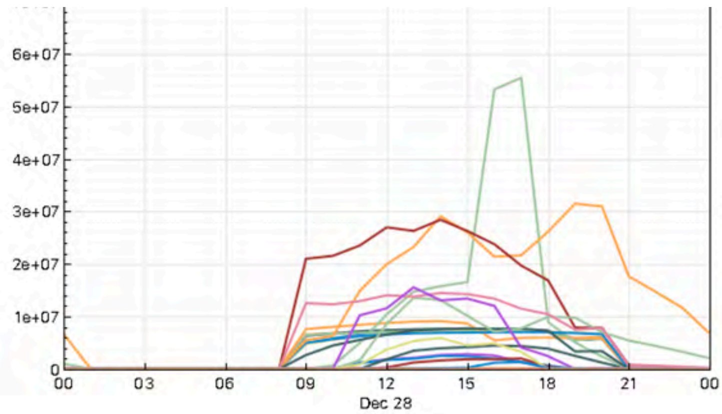


Figure 27: Dec 28 Cooling Energy

As it could have been assumed the cooling energy is the alternative to heating and has maximum values in the summer months, and minimum in winter. Again, the function room is the biggest outlier in the graph, having the largest values as it is the largest space.

IMPROVED DESIGN

There are a variety of design improvements which can be made to designs to help them reach that net-zero energy target. With net-zero becoming an increasingly popular target to achieve and the introduction of new renewable sources and alternatives, it is quite easy to search for design improvements both structurally and with renewable technologies, to make the building more energy efficient.

DESIGN MODIFICATIONS

To further reduce the net energy of the model, the following modifications have been made to the design and simulation model:

- Window glazing was set to double glazed, using the "Dbl Blue 6mm/13mm Arg" function in OpenStudio.
- Overhangs (0.5 projection factor) where placed on the ground floor windows which experience the most direct light, can be seen in figure 28.

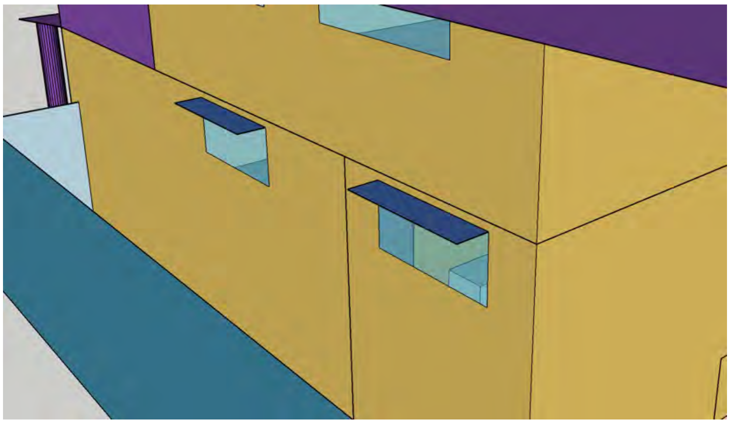


Figure 28: Overhangs on OpenStudio

- Reduced surface area of windows to reduce heat transfer through the glass
- The entrance glass door was made smaller to reduce area of glass and heat transfer, can be viewed in figure 29.

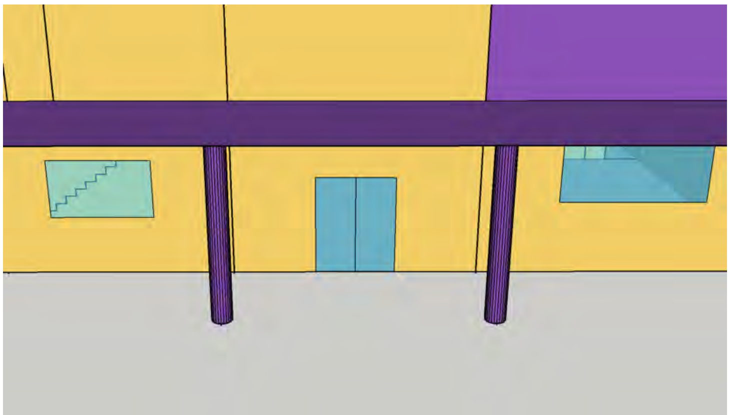


Figure 29: Smaller entrance door on OpenStudio

- Interior blinds were added, scheduled for “On High Outdoor Temp and High Solar on Window”. This setting proved to be one of the most effective and suitable for the function and schedules of the building.

The simulation was run after each of these modifications were added, and each of them effectively brought down the net site energy.

FINAL MODEL

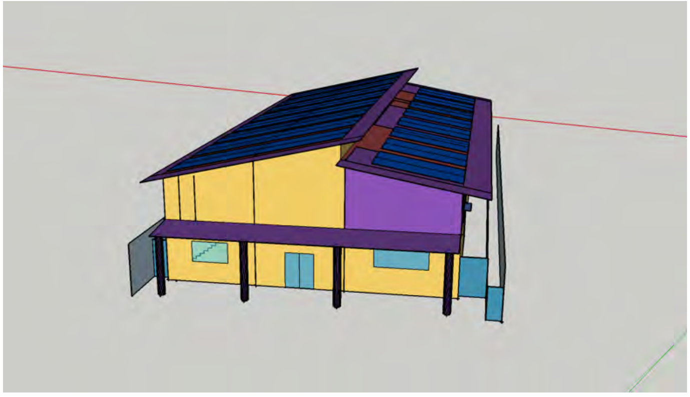


Figure 30: Final Model on OpenStudio

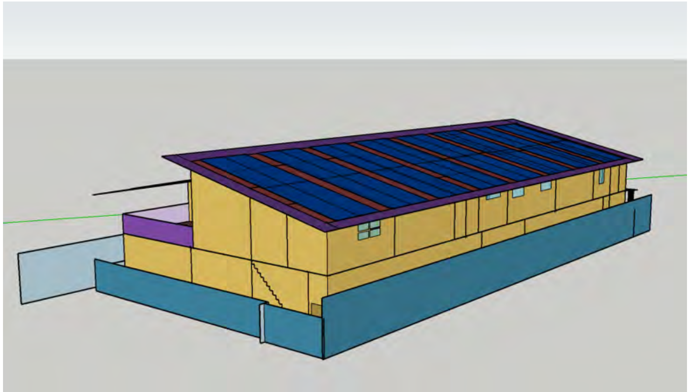


Figure 31: Final Model on OpenStudio

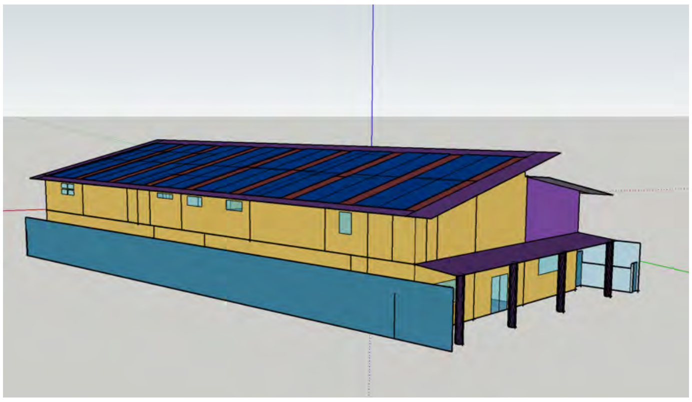


Figure 32: Final Model on OpenStudio

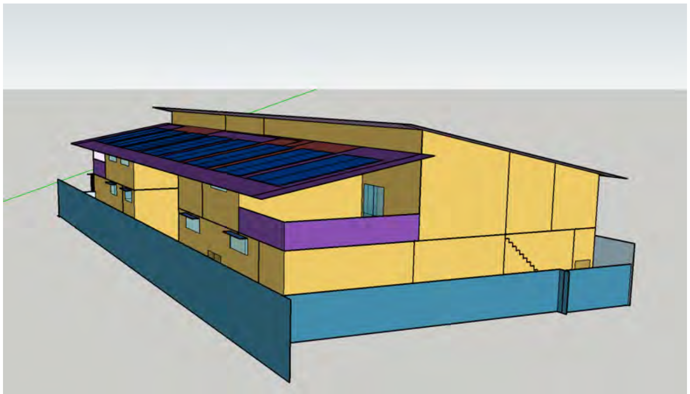


Figure 33: Final Model on OpenStudio

SIMULATION RESULTS

Site and Source Energy:

Table VI: Simulation Results Final Model

	Total Energy [GJ]	Total Energy [kWh]	Energy / Conditioned Building Area [MJ/m^2]	Energy / Conditioned Building Area [kWh/m^2]
Total Site Energy	1062.08	295022.2	1233.76	342.7
Net Site Energy	625.67	173797.2	726.81	201.9

Total Source Energy	1897.28	527022.2	2203.97	612.2
Net Source Energy	515.17	143102.7	598.45	166.2

Peak Energy Demand of the Heating and Cooling:

Table VII: Peak Energy Results Final Model

Load	Minimum Value [kW]	Time of Minimum	Maximum Value [kW]	Time of Maximum
Heating	0.00	01-JAN-00:10	46.58	24-JUL-08:10
Cooling	0.00	06-JAN-04:50	133.95	20-JAN-16:00
Electrical Equipment	4.84	01-JAN-00:10	23.47	02-JAN-13:10
Interior Lightning	1.02	01-JAN-00:10	9.82	02-JAN-11:10
Natural Gas	0.327	01-JAN-00:10	4.91	01-JAN-18:10

CONCLUSION

In conclusion, the OpenStudio model and simulation has brought about a lot of results and guidance regarding the LRLALC proposed building. In observing the results from the simulations, it has been made clear that the addition of solar PV panels and other design modifications can significantly reduce the buildings net energy and thus reduce its carbon footprint. The original base design included a few structural elements to reduce the buildings energy consumption, such as large eves, minimal windows, and environmentally friendly materials. However, after further design modifications and PV panels were added the site's net energy saw a positive reduction.

The first change to the model involved the addition of solar PV panels to the buildings large roof area. The panels covered 53.5% of the roof area and had an efficiency of 15%. With the panels providing a renewable energy source to the site they made a massive difference to the building net energy reducing it by 40%. Along with the panels modifications were made to the building to help further reduce the site energy consumption, the simulation was run after every addition to ensure they had a positive effect. Windows were double glazed to help conserve energy and improve efficiency. Triple glazing was decided against as it didn't produce enough annual benefit for the unit cost of installation. Overhangs were added to all windows reducing direct solar on the window's as lightning ridge is a hot climate, and for this reason internal blinds were also installed. Some windows and glass doors were reduced in size also. With modification completed the final design's net energy decreased from the initial 302816kWh to 173797.2kWh, a reduction of about 57.4%.

The client should note when observing the results and information proposed in the report, that the simulation includes several estimated values, for example schedule and operation times. The values also include a buffer time to ensure the calculated energy consumption is overcalculated rather than under, meaning the values could potentially be less than the ones suggested. For example, the function room, being such a large space requires a lot of energy to heat and cool the area. In the simulation the function room was put on a consistent schedule, however in reality this may not be the case, the room may be used less frequently and thus may dramatically reduce the overall energy.

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APPENDIX: SIMULATION ASSUMPTIONS

HOURS OF OPERATION

This table represents the estimated hours of operation of the different spaces in the building. The simulation model accounts for an hour other side of these hours as leeway time as they are only assumed operation hours, also accounting for the spaces which will need to be set up and closed for operation.

Table VIII: Hours of Operation of Spaces in LRLALC Building

	Weekdays	Saturdays	Sundays
Restaurant	11am-3pm, 5pm-11pm	11am-3pm, 6pm-11pm	11am-3pm, 5pm-10pm
Kitchen	10am-12am	10am-12am	10am-11pm
Coffee Shop	7am-2pm	7am-2pm	7am-2pm
Souvenir Shop	9am-5pm	10am-4pm	10am-4pm
Top Floor	9am-5pm	-	-
Function Room	8am-8pm	-	-

HEATING AND COOLING

As per the assessment guideline, 'Ideal Air Loads' were used in OpenStudion for all modelled spaces. The heating and cooling schuedules were input relevant to the space type under 'Thermal Zones'.

Some loads were applied to more than one thermal zone, particularly those ending in 'Spaces', where it was believed that the hours of operation and setpoint temperatures would have remained the same across these spaces.

Table IX: Setpoint Minimum and Maximum and Hours of Operation for Spaces

	Heating Setpoints		Cooling Setpoints	
	Min., Time	Max., Time	Min., Time	Max., Time
Coffee Shop	16°C, all other	21°C, 6am-3pm	24°C, 6am-3pm	27°C, all other
Function Spaces	15.6°C, all other	21°C, 8am-8pm Weekdays	24°C, 8am-8pm Weekdays	30°C, all other
Entry Hall Spaces	15.6°C, all other	21°C, 6am-12am Mon-Sat and 6am-11pm Sun	24°C, 6am-12am Mon-Sat and 6am-11pm Sun	30°C, all other

Kitchen	15.6°C, all other	19°C, 10am-12am Mon-Sat and 10am-11pm Sun	26°C, 10am-12am Mon-Sat and 10am-11pm Sun	30°C, all other
Office Spaces	15.6°C, all other	21°C, 8am-6pm Weekdays	24°C, 8am-6pm Weekdays	26.7°C, all other
Restaurant	15.6°C, all other	21°C, 10am-12am Mon-Sat and 10am-11pm Sun	24°C, 10am-12am Mon-Sat and 10am-11pm Sun	30°C, all other
Souvenir Shop	15.6°C, all other	21°C, 8am-6pm Mon-Fri and 9am-5pm Sat-Sun	24°C, 8am-6pm Mon-Fri and 9am-5pm Sat-Sun	30°C, all other

LIGHTING AND EQUIPMENT

In the model, it was assumed that energy loads of LED lights, and values for space type equipment in accordance with ASHRAE 189.1 - 2009, would be utilised. Wattage values for lighting were obtained from Prolux (2014) in accordance with NCC regulations for 'Artificial Lighting & Power' and 'Building Classes'. Wattage values for electrical and gas equipment were obtained from OpenStudio's inbuilt ASHRAE 189.1 – 2009 standard for 'High-Performance Green Buildings'. Whilst the model was set up as an office building under this standard, definitions for restaurant, retail, school, hotel, and hospital buildings were also imported into the model, seen in Table X under 'Building Type'.

Table X: Lighting and Equipment Wattage Definitions

Space Type	Building Type	Lights Definition (W/m^2)	Electrical Definition (W/m^2)
Stairs	Office	8	-
Atrium	Retail	15	-
Bathrooms	Office	6	0.753474
Closed Offices	Office	9	6.888903
Coffee Shop	High School	22	13.993084
Conference Room	Office	10	3.982647
Entry Hall	Retail	15	-
Function Room	High School	10	3.659730
Stage	High School	10	3.659730
Kitchen	Restaurant	22	274.47934
Breakrooms	Office	10	48.007040

Medical Room	Hospital	10	15.715309
Restaurant	Restaurant	22	43.916773
Souvenir Shop	Retail	22	2.368061
Staff Lounge	Small Hotel	10	39.503551
Storage Room	Office	8	-

Overall, it can be said that the energy load definitions rarely exceed a maximum fraction of 0.9 and never go below the minimum fractions of 0.05 for lighting and 0.1 for electric equipment. Particularly for gas equipment, a maximum fraction of 0.3 meant that gas energy used on the site would never go above 262 W/m^2, despite a wattage definition of 872.938351 W/m^2. It can also be noted that on weekends, where office spaces, the souvenir shop and function spaces were not open, the lighting and equipment operation values remained at their minimum fractional values for all space types covered under these spaces.

Table XI: Lighting and Equipment Wattage Definitions

Space Type	Lighting Min.	Lighting Max.	Electrical Min.	Electrical Max.
Stairs	0.05	0.9	-	-
Atrium	0.05	0.9	-	-
Bathrooms	0.05	0.9	0.3	0.9
Closed Offices	0.05	0.9	0.3	0.9
Coffee Shop	0.1773	0.9	0.35	0.95
Conference Room	0.05	0.9	0.3	0.9
Entry Hall	0.05	0.9	-	-
Function Room	0.1773	0.9	0.35	0.95
Stage	0.1773	0.9	0.35	0.95
Kitchen	0.15	0.9	0.1	0.35
Breakrooms	0.05	0.9	0.3	0.9
Medical Room	0.05	0.9	0.3	0.5
Restaurant	0.15	0.9	0.1	0.35
Souvenir Shop	0.05	0.9	0.15	0.9
Staff Lounge	0.05	1	0.11	1
Storage Room	0.05	0.9	-	-

ACTIVITY AND OCCUPANCY

Occupancy schedules we set in respect to the estimated operation hours for the spaces and adjusted according to the default schedules set out in OpenStudio's ASHRAE 189.1 – 2009 standard. Activity was also taken from the values given in OpenStudio, which mostly proved to be 132 W/person in office spaces and 120 W/person in retail spaces, though this did not matter too much to change. People definitions were based on the size of the space and the client's needs.

Table XII: Inputs based on Modelled Space Types

Space Type	People Definition	Activity (W/person)	Occupancy Times	Occupancy Max.
2F Bathrooms	2 people	132	8am-6pm Mon-Fri	0.5
GF Bathrooms	2 people	132	8am-12am Mon-Fri, 9am-12am Sat, 9am-11pm Sun	0.4 Mon-Fri, 0.25 Sat-Sun
Closed Offices	4 people	132	8am-6pm Mon-Fri	0.85
Coffee Shop	3 people	120	6am-3pm	0.7
Conference Room	20 people	132	8am-6pm Mon-Fri	0.4
Entry Hall	15 people	120	8am-12am Mon-Fri, 9am-12am Sat, 9am-11pm Sun	0.8 Mon-Sat, 0.4 Sun
Function Room	200 people	120	8am-6pm Mon-Fri	0.95
Stage	5 people	120	8am-6pm Mon-Fri	0.95
Kitchen	5 people	120	10am-12am Mon-Sat, 10am-11pm Sun	0.8 Mon-Fri, 0.9 Sat, 0.7 Sun
Breakrooms	0.2 people/m^2	132	8am-6pm Mon-Fri	0.4
Medical Room	2.5 people	120	8am-6pm Mon-Fri	0.5
Restaurant	40 people	120	10am-12am Mon-Sat, 10am-11pm Sun	0.8 Mon-Fri, 0.9 Sat, 0.7 Sun
Souvenir Shop	15 people	120	8am-6pm Mon-Fri	0.8 Mon-Sat, 0.4 Sun
Staff Lounge	10 people	120	8am-6pm Mon-Fri	0.7

VENTILATION AND INFILTRATION

Ventilation was input by considering the minimum requirements, an outdoor air flow per person value of 0.01 m^2/s per person, following the minimum requirements for 10 litres/s per person, where 1000 litres = 1 m^2. A fresh air supply value of 0.35 litres/s per m^2 was input into the spaces under the same ventilation section of 0.00035 m/s for outdoor air flow per floor area in all spaces.

For infiltration schedules the spaces were categorised into infiltration groups and factored whether there where adjoined rooms and the operation times were taken based on the occupancy schedules. The system schedules were set using default values set out by OpenStudio's ASHRAE 189.1 – 2009 standard.

Table XIII: Infiltration Groups and Schedules

Infiltration Group	Space	Infiltration Times	System Schedule
1	Entry Hall	6am-12am Mon-Sat and 6am-11pm Sun	Half On
	Atrium		Half On
	GF Bathrooms		Quarter On
	Coffee Shop		Half On
	Souvenir Shop		Half On
	Restaurant		Half On
	Function Room		Half On
	Stage Space		Half On
	Kitchen		Half On
	Storage Room		Quarter On
2	Front Stair	8am-6pm Weekdays	Quarter On
	Medical Room		Quarter On
	Large Breakroom		Quarter On
	2F Front Bathrooms		Quarter On
3	Staff Lounge	8am-6pm Weekdays	Half On
	Conference Room		Quarter On
	Small Breakroom		Quarter On
	Closed Offices		Quarter On
	Back Stair		Quarter On
	2F Back Bathrooms		Quarter On

UNIVERSITY
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ENGG210
Building Physics and Building Services

Net Zero Energy Design

Against

Business As Usual Case

Executive Summary

The aim of the project was to improve a baseline design, or business as usual case, of the proposed building for the client, the LRLALC, in achieving a net zero energy design in the location of Lightning Ridge. The software used to simulate these designs were SketchUp for designing the model and Openstudio for determining energy results. To do this, the baseline design had to first be finalised in SketchUp by incorporating feedback from the consultants in ensuring functionality and NCC minimum requirements were met. The first change made to finalise this design included adjusting the floor heights of the building from 2.8 m on the first floor and a minimum of 2 m on the second floor, considering the angled roofing, to 3.6 m and 2.6 m, respectively. The second change made was to add more windows to the design in achieving improved thermal and visual comfort of the design. The third change was to reorient the modelled design by 27° to face northwest so that the energy simulation could provide results that further reflect realistic values for the building's performance within the site location. The last change was to remove the COO office and computer rooms of the initial design and replace them with space utilised by the CEO and CFO offices. This change could not meet the client's spatial requirements for a COO office, though did provide the finalised design with improved ventilation, functionality, and visual comfort aspects of design. Once the baseline design was ready for simulation, a nearby weather file was input into OpenStudio from Moree, of which reflected the climate of Lightning Ridge where both locations were situated in the NCC's climate zone 4 for hot, dry summers and cool winters. Many assumptions were made on simulation inputs, such as construction materials, hours of operation, lighting and equipment, heating and cooling, occupancy, infiltration, and ventilation, where these can be found in the report and in **Appendix B**.

Running a baseline simulation produced energy results that could be used to determine next steps in modifying the design towards the net zero goal. The end use energy demands of the site were determined to be 24.36 GJ for heating, 672.82 GJ for cooling, 344.17 GJ of electricity (121.78 GJ from lighting and 222.39 GJ from electrical equipment) and 53.51 GJ of natural gas. These results gave for percentage breakdown values of the site's energy demand where cooling made up 62% of the total site's energy load, electricity made up 33%, natural gas made up 5% and heating made up 2%. Peak energy demand revealed that heating was highest in the month of July at 49.14 kW around 8AM and cooling was highest in January at 134.52 kW around 4PM. Equipment and lighting were found to be constant throughout the year, particularly in looking at daily energy use profiles from both summer and winter, with minimum peaks never reaching below 0.33 kW. Maximum demand values were 13.65 kW for electric equipment, 9.82 kW for lighting and 4.91 kW for gas equipment. Electric equipment and lighting were mostly utilised around the middle of the day and gas equipment was only used in the kitchen, peaking around dinner service. These high demand values, particularly peaking at different times of the day, required a design that could utilise renewable energy to lower the site's annual net energy for a more net zero design.

Step modifications of adding PV panels, external shading, EC glazing, and thicker wall insulation were undertaken to increase the average REF of the site towards a value of 1. Adding PV panels to 53.5% of the roof and inputting a nominal efficiency of 15% revealed a 40% decrease in the net site energy. The total energy was initially 1094.86 GJ in the baseline design and was reduced to 1086.90 GJ, where the panelling provided an insulative and additional construction layer to the roof. Because of this, the cooling load decreased by 8.51 GJ from the baseline to 664.31 GJ in this model version, whereas the heating load only decreased by 0.56

GJ to 24.92 GJ annually. The annual energy generated by the PV panels were 436.41 GJ and the average REF for this model version was 0.40. Simulation results revealed that for 4086 hours of the year, the panelling would not be able to generate any renewable energy due to no access to sunlight at night-time. Daily energy use profiles showed that no heating occurred in summer and no cooling occurred at night during winter. Also, due to the high ambient temperature of Lightning Ridge during summer, generated renewable energy would not be enough to satisfy the high cooling load of the site, where cooling demands were 40 kW higher than renewable energy values. In wintertime, a high peak of heating occurs at 8AM when occupancy levels rise dramatically due to the start of service hours where infiltration rates would be highest. For majority of the hours of the year, generated renewable energy was less than the energy demand of the site and highlighted the need to bring site energy values down. External shading was then added to all the exterior windows of the building, where the façade windows utilised box-shaped side fins that extended outwards from the window by half the window's height and other windows were made to extend out by a factor of 0.7 of the height. The overhangs were angled downwards by a factor of 0.3 of the window's height and this was found to provide a perfect balance between visual and thermal comfort for the different spaces of the building. A reduction of 5.85 GJ to 645.16 GJ of the site's energy demand was achieved in this modification, providing the greatest results out of all modifications made after adding the PV panels. However, the heating load did increase by 0.51 GJ to 25.43 GJ in achieving a decreased cooling load of 658.46 GJ. The average REF was improved to 0.402 by a 0.003 increased factor where some hours of the year jumped to above an REF value of 0.95.

The next step was to adjust the window constructions of the model from clear glass in the baseline to EC double-glazing, where 6 mm panes were utilised with a 13 mm air gap for argon gas. These options produced the best overall results in terms of site energy and average REF values, where thicker panes and larger air gaps provided greater levels of insulation to the building. Double-glazing was more efficient than other types of window constructions, where a balance between insulation and low-cost could be achieved. Furthermore, this window type had the ability to grow darker by absorption, proving more effective than becoming darker by reflection. Also, where EC glazing has a DGP of 0.22, visual comfort of imperceptible glare could be achieved, beneficial to the building's design. The results showed an increase of average REF to 0.406, by 0.003 once again, with more hours jumping to above an REF of 0.95. The site energy dropped by 4.33 GJ to 640.83 GJ, proving less effective than the previous model version at lowering the building's energy demand, but still managing to work successfully. The last step made did not improve the average REF, in fact lowering it by 0.001 to 0.405, where both this modification and the previous one achieved an average REF rounded to 0.41. This modification was to increase the thickness of the exterior wall insulation from 79.4 mm in the baseline to 140 mm, where the net site energy decreased by 3.07 GJ to 637.76 GJ. Heating decreased by 2.93 GJ to 23.84 GJ and cooling decreased by 0.14 GJ to 652.65 GJ annually, however, the REF values were made worse by a couple of hours. It was evident that insulation lowered the amount of heat gains and losses to the building but could not improve the utilisation of renewable energy alongside this, calling for other improved measures to be implemented into the proposed design. But no other modifications were made to the design after this, and it was determined that this design would only satisfy 41% of the goal of the project in achieving net zero energy. However, a NABERS energy rating of the proposed building proved that it had excellent operational performance when utilising renewable energy on-site, giving it a 5.5-star rating. In reflection, the modifications made to the design provided improvements in acoustics, visual comfort, thermal comfort, aesthetics, and functionality. Hence, the client should consider the benefits that these design measures can offer in constructing their building within the location of Lightning Ridge.

Table of Contents

1 Introduction

The team was tasked with developing a net zero energy design that would satisfy the needs of the client, the LRLALC, both aesthetically and functionally. Considering the feedback received from the client and the consultants for this project, a decided base case design could be made and utilised in forming a baseline energy simulation model. To do this, the team agreed to use the OpenStudio energy simulation tool, in addition to the SketchUp design tool, to produce a model for testing. This baseline model was set as the benchmark standard, or business as usual case, for determining a more net zero energy design, with net zero being the goal of the project. This finalised model had to meet the LRLALC's operational and aesthetic expectations, whilst utilising the maximum amount of renewable on-site energy to achieve an optimised design for proposal. In addition to this, the model had to satisfy thermal comfort requirements of the building's occupants, as well as follow the National Construction Code (NCC) regulations to ensure minimum performance was met.

In this report, the baseline model is described in its development and assumptions, and how energy flows through the spaces in determining energy values for the base case of the proposed design. With these obtained energy values, an analysis of the results could give insight into the next steps for improving the design towards the net zero goal. With step modifications of adding on-site renewable energy introduced by photovoltaic (PV) panels, external window shading, EC glazing and thicker wall insulation, the baseline model could be improved in net energy values of the site. Whilst net zero is the goal, it is not always possible to achieve such an ideal situation where a building is self-sustaining. However, by exploring these step modifications, there are many measures that can be put in place to get closer to this possibility. Alongside these step modifications, the building must not compromise the client's requirements of functionality, aesthetics, acoustics, and thermal and visual comfort, which were considered alongside any changes made to the baseline design. In addition, the site will be described in how climate and solar access influence the energy demand of the building, posing as an issue in the proposed design in reaching net zero energy.

Attached to this report is a critical analysis and reflection on how the proposed design fits into the WELL Building Standard and NABERS Government Certification Scheme. Also attached are the simulation assumptions that gave for a more realistic representation of modelled results, utilised in both the baseline and proposed designs. It should be noted that whilst realistic assumptions do represent a truer version of energy values, some assumptions aim for ideal values, which could not be possible in real life. Moreover, daily energy use profiles, glazing simulation results and shading diagrams can also be found in the appendices, which give a visual depiction of how the proposed building performs.

2 Description of the Site

34 Morilla St, Lightning Ridge is situated in northern NSW, about 60 km south of the NSW-QLD border and 200 km west of Moree. The site is located on the main road of the town, which holds the main attractions of the place of retail stores, such as the local post office and opal shops, as well as restaurants of a bowling club, Italian cuisine, and a café. The proposed site lies between Vinnies on the left and a motel on the right, facing the façade. Connectivity of the site is difficult, only accessible by road or by air, however the site is situated in a location that

attracts tourists, likely to have visitors passing through. A key feature of the site is its climate, receiving a lot of sunlight due to the location being arid nearer central Australia. According to CSIRO (2019), Lightning Ridge lies in NCC's climate zone 4, known to have hot dry summers and cool winters, as seen in *Figure 1*. In summertime, temperatures can reach as high as 40°C and the site receives about 14 hours of solar access. In wintertime, temperatures can be expected to go lower than 5°C, potentially below 0°C, and the site only obtains about 10 hours of solar access (Hoffmann 2021 & WillyWeather 2021). Total monthly rainfall rarely reaches about 100 mm and humidity is highest during wintertime at 75%, compared to 25% in summertime (WillyWeather 2021). Lightning Ridge has a maximum elevation of 175 m and minimum elevation of 140 m, with the site having an approximate elevation of 149 m (Topograhic-map.com 2019). Wind speeds are highest in summer than winter, though has never gone beyond 100 km/h, and predominant wind direction comes from the south. Almost no wind is expected to come from the northwest or southeast directions (WillyWeather 2021). These features of the site had a significant effect on the energy simulation modelling undertaken and is described later in this report.

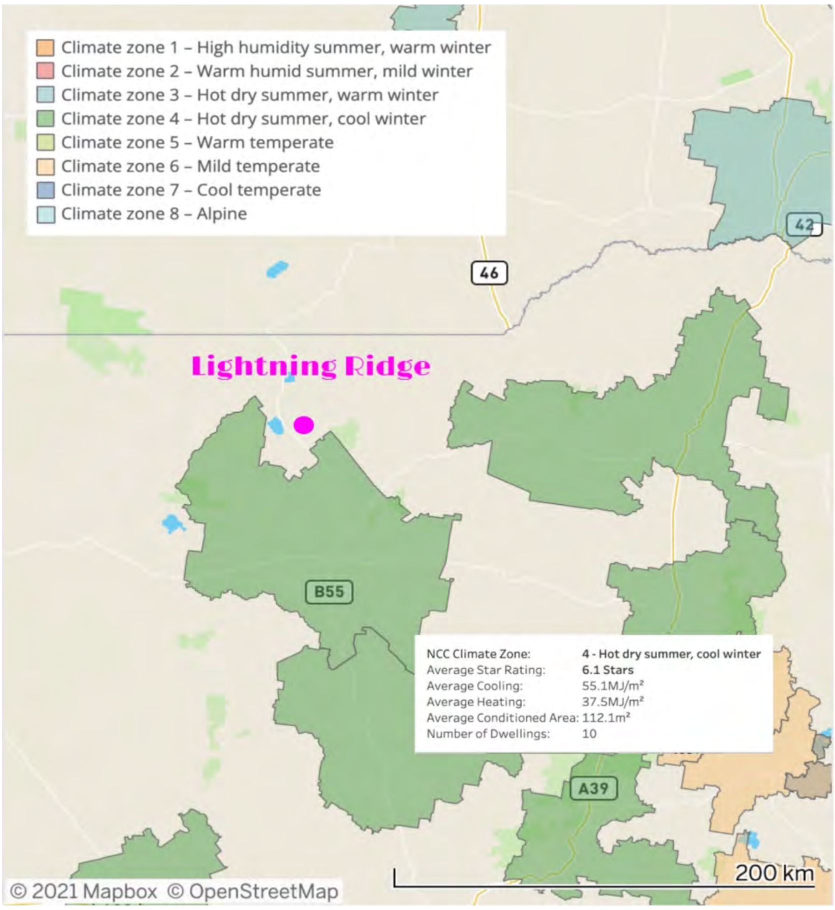

Figure 1: Lightning Ridge Map Location and NCC Climate Zone (CSIRO 2019)

3 Description of Baseline Model

3.1 Initial Development of Baseline Model

In initially developing the baseline model, the model required a building type input, which was set out to be an office building. The template input was to follow ASHRAE 189.1 (ASHRAE 2009) standard for 'High-Performance Green Buildings'. For simplicity, the model was set with the façade facing true north, in the direction of the green axis, in ease of building the model. A floorplan was made for the first floor and projected up to a floor height of 2.8 m for one floor to create the required spaces for that level. Second floor spaces were added in one by one on top of the first floor, set at varying heights due to an angled roof, though with a minimum height of 2 m. Windows and doors were then added to the model, following the initial SketchUp design (see *Figure 2*), though with some modifications to dimensions where wall thicknesses could not be drawn in the energy model and door heights had to reach a minimum height of 2.04 m per standard sizing (Fantastic Handyman Team 2018). All interior doors were made to be 2.2 m in height and all exterior doors were made to be 2.04 m in height. Door widths varied throughout the building but followed standard width sizes for Australian doors, detailed by the Fantastic Handyman Team (2018). The model was then surface matched and manually edited to ensure that all interior and exterior surfaces were defined correctly. Each space was attributed with their own space type, building storey and thermal zone, where a new building storey had to be created for the second floor. All spaces had an ideal air load status and were initially assigned with an office building construction set, following the office building type input. Shading groups were added for the roof overhangs, roofing of the verandas, façade shading, neighbouring buildings, gates, hedges, fences, and veranda railings. These were manually set to ASHRAE 189.1 construction materials for exterior walls, exterior roofing, and interior partitions, where interior partitions were simple thermal mass inputs of wood material. Interior partitions were also added into the model's interior for bathroom cubicles, stairs, some desks and tables, kitchen equipment, and stage flooring and steps, where it could be assumed that these equipment/materials would likely be situated. These interior partitions were assigned construction materials of interior partitions for simplicity.

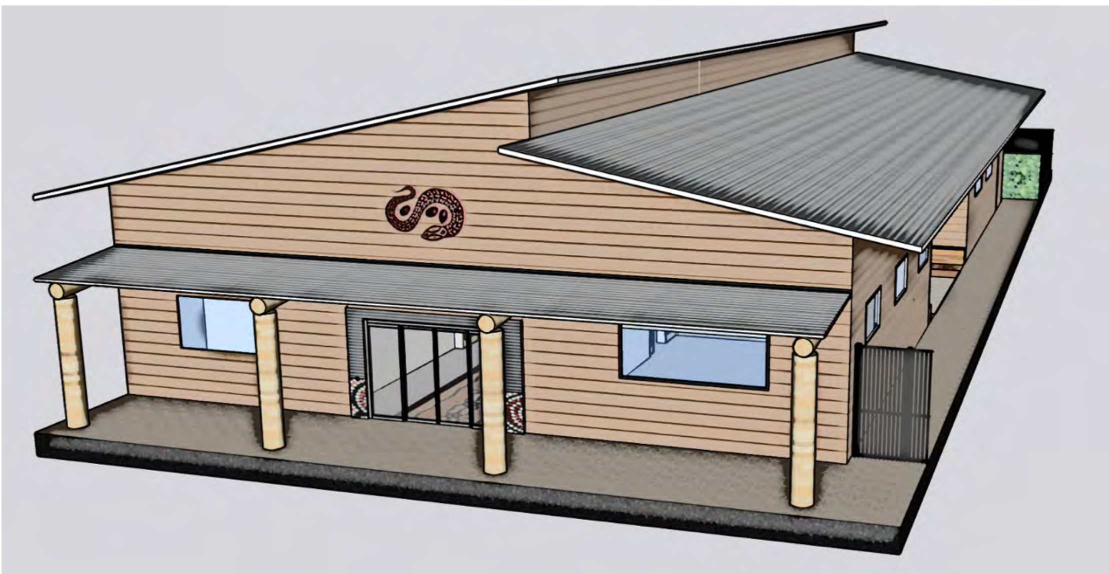

Figure 2: SketchUp Design used in Dimensioning the Initial Baseline Model

3.2 Incorporating Feedback

In further developing the baseline model, the feedback received from the client and the consultants had to be incorporated into the design. These design changes would have had a significant impact on the energy simulation results, however they were necessary to achieve a functional design that would meet the NCC's minimum requirements and the client's needs. These changes concerned the floor heights, stair heights, number of windows, building orientation and room placement.

A major modification to the baseline design was the height increase of the floor levels, where the consultants stated that the ground floor required a roof height of 3.6 m for the function space, originally 2.8 m in height. The second-floor roofing also needed to be raised from the minimum height along the sides of the structure of 2 m to a height of 2.6 m. This is because interior doors had to be 2.2 m in height and the consultants stated that this floor needed to be at least 2.4 m to meet minimum height requirements. This had a big impact on the stairs of the building, which had to rise from ground level to 3.6 m on the second floor. However, it was determined by Edmiston Jones consultants that the 20 steps utilised in the design to reach this stair set height would not meet standards of a maximum of 18 steps per flight of stairs, posing a challenge for the design. It was too late to make a change to this element of the model, though should be considered if the client is to go through with the proposed design. It may be that the floorplan of the second storey must change slightly to allow more room for stair space, which is achievable, though was not done in the simulation models. The consultants also suggested adding in more windows to the building's design, which would allow for more natural light to enter the interior spaces and give occupants a greater connection to place. This was a valuable change to make, particular for the client who wanted spaces to appear more connected than closed off. Though by doing so, this change would have significantly decreased the thermal performance of the building, where Lyons et al. (2021) states that windows can achieve site heat gains of up to 87%, or heat losses of 40%. However, this gave for more opportunity to implement step modifications of exterior shading and improved window glazing in having a larger impact on the finalised design, explored later in this report.

Another change made was the building's orientation, where the façade of the building was determined to face about -27° from true north, requiring the model to be rotated 27° towards northwest. This meant that solar access would be greater on the left side of the building, facing the façade, than on the right side. As the left side was mostly covered by the Vinnies building, this meant that a fair amount of heat gains would be reduced than if solar access were greater on the right side with the motel. This is because the motel is not right up against the property line, unlike the Vinnies building. This was also why the outdoor area of the site was intended to lie on the right side of the building, where more visible sky could be seen. With less solar access on the right side, this is ideal for summertime when occupants utilise the outdoor space. It is also ideal when concerning predominant wind direction, which comes from the south, and may provide some cooling in the outdoor spaces, particularly the back veranda.

Changing the room placement was a complicated task, where the feedback from the consultants contradicted the client's needs. As seen in the initial floorplan of *Figure 3*, the COO office and computer room were situated behind the CEO and CFO offices, respectively. To enter these spaces, there was a walkway between the CEO and CFO offices. According to the consultants, the issue here was that the room placement appeared random and could be better thought out by minimising the amount of corridor space that could otherwise be utilised as office space. In addition to this, the SketchUp design model displayed a large gap between the office spaces and the external walls. This gap needed to be utilised as office spaces instead to maximise natural light entering the office spaces and to achieve the required air flow in these spaces for proper ventilation. In the end, the changes made to the model were to remove the COO office and computer rooms, along with the walkway between the offices and the unnecessary gaps between walls, which were replaced with CEO and CFO office spaces. The concern here is that the client's needs for a COO office could not be fulfilled in this design. However, if the client were to go through with this proposed design, the CFO office could be made to also hold COO office space by implementing a dividing wall into the space if needed, though this is just a suggestion.

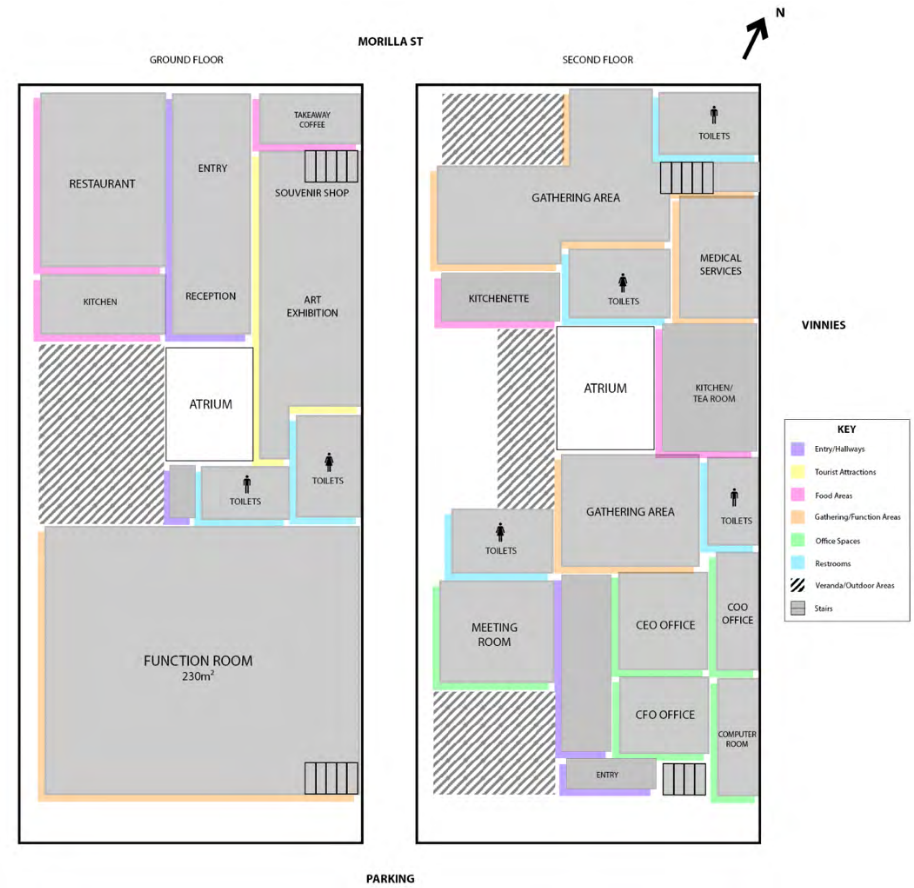

Figure 3: Initial Design Floorplan used in Highlighting Spacial Issues

With these changes made, the baseline model was ready for simulation, utilising the closest weather file to the area, which was from Moree. As was mentioned previously, Moree is situated 200 km to the east of Lightning Ridge, which does not satisfy the NCC's requirements for a local weather file within 50 km of the site, under Section 4.5.2.1. However, the NCC states that, "where no such weather station exists, select two weather stations which can reasonably be expected to have similar climates", and then to select the one, "based on the climate zone which results in a higher energy consumption" (ABCB 2019). Two weather files were selected, one from Moree and one from Cobar, with both being in the same climate zone as Lightning Ridge: climate zone 4. A simulation was run using both weather files and it was determined that the building had a higher energy consumption of 1094.86 GJ for Moree than the 1063.03 GJ for Cobar. Hence, the weather file from Moree was utilised. Also, the file from Moree had an altitude of 218 m, which was within 100 m of the building's determined altitude of 149 m, suiting all NCC requirements.

3.3 Finalised Baseline Model

Once the consultants' feedback was incorporated into the initial baseline model, a finalised model of benchmark standard could be formed. *Figure 4* displays the baseline model in four different renders relevant to this project. *Figure 4 (a)* shows the boundary conditions of the benchmark model, where the blue surfaces represent the external surfaces of the model, and the white surfaces represent the shading groups of the model. Although not shown in this figure, the interior surfaces of the model appear green, which means the exterior surfaces of the model were successfully defined and attributed as an exterior surface. *Figure 4 (b)* shows the render based on construction type, where the olive-green surfaces represent external roofing, blue surfaces represent external walls, green represents external doors and light blue represents external windows. Although not seen in this figure, the interior floor surfaces appear cream coloured and the interior walls appear pale pink. Once again, the model was assigned appropriate construction types for simulation based on construction render appearance. In *Figure 4 (c),* each space can be seen as a different colour. This is because the model is rendered by thermal zones and all the spaces were initially assigned a different thermal zone. This is particularly important as it means that simulation results can give different expected thermal energy values for each space within the modelled building, in accordance with energy flow paths. In *Figure 4 (d),* the model is rendered by space type, which means that spaces such as bathrooms will all be the same colour, breakrooms will all be the same colour, etc. As there are many spaces, not all space types will be mentioned, though it is worth noting that the entry hall and atrium spaces were set as the same space type due to the two spaces being connected. Similarly, the function room and stage spaces were of the same space type for this reason. Some spaces may appear the same space type in the figure, such as the coffee shop and restaurant spaces, but OpenStudio recognises them as different space types. For reference, the green line is directed toward true north, which can be seen in all figures of *Figure 4*. Also seen in *Figure 4*, the model is facing northwest, as is realistic of the site's orientation.

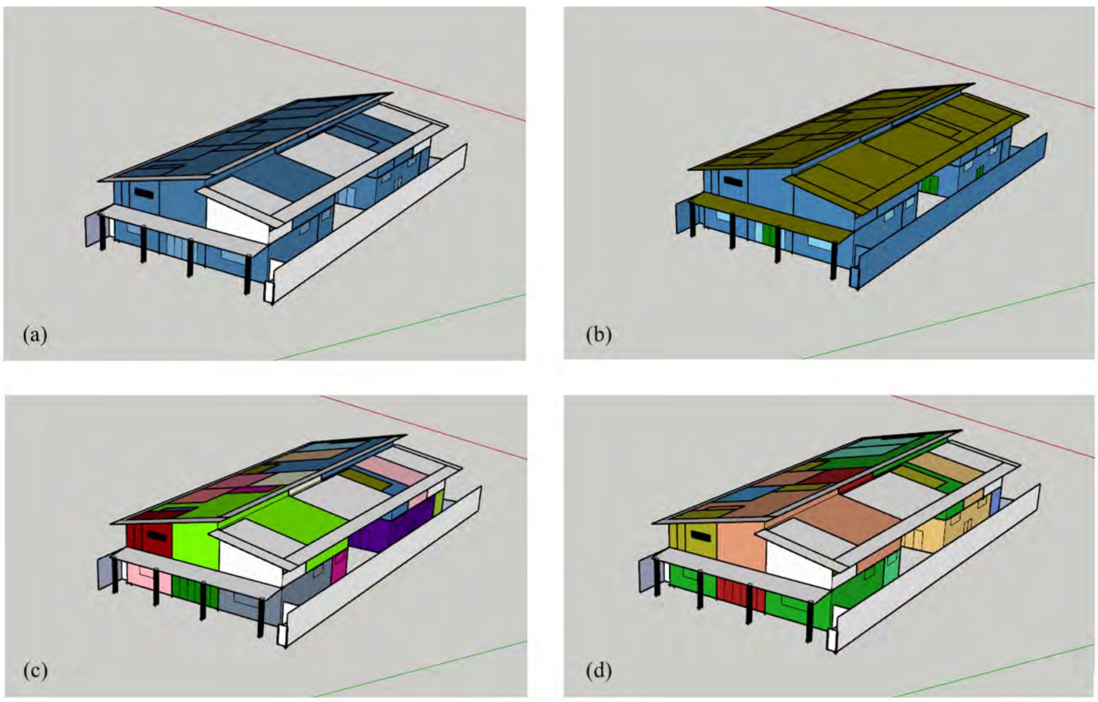

Figure 4: Renders by (a) Boundary Condition, (b) Construction Type, (c) Thermal Zone and (d) Space Type

By looking at the floorplan for the finalised model, seen in *Figure 5*, it can be seen the changes made to the initial floorplan. Colours shown in the figure are representative of the thermal zones within the building. Again, it is worth mentioning that some colours may appear the same for different spaces, however each space is a different thermal zone. As was mentioned previously, the COO office and computer room were removed to ensure proper air flow and lighting could be reached in the CEO and CFO office spaces. The outdoor area of the ground floor, along with the three verandas on the second floor do not have thermal zones and so some are coloured the same as the spaces below them. They were included in the floorplan to show their presence in a realistic representation of the building, though were not a part of the energy model, as they were outdoors. The interior partitions can be seen in the entry hall, kitchen, bathrooms, stairs, stage, and souvenir shop spaces. It should be noted that the tearoom and gathering area of the second floor were named small breakroom and large breakroom within the model. Also, the meeting room was considered a conference room, function and stage spaces an auditorium, CEO and CFO offices as closed offices, and coffee shop as a cafeteria.

Figure 5: Finalised Model Floorplan showing Modelled Spaces and their Thermal Zones

3.3.1 Main Assumptions

There came quite a few assumptions in modelling the base case design for this project, specifically related to the energy simulation. Assumptions were made on simulation inputs, construction materials, energy sources and weather data. Some of these assumptions were briefly mentioned earlier in the report, however, are worth mentioning again formally. The assumptions made on simulation inputs concern hours of operation, hot water, lighting and equipment, heating and cooling, people activity and occupancy, and ventilation and infiltration.

Table B-1 (see **Appendix B**) outlines the assumed hours of operation for the different spaces within the building being modelled, according to different days of the week. For clarity, 'Office Spaces' refers to the entirety of the second floor of the building and does not mean all spaces of office building type. The hours of operation listed within the table, however, do not reflect realistic building use and so it was assumed for model schedule inputs that an hour buffer time should be added before and after the hours of operation. This buffer time relates only to spaces where staff may arrive early to the building to set up workplaces for service, such as the restaurant, coffee shop, souvenir shop and office spaces. The kitchen is open in accordance with hours of operation, as it is only staff who operate in this space. Function spaces were not assumed to open/close an hour early/late because it was understood from the client that the function room was not like a retail space to be operated by staff, but rather utilised solely for visitors. Also, it was outlined in the requirements for this project that a hot water system did not have to be created for the model and implemented into the design. However, a hot water electrical demand was assumed to run from 8am to 8pm at a constant of 2 kW, and at all other times, a constant of 0 kW, to represent a hot water system. This was input as 2000 W into all the spaces that would be assumed to have taps, which were the bathrooms, breakrooms, coffee shop, kitchen, and medical room.

In the model, it was assumed that energy loads of LED lights, and values for space type equipment in accordance with ASHRAE 189.1 (ASHRAE 2009), would be utilised. *Table B-2.1* (see **Appendix B**) shows the input lights and electrical equipment definitions for the different space types that exist within the base case model. It should also be noted that gas equipment was inputted into the design as well, though for the kitchen space only, with a power definition of 872.938351 W/m². Wattage values for lighting were obtained from Prolux (2014) in accordance with NCC regulations for 'Artificial Lighting & Power' and 'Building Classes'. Wattage values for electrical and gas equipment were obtained from OpenStudio's inbuilt ASHRAE 189.1 (ASHRAE 2009) standard for 'High-Performance Green Buildings'. Whilst the model was set up as an office building under this standard, definitions for restaurant, retail, school, hotel, and hospital buildings were also imported into the model, seen in *Table B-2.1* under 'Building Type'. The lighting and equipment operation schedules associated with each space type varied according to hours of operation in following a logical usage profile. The fractional minimum and maximum values for lighting and electrical equipment loads can be seen in *Table B-2.2* (see **Appendix B**), and for gas equipment used in the kitchen, the minimum was 0.02 and maximum was 0.3. Though overall, it can be said that the energy load definitions rarely exceeded a maximum fraction of 0.9 and never went below the minimum fractions of 0.05 for lighting and 0.1 for electric equipment. Particularly for gas equipment, a maximum fraction of 0.3 meant that gas energy used on the site would never go above 262 W/m², despite a wattage definition of 872.938351 W/m². It can also be noted that on weekends, where office spaces, the souvenir shop and function spaces were not open, the lighting and equipment operation values remained at their minimum fractional values for all space types covered under these spaces.

For heating and cooling, 'Ideal Air Loads' was turned on for all modelled spaces in OpenStudio, as per the project requirements. Once this was done, heating and cooling schedules relevant to the building type were imported into the model and added to their associated spaces, under 'Thermal Zones'. Values were once again taken from different building types of retail, restaurant, office, and school buildings thought to be best suited to the spaces. For example, a kitchen would have a smaller range between setpoints than other spaces, specifically for cooling where the kitchen is typically the hottest space in the building. These setpoint minimum and maximum values, along with hours of operation, for the different spaces can be seen in

Table B-3 (see **Appendix B**). Some loads were applied to more than one thermal zone, particularly those ending in 'Spaces', where it was believed that the hours of operation and setpoint temperatures would have remained the same across these spaces. As per these hours of operation, occupancy schedules followed this assumption accordingly and were adjusted from default schedules set out by OpenStudio's ASHRAE 189.1 (ASHRAE 2009) standard. As seen in *Table B-4* (see **Appendix B**), the times certain spaces were assumed to be occupied varied depending on different retail and office spaces. Also, the maximum occupancy of these spaces would typically be higher in retail spaces than office spaces, due to the variability of numbers of visitors. Activity definitions were also taken from the standard values given in OpenStudio, which mostly proved to be 132 W/person in office spaces and 120 W/person in retail spaces, though this did not matter too much to change. People definitions were input based on the client's needs and the sizing of the different spaces. Most of these values could be input as direct numbers of people, however it was determined that breakrooms could be input in people per square metre instead. This is because there are two breakrooms in the building – one larger and one smaller – where an input of 0.2 people/m² gave for 22.8 people and 6.8 people, respectively, which seemed reasonable.

To model ventilation, values were input into the 'Design Specification Outdoor Air' column of the 'Space Types' section in OpenStudio. From there, all occupied spaces could be input with an outdoor air flow per person value of 0.01 m²/s per person, following the minimum requirements for 10 litres/s per person, where 1000 litres = 1 m². Also, a fresh air supply value of 0.35 litres/s per m² was input into the spaces under the same ventilation section of 0.00035 m/s for outdoor air flow per floor area in all spaces. For infiltration, schedules were determined by first categorising each space into infiltration groups depending on adjoined rooms and sections of the building, as seen in *Table B-5* (see **Appendix B**). Secondly, the operation times were taken based on occupancy schedules to give an overall operation time across each infiltration group. E.g., group 1 would be open from 6am, when the coffee shop is first occupied, and closed when the restaurant spaces are no longer occupied. Lastly, system schedules were set using default values set out by OpenStudio's ASHRAE 189.1 (ASHRAE 2009) standard, imported into the model along with other schedules for different building types. Construction materials were assumed to be the default constructions of both interior and exterior walls, floors, roofs, doors, and windows, as well as interior partitions. These default materials were given in accordance with OpenStudio's ASHRAE 189.1 (ASHRAE 2009) standard. For the base case model, it was also assumed that energy sources were completely non-renewable, with no renewable energy generated on-site. The last assumption to mention is the weather file, which was not sourced from the local area of Lightning Ridge, however, was of the same NCC climate zone for hot dry summers and cool winters. Whilst these assumptions do not fully reflect realistic values and sometimes produce ideal values, it is important to note that a simulation cannot accurately give results that would be the case in the real world.

3.3.2 Baseline Model Results

The results given by OpenStudio are extensive, however, annual, peak, and daily energy values for different end uses can be explored and analysed to determine key information about the efficiency of the baseline design. These results can also be used to determine next steps in modifying the model to achieve a more net zero energy design. Running the simulation, utilising the local weather file from Moree, gave annual energy requirements of 24.36 GJ for heating and 672.82 GJ for cooling. Other annual energy requirements by end use were 344.17 GJ of electricity from interior lighting and electrical equipment, and 53.51 GJ of natural gas for certain kitchen equipment. For annual site energy requirements, the values were the same as the end use requirements, because there is no renewable energy generated on-site for this model. However, the energy use for electricity could be split up into 121.78 GJ for interior lighting and 222.39 GJ for interior electrical equipment. A graph of these results can be seen in *Figure 6*, which displays the percentage breakdown of site energy requirements by end use. Cooling makes up most of the energy requirements for the site, by almost two thirds at 62%, and electricity makes up one third at 33%. Natural gas only makes up 5% of the site's energy use and heating uses the least amount of energy at 2%. It makes sense that cooling energy would be much higher than heating energy when considering the climate of Lightning Ridge. On top of the heat gains from the sun and high absorption values of thermal energy from these heat gains, the operational energy also produces heat gains that require further cooling of the site (Custom Air & Plumbing 2013). Since there is plenty of heat gain all year round, considering that service hours of operation are 111 hours weekly and operational energy maintains high levels of heat gain, there is little need for heating to make up for heat losses in the cooler months. Also, as natural gas energy requirements come solely from the kitchen space of the building, it is evident that the hours in which operation occurs in this space is high, along with the daily energy load from gas equipment.

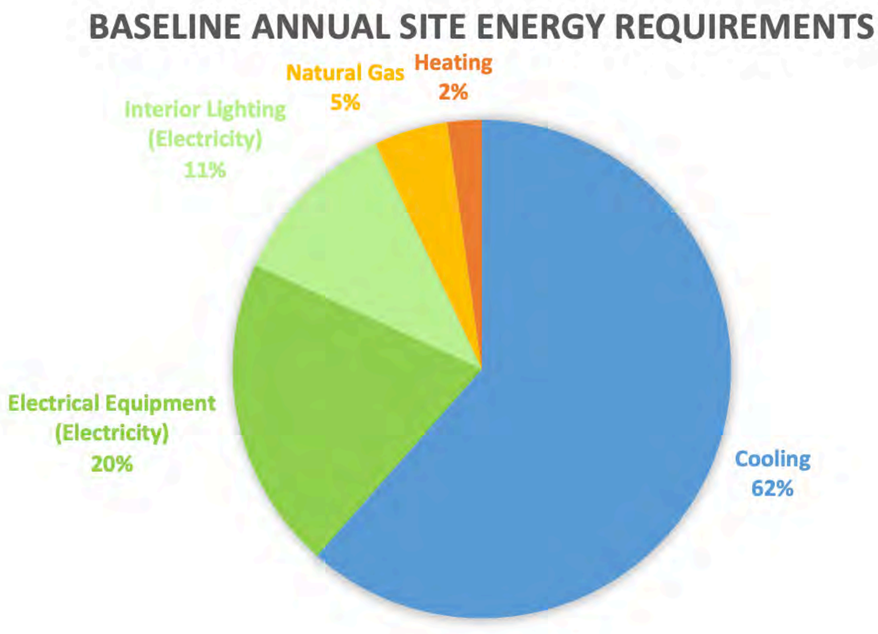

Figure 6: Percentage Breakdown of the Annual Site Energy Requirements for the Baseline Model

Peak energy demand of the site's loads can be seen in *Table 1*. The minimum energy demands occur during the night-time when all operational equipment and lighting are at their lowest due to no hours of operation. Since the lighting and equipment inputs were never set to completely turn off, as per default daily profiles set out by OpenStudio's ASHRAE 189.1 (ASHRAE 2009) standard, therefore the minimum demand is not 0 kW. It can be seen, however, that heating, and cooling, do both reach 0 kW energy demands at different times of the year depending on a balance between climate conditions and operational energy. Maximum values for lighting and equipment occur at the start of the year, as for the whole year, the energy loads produced by these sources are maintained at constant, repetitive values. This means that this maximum value is expected to occur at other, regular dates and times throughout the year and not just at the date and time stated in the table. The cooling load is maximum in summertime, which is when ambient temperatures are at their highest, as seen in *Figure C-1.1* of **Appendix C**. Also, this maximum value occurs in the middle of the afternoon when combined heat gains from the outdoor temperature and the operational equipment are also at their highest. Heating is much lower than cooling in maximum energy demands, as with annual energy requirements, though reaches this peak in wintertime when ambient temperatures are at their lowest. Referring to the daily energy use profile for this model in winter, as seen in *Figure C-1.2* of **Appendix C**, the operational energy peaks at its highest just after 8AM. This coincides with the maximum heating load, as the site requires the most heating right before operational heat gains begin to occur in the morning, from the start of hours of operation. When operation begins in the building and occupancy levels rise, so does the infiltration of cooler outside air entering the building, accounting for the rise in heating required in the building.

Table 1: Peak Energy Demand of Site's Loads for Baseline Model

Load	Min Value (kW)	Time and Date of Min	Max Value (kW)	Time and Date of Max
Heating	0	12:10AM 1 Jan	49.14	8:10AM 27 July
Cooling	0	12:10AM 23 Feb	134.52	4:00PM 20 Jan
Electric Equipment	3.82	12:10AM 1 Jan	13.65	1:10PM 2 Jan
Interior Lighting	1.02	12:10AM 1 Jan	9.82	11:10AM 2 Jan
Natural Gas	0.33	12:10AM 1 Jan	4.91	6:10PM 1 Jan

4 Design Improvements

4.1 Photovoltaic (PV) Panels

The project's requirements stated a limitation of no more than 60% of the roof area to be PV panels and for the nominal efficiency of these panels to be no more than 15%. Ensuring that this limitation was not exceeded, the roof area was calculated and multiplied by 0.6 to achieve a maximum panel area value for the improved model. The roof area was calculated to be 775.58 m², and when multiplied by 0.6, this gave a maximum allowable panel area of 465.35 m². However, the team was aware that placing panelling on the roof overhangs was a dangerous way to implement them into the design. It was decided that the panels would run from the apex of the roof to the gutter, though not overhanging the ceilings. This gave a length of 10.25 m for the panels on the upper roof of the model. Since the lower roof was slightly shaded by the overhang of the upper roof, the team agreed that the panels on this roof should only run a length of 5 m from the gutter end of the roof (see *Figure 7*). Also, considering that standard panel sizes in Australia are 1.7 x 1 m, it was decided that the panels should be 1.7 m wide. Then, it was determined that the panels should be spaced 1 m apart, with two panels joined together, which was found to utilise more space for panelling without exceeding the 60% area limitation. By doing this, the total panel area was found to be 414.80 m², which was less than the maximum allowable area of 465.35 m², only taking up about 53.5% of the roof area. Whilst the panelling does run lengths of 10.25 m and 5 m on the respective upper and lower roofs, this does not reflect real-life standard panel sizes of 1 m lengths. However, as it is an energy simulation model, it can be assumed that these panels are split up into approximate 1 m lengths yet modelled together as one. The thicknesses of the panels were made to be 40 mm by initially projecting the shading groups upwards by this length, following standard sizing for panels.

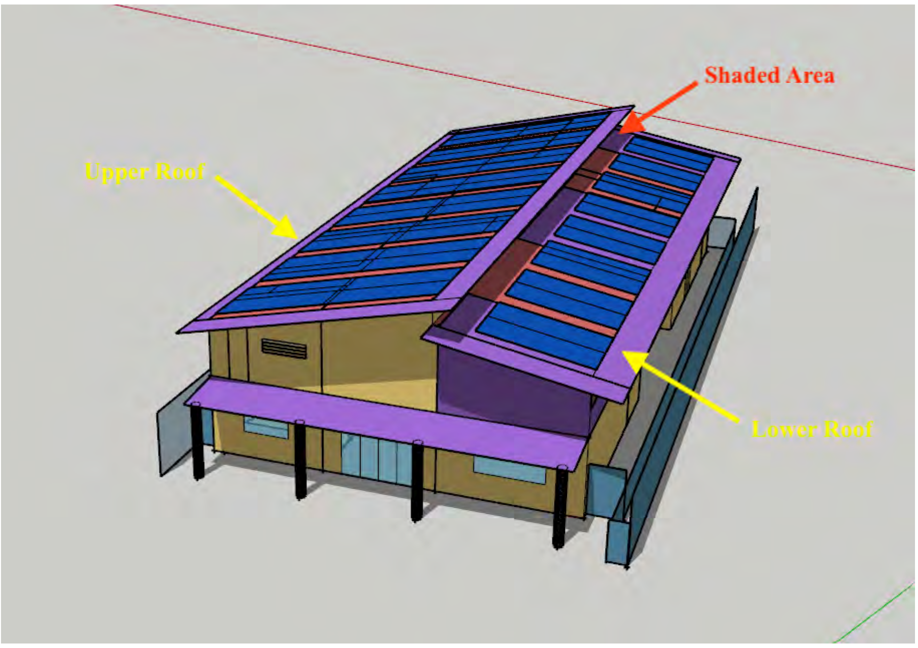

Figure 7: Improved Baseline Model with added PV panels

By adding in shading groups for all the panels, this lowered the total annual energy requirements of the site by 7.96 GJ, where the total energy was now 1086.90 GJ instead of the baseline value of 1094.86 GJ. In addition to this, the annual net site energy was greatly decreased to 650.49 GJ due to an annual energy generation of 436.41 GJ from the PV panels. This meant that, for this improved model, the annual on-site renewable energy generated was about 40% of the total energy requirements for the site. The heating load for this model increased by about 0.56 GJ to 24.92 GJ annually from the baseline, though the cooling load decreased by 8.51 GJ to 664.31 GJ annually. In looking at the daily energy use profiles shown in section C.2 of **Appendix C**, the values for heating and cooling did change for most hours of the day. In summertime the heating is always 0 kW, and in wintertime cooling is always 0 kW at night. From the baseline model, adding PV panels decreased the cooling load of the site for every hour in summer by a minimum of 0.34 kW and maximum of 1.28 kW. In winter, the average cooling loads for the day did not change but the change in cooling per hour fluctuated by increasing to 80 W maximum in the morning and decreasing to 350 W maximum in the afternoon. Also in winter, change in heating fluctuated by decreasing between 8-10AM to a maximum of 260 W and increasing to a maximum of 320 W in the other hours of the day. All energy loads of lighting and equipment remained the same, where generated PV did not affect these values. In summertime, the generated PV energy is not enough to bring the site's net energy to zero, as the cooling load is much higher, by 40 kW. Even if the generated PV surpassed the energy load of cooling, it may not surpass the total site's energy requirements. This reflects the difficulty of achieving net zero energy building designs, particularly in hotter climates during summertime. In wintertime, heating reaches a peak at the beginning of service hours that is also higher than the generated PV energy of just over 10 kW. As mentioned previously, this peak occurs due to rising infiltration and lack of heat gains from operational energy. Because of this peak, not enough renewable energy can be generated to ensure net zero levels of the site's energy. Even though the cooling is about 10 kW less than the generated PV, renewable energy is not enough to surpass the total energy requirements of the site in wintertime. Yet again, this profile displays the difficulties of achieve net zero energy designs, though for buildings in cooler winter climates. Renewable Energy Fraction (REF) values were taken for the 8760 hours simulated of the model, where the average REF over the year was found to be 0.40. This number displays a low renewable energy value in relation to the site's energy requirements. An REF of 1 would be ideal in achieving a net zero energy design, however ideal is unachievable in this version of the model. The REF values were taken for each hour simulated and *Table 2* displays what range these hours fit into. Most REF values are equal to zero, as generated PV energy will not occur at night-time when no sun is around to provide solar energy for the panels. With 10 hours of darkness in summer and 14 hours of darkness in winter and assumed average hours of darkness at 10.4 hours for autumn and spring, 4086 hours of 0 REF values makes sense. Though the average REF is not 1, most of the REF values that occur in daylight lie within the 0.3<REF≤0.95 range. This is useful to know in determining next steps in modifying the modelled design, as it means decreasing the site's energy requirements is achievable in reaching net zero energy of the site. If values were below this range, e.g., below 0.3, net zero energy would be harder to reach.

Table 2: Ranges of REF values across 8760 hours of Simulation of the PV Panel Model

REF Ranges	**REF=0**	**0<REF≤0.3**	**0.3<REF≤0.95**	**0.95<REF≤1.05**	**1.05<REF**
No. Hours	4086	1332	2200	154	988

4.2 External Shading

The next design improvement was to add external shading to the model's exterior windows, which would not impact the added PV panels' efficiency or sizing. To do this, a few different types of external shades were tested to determine the most suitable option that would work functionally without compromising natural light from entering the building's spaces. These shadings were sized according to each window to extend outwards by half of the height (h) of the windows for the first four modifications. The first modification was a simple shade overhang running the width of the window and extending out by half the window's height. The second modification was to add two angled side fins to the first modification, which went from the base of the window to the protruded end of the overhang. The third modification was adding simple box-shaped side fins, replacing the angled side fins, extending outwards by half the height of the window along the height of the window. The fourth modification was to lower the protruded end of the overhang by 200 mm so that it was angled downwards from the top of the window, mimicking regular awnings. The fifth and last modification was undertaken based on the results of the first five modification simulations. This modification extended the box-shaped side fins outwards to 0.7 of the height of the window. It also brought the overhang's protruded end to 0.7 of the height, from the base of the side fins, angled downwards, as in the fourth modification. However, the fifth modification was not applied to all the exterior windows, as in the previous modifications, because the façade windows were much larger than the other windows of the building. The restaurant window height was 1.5 m, and the coffee shop window height was 1.2 m, which meant a 0.7 overhang factor would extend outwards to be 1050 mm and 840 mm, respectively. Considering functionality, where visitors would walk up to the coffee shop window, or gather outside the façade, it seemed impractical to have such a large overhang. However, a 0.5 overhang factor would give shading protrusions of 750 mm and 600 mm for the respective restaurant and coffee shop windows. This was more reasonable, though may still be of concern to the client who may decide to remove the façade's external window shading where façade shading is already present in the design despite this. Sectional views of the modelled external shades can be seen in *Figure 8* in order of step modifications undertaken.

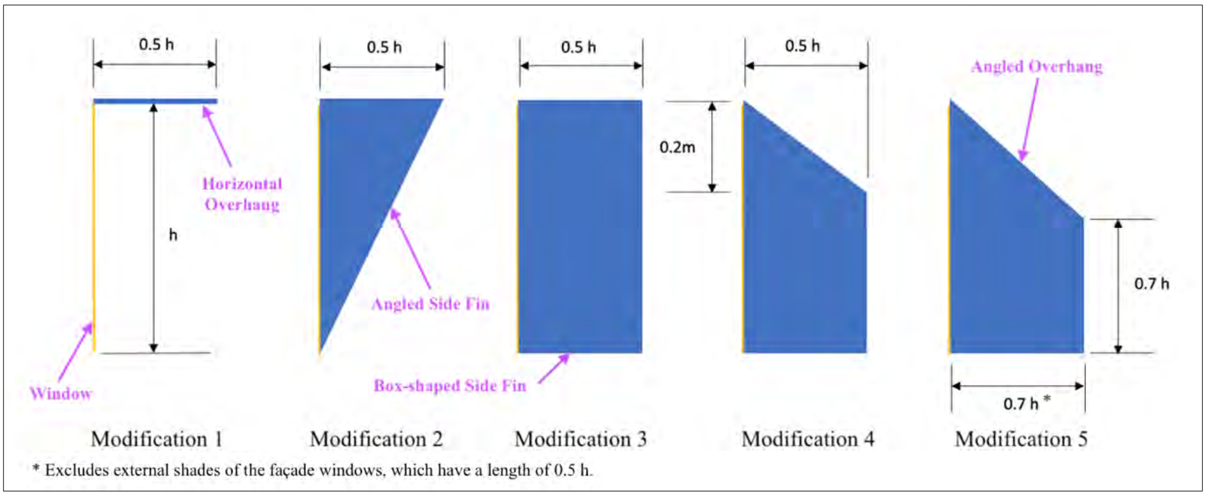

Figure 8: Model Step Modifications of External Shading showing Shading Sectional Views

It should also be mentioned that modifications 4 and 5 gave more improved results than the other modifications, where the downward angle of the overhang was able to block out more heat gains from solar radiation than horizontal overhangs. Furthermore, the side fins demonstrated improvement in the thermal properties of the building, where total and net site values decreased with more side fin shading area, as seen in *Table 3*. Modification 5 utilised a greater side fin area for majority of the building's windows, whilst allowing for the angled overhang to provide more optimised shading. Another major difference between modifications 4 and 5 were the vertical lengths of the angled overhangs, where modification 4 had these vertical lengths at 200 mm for all windows. Modification 5, however, had varying vertical lengths, dependent on the height of each window, of 0.3 h. This was done in consideration of smaller windows, where a 200 mm angled overhang height blocked out almost half the view of the outdoors for windows of 500 mm heights. A factor of 0.3 would vary more appropriately across all windows to ensure a design that utilises as much natural light as possible, whilst preventing too much direct sunlight from greatly increasing heat gains. This is especially important considering the high cooling load of the site, which was decreased from 664.31 GJ in the PV panel model to 658.46 GJ in the external shading modification 5 model.

Table 3: Annual Energy and Average REF Values of External Shading Modifications

Modification No.		**1**	**2**	**3**	**4**	**5**
Annual Energy (GJ)	***Heating***	25.02	25.05	25.08	25.34	25.43
	Cooling	662.85	662.28	661.77	659.56	658.46
	Generated PV	436.41	436.41	436.41	436.41	436.41
	Net Site	649.14	648.60	648.12	646.18	645.16
	Total Site	1085.55	1085.01	1084.53	1082.59	1081.57
Average REF Value		0.399469	0.399847	0.400198	0.401367	0.402082

In gathering REF values for the different modification models, where the average REF values could be seen in *Table 3*, it was evident that external shading did not greatly improve the energy demand of the site. The average REF values remained 0.40 when rounded to two significant figures, though slight improvement occurred when taking these values to three significant figures of 0.399 to 0.402. In looking at the number of hours these values occurred in their REF ranges, as seen in *Table 4*, the REF values gradually decreased below 0.95 and typically increased above this value. This meant that, for a few more hours in the year, enough renewable energy was generated to meet the energy demands of the site, getting closer towards a net zero energy design.

Table 4: Ranges of REF values across 8760 hours of Simulation of the External Shading Models

Model No.		REF Ranges				
		REF=0	***0<REF≤0.3***	***0.3<REF≤0.95***	***0.95<REF≤1.05***	***1.05<REF***
1	**No. Hrs**	4086	1330	2199	155	990
2		4086	1329	2199	154	992
3		4086	1328	2198	157	991
4		4086	1326	2192	161	995
5		4086	1326	2189	163	996

4.3 EC Glazing

In determining the best glazing type for the external glass windows and doors, a handful of default constructions, given by OpenStudio's Building Component Library (BCL), were chosen for modelling modifications. The BCL had single, double, triple, and quadruple sets of glazing constructions, however, only double glazing was tested for this model. This is because single glazing is not efficient enough to deal with the large level of heat gains and losses of the site, and triple and quadruple glazing are often too large and expensive to be worth using (Lyons et al. 2021 & Brennan 2020). However, there were 144 different double-glazing constructions available. Therefore, initial testing, not shown here, was conducted to eliminate ineffective constructions, which revealed that thicker panes gave for better insulation and that argon gas filled windows worked better than air filled windows. Also, Rodriguez (2018) states that, "argon is an inexpensive, non-toxic, colorless, and odorless gas that occurs naturally", providing improved insulation and other thermal properties, such as reduced condensation of the glass, when compared to air. In addition to this, bleached, low-iron and low-emissivity (low-e) constructions, where e2 = 0.2 instead of e2 = 0.1, could be removed, as bleached and low-iron glazing types had higher transmittance values and low-e was more effective when e2 was equal to 0.1. Since thicker panes and a larger layer of argon gas improved insulation, the larger double pane constructions of 6 mm pane and 13 mm air gaps were chosen for analysis. The results for these modifications can be seen in **Appendix D**, where *Table D-1* displays the annual energy and average REF values of each glazing type modification. A trend can be seen where clearer glazing types did not offer enough reflectance of solar radiation, transmitting more of the heat from the outdoors into the building through the windows. Tinted glazing types did offer slight improvement to the reflectance of the panes, however, the average REF values remained below 0.400. Low-e constructions greatly improved the average REF values, particularly with combined electrochromic (EC) and spectrally selective tinted panes. For low-e glazing combined with EC panes, the construction that becomes darker by absorption (Abs) proved equally as effective as the construction that becomes darker by reflectance (Ref). However, where glazing was not low-e and yet had EC panes, the Ref type became less effective than low-e and the Abs type became more effective than low-e. Overall, EC Abs coloured glazing provided the highest average REF value of 0.406, which can be rounded to 0.41. Whilst this is only a 0.01 REF improvement from previous modifications, it is a step closer to the net zero energy goal. For this building's design, it is highly recommended that double paned EC coloured glazing that becomes darker by absorption of 6 mm-13 mm argon dimensions should be utilised.

It should also be noted that the results show a trend in a decline of cooling alongside improved REF values, where the recommended glazing type improved the annual cooling load by 5.67 GJ to a value of 652.79 GJ. Heating increased by 1.34 GJ to 26.77 GJ, but this is expected because of the decreased cooling load produced by reduced heat gains and is much smaller than the cooling load in comparison. Both the annual net and total site energy values decreased with improved glazing, where both were reduced by 4.33 GJ to 640.83 GJ and 1077.24 GJ, respectively. As seen in *Table D-2* of **Appendix D**, 13 more hours of the year reached above an REF value of 0.95, which is within range of achieving a net zero design for these hours. However, in comparison to the 4674 hours needed to be in this range (excluding the 4086 hours of night-time), where only 1172 of these hours are above 0.95 REF, this improved model is still only 25% of the way to reaching a net zero energy design.

4.4 Thicker Wall Insulation

The final modification made to the model was to add thicker external wall insulation, where thicker roof insulation was determined to be ineffective for this design. This was because the PV panels added into the model provided an extra layer of insulation to 53.5% of the roof, where adding more insulation layer would not reach a more net zero design. However, the external wall mass construction set out by OpenStudio's default constructions, in accordance with the ASHRAE 189.1 (ASHRAE 2009) standard, gave a baseline wall thickness of 79.4 mm. Simplee Green (2013), a supplier of wall insulation in Australia, stated that wall batts can come in thicknesses as great as 140 mm. Since the design of this model had a high cooling load, added an extra 60.6 mm of wall insulation to the building's envelope seemed a reasonable step to make. OpenStudio's ASHRAE 189.1 external wall construction is made up of 1-inch stucco, 8-inch heavyweight concrete, 79.4 mm insulation and ½-inch gypsum. This modification only focused on the insulation layer, where the greatest amount of wall insulation provided by OpenStudio's library had a thickness of 110.4 mm. To utilise a thickness of 140 mm, the input thickness of the insulation was adjusted to 0.14 m. This gave for annual total and net site energy values of 1074.16 GJ and 637.76 GJ, respectively, which was a 3.07 GJ decrease from the last model version. The change made impacted only the heating and cooling end use loads once again, which were now 23.84 GJ and 652.65 GJ, respectively. Interestingly, the annual cooling load for this modification decreased by only 0.14 GJ compared to the last modelled version, whilst the heating load decreased by 2.93 GJ annually. This makes sense, as improving the insulation layer of the building's envelope prevents more heat from passing through the walls and escaping internal spaces, particularly in the cooler winter months. With less heat loss from thicker insulation, less heating is required to keep the site thermally comfortable, decreasing the annual heating load. As insulation works both ways, the cooling load was slightly decreased where it can be said that heat from the outdoors would be less likely to make it through the insulation layer when it is thicker. In summer months when cooling loads are greater, thicker insulation would provide some cooling of internal spaces, though not by much considering the climate of Lightning Ridge. *Table 5* shows the REF values for the 8760 hours of simulation run on this model, where only one more hour made it into the ranges above 0.95 REF from the last model. However, the last model had an average REF of 0.406490, which was higher than what was obtained in this model. Despite the improvements made to the total energy requirements of the site, the ratio of renewable energy to required site energy decreased. This slight issue may be due to the shift of more REF values into the $0.95 < REF \leq 1.05$ range, where the previous model had more hours in the $1.05 < REF$. This highlights an issue with designing for net zero energy, where hourly REF values make a big difference to the average REF for the site and should be addressed as such. Whilst the thicker insulation decreased the average REF, this value can still be rounded up to 0.41, as with the previous model. Hence, this version was kept in the finalisation of the proposed design.

Table 5: Ranges of REF values across 8760 hours of Simulation of the Thicker Insulation Model

REF Ranges				Average REF
0 < REF ≤ 0.3	***0.3 < REF ≤ 0.95***	***0.95 < REF ≤ 1.05***	***1.05 < REF***	
1323 hrs	2178 hrs	168 hrs	1005 hrs	0.405100

5 Description of Shading Diagrams

In **Appendix E**, the shading diagrams for this finalised model can be found. Section **E.1** shows the impact of sunlight on the building during summer and section **E.2** shows this impact in winter. In the morning, sunrise occurs at 5:30AM in summer and 7:00AM in winter, where 1.5 hours of additional solar access takes place in summer and provides more heat gains to the building. Additional natural heating also occurs due to the south-eastern orientation of the sun providing sunlight to the back face of the building. The back of the building would receive more lighting due to the building being oriented to face north-west than if it were facing directly north. However, in wintertime the back face of the building does not receive direct sunlight due to the sun being oriented in the north-east, where only the left face of the building receives lighting. Once again, due to the orientation of the building, no direct sunlight reaches the façade of the building either in the cooler months. The shading diagrams show that shading provided by neighbouring buildings, roofing and external window shades block out direct sunlight, which allows for reduced cooling loads to the building's energy demand. The upper roof of the building completely shades the lower roof during the morning, which would lower the efficiency of the solar panels on the lower roof that do not receive as much solar energy. The upper roof, however, receives direct sunlight in the early mornings, where the solar panels that account for 67% of the total panelling area of the site gain sufficient solar energy.

In looking at the midday shading diagrams of the two seasons, both roofs receive direct sunlight and allow for efficient energy input for the PV panels of both roofs. The PV panelling can clearly be seen in these two diagrams to provide shading to the building for 414.8 m^2 of the roof area, where panelling acts as part of the roof's outer construction layer. The exterior shades of the window overhangs prove ineffective in blocking direct sun in summer at this time, where the roof overhangs completely cover all the walls and windows of the site. However, in wintertime at midday, the sun is orientated further north and provides more lighting to the façade and left face of the building. This allows for additional heat gains to occur in cooler months, which would lower the heating load of the building. The shading provided by the roof overhangs and façade shading give enough coverage for the second storey and façade windows, though the external window shading side fins may provide some heat gain by reflectance of solar radiation hitting these surfaces. The façade glass entrance doors and windows would appear to benefit from an addition of blinds or shades during this time of year.

At sunset, the sun directly reaches the right face of the building and the lower roof regardless of the time of year. This means that 33% of the PV panelling area works efficiently at this time of day where only the lower roof has solar access. In summertime, the atrium's external window would benefit from blinds or shades that could block out heat gains from solar radiation. Also, at this time of year, the verandas would receive the most sunlight, though never fully gain solar access due to the shading provided by adjacent spaces of the building. The outdoor space on the ground floor would have no solar access at sunset due to the coverage from the motel building next door. The angled overhangs of the external shades can be seen to be more effective at this time of day than if the overhangs were simply horizontal, as they block out 30% of the sun's rays from entering the internal spaces. The façade, once again, only receives direct sun in winter at this time of day where the external window shades would work effectively to block the direct sunlight from entering the restaurant and coffee shop spaces. Sunset occurs at 7:00PM in summer and 5:00PM in winter, where the building would have a greater cooling load in the summer months due to the additional 2 hours of sunlight. These diagrams portray the effectiveness of shading from roof overhangs, external window shades and neighbouring buildings in reducing visual discomfort from glare and providing thermal comfort for the interior spaces of the building.

6 Maintained Design Constraints

In the modification process, there came design constraints from both the design requests of the client and general design considerations in improving the baseline design towards the net zero energy target. Before finalising the baseline design, feedback from consultants had to be incorporated into the model to ensure that design aspects, such as functionality, aesthetics, and visual comfort, were properly addressed. Some of these changes made were to increase the floor heights, add more windows and to reconsider some of the room placements. Increasing the floor heights enabled the client to utilise more space, particularly for rooms such as the function space and exhibition areas where decorations or display items could be placed up higher. More windows improved the aesthetics of the building, both internally and externally, whilst providing more visual comfort to the building. Internally, features such as natural light and a view of the outdoors could provide visitors with a sense of enjoyment and productivity. Externally, more windows allowed for the utilisation of extra shades/awnings where visual comfort could be further improved, whilst the building itself would appear more inviting. However, there were concerns in adding more windows that the acoustics of the building would be compromised. By employing double-paned EC glazing where the panes and air gaps were largest at 6 mm and 13 mm, respectively, this would have improved the sound reduction index of the building from the baseline's 3 mm clear glass windows (Kokogiannakis 2021a). Considering the needs of the client, more windows would also allow for a greater connection to place, meeting cultural aspects of the design. One design aspect was not able to be fully met, which was the spacial requirements of three office spaces, where only two were modelled. For the sake of both thermal and visual comfort, the finalised design did not utilise three office spaces, as air flow and natural light from the exterior windows were compromised, not properly reaching these internal spaces. An image of this dilemma can be seen in *Figure 9*, which shows the tight spacings and odd placement of the office rooms away from the exterior walls from the initial design. The finalised design utilised the highlighted green areas for the two office spaces, allowing for each office to run against the exterior walls where they both had in-built windows. Whilst this does not fully satisfy the client's requirements, it does maintain comfort aspects of the design.

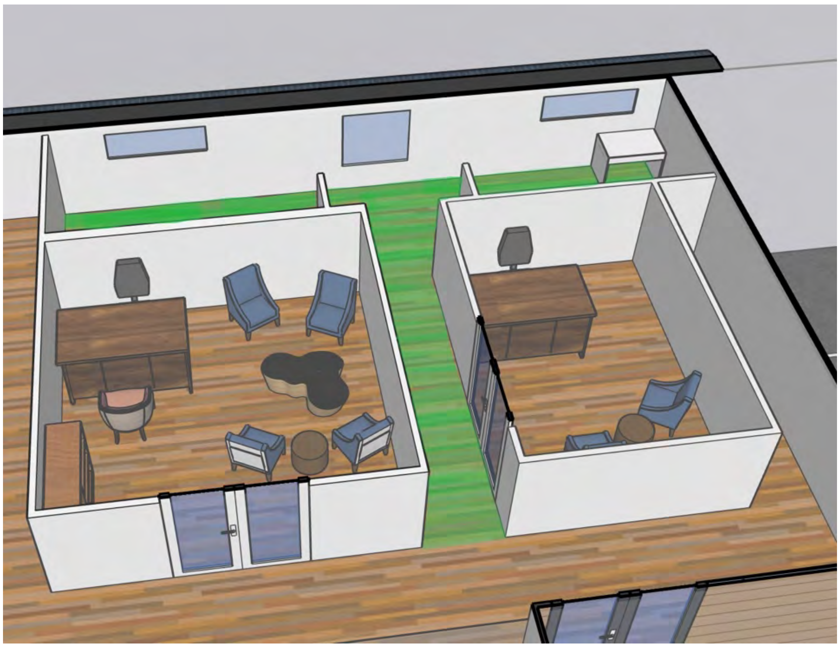

Figure 9: Initial Design Implication with Highlighted Changes made to the Finalised Model

Similar design aspects were maintained in the step modifications of the project, which were the functionality of shading, acoustics of insulation, visual comfort of glazing and thermal comfort from all three. Exterior shading, whilst minimising the effects of glare and solar heat gains, had to not compromise the view of the outdoors. For example, the fourth type of shading tested did impact some of the smaller windows where a 200 mm downward-angled overhang blocked 40% of the view of outside for windows of 500 mm heights. In making the fifth shading type, an overhang height factor of 0.3 from the top of the window ensured that only 30% of each window had a compromised view of the outdoors. This appeared not to greatly impact the aesthetics of looking outside the windows, whilst achieving improved thermal and visual comfort within these spaces. In addressing the façade window shadings, the finalised design employed side fins that extended out by up to 750 mm for the restaurant window. An issue with this might be concerning the functional use of the outside space in front of the façade, though there is still enough room to walk around this, and the side fins add some privacy/security for visitors dining inside. As the client was looking for a greater implementation of security on-site, there was no reason to doubt the sizing of the external shades, or the utilisation of side fins. Thicker insulation ensured improved thermal comfort throughout the entirety of the building, providing plenty of additional heating to the site, and would have slightly improved the acoustics of the building as well. Since the external wall construction utilises about 200 mm of heavyweight concrete, this would have doubled the sound reduction index provided by the doubled glazed windows (Kokogiannakis 2021a). The glazing itself, being of EC glass material, has a daylight glare probability (DGP) of 0.22, which lies in the range of imperceptible glare (Kokogiannakis 2021b). This window property ensured that visual comfort aspects of the model could be met in the finalised design, alongside improved thermal comfort. For the most part, the design aspects mentioned are maintained in the finalised model, though may or may not compromise the client's needs and so should be discussed further with them.

7 Discussion and Conclusion

In determining a more improved energy design model, the implementation of on-site renewable energy generation, exterior shadings, glazing of external glass windows and doors and thicker wall insulation were explored. These step modifications did show thermal improvements of the model versions, slowly growing closer to the net zero energy design target. From the baseline design, it was evident that cooling and site electricity loads were of particular concern, accounting for 62% and 33% of the total annual energy demand, respectively. In looking at daily energy profiles of this model, it was clear that heating loads could also pose an issue in winter months, despite having little impact annually. Issues with infiltration causing peak heating at the start of operation hours was another area of concern. However, not all issues could be addressed in finalising an energy efficient model for this project. In dealing with the daily electricity loads of the site, the addition of PV panelling that took up 53.5% of the roof area and had an efficiency of 15% provided a 40% improvement of the site's annual energy requirements. The panelling itself gave for a total site energy decrease of 7.96 GJ annually where shading and insulation was provided for the roof layer of the building's envelope. Despite this, the heating and cooling loads of the site did not change by much, requiring step modifications that could tackle this issue with the baseline and PV modification designs.

After adding PV panels to the baseline model, external shading of the exterior windows was added to the design to lower the heating and cooling loads of the site. This design modification improved both thermal and visual comfort aspects to the building, whilst ensuring functionality and aesthetics were not compromised. In investigating different types of overhangs, a conclusion could be drawn on the most appropriate features for implementation in the finalised design. These were to have as much side fin area and angled overhang as possible, though maintaining a clear view of the outdoors with minimal view blocked out by the shadings. Also, the shadings could not be made to extend any more than an overhang factor of 0.5 for larger windows to address spatial requirements, particularly on the ground floor. The optimal shade was to have overhang factors of 0.7 for smaller windows and 0.5 for larger windows, with box-shaped side fins and an overhang angled to block only 30% of the outdoor view from above. The result was a decrease in the cooling and site energy demands of 5.85 GJ and 5.33 GJ annually and an increase of heating load by 1.07 GJ annually. This balance ensured minimised heat gains from solar radiation and improved visual and thermal comfort to the interior spaces of the building.

Following this modification, double glazed EC glass was input as the external glass window and door constructions from a theoretical single pane clear glass of the baseline model. This double-glazed window utilised 6 mm panes with a 13 mm air gap filled with argon gas. Thicker double panes and air gaps allowed for improved insulation, and argon gas reduced the issue of condensation occurring on the windows from moisture when compared with air. Double glazing would also provide a reduction in costs and spatial usage when compared with triple or quadruple glazing. Other glazing types were tested against the EC glazing type, yet it was determined that EC glazing on its own gave for a greater reduction in the site's energy demand annually by 4.33 GJ. In addition to this, the glazing type best suited to the proposed design worked better when the glass became darker by absorption rather than by reflectance, where this property allowed for additional energy efficiency. It was proven that EC glazing worked far more efficiently than clear glass, as this type of glazing could work better in reflecting solar radiation. Tinted glass was a step up from clear glass in terms of reflectance, however, did not provide enough barrier against solar radiation to surpass low-e or EC glazing types. Low-e glazing, when more spectrally selective, gave greater results in improving energy efficiency levels of the site, though did work as well when used in combination with EC glazing. EC glazing alone, however, provided the best results and decreased the annual cooling load by 5.67 GJ. EC glazing could also be found to improve the sound reduction index of the building from the baseline's glass windows, giving the building acoustic consideration. Also, EC glazing has a DGP of 0.22, giving the visual comfort property of imperceptible glare, beneficial to the building's design.

In finalising the design for proposal, exterior walls were given thicker insulation to improve thermal comfort and energy demands of the building. Insulation in the baseline model was 79.4 mm thick, which was increased by 43% to 140 mm in the finalised model. The results highlighted that thicker insulation would work to minimise the effect of heat passing through the walls of the building. An annual decrease in site energy demand, heating, and cooling loads were determined to be 3.07 GJ, 2.93 GJ and 0.14 GJ, respectively. This was found to be the case as thicker insulation prevented some heating from taking place in cooler months where heat was less likely to escape the building. Also, some cooling was reduced where less heat was able to enter the building through thicker layers of envelope. Whilst this step modification was not as effective or innovative as the other changes made to the baseline design, its investigation did indicate further ideas for improving the building's design. For example, in looking at the exterior wall's construction layers other than the insulation, it could be seen that 200 mm of heavyweight concrete was utilised in the baseline design. This material could be tested against other materials, such as phase change materials (PCMs), to determine a more improved design in terms of energy. PCMs, investigated in the previous project, proved to be an efficient source of thermal mass in replacing heavyweight concrete, also being lightweight and having less embodied carbon. However, PCMs were not utilised in the final design, along with many other design improvements, as not all possibilities could be investigated in the timeframe for this project. Though, for the sake of the client, PCMs should be considered in addition to what is being proposed in this report.

Alongside these modifications, REF values were taken for each hour of simulation to see how much of the site's energy demand utilised the generated renewable energy from the PV panels. The panel model gave an initial average REF value of 0.40, which could only be improved by 0.01 to an REF 0.41 in the finalised model. This meant that only 41% of the finalised model would utilise renewable energy on-site, which did not reach anywhere near the net zero goal of 100% renewable energy utilisation. However, considering that the panels do not generate any energy for 4086 hours of the year when night-time occurs, only 4674 hours would have non-zero REF values. Additionally, with only 4674 hours of renewable energy generation occurring, these hours would have to average REF values of about 1.874 to achieve an annual average REF of 1 in accounting for the night-time hours. For the 4674 hours of daylight, the average REF was 0.748 and 0.759 for the panel and final models, respectively, which are not anywhere near the required 1.874 value. However, REF values were also investigated in terms of their REF ranges of (1) REF = 0, (2) $0 < \text{REF} \leq 0.3$, (3) $0.3 < \text{REF} \leq 0.95$, (4) $0.95 < \text{REF} \leq 1.05$, and (5) $1.05 < \text{REF}$ for the 8760 hours of simulation. Excusing the 4086 hours within the first range for each model, representative of night-time hours, the other hours could be explored and compared. In the second REF range, each step modification decreased the number of hours that sat below a 0.3 REF where the finalised model had 1323 hours in this range. The third REF range was like the second in terms of trend, though there was a discrepancy where adding thicker insulation to the model lowered an REF value to within this range for one of the hours from the glazing model. This gave the finalised model 2178 hours within this range, where the glazing model had 2177 hours. The fourth REF range showed an increase in the number of hours for each modification made to the design where the finalised model had 168 hours within this range. The fifth and last REF range was like the fourth in terms of trend, though there was another discrepancy where adding thicker insulation to the model lowered some REF values to outside this range for two of the hours from the glazing model. This gave the finalised model 1005 hours within this range, where the glazing model had 1007 hours.

In conclusion, it could be seen that the step modifications allowed for more utilisation of renewable energy on-site where the energy demand of the site was increased. However, little change occurred overall in the number of hours that placed within the first three REF ranges with only 17 hours changing to be in the ideal REF ranges of ranges four and five in the final model from the baseline model. An issue with the final model was that adding thicker insulation ended up decreasing the average REF to 0.405 from 0.406, though both could be treated as 41% renewable energy. Whilst aiming to decrease the energy demand of the site, this may not always ensure that utilised renewable energy is increasing with it. In reflection, the site would work better in achieving net zero if more renewable energy were utilised regardless of the site's energy demand. From the results, more energy is being generated than the site requires for 1005 hours of the year. A more energy efficient balance could be achieved in utilising a battery to store the excess energy generated in the 1005 hours and output the energy in the night-time hours. However, as most of the hours lie below an REF of 1, the site's energy demand should still be addressed in attempt to reduce the energy loads creating this issue. By directly changing inputs such as lighting, equipment, and construction materials, or by implementing other more energy efficient and innovative measures, the net zero energy goal would be achievable. Whilst the goal of this project was not achieved, the investigation into energy efficient measures has shown that net zero is possible with more design modifications made to the baseline design. For this design, adding external shading to the windows provided the greatest energy improvement, followed closely by EC glazing, which both directly addressed the issue of the baseline's cooling load that made up 67% of the site's energy demand. The site's poor energy demand is majorly a direct result of the hot climate of Lightning Ridge and the client should consider as many design improvements as possible to minimise the cooling load from this. Also, the client should consider adding external shades, PV panels and EC double-glazing into their building in aiming for a net zero energy design far improved from the baseline. Not only this, but occupants would also find the place more comfortable to be in with improved thermal, visual, acoustic, and functional aspects of the design considered.

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Appendices

Appendix A – Reflection Report

In looking at the WELL Building Standard and NABERS Government Certification Scheme, quite a few proposed design features would prove opportune to human health and environmental performance. Features concerned with human health are covered under WELL's standards for air, light, and mind. Other features present within the proposed design are covered under the fitness and comfort sections of the WELL Building Standard, however, these will not be addressed here. Under Section 6.2.2.1 of ASHRAE 62.1 (ASHRAE 2013) for 'Breathing Zone Outdoor Airflow', the ventilation rates must be a minimum of 2.5 L/s per person in majority of the spaces covered in the proposed design. Spaces of retail or restaurant types must have rates of at least 3.8 L/s per person, and stage and medical spaces must have at least 5 L/s per person of airflow. Since the assumption for this project was that all occupied spaces were to have a minimum of 10 L/s per person of supplied outdoor air, this criterion is beyond satisfactory. However, there were also requirements for spaces such as kitchens, breakrooms, retail shops and bathrooms to have a minimum of 0.6 L/s per m^2 ventilation rates. In addition to this, the medical and restaurant dining spaces had to have at least 0.9 L/s per m^2 of supplied outdoor air. Input into the proposed design energy model was a minimum amount of 0.35 L/s per m^2 for all spaces, which could not be satisfied by this criterion. For the spaces requiring more outdoor airflow, the input rates should be adjusted to ensure appropriate values are utilised in improving the air quality of the building. However, in Section 15 of the WELL Building Standard for 'Increased Ventilation', it is stated that acceptable indoor air quality must be at least 30% higher than the minimum rates given in the ASHRAE 62.1 standard. This is particularly important for cases where occupancy rates are higher than expected and would require an adjustment to most inputs utilised in the proposed design. In looking at other air requirements from WELL, the proposed design should consider implementing air filtration in minimising pollutant air. Also, entryway walk-off systems, such as mats, and air seals should be used to ensure contaminants brought inside from the outdoors are minimised or removed effectively. In the construction of the building, air flushing should be introduced into the design to allow improved air quality and reduced likelihood of contaminant air entering the building's spaces (International WELL Building Institute 2016).

In looking at the light features under the WELL Building Standard, Section 53 for 'Visual Lighting Design' mentions that a minimum of 300 lux should be provided by ambient lighting to satisfy basic visual performance. In following NCC requirements, this minimum standard was not employed in spaces where visual acuity was not of major concern, such as in walkways like stairs, corridors, and entryways, or in storage spaces (Australian Building Services 2013). This exception is however covered under the WELL standard where the minimum of 300 lux only applies to workstations or desks. This means that the artificial lighting levels implemented in the proposed design satisfy the WELL standard. However, under Section 55 for 'Electric Light Glare Control', it is stated that discomfort glare may be the case if luminance levels are higher than standard values at specific light view angles. WELL provides appropriate luminance levels for different angles of lighting and should be considered additionally in the proposed design, though was not explored in this project. Under Section 56 for 'Solar Glare Control', WELL states that it is necessary to implement at least exterior or interior window shading, or variable opacity glazing, in managing glare. Since the proposed design utilised both external shading and variable opacity glazing of EC glass, the transmissivity of sunlight entering the building could be reduced by at least 90%, providing both visual comfort and reduced visual fatigue. Section 57 for 'Low-Glare Workstation Design' highlights the issue of orienting computer screens to face windows, where glare may be an issue for computers less than 4.5 m from the window. The client should consider this design feature when orienting the desks and computers in the office spaces of the building, where windows are featured in these spaces. Section 61 for 'Right to Light' explains that regular sun exposure can provide physiological and visual benefits. The implementation of windows and an atrium in the proposed design could ensure that regularly occupied spaces would achieve this design feature and its benefits. Part 1 of Section 63 for 'Daylighting Fenestration' describes that working and learning spaces should have at least 20-60% window-wall ratios to improve human health and to provide other visual benefits (International WELL Building Institute 2016). The proposed design did not utilise this kind of window area in the conference room of the building, however, did implement windows of this magnitude in other working spaces. To ensure the design fully satisfies this standard, a window should be added to the conference room of the proposed building.

In the mind section of the WELL Building Standard, Sections 87 and 99 for 'Beauty and Design' touch on the importance of a buildings design aligning with the client's core cultural values. By implementing aboriginal art and design features to the proposed building's façade and interior entryway space, this would allow for human delight, celebration of culture, spirit, and place, whilst publicising meaningful artwork. This WELL standard could be satisfied and create a place where employees and visitors feel comfortable, calm, and aesthetically pleased. Furthermore, the integration of artwork into regularly occupied spaces, such as gathering areas, as well as the entryway, would prove to create a beautiful and meaningful space for occupants in the building. In accordance with WELL, the ceiling height of the second floor should be increased yet again to a minimum of 2.75 m for the second floor from the 2.6 m set in the proposed design. This would achieve a more expansive and open feel to the upstairs spaces, particularly those in view of the outdoor area or the atrium of the building, where a further sense of comfort would be reached (International WELL Building Institute 2016). In conclusion, an estimation of the proposed design under the NABERS (2018) energy rating was conducted to determine the building's energy efficiency and environmental performance. The inputs for this estimation were an office building type, base building scope, 872.9 m² floor area, 111 hours of occupancy (standard business hours), 95602.8 kWh of annual electricity use, 41% green power, 53510 MJ annual natural gas use, and 0 L annual diesel use. This gave for a 5.5-star rating with green power and a 5-star rating without green power (base case), where the energy intensity of the building was determined to be 445 MJ/m². However, in looking at the results from the proposed model simulation, this energy intensity only covers electricity and gas loads of the building and does not include heating and cooling loads. An additional energy intensity of 775 MJ/m² from the heating and cooling loads would properly represent the proposed building's energy efficiency. By adjusting the annual electricity use to an estimated value of 280000 kWh in representing the heating and cooling loads as well as the electricity load, this equated to an energy intensity of 1216 MJ/m². This energy intensity could account for the site's total energy demand, and with a 41% implementation of renewable energy, this gave for a 4-star rating. Without green power at this degree of energy intensity, the star rating would be 1.5-star, which highlights the importance of implementing PV panels into the building's design. However, this second test was simply an estimation of the building's energy efficiency that would account for all loads of the site, where this rating may not be an appropriate reflection of actual energy values. Either way, the proposed building provides good, if not excellent, building performance in terms of energy use in accordance with NABERS ratings (NABERS 2020).

Appendix B – Simulation Assumptions

B.1 Hours of Operation

Table B-1: Hours of Operation according to Main Building Spaces and Days of the Week

Spaces	**Days of the Week**		
	Weekdays	***Saturdays***	***Sundays***
Restaurant	11am-3pm, 5pm-11pm	11am-3pm, 6pm-11pm	11am-3pm, 5pm-10pm
Kitchen	10am-12am	10am-12am	10am-11pm
Coffee Shop	7am-2pm	7am-2pm	7am-2pm
Souvenir Shop	9am-5pm	10am-4pm	10am-4pm
Office Spaces	9am-5pm	-	-
Function Room	8am-8pm	-	-

B.2 Lighting & Equipment

Table B-2.1: Lighting and Equipment Wattage Definitions for all modelled Space Types

Space Type	**Building Type**	**Lights Definition (W/m^2)**	**Electrical Definition (W/m^2)**
Stairs	Office	8	-
Atrium	Retail	15	-
Bathrooms	Office	6	0.753474
Closed Offices	Office	9	6.888903
Coffee Shop	High School	22	13.993084
Conference Room	Office	10	3.982647
Entry Hall	Retail	15	-
Function Room	High School	10	3.659730
Stage	High School	10	3.659730
Kitchen	Restaurant	22	274.47934
Breakrooms	Office	10	48.007040
Medical Room	Hospital	10	15.715309
Restaurant	Restaurant	22	43.916773
Souvenir Shop	Retail	22	2.368061
Staff Lounge	Small Hotel	10	39.503551
Storage Room	Office	8	-

Table B-2.2: Lighting and Equipment Operation Fractional Schedules for all modelled Space Types

Space Type	Lighting Min.	Lighting Max.	Electrical Min.	Electrical Max.
Stairs	0.05	0.9	-	-
Atrium	0.05	0.9	-	-
Bathrooms	0.05	0.9	0.3	0.9
Closed Offices	0.05	0.9	0.3	0.9
Coffee Shop	0.1773	0.9	0.35	0.95
Conference Room	0.05	0.9	0.3	0.9
Entry Hall	0.05	0.9	-	-
Function Room	0.1773	0.9	0.35	0.95
Stage	0.1773	0.9	0.35	0.95
Kitchen	0.15	0.9	0.1	0.35
Breakrooms	0.05	0.9	0.3	0.9
Medical Room	0.05	0.9	0.3	0.5
Restaurant	0.15	0.9	0.1	0.35
Souvenir Shop	0.05	0.9	0.15	0.9
Staff Lounge	0.05	1	0.11	1
Storage Room	0.05	0.9	-	-

B.3 Heating & Cooling

Table B-3: Heating and Cooling Setpoint Ranges and Times for different Modelled Spaces

Spaces	Heating Setpoints		Cooling Setpoints	
	Min, Time	***Max, Time***	***Min, Time***	***Max, Time***
Coffee Shop	16°C, all other	21°C, 6am-3pm	24°C, 6am-3pm	27°C, all other
Function Spaces	15.6°C, all other	21°C, 8am-8pm Weekdays	24°C, 8am-8pm Weekdays	30°C, all other
Entry Hall Spaces	15.6°C, all other	21°C, 6am-12am Mon-Sat and 6am-11pm Sun	24°C, 6am-12am Mon-Sat and 6am-11pm Sun	30°C, all other
Kitchen	15.6°C, all other	19°C, 10am-12am Mon-Sat and 10am-11pm Sun	26°C, 10am-12am Mon-Sat and 10am-11pm Sun	30°C, all other
Office Spaces	15.6°C, all other	21°C, 8am-6pm Weekdays	24°C, 8am-6pm Weekdays	26.7°C, all other
Restaurant	15.6°C, all other	21°C, 10am-12am Mon-Sat and 10am-11pm Sun	24°C, 10am-12am Mon-Sat and 10am-11pm Sun	30°C, all other
Souvenir Shop	15.6°C, all other	21°C, 8am-6pm Mon-Fri and 9am-5pm Sat-Sun	24°C, 8am-6pm Mon-Fri and 9am-5pm Sat-Sun	30°C, all other

B.4 People, Activity and Occupancy

Table B-4: People, Activity and Occupancy Inputs based on Modelled Space Types

Space Type	People Definition	Activity (W/person)	Occupancy Times	Occupancy Max.
2F Bathrooms	2 people	132	8am-6pm Mon-Fri	0.5
GF Bathrooms	2 people	132	8am-12am Mon-Fri, 9am-12am Sat, 9am-11pm Sun	0.4 Mon-Fri, 0.25 Sat-Sun
Closed Offices	4 people	132	8am-6pm Mon-Fri	0.85
Coffee Shop	3 people	120	6am-3pm	0.7
Conference Room	20 people	132	8am-6pm Mon-Fri	0.4
Entry Hall	15 people	120	8am-12am Mon-Fri, 9am-12am Sat, 9am-11pm Sun	0.8 Mon-Sat, 0.4 Sun
Function Room	200 people	120	8am-6pm Mon-Fri	0.95
Stage	5 people	120	8am-6pm Mon-Fri	0.95
Kitchen	5 people	120	10am-12am Mon-Sat, 10am-11pm Sun	0.8 Mon-Fri, 0.9 Sat, 0.7 Sun
Breakrooms	0.2 people/m²	132	8am-6pm Mon-Fri	0.4
Medical Room	2.5 people	120	8am-6pm Mon-Fri	0.5
Restaurant	40 people	120	10am-12am Mon-Sat, 10am-11pm Sun	0.8 Mon-Fri, 0.9 Sat, 0.7 Sun
Souvenir Shop	15 people	120	8am-6pm Mon-Fri	0.8 Mon-Sat, 0.4 Sun
Staff Lounge	10 people	120	8am-6pm Mon-Fri	0.7

B.5 Infiltration

Table B-5: Infiltration Schedules based on Infiltration Groups and Modelled Spaces

Infiltration Group	Space	Infiltration Times	System Schedule
1	Entry Hall	6am-12am Mon-Sat and 6am-11pm Sun	Half On
	Atrium		Half On
	GF Bathrooms		Quarter On
	Coffee Shop		Half On
	Souvenir Shop		Half On
	Restaurant		Half On
	Function Room		Half On
	Stage Space		Half On
	Kitchen		Half On
	Storage Room		Quarter On
2	Front Stair	8am-6pm Weekdays	Quarter On
	Medical Room		Quarter On
	Large Breakroom		Quarter On
	2F Front Bathrooms		Quarter On
3	Staff Lounge	8am-6pm Weekdays	Half On
	Conference Room		Quarter On
	Small Breakroom		Quarter On
	Closed Offices		Quarter On
	Back Stair		Quarter On
	2F Back Bathrooms		Quarter On

Appendix C – Daily Energy Use Profiles

C.1 Baseline Model

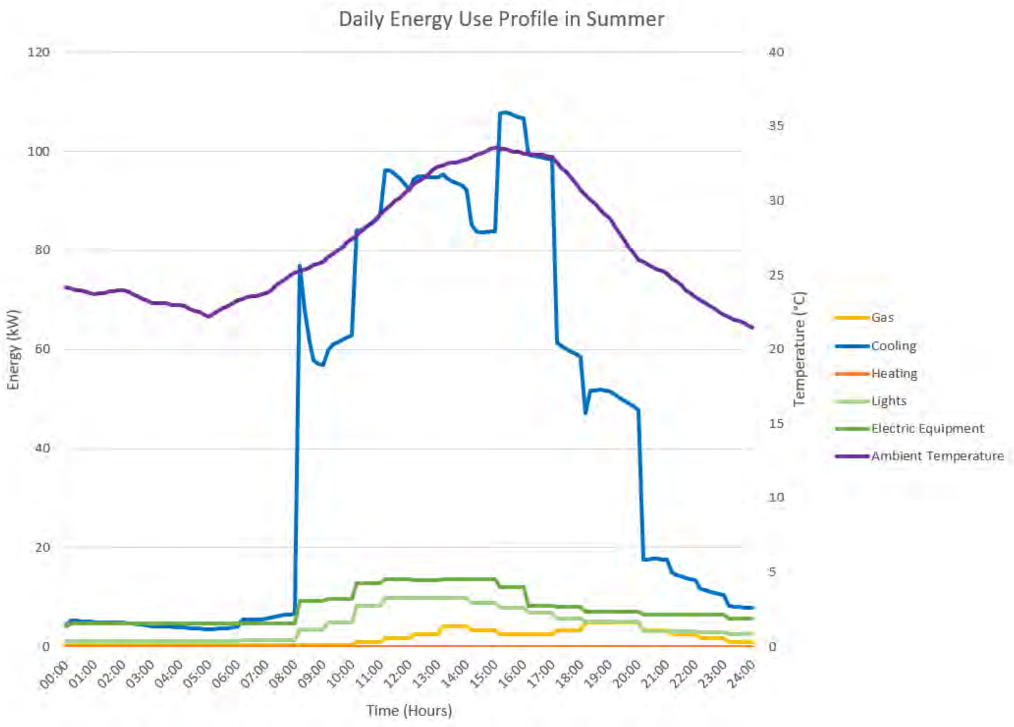

Figure C-1.1: Daily Energy Use Profile of Baseline Model in Summer (taken from 2 January)

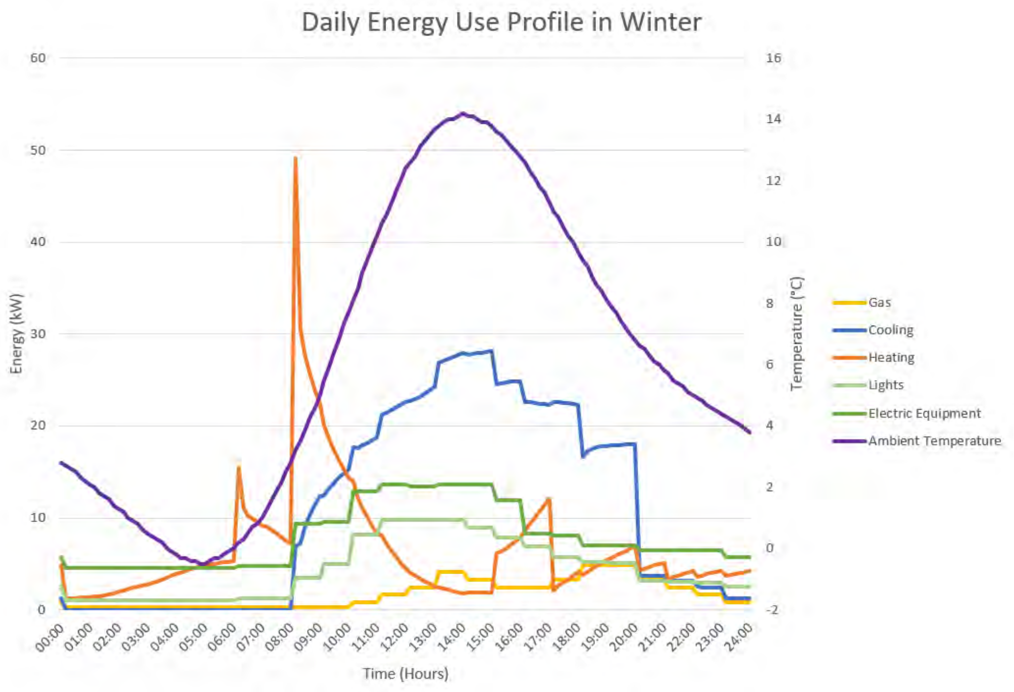

Figure C-1.2: Daily Energy Use Profile of Baseline Model in Winter (taken from 27 July)

C.2 PV Panel Model

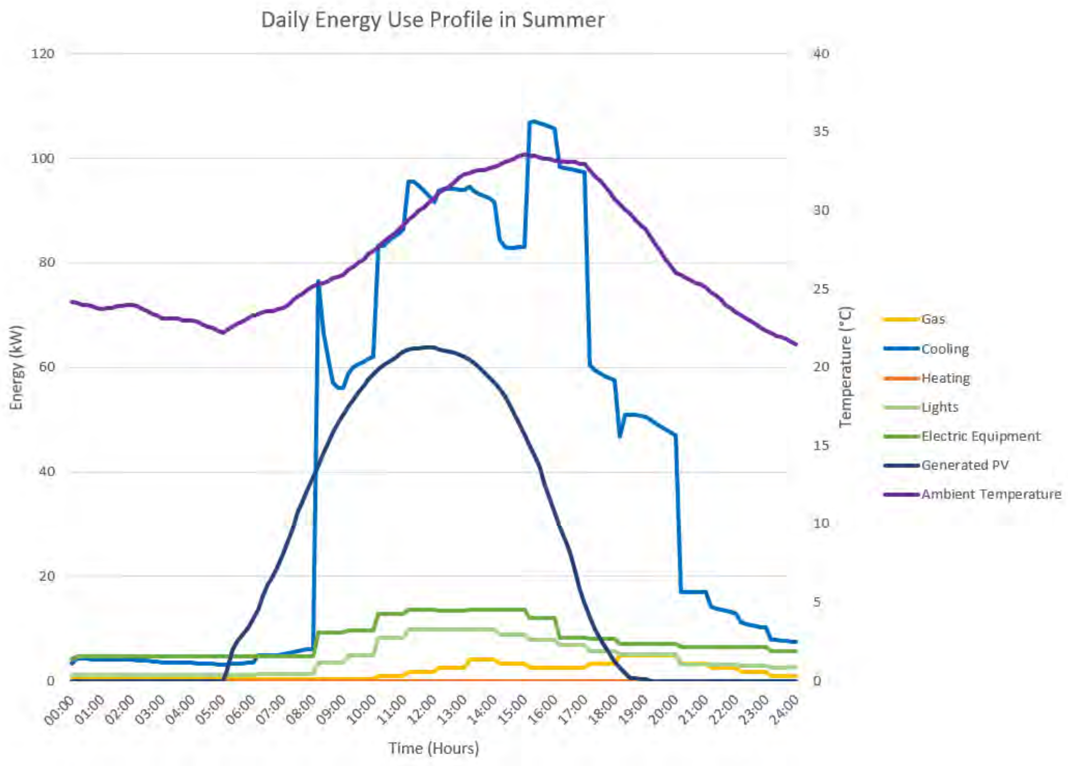

Figure C-2.1: Daily Energy Use Profile of PV Panel Model in Summer (taken from 2 January)

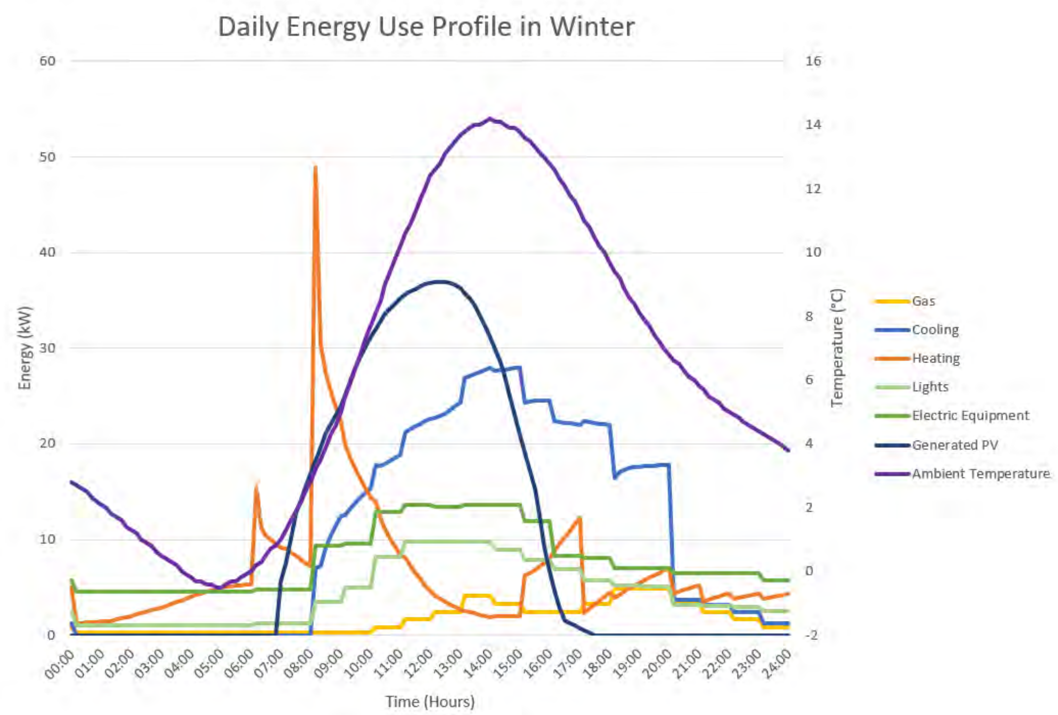

Figure C-2.2: Daily Energy Use Profile of PV Panel Model in Winter (taken from 27 July)

Appendix D – Glazing Modification Results

Table D-1: Annual Energy and Average REF Values of Glazing Type Modifications

Glazing Type	Annual Energy (GJ)				Average REF Value
	Heating	*Cooling*	*Net Site*	*Total Site*	
Clear	24.47	674.30	660.04	1096.45	0.396027
Low-E Clear	23.25	670.60	655.11	1091.52	0.397549
Green Tint	24.97	667.06	653.30	1089.71	0.398922
Bronze Tint	24.98	666.94	653.19	1089.59	0.398970
Blue Tint	24.98	666.90	653.15	1089.56	0.398984
Grey Tint	25.02	666.28	652.57	1088.98	0.399234
Low-E Spectrally Selective Clear	23.37	665.10	649.74	1086.15	0.399793
Low-E Tint	23.73	663.68	648.68	1085.09	0.400384
EC Ref Coloured	24.42	654.99	640.68	1077.09	0.403890
Low-E EC Abs Coloured	24.19	653.97	639.43	1075.84	0.404321
Low-E EC Ref Coloured	24.19	653.97	639.43	1075.84	0.404321
Low-E Spectrally Selective Tint	24.22	653.64	639.13	1075.54	0.404451
EC Abs Coloured	26.77	652.79	640.83	1077.24	0.406490

Table D-2: Ranges of REF values across 8760 hours of Simulation of the Glazing Models

	Glazing Type	REF Ranges			
		0<REF≤0.3	*0.3<REF≤0.95*	*0.95<REF≤1.05*	*1.05<REF*
No. Hrs	*Clear*	1343	2207	142	982
	Low-E Clear	1341	2197	148	988
	Green Tint	1336	2201	150	987
	Bronze Tint	1336	2201	150	987
	Blue Tint	1336	2201	150	987
	Grey Tint	1335	2201	150	998
	Low-E Spectrally Selective Clear	1334	2190	155	995
	Low-E Tint	1332	2189	155	998
	EC Ref Coloured	1322	2187	163	1002
	Low-E EC Abs Coloured	1322	2184	161	1007
	Low-E EC Ref Coloured	1322	2184	161	1007
	Low-E Spectrally Selective Tint	1321	2184	163	1006
	EC Abs Coloured	1325	2177	165	1007

Appendix E – Shading Diagrams

E.1 Summer

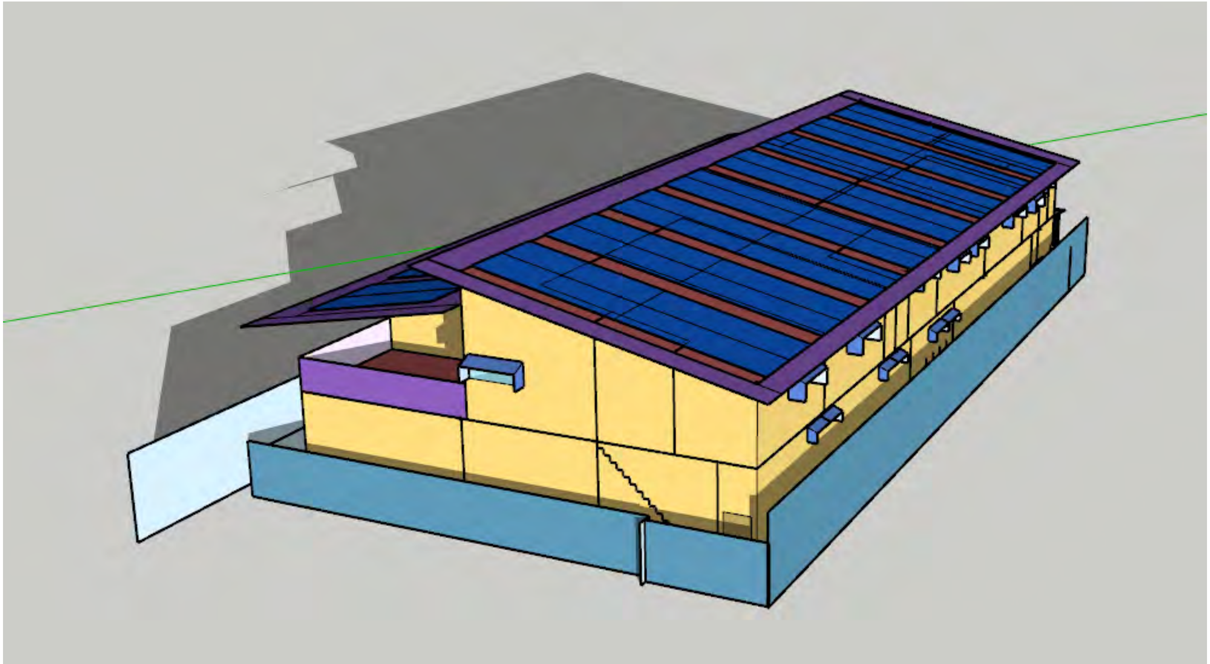

Figure E-1.1: Shading Diagram of Finalised Model at 5:30AM in Summer (East Side)

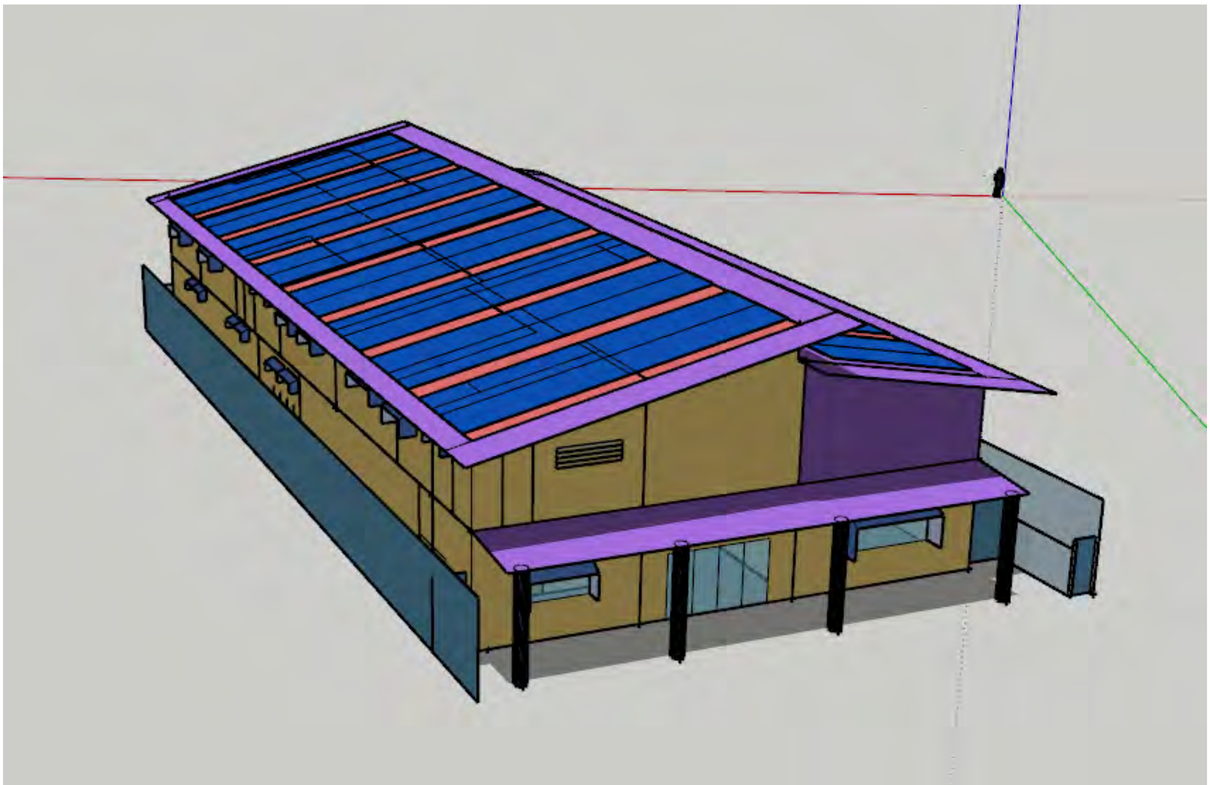

Figure E-1.2: Shading Diagram of Finalised Model at 12:00PM in Summer (North Side)

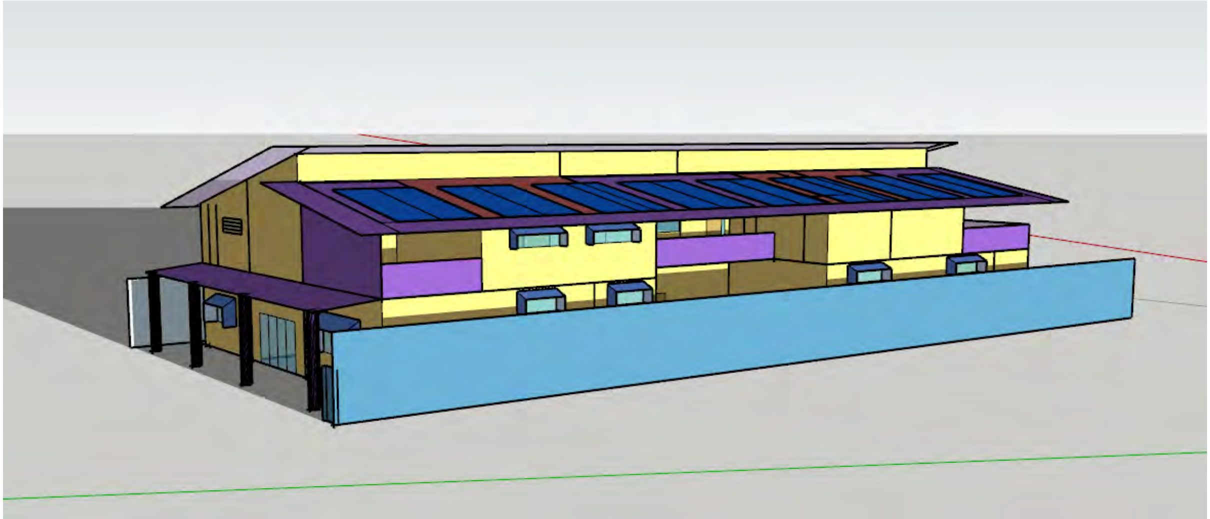

Figure E-1.3: Shading Diagram of Finalised Model at 7:00PM in Summer (West Side)

E.2 Winter

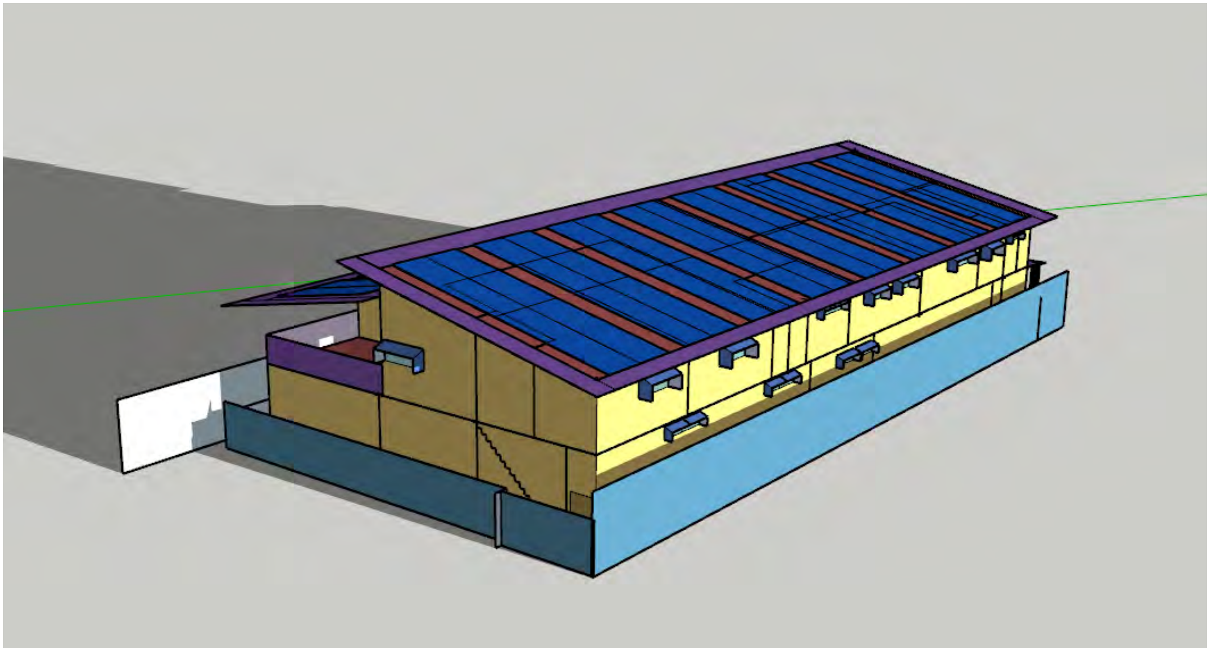

Figure E-2.1: Shading Diagram of Finalised Model at 7:00AM in Winter (East Side)

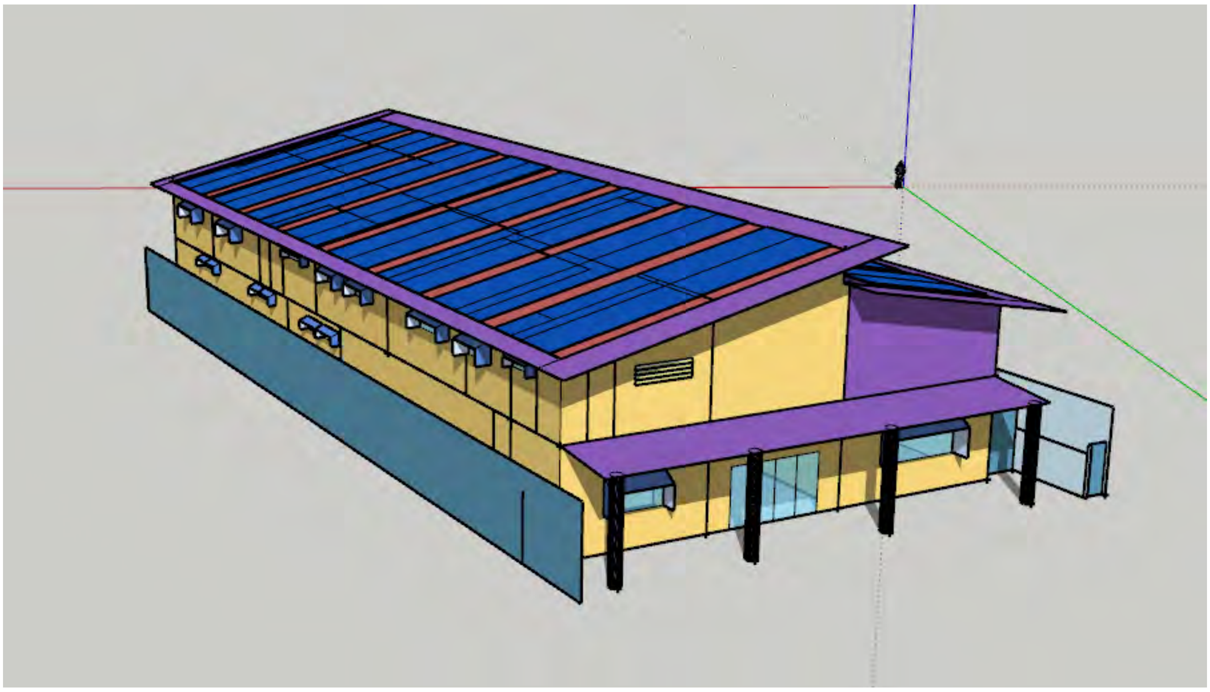

Figure E-2.2: Shading Diagram of Finalised Model at 12:00PM in Winter (North Side)

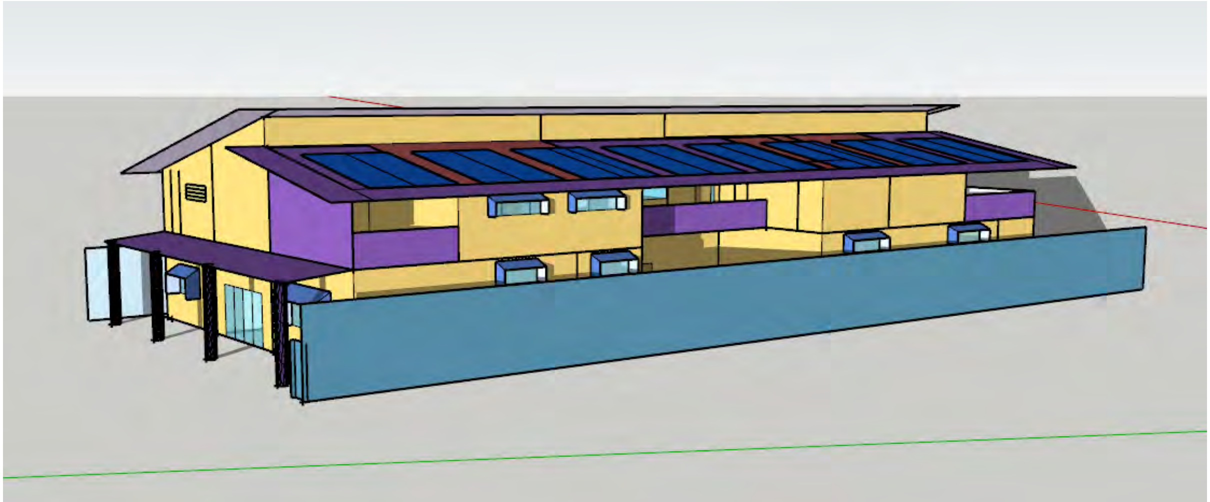

Figure E-2.3: Shading Diagram of Finalised Model at 5:00PM in Winter (West Side)

University of Wollongong

LRLALC Project

ENGG210 Building Physics & Services

Executive Summary

This report presents the energy modelling findings of the proposed design for the multi-purpose community centre for the Lighting Ridge Local Aboriginal Land Council (LRLALC). The simulation process allowed the comparison of various passive solar design strategies and products to determine the solution that most effectively responds to the requirements of the client brief.

The passive solar design strategies investigated include;

- Lighting
- Heat Ventilation Recovery (HVR)
- Materials
- Glazing
- Shading

The process of energy modelling this building in Design Builder found that the development of a design package that involved a combination of the aforementioned strategies was most effective at achieving the net-zero energy target of a REF value greater than or equal to one. Careful analysis of which strategies would complement each other was undertaken to determine the strategies that form part of the proposed package.

Despite this, it should be noted that although the design package proposed will theoretically perform most effectively, a comprehensive monitoring and maintenance plan should be implemented throughout the operation of the building to ensure this continues to be the case. Overall, it is evident that the double glazing with electrochromic glass, 0.5m eaves, LED with linear control (return air) and PCMs design package will most effectively meet the requirement of the client brief.

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1. Project Brief

The proposed building is to be constructed in Lightning Ridge which is a black opal mining town located approximately 715km NW of Sydney. It is characterised by a relatively hot and dry climate, thus passive solar design and efficient active systems are essential to maintaining a comfortable IEQ for occupants. The LRLALC building is to be located on the main street of Lightning Ridge and encompass a variety of spaces with a variety of uses that can be easily adapted to accommodate small or very large groups. The LRLALC wishes to expand its current operations to encompass a gallery, restaurant, offices, meeting/ teaching rooms, and a large function hall.

This project is to be delivered in a timely and cost-effective manner that incorporates community involvement and consultation at every stage of the project. As such, considering the nature of the client, net-zero requirement, climate, and proposed purpose, a unique set of design parameters is created. The following goals outline some of the ideals the consultation team wishes the project to embody;

- To design a building that services both the public and private sectors of the community and utilises open-plan, free-flowing spaces to promote connectivity.
- To celebrate, facilitate and educate on the surrounding cultural traditions and heritage of the area.
- To design a building that complements its environment through passive principles and sustainable practices.
- To design a building that is resilient to its environmental and socio-economic surroundings.
- To explore forward-thinking and innovation to promote new incentives.

*NOTE: these project goals are from the ENGG210 task 2 report.

These goals will be implemented throughout the energy modelling and decision-making process to ensure the client's values are maintained throughout the project. Specifically, the passive solar design strategies that were chosen to be modelled and ultimately form part of the design package proposed, embody these ideals thus ensuring the most holistic and effective solution is recommended.

Figure 1 - Street View Render of Proposed Building

2. Proposed Design

Minor modifications were made to the second floor of the proposed design after the task 2 submission in response to feedback received regarding the excess space. A key concern identified was the capital cost associated with constructing a space that would rarely be used as well as the operational costs associated with heating and cooling the space. These revisions include;

- Increased area and relocation of kitchenette
- Modification from two bathrooms to a single unisex bathroom
- Addition of storeroom upstairs

These amendments streamline the flow and circulation of people throughout the space, thus reducing wasted space that will be costly in both capital and operational sense. It also reduces the number of amenities and relocating the kitchen ensures like services are located nearby. Lastly, the location of a storage room secured within the office areas upstairs provides a safe space to store important documents and other objects of importance.

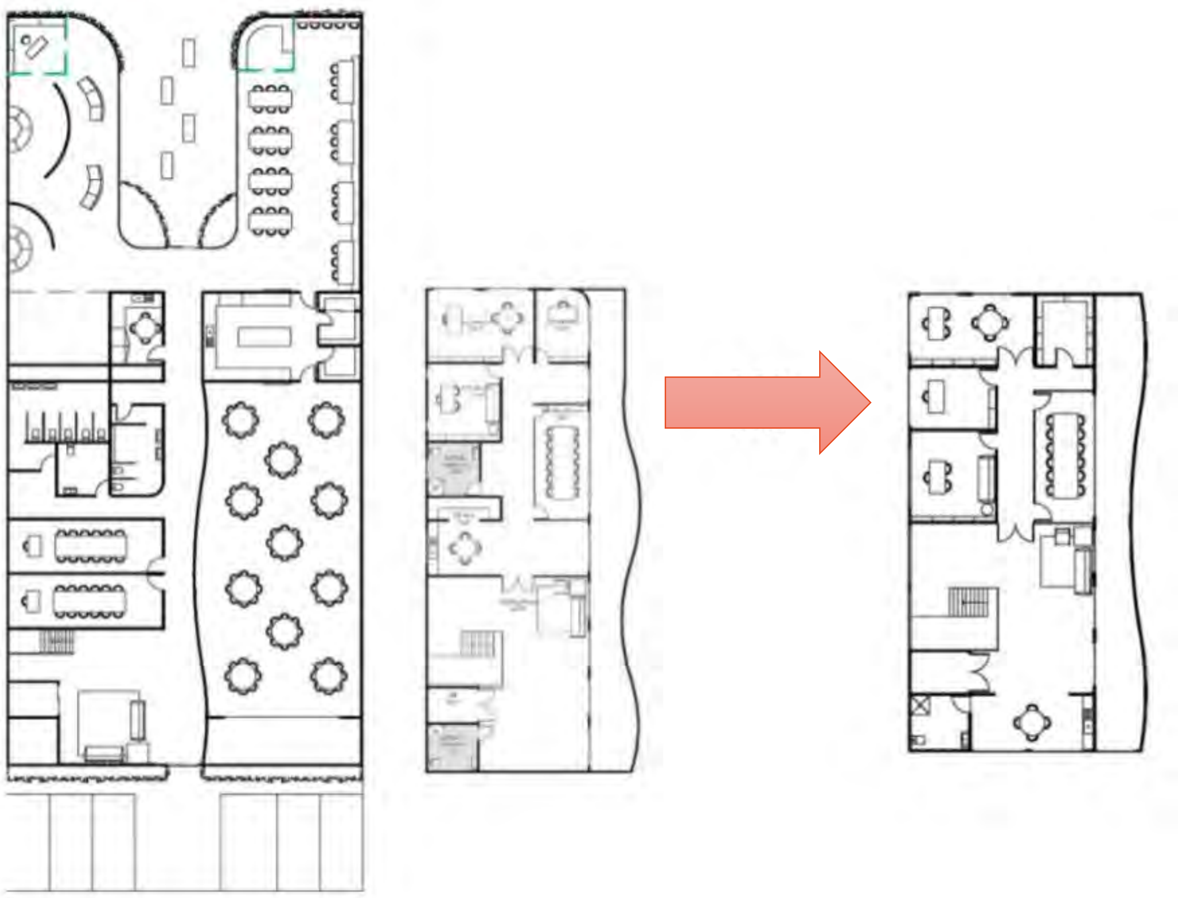


Figure 2 - Concept (left) and Proposed (right) Design

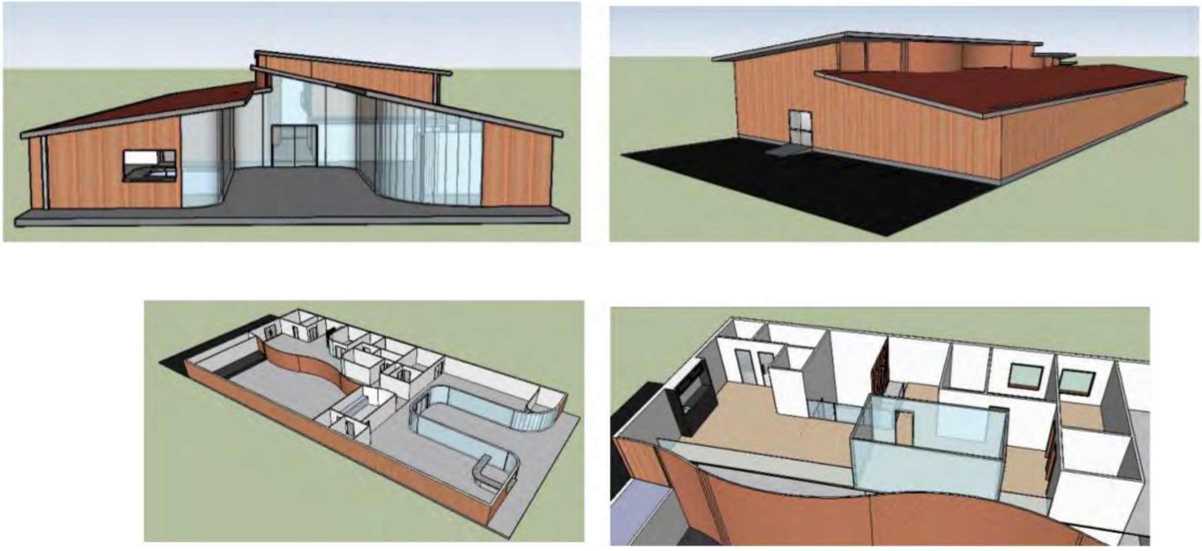


Figure 3 - Proposed Design SketchUp Renders

3. Benchmark Model

From this amended design, a model was generated in Design Builder, albeit some simplifications and assumptions were made to ensure the simulations would run smoothly. These include but are not limited to;

- The weather file used for the simulation process is from a weather station located in Walgett which is 80 km SSW of the site at Lightning Ridge.
- All walls are assumed to be flat.
- Four different schedules were applied to the various zones throughout the building, namely building classification 5, 6, and 9b. The lightning and occupancy schedules used were derived from NCC Section J and were assumed to sufficiently mimic the diverse uses of the building.
- The reliability of the electricity network and voltage stability is assumed to be ideal.
- The client's budget is assumed to be negligible during the simulation process.
- It is assumed that the air loads and the HVAC system are ideal.
- Constant hot water demand of 2kW is required between 08:00 and 20:00.
- When calculating the airflow and ventilation values, the number of people occupying each zone is derived from the space size and allocation table from Task 1 and is assumed to adequately reflect the use of the building.

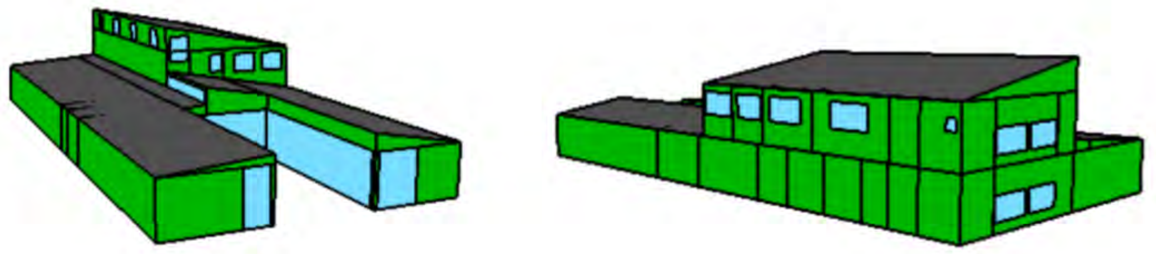


Figure 4 - Benchmark Model in Design Builder

3.1 Model Zones

When developing the energy simulation model in Design Builder, each space had to be defined to allow specific properties regarding its use to be assigned. The spaces included in the model are as follows.

Table 1 - Design Builder Model Zones

Ground Floor	First Floor
• Gallery • Artist workspaces • Accessible bathroom • Female bathroom • Male bathroom • Teaching room 1 • Teaching room 2 • Lift • Corridor 1 • Restaurant • Commercial kitchen • Pantry • Fridge and freezer • Staffroom • Storeroom • Entertainment hall	• Common area • Unisex bathroom • Lift • Corridor 2 • Meeting room • COO office • CFO office • CEO office • Storeroom

3.2 Schedule Data Used

The schedule data inputted into the model was derived from the NCC Volume One Section J and is as seen in the table below.

Activity

See appendix 8.3.

Construction

The 'best practice medium weight' Design Builder construction template was selected for the benchmark model as it most closely reflected the minimum requirements in NCC Volume One Section j1.3, Table J1.5a, and Table J1.6.

Openings

Double glazed windows with internal shading were used for the benchmark model, as required by NCC Volume One Section J1.5. however, it should be noted that this configuration doesn't meet the requirements of Table J1.5b, thus will need to be addressed in the design modifications section of this task.

Lighting

The 'LED with liner control' lighting template was selected for the benchmark model, whilst the required power density for each space in the building was calculated using NCC Volume One Table J6.2a.

HVAC

As outlined in the project brief, a spilt system air conditioning unit with mechanical ventilation was used in the benchmark model, which had a COP of 4. The airflow, including fresh air, and ventilation requirements to each space were derived from NCC Volume One Section J5.

3.3 Benchmark Model Results

Applying the schedules and template data discussed above, an energy simulation of the benchmark model was conducted, and the following results were derived.

Table 2 - Benchmark Model Tabulated Results

Category	Energy Consumption (MJ)
Cooling	256,387.4
Heating	13,883.5
Water system heating	47,929.4
Interior lighting	36,424.6
Interior equipment	9,239.8
Total	363,864.7

To determine the accuracy of the benchmark model energy simulation results comparison to the business-as-usual case study conducted in assignment 2 can be made. The business-as-usual case was established to achieve a 6-star NABERS rating for the site which resulted in an annual energy requirement of 367,642 MJ. Therefore, it can be established that the results derived from the benchmark model are both accurate and valid.

Annual Heating and Cooling Loads

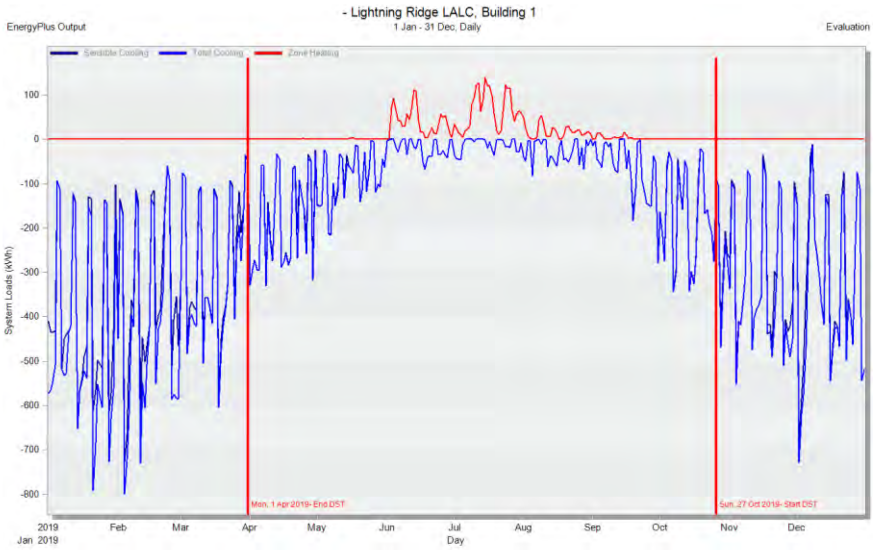


Figure 5 - Benchmark Model Annual Heating and Cooling Loads

Close analysis of the annual heating and cooling loads reveals the building has a significant cooling load and a very low cooling load for most of the year. Considering the climatic context of the building it is unsurprising that the building has a higher cooling compared to the heating load. Even so, these cooling loads are extremely high for climatic reasons alone, thus it was derived that the internal gains of the building also contributed to this result. As such, design modifications that address lighting, occupant activity, equipment, and solar gains will need to take place to lower the cooling load and ultimately the annual energy consumption of the building.

Peak Heating and Cooling

Peak heating and cooling loads were investigated by simulating 24 hours of the most extreme days as derived from the figure above. It was derived that the annual peak cooling load of the building will take place at approximately 14:00 on February the 4th, whilst the peak heating load occurs at approximately 07:30 on July 14th. Therefore, scheduled/ automated design modifications during these periods will reduce the variance in peak loads, thus placing less strain on the system and ensuring its efficiency.

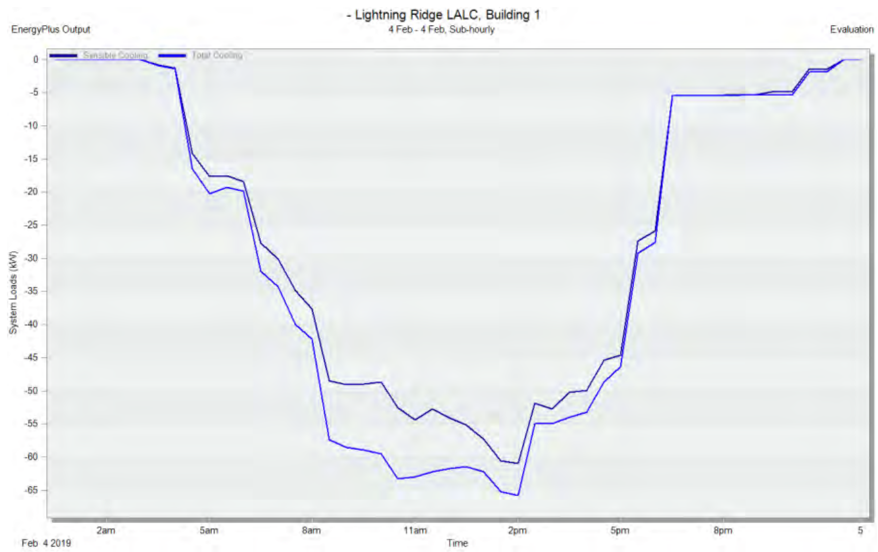


Figure 6 - Benchmark Model Peak Cooling

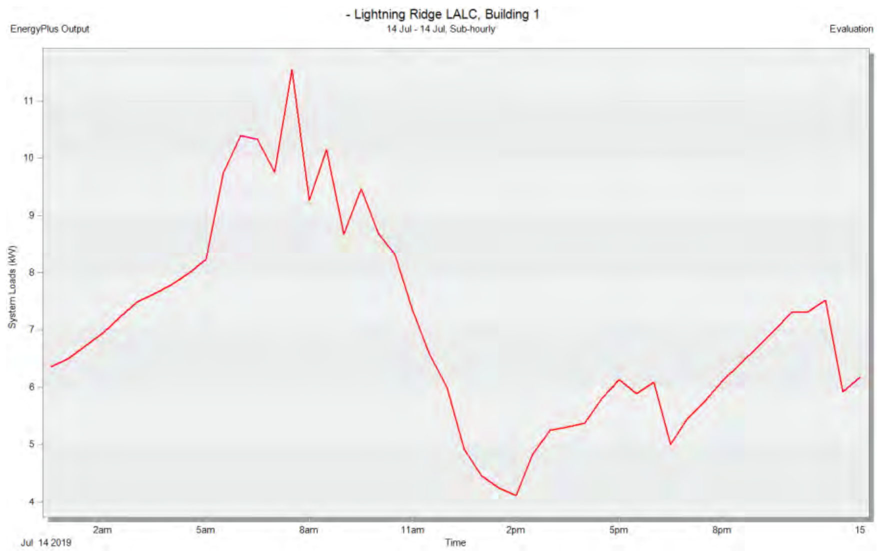


Figure 7 - Benchmark Model Peak Heating

3.4 PV Benchmark Model

After the annual energy generation requirements for the benchmark model were derived, onsite photovoltaic (PV) was added to the energy model in order to offset the energy requirements and strive toward a net-zero energy building. As required by the project brief, 60% of the roof space was used for PV (see appendix 8.2) with panels angled at 24 degrees to achieve an optimum solar consumption angle of 29 degrees when combined with the already 5-degree roof slant. Other assumptions made for the PV benchmark model are as follows.

- For ease of simulation of the PV panels, the roof is assumed to be flat.
- The nominal efficiency of the PV panels was assumed to be 15%.
- Spacing between PV panels is 0.2m which is assumed to be sufficient to prevent overshadowing.

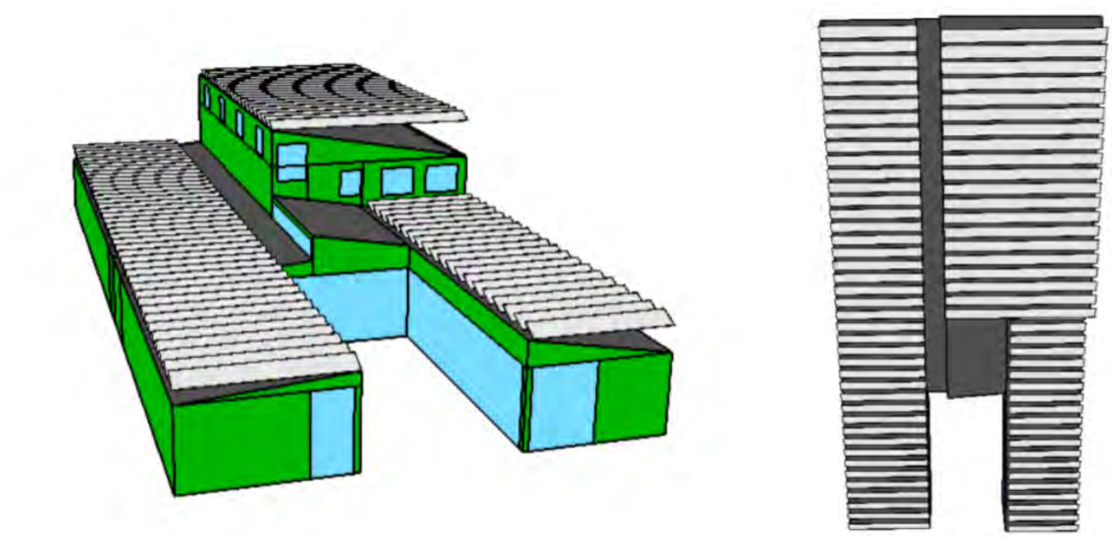


Figure 8 - PV Benchmark Model in Design Builder

3.5 PV Benchmark Model Results

Energy simulations of the PV benchmark model reveal onsite annual generation to be approximately 243,755 MJ. Therefore, as can be seen in the figures below that onsite generation will provide sufficient energy to run the HVAC for heating loads in winter but not cooling loads in summer. As a result, further design modifications that address passive solar design must take place to reduce the summer cooling load and ensure the building achieves a net-zero energy status.

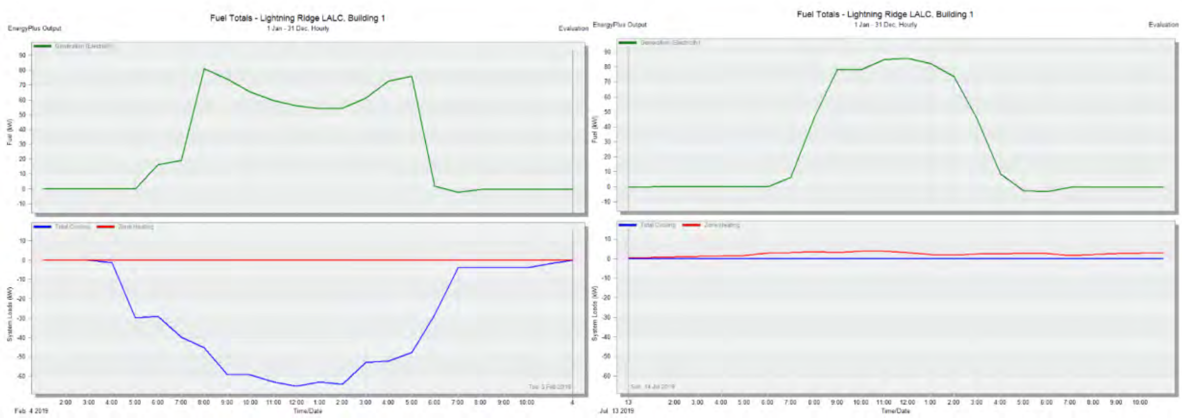


Figure 9 - PV Benchmark Model Generation for Peak Load Days

4. Design Modifications

Various passive solar design modifications were simulated to determine which strategies would aid in achieving a net-zero energy building. The scenarios modelled are listed below.

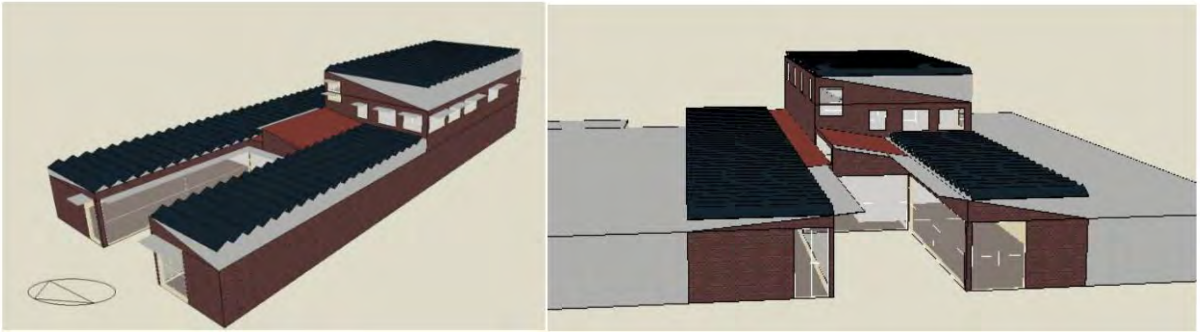


Figure 10 - Rendered Design Builder Model

Lighting

- LED with linear control (suspended) (benchmark)
- Best practice (suspended)
- LED (suspended)
- Fluorescent (suspended)
- Best practice (recessed)
- LED with linear control (recessed)
- LED with linear control (return air)

In many buildings, lighting is often the biggest contributor to heat in the indoor environment, therefore modification of this building element will address the high cooling load derived from the benchmark energy simulations. The LED with linear control was selected as the benchmark as it aligned most closely with the client and legislative requirements. This template was also most effective at achieving similar results to the 6-star NABERS rated business-as-usual case. Linear control refers to the changing lux level output of the lights throughout the day in response to changing daylight levels, thus allowing a constant lux level of 400 to be maintained throughout the building as required by NCC Volume One Section J. As such the linear control mechanism is a highly effective way of reducing unnecessary internal heat gains associated with lighting, ultimately reducing the building's cooling load and associated energy requirements of both running the lights and cooling the building. Further, having the lights recessed into the ceiling cavity and the return air flowing past the lights are other modifications that have the potential to greatly reduce the residual heat produced as a result of running lights.

HVR

- No HVR (benchmark)
- HVR

Heat ventilation recovery is an effective way of retaining heat from waste air which can then be used to heat the building using no additional energy requirements. Although heating loads are minimal in this project, this design modification will be simulated to determine whether it has the ability to complement other modifications when modelled simultaneously as a design package.

Exterior Shading

- No shading (benchmark)
- 0.5m eave
- 1.5m eave

Exterior shading is an effective way to reduce unwanted solar heat gains, thereby reducing the cooling load of the building. However, there may be a point of diminishing benefit where the cost and logistics of building the eave may outweigh the reduction in solar gain benefits.

HVAC

- Split air system (benchmark)
- Heat pump

Although the spilt system air conditioning unit was chosen for use by the client, the research conducted in task 2 revealed that a heat pump may be a more effective HVAC system for the climate and context of the project. As such, both systems will be modelled to determine which yields the higher REF value.

Glazing

- Single glazing with no internal shading (air-filled)
- Single glazing with internal shading (air-filled) (medium reflectivity shading)
- Double glazing with no internal shading (air-filled)
- Double glazing with electrochromic glass (air-filled) (medium reflectivity shading)
- Triple glazing with no internal shading (air-filled)
- Triple glazing with internal shading (air-filled) (medium reflectivity shading)

The type of glazing can also be another source of unwanted heat gains that result in high cooling loads. Considering the amount of glass located on the façade of the proposed building, it is predicted that changing the type of glazing to one with a lower U-value will significantly reduce the cooling load of the building, as such allowing the net-zero energy goal to be achieved.

4.1 Results

Below are the tabulated results of the renewable energy factors (REF) achieved for each design modification.

Table 3 - Energy Modelling Tabulated Results

Design Modification	REF	REF = 0	0<REF<0.3	0.31<REF<0.95	0.95<REF<1.05	REF>1.05
Lighting						
LED with linear control (suspended)	0.747	5	4234	2131	161	2229
Best practice (suspended)	0.735	5	4251	2136	155	2213
LED (suspended)	0.702	5	4268	2201	143	2143
Fluorescent (suspended)	0.601	5	4365	2439	197	1754
Best practice (recessed)	0.741	5	4245	2133	158	2219
LED with linear control (recessed)	0.749	5	4228	2125	159	2243
LED with linear control (return air)	0.752	5	4221	2118	165	2251
HVR						
No HVR	0.747	5	4234	2131	161	2229
HVR	0.809	5	4186	2019	143	2407
Exterior Shading						
No shading	0.747	5	4234	2131	161	2229
0.5m eave	1.00	5	4137	1974	105	2539
1.5m eave	1.12	5	4042	1894	103	2716
HVAC						
Split air system	0.747	5	4234	2131	161	2229
Heat pump	0.724	5	4287	2199	162	2107
Glazing						
Single glazing with no internal shading (air-filled)	0.596	5	4375	2492	191	1697
Single glazing with internal shading (air-filled) (medium reflectivity shading)	0.670	5	4263	2215	184	2093
Double glazing with	0.697	5	4248	2364	177	1966

no internal shading (air-filled)						
Double glazing with electrochromic glass (air-filled) (medium reflectivity shading)	0.876	5	4204	1866	144	2541
Triple glazing with no internal shading (air-filled)	0.707	5	4253	2347	175	1980
Triple glazing with internal shading (air-filled) (medium reflectivity shading)	0.753	5	4243	2140	148	2224
Combined Design Modifications						
Glazing, shading, lighting, materials	1.40	5	4194	1673	135	2628

4.2 Discussion

The aim of the energy modelling simulation in Design Builder was the see which design modifications would yield a REF value greater than or equal to 1. This would indicate that the energy requirement of the building is equal to the amount of energy generated. A value less than one indicates there is a higher requirement, whilst a value greater than one indicates a surplus of energy generated onsite. Therefore, from the results table above it is evident that exterior shading had the most significant stand-alone impact on the REF value, followed by double glazing with electrochromic glass and HVR. However, the design modification that achieved the greatest REF value was a combination of double glazing with electrochromic glass, 0.5m eaves, LED with linear control (return air) lighting, and PCM materials. It was found that these passive solar design strategies complemented each other in such a way that 140% of the building's energy requirements were generated. It was found that the site annual energy consumption was 170,915MJ which is approximately half that of the benchmark model. During this simulation it was also found the PV system was generation 213,928MJ per year, thus the excess energy can be sold to nearby buildings, stored in batteries onsite, or redistributed in the grid.

It is of utmost importance that the design package chosen doesn't compromise other aspects of the building such as functionality, aesthetics, acoustics, and visual comfort. Since the design modifications are like for like replacements in most cases it is safe to assume that these aspects of the building aren't impeded. A more detailed analysis of these impacts is undertaken in the table below.

Table 4 - Criteria for Design Package

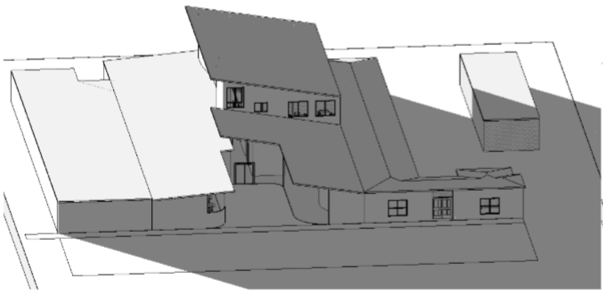
	Functionality	Aesthetics	Acoustics	Visual Comfort
Double Glazing with Electrochromic Glass	Is operated in the same manner as single pane glazing	Appears aesthetically the same as single pane glazing	Improved acoustic insulation	Increases daylight without unwanted solar gains and controls glare
0.5m Eaves	Static element	May be slightly longer than typical eaves, as such as having a slightly negative impact	N/A	Reduces daylight and glare, thus having a slightly negative impact
LED With Linear Control (Return Air)	Operated in the same manner as typical lights	Appears aesthetically the same as typical lighting	N/A	Ensures appropriate lux level is achieved
PCM	Static element	Usually stored within cavities	Improved acoustic insulation	N/A

Thus, it is evident that the overall design package chosen has a positive impact on functionality, aesthetics, acoustics, and visual comfort. It is also important that the client's requirements, as set out in the project brief are also addressed. Some of the main aspects of the project to address as identified by the client include the types of spaces within the building, security, adaptability of the building, budget keeping, community involvement in construction, approachability, and celebrating connection to Country and culture. These notions are embodied in the goals outlined in the Project Brief section of this report and were pursued throughout the design and simulation process. Ultimately, the client's requirements formed the basis upon which design strategies scored highest in the net-zero energy design matrix of task 2 which acted as a guide for which design modifications were energy modelled. Thus, the highest-performing design package also sufficiently addresses the client's requirements.

Figure 11 - Axonometric View of Rendered Model

5. Shading Diagrams

Shading diagrams are an effective way to determine the amount of natural light entering various spaces within the building and by extension each space's reliance on artificial lighting. Artificial lighting plays a major role in increasing cooling loads, as such analysis on how to improve a design by increasing the amount of natural light is crucial to aid in achieving net-zero energy. The figures below depict the movement of the sun across the site at key times in the day on the summer and winter solstice.



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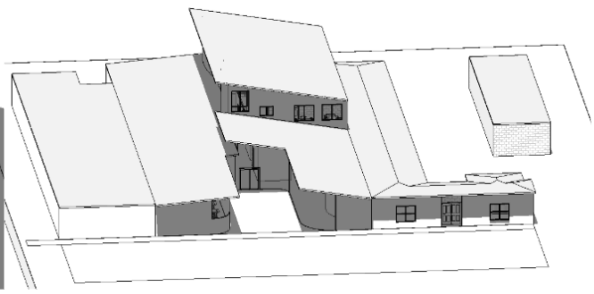

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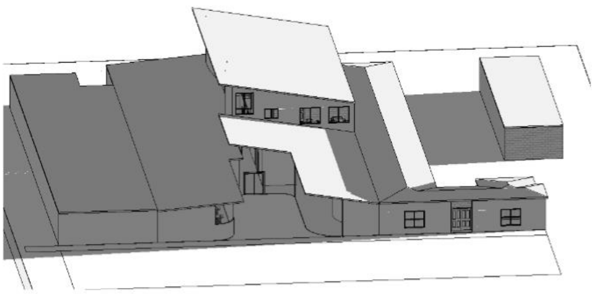

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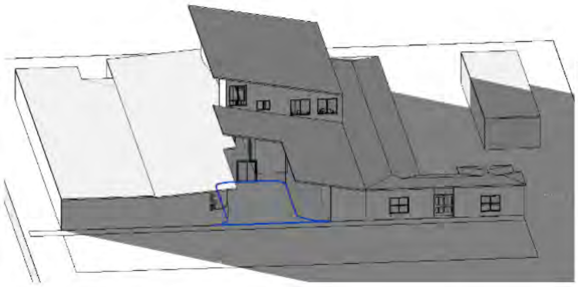
Figure 12 - Summer Solstice (20/12/2021)



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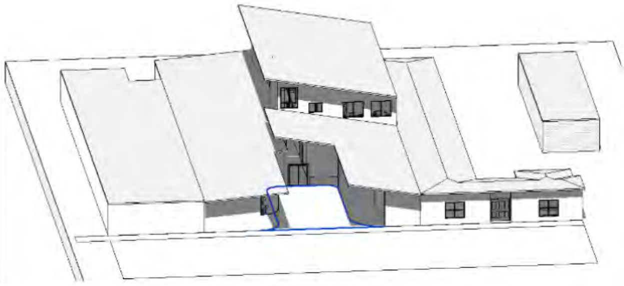

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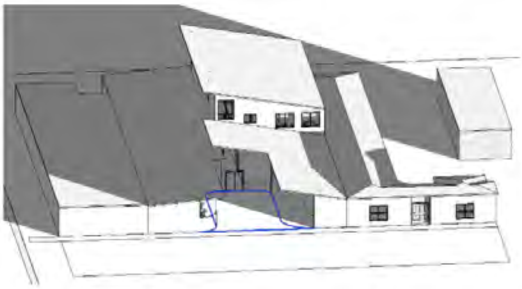


17:16

Figure 13 - Winter Solstice (20/06/2021)

This analysis reveals that the positioning of glazed elements and the thermal mass wall in the centre of the building is appropriate for taking advantage of the solar movement across the site. It is also revealed that the sizing of the eaves is appropriate for shading the building from the midday sun at all times of the year and that the positioning of the restaurant within the building means that it will remain warm and inviting space even in winter. Further, the shading diagram highlights the shading the proposed LRLALC building creates on neighbouring properties. The motel courtyard located on the left-hand side in the figures above continues to receive the afternoon sun all year round which is likely beneficial as it allows occupants to enjoy the outdoor space in the cooler evening temperatures.

6. Recommendations

Overall, it is recommended that the design package of double glazing with electrochromic glass, 0.5m eaves, LED with linear control (return air), and PCMs be implemented within the LRLALC building. This design package is the highest performing design modification to the energy model completed in Design Builder and sufficiently addresses functionality, aesthetic, acoustic, visual comfort, and client requirements.

Figure 14 - Street View of Rendered Model

7. References

- 2021, Wellcertified.com, viewed 4 November 2021, <https://v2.wellcertified.com/wellv2/en/overview>.
- *Design & As Built | Green Building Council of Australia* 2021, Gbca.org.au, viewed 4 November 2021, <https://new.gbca.org.au/green-star/rating-system/design-and-built/>.
- bessiebouchier 2018, *What is NABERS?*, NABERS, viewed 4 November 2021, <https://www.nabers.gov.au/about/what-nabers>.

8. Appendices

8.1 Government Certification Schemes

Government Certification Schemes play a vital role in ensuring infrastructure remains on track in achieving the Sustainable Development Goal targets among other objectives such as Net-Zero Emissions by 2050 in NSW. Many government certification schemes address various aspects of sustainability, with the NABERS, Green Star, and WELL schemes described below.

NABERS

The NABERS (National Australian Built Environment Rating System) scheme focuses on the wellbeing of residents and the environment and is used for public and commercial buildings such as offices, shopping centres, apartments, etc. The scheme uses a maximum 6-star rating system that focuses on the key areas of energy, water, waste, and indoor environment during a building's actual operation. The rating system also considers the building's location, area of space, hours of operation, occupancy, and occupant density, which allows a fair comparison between buildings. There are many benefits of aiming to achieve a high NABERS rating including but not limited to;

- Low energy and water bills
- Reduced environmental impact
- Attract premium tenants
- Market recognition as a leading asset manager
- Compare asset performance across portfolios

When energy modelling the LRLALC building, a 6-star rated NABERS building was used as a base case in order to ensure the building was a market leader in net-zero buildings. Considering the net-zero energy goal of the project, minimal alterations were made to the water and waste base case input data, rather there was a focus on ways to passively reduce the heating and cooling demand of the building in order to ultimately achieve net-zero energy. As discussed above, the design package chosen achieved this goal successfully through the implementation of passive solar design strategies. Further amendments to the way in which water and waste are derived and processed will ensure the building operates above and beyond the 6-star NABERS rating.

Figure 15 - NABERS Star Rating System

As evident in the discussion above, the application of a single government certification scheme to a building may be limited by the extent and scope the rating criteria covers and the nature of the project. Therefore, careful consideration should be given as to which government certification scheme is used in a project and whether multiple schemes would be appropriate.

Green Star

Green Star is a government certification scheme that has four facets, namely Communities, Design & As Built, Interiors, and Performance. The Green Star – Design & As Built is the most relevant facet for the LRLALC project and it is composed of nine criteria as described below.

- Management – the adoption of strategies that support best practices in sustainability.
- Indoor environmental quality – initiatives that enhance comfort and well-being of occupants, i.e., thermal comfort, acoustic comfort, indoor air quality.

- Energy – efficient use of energy and renewable generation to reduce emissions.
- Transport – encourage the use of alternative forms of transport.
- Water – incorporation of measures such as water-efficient fixtures and on-site recycling.
- Materials – encourage the use of low-impact materials.
- Land use & ecology – minimise harm and enhance the quality of local ecosystems.
- Emissions – reduce water, air, and soil pollution associated with the construction and operation of the building.
- Innovation – recognise the implementation of innovative design strategies that promote sustainability.

The final design package is chosen for implementation in the project addresses all nine of the criteria described above as described below.

- Management – the proposed building is unlike any other in the area, therefore it will be a market leader in the area.
- Indoor environmental quality – since all design strategies that form part of the design package are aiming to reduce the cooling load of the building, thus improving occupant comfort, this criterion is addressed to a high extent.
- Energy – the building generates more energy than it consumes, hence performing to a high standard in this criterion.
- Transport – due to the rural nature of Lightning Ridge it is difficult for occupants to access the building without a car due to the lack of public transport. However, the absence of a visitor carpark encourages occupants to park in one location and walk between the various buildings of Lightning Ridge's main street.
- Water – although not explicitly mentioned in this task, the net-zero energy design matrix in task 2 outlined solutions are onsite rainwater detention and recycling which would form part of a more holistic design package.
- Materials – various unique materials such as PCMs and rammed earth walls were incorporated into the proposed design for the LRLALC building. Other materials considered include mine tailings and a partial substitute in rammed earth or concrete and Cyprus wood, both of which can be sourced locally and have a positive impact on passive solar design.
- Land use & ecology – considering the design is proposed for a green site it is difficult to minimise the capital impacts to the land and surrounding ecosystems. However, throughout its operation, the proposed design has space for native vegetation to grow in order to encourage some biodiversity in the area.
- Emissions – the REF value of the chosen design package is 1.4, thus the building produces more than it consumes, ultimately leading to net-positive operational emissions.
- Innovation – this criterion is addressed through the implementation of PCMs into the building fabric which is a relatively new and emerging technology in the construction industry.

This government rating scheme was addressed in the net-zero energy design matrix of task 2, thus playing a significant role in determining which strategies were to be implemented to ensure a rating as close to 6-stars is achieved as is possible.

Figure 16 - Green Star Rating System

WELL

The WELL rating scheme provides a roadmap to prioritizing the health of occupants, through ten concepts that are rated out of 100 in total as seen in the table below.

Table 5 - WELL Rating System

Total points achieved	WELL Certification		WELL Core Certification	
	Minimum points per concept	Level of certification	Minimum points per concept	Level of certification
40 pts	0	WELL Bronze	0	WELL Core Bronze
50 pts	1	WELL Silver	0	WELL Core Silver
60 pts	2	WELL Gold	0	WELL Core Gold
80 pts	3	WELL Platinum	0	WELL Core Platinum

These concepts are founded on the following principles.

- Equitable – benefit all people
- Global – solutions that are universal
- Evidence-based – based on the latest research
- Technically robust – reviewed by third-party

- Customer-focused – personalised technical support
- Resilient – ability to evolve.

It is evident that the WELL rating scheme is more comprehensive than both the NABERS and Green Star government certification schemes discussed previously, with the ten focus concepts listed below.

- Air
- Water
- Nourishment
- Light
- Movement
- Thermal Comfort
- Sound
- Materials
- Mind
- Community
- Innovation

Many of these concepts overlap with the criteria of the Green Star rating system, thus it is evident that these focus points are addressed both directly and indirectly in the proposed final design package.

Ultimately, it is evident that although there are many similarities between Government Certification Schemes, the complexity can also vary greatly. The LRLALC building performed best under the NABERS rating scheme due to its use as a base case model, whilst performance for the Green Star and WELL schemes which are significantly more comprehensive, the rating was lower. Rating schemes must have the ability to evolve alongside advances in technology and as the definition of sustainable innovations changes. Therefore, the LRLALC's moderate performance in the WELL certification scheme highlights its robust ability to maintain its rating as the industry evolves.

8.2 Solar Panel Calculations

$North - east\ roof\ area = 43.48 \times 8.22 = 357.41m^2$

$Top\ roof\ area = 23.1 \times 7.47 = 163.59m^2$

$South - west\ roof\ area = 279.05m^2$

$Front\ roof\ area = 45.06\ m^2$

$Total\ roof\ area = 845.11\ m^2$

$Allowable\ solar\ area = 845.11 \times 0.6 = 507.07\ m^2$

$Solar\ size = 1651 \times 990\ mm$

$Optimum\ tilt\ angle = 29.4\ ^o$ (Sunrise and sunset times in Lightning Ridge, June 2021, 2021)

$Solar\ angle\ for\ roof\ slope = 23.7^{o}$

$Top\ roof\ with\ PV\ spacing = 180.4\ m^2$

$North - east\ roof\ with\ PV\ spacing = 235.34\ m^2$

$South - west\ roof\ with\ PV\ spacing = 98.4\ m^2$

$Total\ PV\ area = 514.14\ m^2$

It should be noted that the PV added to the roof covers 61.37% of the roof area which is over the allowable 60%, however, the 0.5m eaves were not considered during this calculation.

8.3 Model Schedule Data

Activity

Table 6 - Activity Schedule Data

Zone	Template Name	Occupancy	Heating & Setback	Cooling & Setback	Office Equipment
Accessible bathroom	Toilet	Unchanged 8am – 8pm in template	21.0, 19.0	25.0, 28.0	Off
Artist workspace	Generic office block	NCC table 2f	18.0, 16.0	25.0, 28.0	Off
CEO office	Generic office block	NCC table 2c	21.0, 19.0	25.0, 28.0	On
CFO office	Generic office block	NCC table 2c	21.0, 19.0	25.0, 28.0	On
Commercial kitchen	Food preparation area	NCC table 2f	18.0, 16.0	25.0, 28.0	On
Common area	Reception	Unchanged 8am – 8pm in template	18.0, 16.0	25.0, 28.0	Off
COO office	Generic office area	NCC table 2c	21.0, 19.0	25.0, 28.0	On
Corridor 1	Circulation area	Unchanged 8am – 8pm in template	18.0, 16.0	25.0, 28.0	Off
Corridor 2	Circulation area	Unchanged 8am – 8pm in template	18.0, 16.0	25.0, 28.0	Off
Entertainment hall	Hall/ lecture theatre/ assembly area	NCC table 2h	21.0, 19.0	25.0, 28.0	Off

Female bathroom	Toilet	Unchanged 8am – 8pm in template	21.0, 19.0	25.0, 28.0	Off
Fridge and freezer	Light plant room	Unchanged 8am – 8pm in template	0.00, 0.00	0.00, 0.00	Off
Gallery	Gallery	Unchanged 8am – 8pm in template	21.0, 19.0	25.0, 28.0	Off
Lift	Circulation area	Unchanged 8am – 8pm in template	18.0, 16.0	25.0, 28.0	Off
Male bathroom	Toilet	Unchanged 8am – 8pm in template	21.0, 19.0	25.0, 28.0	Off
Meeting room	Generic office area	NCC table 2c	21.0, 19.0	25.0, 28.0	On
Pantry	Storeroom	Unchanged 8am – 8pm in template	18.0, 16.0	25.0 28.0	Off
Restaurant	Eating and drinking area	NCC table 2f	18.0, 16.0	25.0 28.0	Off
Staff room	Generic office area	Unchanged 8am – 8pm in template	18.0, 16.0	25.0 28.0	Off
Storerooms	Storeroom	Unchanged 8am – 8pm in template	18.0, 16.0	25.0 28.0	Off
Teaching room 1	Teaching areas	Unchanged 8am – 8pm in template	21.0, 19.0	25.0 28.0	Off
Teaching room 1	Teaching areas	Unchanged 8am – 8pm in template	21.0, 19.0	25.0 28.0	Off
Unisex bathroom	Changing facilities with showers	Unchanged 8am – 8pm in template	21.0, 19.0	25.0 28.0	Off

Air Flow and Ventilation

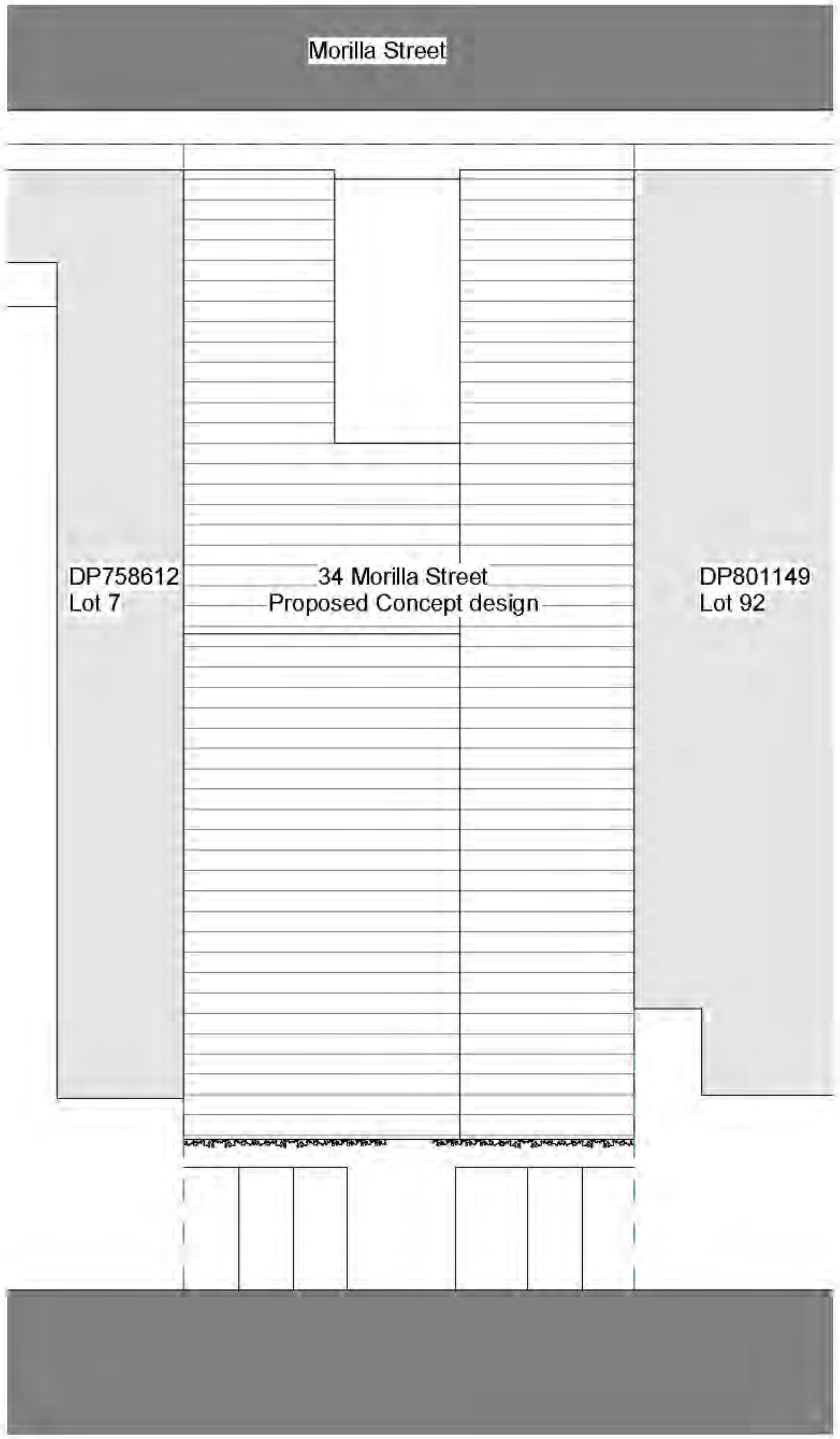
Table 7 - Air Flow and Ventilation Schedule Data

Zone	Floor Area (m^2)	Zone Volume (m^3)	Occupancy Expectations	Fresh Air Supply (L/m^2)	Minimum Supply When

					Occupied (L/s per person)
Accessible bathroom	8.1	28.4	2	2.84	17.2
Artist workspace	26.8	93.7	10	9.37	90.6
CEO office	15.9	53.9	6	5.55	54.5
CFO office	10.7	36.4	3	3.75	26.3
Commercial kitchen	31.1	109	15	10.9	139
Common area	69.0	260	4	24.1	15.9
COO office	15.8	53.7	3	5.52	24.5
Corridors	121	425	20	42.5	158
Entertainment hall	182	638	200	63.8	1936
Female bathroom	28.9	101	5	10.1	39.9
Fridge and freezer	5.79	20.3	1	2.03	7.97
Gallery	85.5	299	30	29.9	270
Lift	4.61	16.1	2	1.61	18.4
Male bathroom	17.8	62.3	5	6.23	43.8
Meeting room	17.5	59.5	12	6.13	114
Pantry	3.76	13.2	1	1.32	8.69
Restaurant	97.1	340	50	34.0	466
Staff room	13.8	48.3	4	4.83	35.2
Storerooms	5.69	19.9	1	1.99	8.01
Teaching rooms	24.3	85.0	15	8.50	142
Unisex bathroom	1.84	18.9	2	0.64	19.4

8.4 Proposed Design Drawing Sheets

The drawings sheet below would not have been possible without the assistance of Cooper Reynolds, Tyla van Duin, and Jacomb Graham.



Site

1
1 : 300

Vision Artisans

No.	Description	Date

Vision Artisan's

Lightning Ridge LALC

Site Plan

Project number	210922
Date	22/09/21
Drawn by	Vision Artisans

A102

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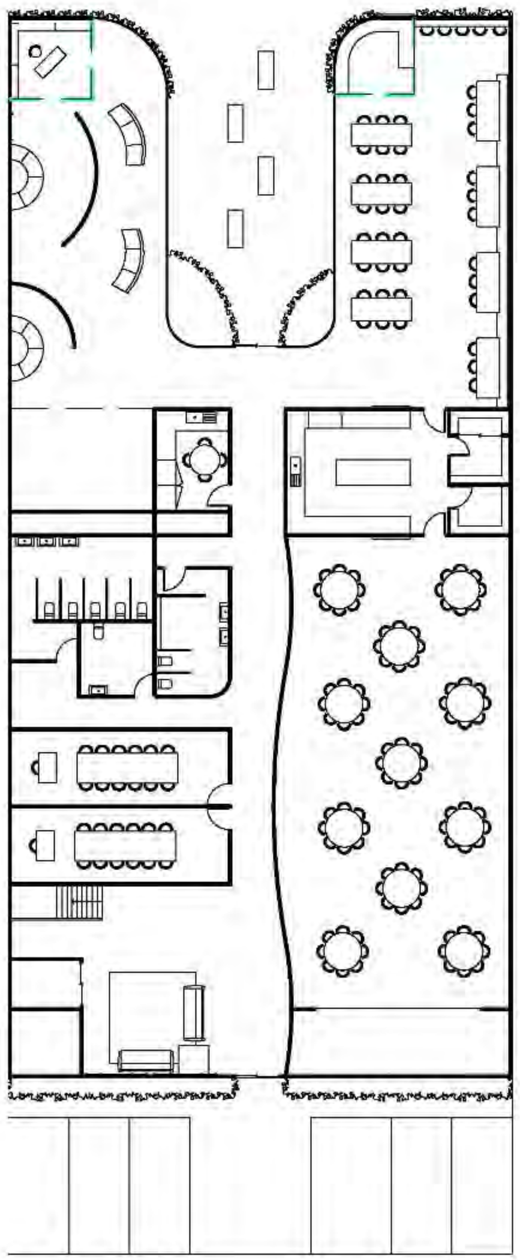
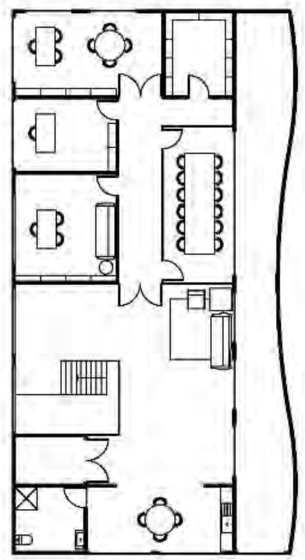


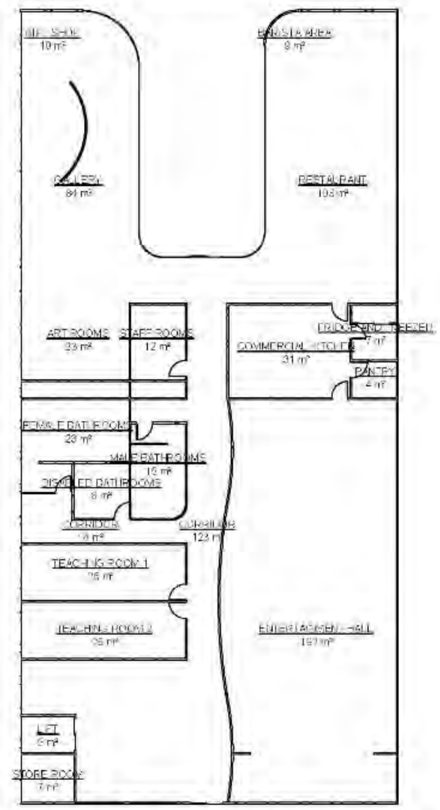
1 Ground Floor

1 : 300



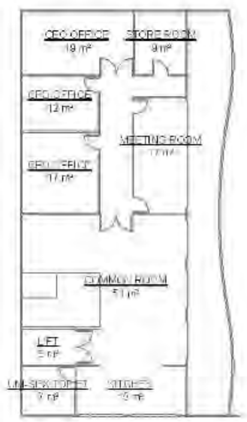
2 Floor 1

1 : 300



3 Ground Floor

1 : 400



4 Floor 1

1 : 400

Vision Artisans

No.	Description	Date

Vision Artisan's

Lightning Ridge LALC

Floor and Area Plans

Project number	210922
Date	22/09/21
Drawn by	Vision Artisans

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Task 3- ENGG210

BUILDING PHYSICS AND BUILDING SERVICES

Faculty of Engineering and Information Sciences

School of Civil, Mining and Environmental Engineering

Figure 1: Rendered street view of model

Executive Summary

The following report details a proposal submitted by the Lightning Ridge Aboriginal Lands Council (LALC) to design and model a multi-purposed building to suit the needs of the client, and the wider community of Lightning Ridge. A base case model was developed to determine areas of the building that required significant improvement to maintain a net-zero energy design. Design parameters such as net zero energy strategies, potential energy and carbon emission savings, cost comparisons, feasibility, and inclusion of innovative techniques and technologies included in the interim report and corresponding design matrix allowed an accurate representation of the base case model. The steps taken to improve the base case model to achieve client satisfaction in building design while simultaneously implementing net-zero energy principles were undertaken using DesignBuilder, a program that specialises in energy simulation.

It was found through simulation of the base line model that the building consumed excessive energy dedicated to cooling loads for 9 months of the year. This could be attributed to internal heat generation from solar gains, occupant level and computers and relevant electrical equipment.

Through the additions of solar panels and other modifications, it was found that improvements to glazing and shading were crucial to raising the REF value above 1. These included 0.9 metre overhangs in addition with double glazed electrochromic glass having the biggest impact out of their respective iterations. These values and modifications were successfully meet the client brief as well as the chosen GreenStar government certification scheme.

The final proposed design presented represents a system of balance between community resilience, cultural traditions and sustainability that complement its surrounding environment.

Table of Contents

Introduction

This report builds upon the interim report and business-as-usual case model for the proposed multi-purpose building for the Lightning Ridge Aboriginal Land Council (LALC). The proposed building resides on 34 Morilla Street, Lightning Ridge, accessible from the main street or rear back street. The site is boarded by Vinnes to the east and the Bluey's Motel to the west.

The Lightning Ridge project revolves around designing a building that aligns with the LALC mission statement: working towards social sustainability and resilience within the indigenous community and immersing itself into the community character. This is achieved by incorporating practices and wishes established by the community and the client Dr Steve Burroughs, while practicing net zero energy design strategies.

The Australian software program DesignBuilder was selected to finalise the business-as-usual case model, while providing access to energy analysis simulations. DesignBuilder was selected at it provides a graphical user interface (GUI) compared to other programs, as well as incorporating EnergyPlus, a databank developed and maintained by the US Department of Energy (USDOE) (DesignBuilder, 2021). It similarly implements ASHRAE heat and mass balance equations and is NCC compliant, providing accurate simulations of the modelled building.

Base Line Model

Model Alterations

The model was developed through previous reports through communications with the client. The base line model draws on from the model detailed in the interim report, based off a design matrix.

In conjunction with the client, the building aimed to enhance the open floorplan design while still maintaining boundaries within the various rooms based on usage. The glass façade aimed to draw people in from the footpath, with clear viewing into the public area of the building containing the restaurant and art gallery. The clear circulation path through the middle helped define the public front area from the rear function area, teaching rooms and stairway. The rammed earth wall present similarly serves as a transition between area.

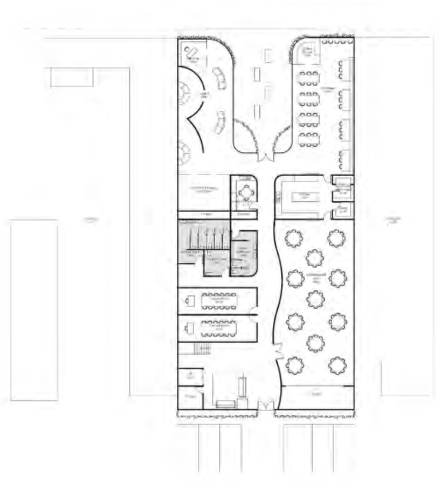


Figure 3: Ground floor

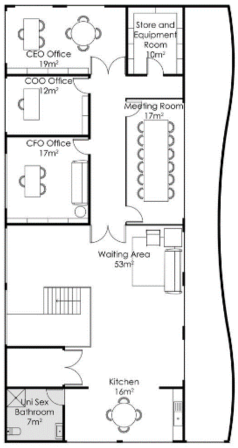


Figure 2: Level 1

The upstairs area underwent several modifications to improve the special efficiency of the offices and circulation space. The rearrangement resulted in a reduced number of amenities, eliminating 'dead' space that would generate unwanted costs in both material and cooling and heating usage. These alterations to design were result of both client and architectural feedback.

Figure 4: Rendered architectural model

Energy Analysis Model

Although the design model had many features, the energy analysis model on DesignBuilder underwent several geometrical changes for simplicity. These included:

- Curved surfaces including the glass façade and rammed earth feature wall reduced to straight lines
- Flat rooflines were modelled to simplify the design of the solar panels
- Barista / café area and gallery spaces not modelled due to no geometry separating them from surrounding spaces

These changes were deemed necessary to improve the efficiency of modelling time and simulation effectiveness, with the limited changes providing little to no effect of simulation results.

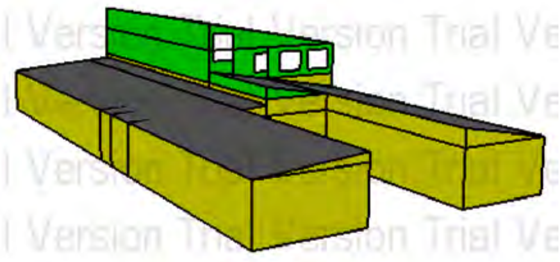


Figure 6: Base line model street view

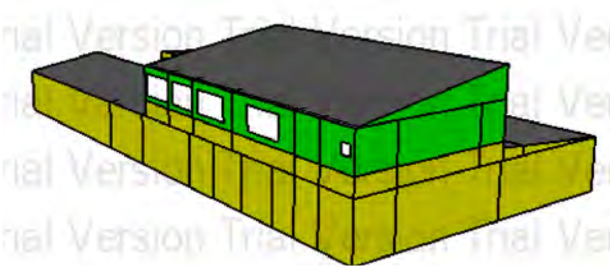


Figure 5: Base line model rear view

Assumptions

The base line energy analysis model was based off multiple assumptions that in turn determined design parameters

The relevant assumptions are listed below:

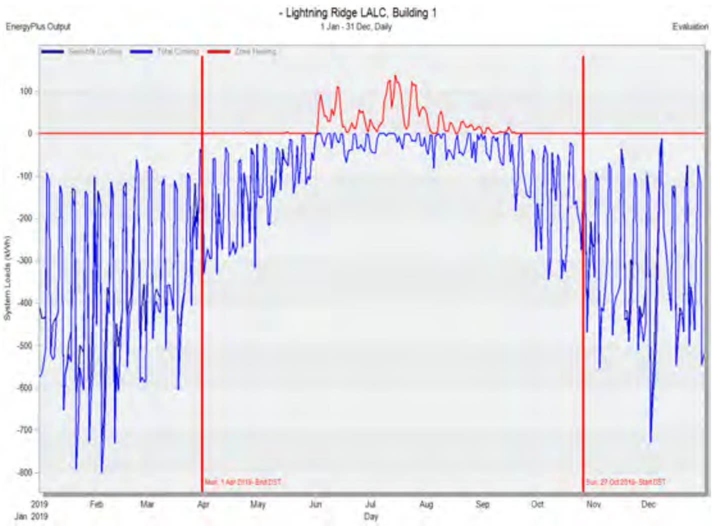
- Hot water demand
  - 8am to 8pm schedule operating at a constant 2-Kilowatt hour demand
- NCC Section J Occupant Profiles
  - Table 2c: Weekday occupancy and operation profiles of a Class 5 building, a Class 7 warehouse, a Class 8 Laboratory, or a Class 9a clinic, day surgery or procedure unit
  - Table 2d: Weekend occupancy and operation profiles of a Class 5 building, a Class 7 warehouse, a Class 8 Laboratory, or a Class 9a clinic, day surgery or procedure unit
  - Table 2f: Occupancy and operation profiles of a Class 6 restaurant or café
- Airflow and Ventilation
  - Background ventilation supply of 0.35 litres / s per m^2
  - Minimum 10 litres / s per person in all occupies spaces

Results

The results obtained for the base line model can be split in two categories to be analysed separately: an annual simulation using the 2019 Lightning Ridge weather file and a typical daily energy use profile for summer and winter.

Annual Simulation

The annual simulations revealed how the building is expected to perform throughout the varying seasonal differences, providing insight into the various energy requirements, demands and schedules. The simulations were run through with local climate and weather conditions over a one-year period comprising of daily time stamps.



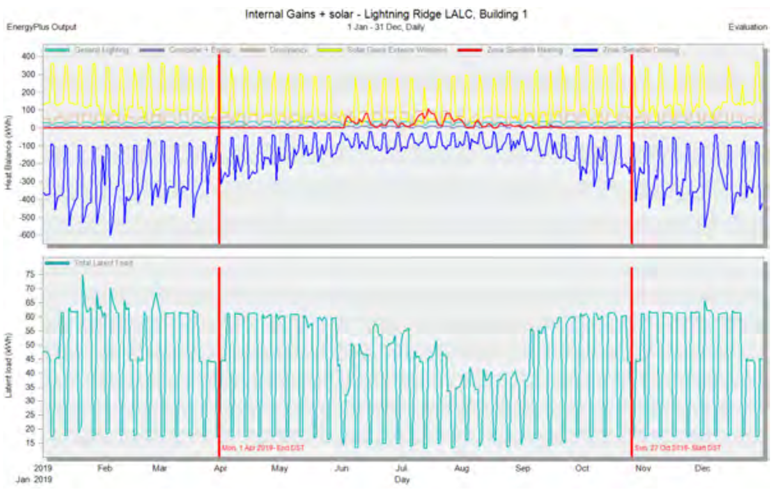


Figure 7: Annual internal and solar gains

Figure 8: Annual heating and cooling energy requirements

Figures 9 and 10 above real the simulated building has an excessive cooling load throughout the majority of the year, while the heating load is minimal. The quantity of the cooling load can be attributed to the level of internal gains present in the building in the form of computers and equipment, general lightning, occupant activity and solar gains through exterior windows. The heat generations from these factors dramatically increases the internal temperature and cooling loads. As a result, the modifications will be focused on reducing the cooling loads present.

Daily Peak Simulations

The peak heating and cooling days were determined using the 2019 climate and weather file for Lightning Ridge and was determined as the 14th of July and 4th of February respectively.

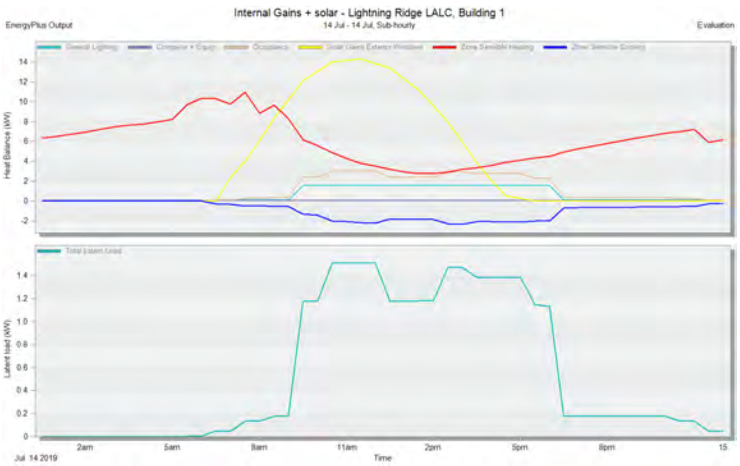


Figure 10: Peak winter daily energy profile

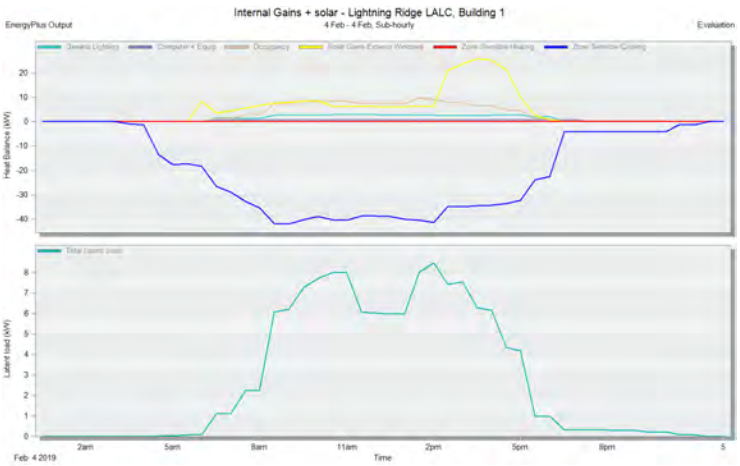


Figure 9: Peak summer daily energy profile

It is immediately noticed via the daily simulations (Figures 11 & 12) at the stark energy fluctuations occurring in the building between peak heating and cooling over a 24-hour period. The resultant [x] kilowatt figure can be seen as a product of several factors including lighting and electrical usages and schedules, occupancy levels, and solar gain. The energy peaks experienced in the zones varied throughout the day coinciding with the solar gains along the respective sun paths, thus determining solar gains to be the dominant factor influencing system loads. Solar gains through exterior windows with a heat balance of 14kW peaking at midday in winter against 27kW peaking at 4pm in summer can be attributed to the varying sun angles throughout the year of 37.1° and 84.1° respectively. It is interesting to note that cooling systems were slightly activated during the winter months, signifying the building fell outside the designated comfort zone, suggesting the building has poor insulative properties that need to be addressed.

Modified Design Model

Solar Generation

Renewable energy generation was then added to the baseline to provide an alternative power source to grid electricity in the form of photovoltaic solar panels. To replicate similar solar panels practices and technologies present today, several assumptions were made and listed below:

- A nominal solar panel efficiency of 15%
- Solar panel area limited to 60% of total roof area

The panels were arranged to receive the northern sun, angled at 30° following the angle of the roof to receive optimum solar exposure. It should be noted that the solar panels were modelled onto a flat, unoccupied component block in DesignBuilder for simplicity and efficiency due to the geometrical challenges of the program. The panels were then angled to the optimal solar angle as seen in figure 12.

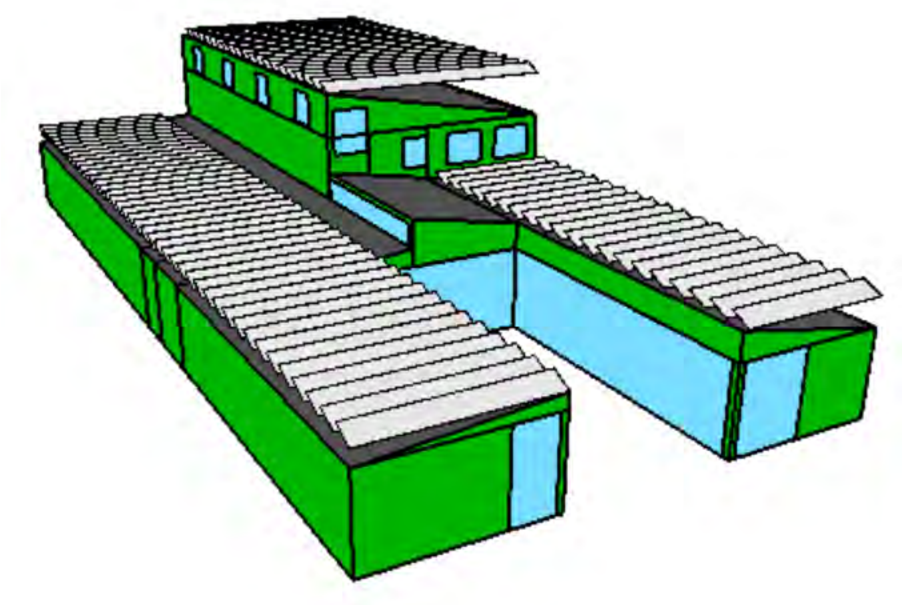


Figure 11: The addition of solar panels to the baseline model

The updated design model was then simulated over a one-year period with the results summarized in table x. These values were then used to calculate the renewable energy fraction (REF) value for each hour of the year, with each REF value categorized depending on the hourly value.

$$REF\ Value = {}^{Renewable\ Energy\ Generation}/_{Total\ Site\ Energy\ Requirements}$$

Table 1: Renewable Energy Fraction values

REF Value	**REF = 0**	**0 < REF < 0.3**	**0.31 < REF < 0.95**	**0.96 < REF < 1.05**	**1.05 < REF**
Number of REF Hours	5	4263	2215	184	2093
Annual REF Value	0.67				

Modifications

Excessive cooling requirements signified excessive thermal gains were present within the building. Due to occupancy and activity levels remaining constant, the main variable can be attributed to solar gains penetrating through external windows. Therefore, glazing and shading were identified as areas that require significant modifications.

Glazing

The building envelope is only as strong as its weakest link, with glazing being a key factor in the transmission of heating and cooling between internal and external environments. Studies show that heating and cooling loads account for approximately 60% of a buildings system load (Qiong He, Thomas Ng, Uzzal Hossain and Skitmore, 2019). Therefore, the glazing design within the building envelope is vital to ensure a more sustainable energy efficiency and thermal comfort for the occupants. The correct design must account for factors including climate and weather, building orientation, and specific room usage.

The external windows were the only glazing feature altered during simulations, with no external blinds or shading features implemented in the design model. This ensured that each glazing iteration was analysed against direct exposure to solar and thermal gains. The following iterations were analysed and with 6mm glass thickness, a set height of 1.4m (excluding frontal glass façade), and 40% wall to window ratios:

- Double glazing with no blinds
- Double glazing, internal blinds
- Double glazed, Electrochromic glass
- Triple glazed with internal blinds

The glazing iterations were simulated over a one-year period with daily timestamps, with the REF results summarised in figure 13. They were then compared against the glazing used in the base case model to determine the most appropriate recommendation for the project.

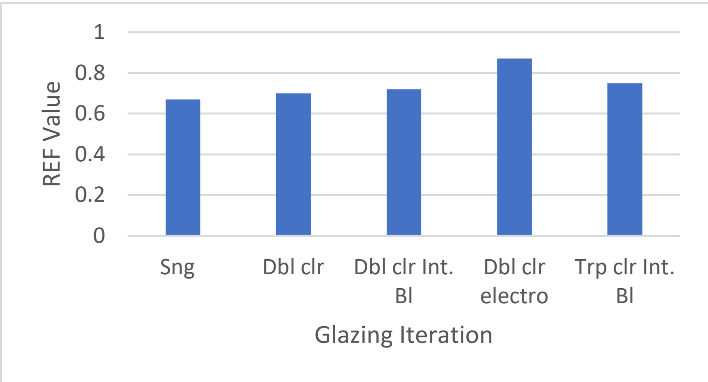


Figure 12: REF Value per glazing iteration

Shading

A simple shading structure was introduced to the base line model if the form of roof eaves, external blinds, and louvres. Eaves not only provide shade but also protect external walls from excessive moisture and leakage damage, increasing the longevity of the build. Eaves were extended out from rooflines facing east, north, and west with a length of 900mm due to the sill to eave length being 1550mm (Your Home, 2013). Eaves were also installed around and across the divot section of the north facing glass façade to reduce solar heat gains into the building.

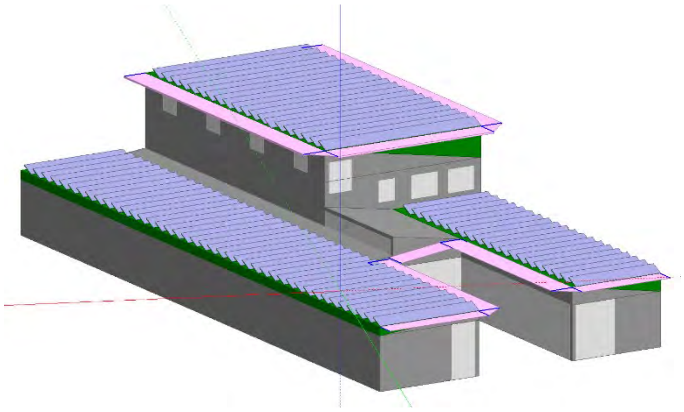


Figure 13: Proposed roof eaves highlighted in pink

Lighting

Analysis of the baseline model simulations revealed lighting account for a percentage of internal heat gains, increasing the load of the cooling system. Although LEDs were used in the base line model, improvements can be made to decrease their load time. Introducing a linear control system, dimmers, and integration with a Building Management System (BMS) and expected occupancy levels have potential to improve efficiency. Due to the limitations of the student version of DesignBuilder, a linear control system with task and display lightings, and best-case lighting system project were modelled.

Results

A final model comprising of all modifications or best-case iterations was then simulated over a one-year period with daily timestamps and compared to the base line model with the results summarized in table 1.

Solution	**REF Value**	**REF = 0**	**0 < REF < 0.3**	**0.31 < REF < 0.95**	**0.96 < REF < 1.05**	**1.05 < REF**
Sng gzl no shade						
Dbl glz int. blnds	0.747	5	4234	2131	161	2229
Dbl glz electro	0.876	5	4204	1866	144	2541
Trp glz int. blnd	0.753	5	4243	2140	148	2224
Shading	1	5	4137	1974	105	2539
Lighting	0.71	5	4233	2234	173	2120

Figure 14: Results from proposed modifications

From the results above it can be found the options that negate direct solar gains and glare entering the building produce the best REF values. This is attributed with the dramatically reduced load on the cooling system.

Shading

Although the effects of shading are predominantly considered for the building in design, the effects of building shading also effect the surrounding environment. The varying angles of the sun effects the depth and width of building shadows, with deeper shadows in summer and shallower shadows in winter. The effect of the sun angles on the designed building throughout the year are presented in the figures below.

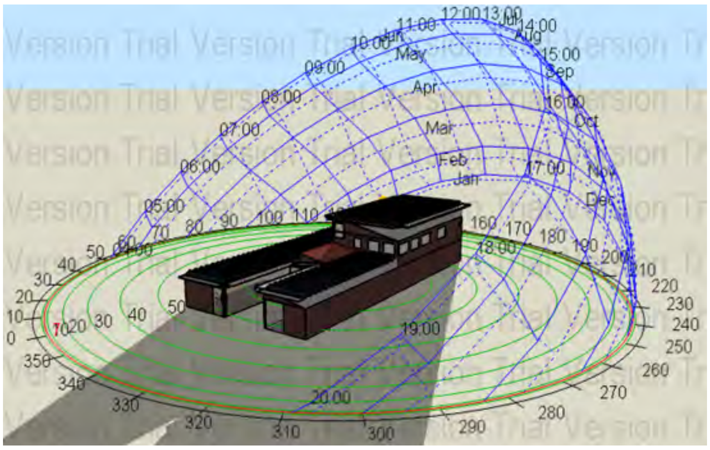


Figure 7: January 15 shading at 9am

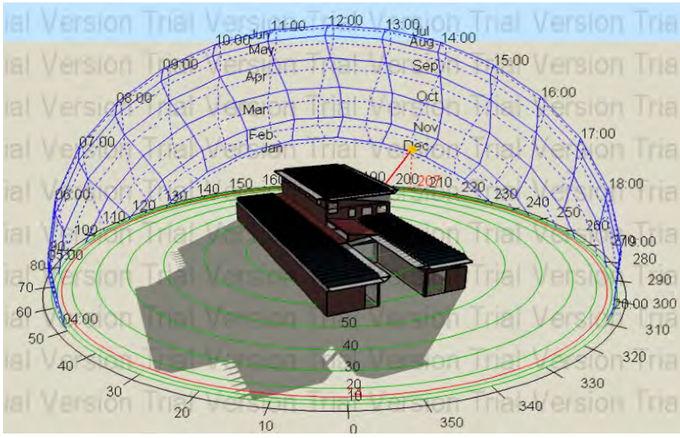


Figure 8: January 15 shading at 2pm

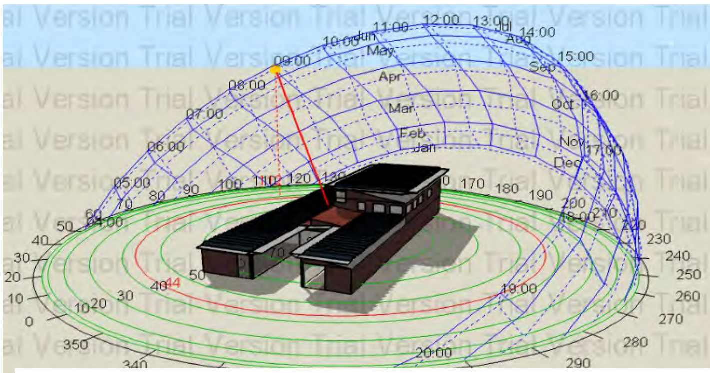


Figure 9: July 15 at 9am

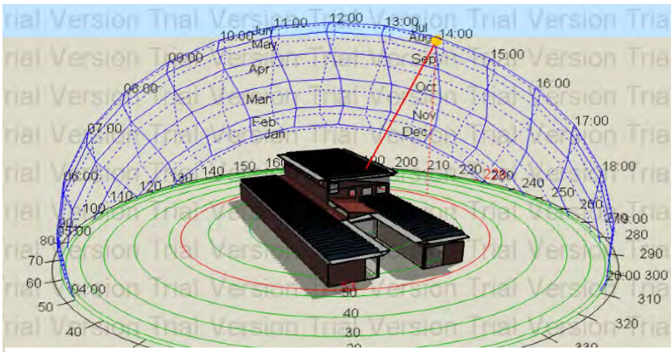


Figure 10: July 15 at 2pm

Using the sun path, it can be determined that the casted shadows will have an influence on the surrounding single-story buildings and roads, predominantly in summer. Although this may affect daylighting levels within the buildings, it has the potential to reduce cooling loads through decreased levels of solar gains and glare that would otherwise be experienced.

Discussion

The building envelope is responsible for the majority of heating and cooling loads, making up to 60% of the total building energy consumption. Glazing, shading and lightning therefore were areas specifically targeted to improve the insulative properties of the envelope, while improving the latent heat produced through lighting were reduced internal heat gains, ultimately reducing the overall cooling load of the building. Drawing conclusions from the results, it can be determined that improving the glazing conditions had the most effect on the building envelope, resultant on the improved REF value of 0.87 using double glazed electrochromic glass for external windows. This is a justified choice when comparing to other glazing, shading, and lighting options with lower REF values.

Electrochromic glass is defined as electronically tintable glass used for windows, skylights, or facades, using a low voltage darkens the ultrathin coating of lithium ions, reducing solar intake through the windows (SageGlass, 2018). The glazing option is becoming more widespread due to its 20% reduction in energy demands while improving indoor air quality depending on occupant requirements. Due to the low voltage input and energy saving potential, this glazing method is a feasible solution to the design project.

Further analysis of the modified energy model simulations revealed effect of the modifications also had on ambient indoor temperature during peak heating times in figure 16. In contrast to the baseline model, the operative temperature became more stable during the year due to improved insulative properties.

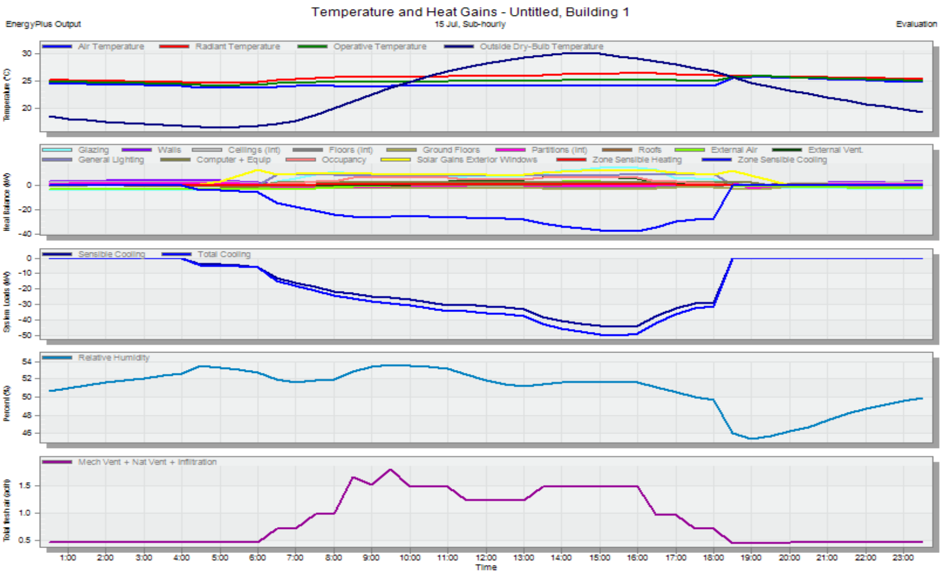


Figure 15: Annual temperature and heat gains

Conclusion

Drawing conclusions from the report, a final net-zero energy design building was developed through previous assignments with the final design capturing a wholistic design strategy that adheres to the clients wishes and requirements. This was constructed in conjunction with select criteria relating to energy and carbon emission savings, cost, feasibility and GreenStar ratings, resulting in a building that could be a figure head to the town and surrounding areas in terms of sustainable practices. Analysis of a baseline model within the Lightning Ridge climate and weather exposed issues experienced in the building, yet was overcome with modifications in glazing, shading, and lighting. The reduced cooling load pushed the building and highlights the importance of the respective modifications to be included in the building envelope. The final proposed design presented represents a system of balance between community resilience, cultural traditions and sustainability that compliments its surrounding environment.

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Appendix 1: Government Certification Scheme

The Australian GreetStar rating scheme has become increasingly used in certifying the sustainability of upcoming building projects, with 48 million sqm of building space being GreenStar certified. The system utilizes a credit-based criteria, with buildings attaining credits through successful achievements in design and demonstration in the respective performance areas. The various ratings are listed in figure 17, with the highest achievable rating being a 6-star rating.

Figure 16: GreenStar 6-star rating criteria

For a building to successfully achieve a 6-star rating, it must exhibit and achieve the following sub-criteria, management, energy, indoor environment quality, transport, water, materials, land use and ecology, emissions, and innovation. Several factors in building design choice led to the following schemes being met.

Energy: The implementation of photovoltaic solar panels achieves several credits towards to energy criteria. However, reducing the predominantly cooling system loads through improvements in glazing and shading improve the effectiveness of the panels and the net-zero design of the proposed building.

Transport: The building locations provides multiple transport alternatives to get to and from the building. Points are awarded due to the proximity of a bus station 250 metres away, and multiple walkways along the main street reduce car traffic and emissions.

Indoor air quality (IEQ): Lightning comfort, daylighting, and thermal comfort lead to an increase of occupant comfort and satisfaction. Utilizing an open floorplan with adequate glazing and shading options provides thermal comfort from solar gains and glare that would otherwise potentially cause discomfort to occupants.

Emissions: The implementation of energy saving technologies such as glazed windows, solar panel electricity generation, phase change materials, and roof eaves are all considered to produce low emissions in construction and operational phases.

Materials: Optimizing areas within the building area in association with the open floorplan and heating and cooling techniques has resulted in less materials needed that would otherwise be needed for insulation and internal walls/doors.

It can therefore be seen that the design initiatives and choices within the building that 5 of the 9 initiatives were met. Through the several modifications and sustainable practices, it can be approximated that the proposed building could attain a 4-star rating. Improvements in management, water, land use and ecology, and innovations would accelerate this building to a 6-star rating.

ENGG210 - TASK 3

BUILDING PHYSICS AND BUILDING SERVICES

Faculty of Engineering and Information Sciences
School of Civil, Mining and Environmental Engineering

Executive Summary

This report stems from a project proposal from clients of the Lightning Ridge Aboriginal Lands Council (LALC) to design a multi-purposed community cultural centre in Morilla Street. Following client requirements and zero net energy principles, this report will detail four energy improvements including shading, lighting, glazing and materials which have been made to a base case concept design previously outlined in a detailed matrix and interim report. These improvements will be calculated using Design Builder, an energy simulation tool, to obtain a renewable energy fraction which will determine its positive/negative impact towards the overall buildings energy performance and satisfy the thermal comfort requirements of the building occupants.

From this assessment, it was found that four design modifications to a base case model, including glazing, materials, shading and lighting had successful impacts towards the overall energy performance of the building. With cooling loads being identified as the major source of the buildings net energy consumption, individual assessment of the four areas to optimise operation schedules were investigated and later combined to produce a 34% improvement in the annual buildings energy consumption. This saw a reduction from 265,072MJ per year of energy down to 170,915MJ per year and producing a final overall REF of 1.4 from the base REF of 0.67. This proved that the building was therefore able to achieve net zero energy performance levels and produced a Renewable Energy Fraction (REF) of 1.4, signifying the possibilities for the excess generated renewable energy to be repurposed for the community or sold to the grid for additional economic benefits.

Moving forward, it can be learnt that much of the individual improvements had small effects to the overall efficiency of the buildings energy usage, however when combined as a whole system of sustainable practices and technologies, noticeable improvements were evident. Hence moving forward, there is room for improvement within each modification area, where further optimisation based on the REF hours can be further investigated. By altering further schedules and design features, more hours spent in lower REF values can be improved to create a greater sample of hours spent in the zero net energy region of an REF=1. It is through this level of analysis that the building can work towards operating at a level approaching 100% efficiency.

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1. Introduction

The Lightning Ridge Aboriginal Land Council building is currently located away from the centre of town and therefore, the LALC wish to relocate and expand their functional capacity as a multipurpose community centre, designed to include a gallery, restaurant, offices, meeting/ teaching rooms and a large function hall. This infrastructure project is to be delivered in a cost-effective manner that aims to integrate the community throughout the construction phase while embracing local cultural traditions in all aspects of the build process.

Through sustainable practices and occupant considerations, the following goals are hoped to be achieved:

- To design a building that services both the public and private sectors of the community and utilize open plan, free flowing spaces to promote connectivity.
- To celebrate, facilitate and educate on the surrounding cultural traditions and heritage of the area.
- To design a building that compliments its environment through passive principles and sustainable practices.
- To design a building that is resilient to its environmental and socio-economic surroundings.
- To explore forward thinking and innovation to promote new incentives.

To meet these end goals, a base case model was developed from a concept design and interim matrix explored in a previous design phase. This was predicted to improve the thermal comfort for occupants, operational running costs, decrease energy usage and increase energy efficiency. From the previous design phase, it was noted: "although this was an in-depth analysis and comparison of a range of building design principles, further detail and optimisation can be undertaken through calculations, modelling and simulating each of the parameters" (Vision Artisans, 2021). Therefore this assessment uses Design Builder to perform numerical comparisons of each design strategy package against another to produce a more efficient and suitable design which is specific to the location of Lightning Ridge.

Design builder was the chosen tool for modelling and simulations. This is an energy simulation tool that analyses building environmental performances in a range of areas including energy, carbon, lighting, comfort and cost performances. Paired with Energy Plus 8.6 which is maintained by the US Department of Energy (USDOE), Design builder is compatible with NCC Section J compliance, GreenStar energy credits and NABERS risk management (Design Builder Software, 2021). Using ASHRAE heat balance equations and detailed HVAC modelling, the software calculates energy consumption, heating and cooling loads and daylight analyses. The simulation period chosen for this study is one year (1st January – 31st December) with data points gathered and analysed on an hourly basis.

2. Base Line Model

2.1 Concept Design Adjustments

In progression from the interim report and design phase, there was a number of design iterations that were performed as a result of client feedback and building functionality. Much of the changes were with regards to the first floor office spaces which were reconfigured to better utilise wasted space. This was addressed, as seen in Figure 2.1 by omitting unnecessary rooms such as the extra amenities, which can be found elsewhere in the building, and integrating closed common spaces such as the kitchenette into shared open spaces. The purpose of such changes was to reduce the anticipated heating and cooling loads within these 'dead' spaces. Another design modification was the degree of wave in the rammed earth wall which was reduced to create a smoother flow throughout the building's corridor. These decisions were determined in order to maximise affordability, occupant functionality and building energy efficiency.

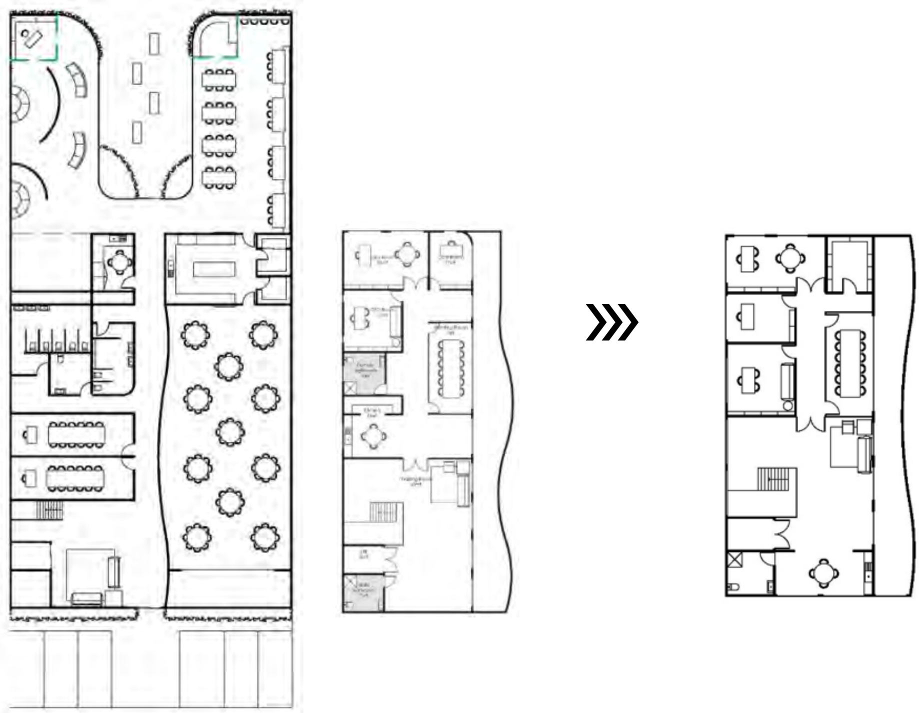


Figure 2.1 – Design Iterations From Concept Design and Interim Report Phase

From these design modifications and concept design strategies developed in the previous interim report phase, a best case model could be determined using the 6-star NABERS rating tool. Through this assessment, a ballpark net energy building consumption figure of 367,642 MJ per year could be determined. The purpose of establishing this best case model and energy consumption figure is to translate this final architectural design into a corresponding energy simulation model derived by further NCC requirements and client design assumptions.

2.2 Design Assumptions

There were a large number of assumptions that were made from client specifications and NCC Volume 1 Section J requirements (refer to Appendix B). These assumptions dictated many of the base line model variables and guided the benchmark REF value attainable as a result of current modern building practices. The following list is a collection of assumptions documented throughout the design modelling phase of the study:

Climate Data

The weather file imported for the simulation process was sourced from Walgett airport. This data was the closest obtainable weather station in the area, situated 75km SSW of Lightning Ridge and sitting at approximately the same level of altitude (170m above sea level). With no major geological obstructions such as escarpment ranges or coastal influences, it was assumed that this data would be an accurate representation of the same climate patterns experienced at Lighting Ridge.

Hot water demand

As specified by the client brief, it is assumed that an 8:00am to 8:00pm schedule with a constant 2kW supply of hot water is operational. This is designed to replicate the amount of hot water consumed by the building and simplify the simulation factors of the building.

Occupancy

NCC scheduling for occupancy requirements within zoned areas was used based on the buildings pre-determined operational hours set out by the client. These occupancy schedules can be seen detailed in Appendix B.

Lighting and Equipment
The lighting and equipment choices have been assumed to operate as LED fittings since these are now typical of modern buildings. The unpredictable nature of artificial light and equipment usage means that it is also assumed that these inputs will be scheduled around the same building operation scheduling determined by NCC occupancy and lighting requirements (further detailed in Appendix B). The reliability of the electricity network and voltage stability is assumed to be ideal.

Heating and Cooling
Design Builder uses EnergyPlus 8.6 data as its inbuild template values. Therefore based off the interim design strategy to use split – separate mechanical ventilation, the heating and cooling is modelled using the "purchased air" system. For the purpose of modelling, it is assumed that the air loads and the HVAC system are ideal.

Airflow and ventilation
The air flow and ventilation determined for the modelling was based upon the NCC section J5 requirements which outlines "the system must have a deactivation functionality for times when the building is unoccupied" as well as it must have an outdoor air economy cycle in accordance with table J5.2, requirement for an outdoor air economy cycle. It is also specified by client requirements that "as a minimum, it should be assumed that a fresh air supply from outside of 0.35 litres/m^2" be in effect at all times and a "minimum supply of 10 litres/s per person in all occupied spaces". This has been applied to each zone and recorded in appendix B

Additional assumptions with regards to the building design are:

- Cost and budgeting factors which have been omitted from the simulation process
- Curved glass facades at the front of the building are modelled as rectangular intersecting walls
- PV panels assumed flat on top of a sloped roof
- PV spacing of 0.2m is assumed sufficient to prevent shading influences from adjacent panels.
- The PV panels are to take up a maximum of 60% roof space and operate at an efficiency of 15%.

2.3 Base Case Model

The base case was constructed using energy simulation modelling in Design Builder and EnergyPlus 8.6 data that had been translated from the developed best case. The overall activity template used was the *'Generic Office Area'* for office and workshop business spaces that was then customised in accordance with NCC Section J occupancy scheduling and running time requirements. Other NCC customisations to the base case included single paned glazing specifications outlined in Section J2, natural ventilation and HVAC requirements in Section J5 and illumination power density (IPD) requirements found in Section J6 lighting. This guided the development of the buildings energy consumption in which the base case simulation model figure was determined at 367,344MJ per year. This figure was verified using the best case figure, where there was a marginal 300 MJ per year difference between the two cases and a 99.91% similarity. For this model, it was assumed that the net energy consumption of the building has no onsite renewable energy contribution.

Within the initial base case modelling, limitations occurred in the architectural elements of the design. Curved walls could not be easily translated from the concept design plans to the model resulting in the wavey rammed earth wall to be constructed using a flat surface representation. This was also the case for the glazing at the front of the building which was replaced with regular rectangular walls and corners as seen in Figure 2.2.

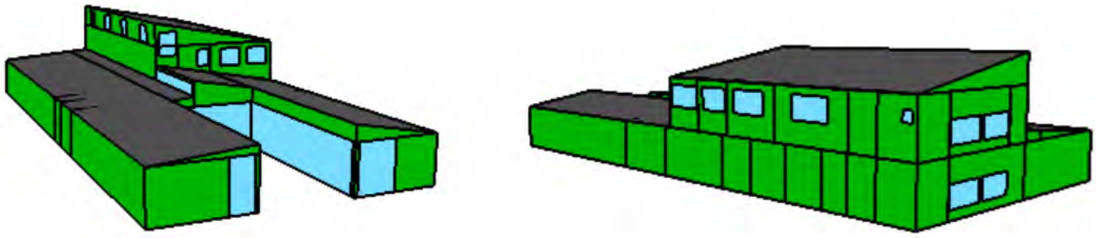


Figure 2.2 – Initial Base Case Model

2.4 Benchmark Model and Initial Results

From this method of construction, the final benchmark figures could be determined with the addition of photovoltaic renewable energy to the base case model. Following project requirements, solar PV panels were added to a maximum of 60% roof space as seen in Figure 2.3. From this addition, the final benchmark net energy consumption model using NCC codes and PV specifications was 265,076 MJ per year and an initial Renewable Energy Fraction (REF) can be calculated.

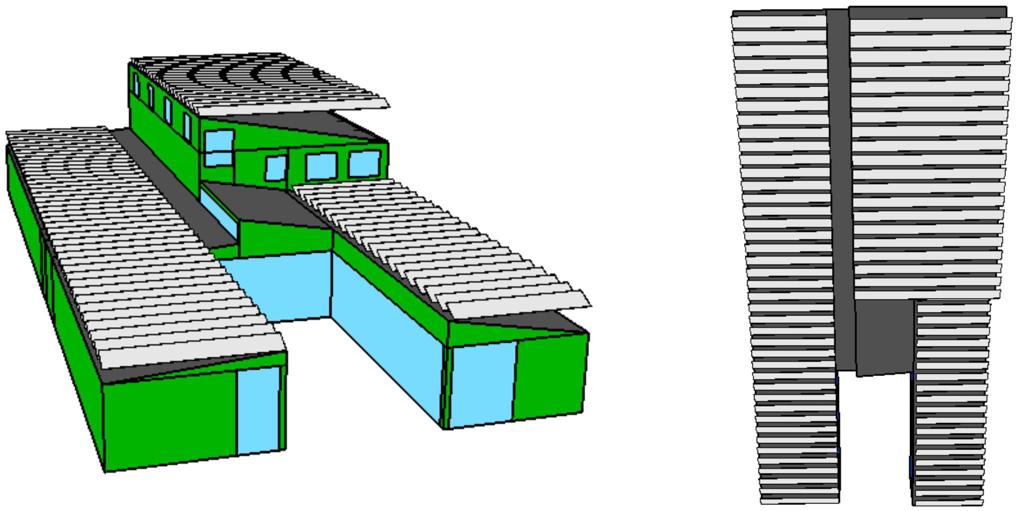


Figure 2.3 – PV Benchmark Model (Left) and 60% Solar Roof Coverage (Right)

The simulation was conducted over a one year period from the 1st of January through to the 31st of December using the weather data from 2019. The total benchmark building energy consumption breakdown can be seen in Table 1 where it can be seen that the majority of the buildings energy consumption is directed towards building cooling.

Table 1 – Base Case Energy Consumption Breakdown

Category	Energy (MJ)	Percentage Consumption (%)
Heating	3,059	1.15
Cooling	153,620	57.95
Lighting	68,940	26.01
Equipment	36,636	13.82
Water Systems	2,817	1.06
Total	**265,072**	**-**

Comparing these results with the annual heating and cooling loads produced over the same time frame in Figure 2.4, it is seen that cooling occurs all year round whereas limited heating is required only during the winter months. This will become the design focus of the study as it is apparent that the cooling loads will be the most important contribution to the building's net energy consumption. The major contributing cause for the dominating cooling requirements can be seen in Figure 2.5 to be a combination of solar gains, occupant activity and lighting.

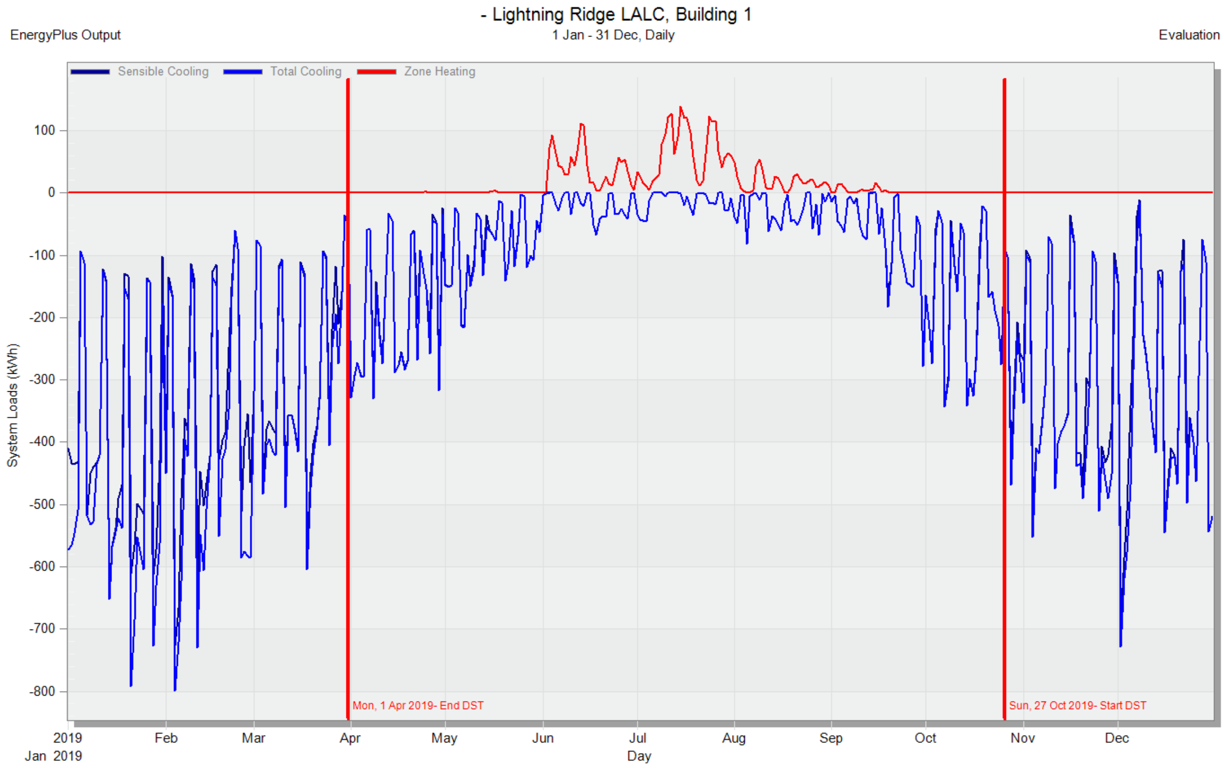


Figure 2.4 – Heating and Cooling Loads for LALC Building (1st Jan – 31st Dec)

Figure 2.5 – Building Heat Gains (1st Jan – 31st Dec)

From the data in Figure 2.4, the peak cooling day for 2019 can be seen to occur on the 4th of February and the peak heating day on the 14th of July. Figure 2.6 shows that for each respective day, the heating and cooling requirements occur at different times based on the solar gains that are occurring. For the 4th of February, solar gains are the strongest between 6am and 6pm, peaking at 3:30pm. This is where the total latent load is seen to be at a maximum. As for the 14th of July, it is seen that the strongest internal solar gains are between 8am and 4pm with a peak at 11:30am. During this time, the heating loads spike between 5am and 8am before significantly dropping for the remainder of the day.

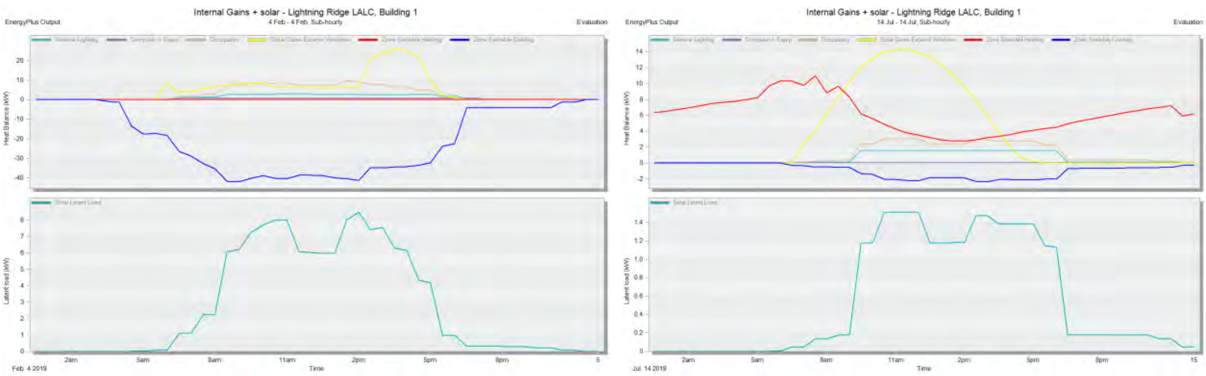


Figure 2.6 – Energy Breakdown for February 4th (Left) and July 14th (Right)

From these trends, it can be seen that internal solar gains are the biggest contribution to cooling loads required throughout the year and this data will be used to guide and justify the design modification choices to come. Using the gathered simulation results and hourly breakdown of the peak hottest and coldest days of the year, a net REF was found at 0.67 as summarised in Table 2.

Table 2 – Benchmark Building Energy Consumption Summary

	Energy (MJ/yr)	REF = 0	0 < REF < 0.3	0.31 < REF < 0.95	0.95 < REF < 1.05	REF > 1.05	Total REF
Best Case	367,642	-	-	-	-	-	-
Base Case	367,344	-	-	-	-	-	-
PV Base Case	265,072	5	4263	2215	184	2093	0.670

3. Design Modifications

3.1 Justification of Changes

With the PV base case model yielding benchmark energy consumption figures of 265,072MJ per year and an REF of 0.67, design modifications were made in order to improve the overall building efficiency and therefore decrease the total energy consumption. With the goal of making the building net zero energy, design modifications were decided upon based on the trends occurring within the energy breakdown results which showed a reduction in solar gains was required. Therefore the chosen modifications selected in conjunction with the interim design matrix strategies proposed in the previous tasks were glazing, shading, lighting and materials.

Shading

It was identified early on in the base case modelling that the main contributor to the high cooling demands was internal solar gains. The most logical solution to overcome this issue is through the addition of shading as seen in Figure 3.1. Shading was modelled in Design Builder by applying window coverings to each of the windows. This was an inbuilt function of Design Builder and so it was assumed that the coverings were adequate to shade the whole window space when required. Additionally, 0.5m eaves, which were absent from the base model due to software configuration, was added around the perimeter of the existing roofline. This was added with the expectation that it would shade much of the buildings walls as well as provide additional shading to ground surfaces to reduce solar reflection and glare back into the building. The two adjacent buildings were also modelled as this was assumed to have influencing shading effects on the building as seen in Figure 3.1. These results for the shading are summarised in Table 3.

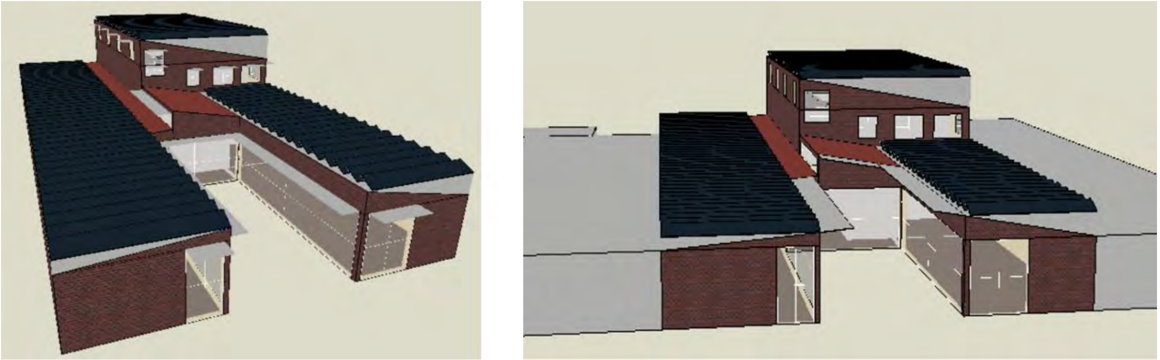


Figure 3.1 – Rendered Building Model with Shading Modification

Glazing
There were three types of glazing investigated to reduce the overall interior solar gains that were being transmitted through these zones. These were double glazed with internal shading, triple glazing with internal blinds and electrochromic glass. These types were selected based on a similar glazing study undertaken on a Lendlease age care facility concept report (van Duin, 2021) which looked at glazing performance comparisons in order to improve occupant thermal comfort and neutralize peak heating and cooling loads for HVAC systems. The study found that the electrochromic smart glass was most effective in overcoming excess solar gains however balancing this with cost restrains of the Lightning Ridge Client, other well performing, lower cost glazing alternatives such as double glazed with internal blind windows were modelled. The results for each glazing outcome are summarised in Table 3.

Materials (PCM)
Phase change material was investigated as a way of increasing the overall insulation of the building against the intense heat that the climate of Lightning Ridge experiences. This was added with the intension that phase change material will "reduce energy loads for HVAC and easier controlling of indoor environmental conditions" (Vision Artisans, 2021). Infinite R was chosen as the appropriate PCM material based off research conducted in the interim design strategy report. This was modelled and the results summarised in Table 3.

Lighting
Results from the base case modelling showed lighting to have a higher than anticipated energy consumption of 68,940MJ of energy per year. This makes up 26% of the base case energy consumption and therefore is an area of modification to optimise the efficiency of the building. Lighting schedules as well as best practice guidelines established in government certification schemes such as NABERs has been implemented as well as minimum lighting requirements from NCC Volume 1 section J6 to ensure no additional or unnecessary lighting is being used. The building has also been updated in the best case model to include extra natural lighting to assist in reducing artificial light dependency. The results of lighting modifications are recorded in Table 3.

3.2 Results

The results can be broken up into two categories of analysis: isolated studies which showed the individual energy efficiency improvements of each design modification and a combined energy model which encompassed all the strategies working as one. In breaking up the data, a more detailed analysis for how many hours the REF values were operating within the designated ranges of REF = 0, 0<REF<0.3, 0.31<REF<0.95, 0.95<REF<1.05 and REF>1.05 could be seen. Table 3 summarises these values and provides a total building consumption figure and REF.

Table 3 – Summary of Final Simulation Model Data

	Building Energy Usage (MJ/yr)	Energy improvement over Base Case (%)	REF = 0	0 < REF < 0.3	0.31 < REF < 0.95	0.95 < REF < 1.05	REF > 1.05	Total REF	REF % Improvement Over Base Case
Best Case (MJ)	367,642	-	-	-	-	-	-	-	-
Base Case (MJ)	367,344	-	-	-	-	-	-	-	-
PV Base Case (MJ)	265,072	-	5	4263	2215	184	2093	0.670	-
MODIFICATIONS									
Glazing (Dbl w/ blinds)	254,382	4.2	5	4234	2131	161	2229	0.753	12.38
Glazing (Tpl w/blinds)	254,378	4.03	5	4243	2140	148	2224	0.753	12.38
Glazing (Electrochromic)	204,851	22.7	5	4204	1866	144	2541	0.876	29.85
Shading	235,872	12.38	5	4137	1974	105	2539	0.799	19.25
Lighting	273,028	-3.0	5	4320	2416	189	2005	0.649	-1.03
Materials (PCM)	260,429	1.75	5	4282	2198	166	2218	0.678	1.19
Total Combined Mods	**170,915**	**35.5**	**5**	**4194**	**1673**	**135**	**2628**	**1.4008**	**52.17**

Comparing the heating and cooling loads from Figure 2.4 and Figure 3.2, it can be seen that there is a reduction in the cooling spikes, particularly in the summer months as well as daily times when the cooling load is at zero rather than continuously running as is the case with the benchmark model. Furthermore, Figure 3.3 shows a significant reduction in the internal solar gains compared to the benchmark results, signifying successful outcomes in the modifications chosen.

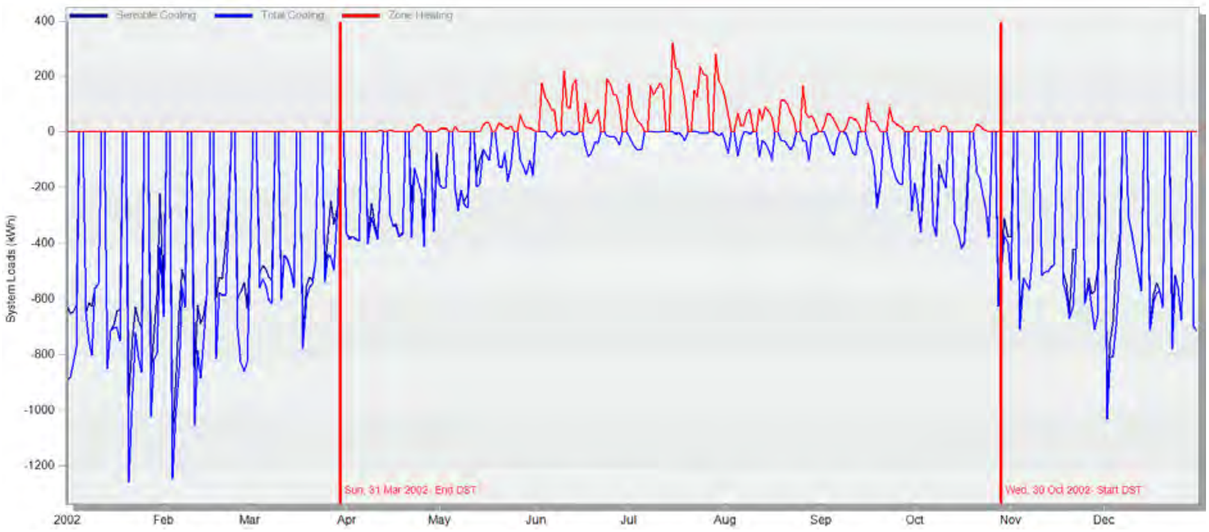


Figure 3.2 – Heating and Cooling Loads for Combined Modifications (1st Jan – 31st Dec)

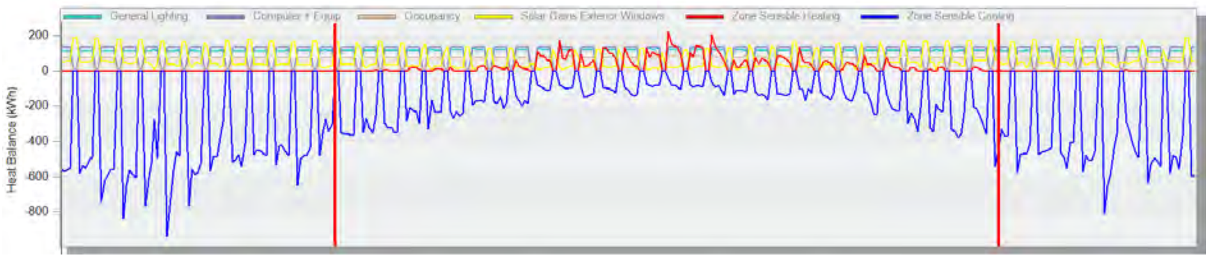


Figure 3.3 – Building Heat Gains with Modifications (1st Jan – 31st Dec)

From the data in Figure 3.2, the peak cooling day for 2019 can be seen to occur on the 4th of February and the peak heating day on the 15th of July. Figure 3.4 shows that for each respective day, the heating and cooling requirements occur at different times based on the solar gains that are occurring. For the 4th of February, solar gains are the strongest between 6am and 5pm but remaining constant for this period. As for the 15th of July, it is seen that the strongest internal solar gains are between 11am and 4:30pm but also remaining constant throughout the day.

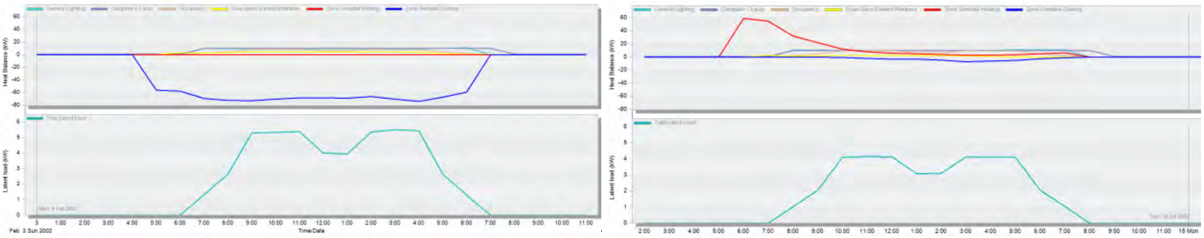


Figure 3.4 – Energy Breakdown with Modifications for 4th February (Left) and 15th July (Right)

4. Discussion and Conclusion

It can be seen from the results produce that the total improvements on building energy consumption based on the combined modifications were able to achieve zero net energy. With an REF of 1.4, the energy consumption figures of the building were reduced to a total of 170,915MJ per year while the buildings solar system was generating 213,928MJ of energy per year. This shows that an excess of 43,013MJ of energy was being produced each year which could be stored on site or redistributed back into the Lightning Ridge Community.

From a close up analysis of the peak heating and cooling days, there is a clear distinction between Figure 2.6 showing the energy breakdown for the base case model and Figure 3.4 which shows the energy breakdown after modifications had been implemented. With respect to the solar gains, noticeable differences occur in the daily peaks where the base model showed consistent solar peaks at approximately 3:30pm and 11:30am whereas the modified model showed consistently low solar gains for the duration of the day. From this trend, it can be concluded that the glazing and shading modifications working in conjunction with each other proved successful in reducing the overall internal solar gains experienced in Lightning Ridge and therefore reducing the overall building cooling demands.

As for the buildings heating requirements, Figure 2.6 demonstrates two times where heating is required on the 14th of July, that being at 7:30am and 9pm. These two heating times are also held for longer periods of about 4 hours each whereas Figure 3.4 shows heating is only required once between the hours of 5:30am and 9:30am. From this trend, it can be seen that the heating requirements have also been significantly reduced and the afternoon heating zone, omitted. This shows that the building, once heated to a required temperature, maintains a steady internal comfort level with limited additional energy. From this observation, it can be concluded that the buildings modifications in materials and glazing was successful in creating a thermally efficient and insulated building.

With the building being optimised at a more consistent operation, the latent loads seen in Figure 3.4 are much smoother and less varying than the curves seen in Figure 2.6. This shows that the building has a much more controlled operation schedule and energy consumption rate, lowering peaks in demand and omitting unnecessary spikes in generation. This overall creates a more efficient energy usage building model when looking into energy consumption and impacts on loads over longer life times.

Through the design modelling and modifications, the initial constraints of the client were not compromised and were maintained, if not improved, as the building progressed in its energy journey. This meant that the initial goals listed were achieved.

- To design a building that services both the public and private sectors of the community and utilize open plan, free flowing spaces to promote connectivity.
- To celebrate, facilitate and educate on the surrounding cultural traditions and heritage of the area.
- To design a building that compliments its environment through passive principles and sustainable practices.
- To design a building that is resilient to its environmental and socio-economic surroundings.
- To explore forward thinking and innovation to promote new incentives.

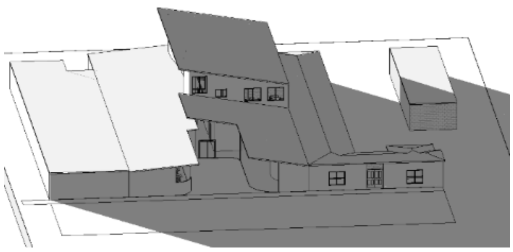
Design aspects such as functionality, aesthetics, acoustics, visual comfort and IEQ were enhanced as a result of innovations explored to improve the overall building efficiency. The aesthetics of the building were improved as the design decisions such as overhanging eaves and gardens were utilised as a way of providing the shading modification required to reduce cooling loads of the building. Furthermore, functionality of the building was also improved as it was the reduction of size that enhanced the way the building was used while also reducing the amount of cooling required for each space. By improving the lighting loads, natural light was introduced as a way of increasing visual comfort. Paired with double glazed windows with blinds, this also reduced the daylight and glare entering the building, assisting further in the overall cooling needs.

As a result, it can be seen that the design choices and modifications made to concept building plans have proved viable and effective in achieving client expectations and energy modelling goals. The decisions had been made as a result of balancing the energy efficiency outcomes with cost considerations which have followed client requirements, zero net energy principles and sustainable practices throughout the multiple design iterations and process.

5. Shading Diagrams and Visuals

5.1 Shading Diagrams

Solar gains were a major contributor to the high cooling loads and therefore overall building energy consumption for this climate. Shading diagrams were developed in order to tailor the window placement and additional shading modifications used to combat the high solar gains being experienced. The shading diagrams used for both summer and winter sun paths can be seen below:



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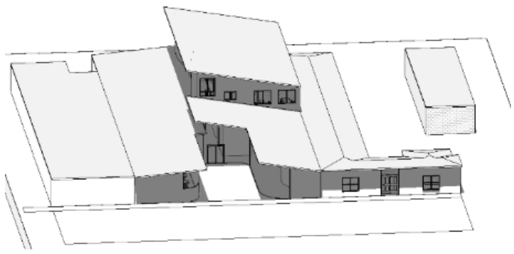
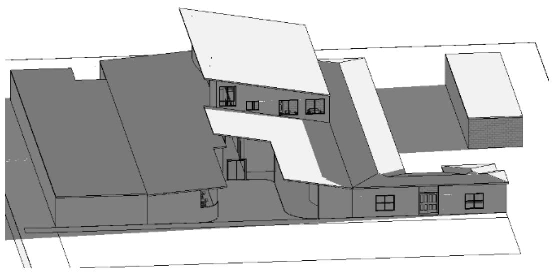
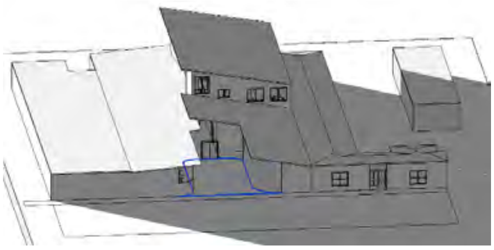


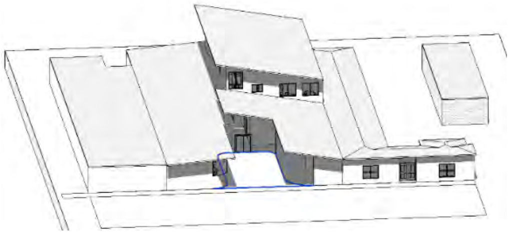
Time: 12:00



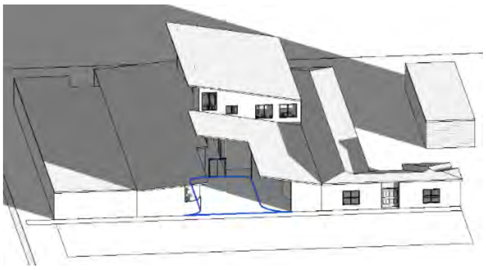
Time: 19:05

Figure 5.1 – Summer Solstice (20 December 2021) Sun Infiltration Diagram





Time: 7:02 Time: 12:00



Time: 19:16

Figure 5.2 – Winter Solstice (20 June 2021) Sun Infiltration Diagram

Through these shading diagrams it can be seen that sun is able to enter the building all year round at the designed glazing spaces. It can also be seen that more sunlight is allowed to penetrate these windows during winter months while the eave extensions shade the walls (and therefore windows) during the summer months. Special attention has also been towards the café area in which sunlight is still present in the winter evenings which will create a warmer and more comfortable environment to attract visitors whereas remains completely shaded for the hotter summer evenings.

5.2. Visuals

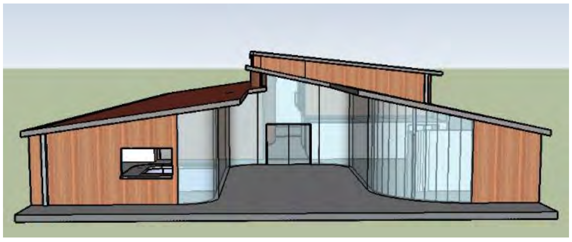
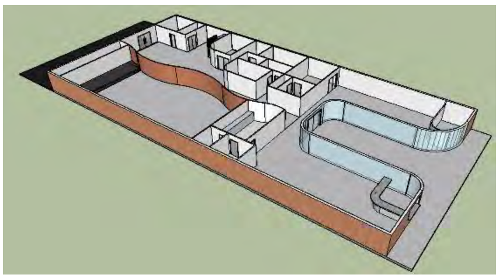


Figure 5.3 – 3D Model Representation of Concept Design



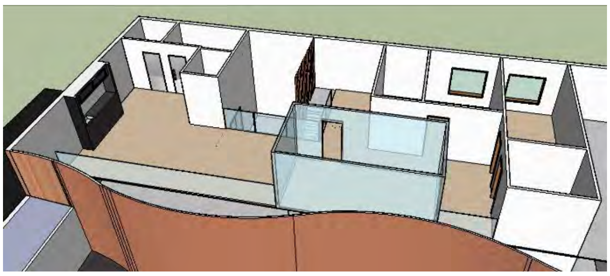


Figure 5.4 – Interior Model Representation of Ground Floor (Left) and First Floor (Right)

Figure 5.5 – Rendered Interpretation of the LALC Building

6. References

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7. Appendix A – Government Certification Schemes

Key government rating schemes are an important consideration when looking into the sustainability performance of a building. This can be found in both categorical qualitative data as well as calculated numerical data. Greenstar and NABERS are two such rating tools that have been used for this project which encompasses the sustainability attributes and efficiencies of the proposed building. Greenstar uses a credit based criteria shown in Figure 7.1, where a building attains these credits through successful achievement and demonstration in each sustainability performance area. The highest rating attained is a 6-star performance rating (Green Star – Performance | Green Building Council of Australia, 2021).

Figure 7.1 – GreenStar 6 Star Rating Criteria (New.gbca.org.au, 2021)

NABERS is a similar rating system in which the performance of commercial office buildings is measured. Based off a six star credential system comprising of energy performance, water usage, waste and indoor environmental quality the buildings operational performance is compared against the population of all other rated buildings using an accumulative points based scoring method (NABERS, 2021). This rating tool was used in developing the best case model of the preliminary design which assisted in attaining our base case benchmark model.

Focusing on Greenstar for the final design proposal, there are nine criterions required to attain the 6 star rating which includes management, indoor environmental quality (IEQ), energy, transport, water, materials, land use and ecology, emissions and innovation. Through design choices such as increased shading, enhanced glazing, modified lighting schedules and material selection, the following schemes were met:

1. **Management** – material selection such as the rammed earth wall and PCM insulation is not standard practice for buildings in these remote locations. Along with the initiative to incorporate community involvement throughout the building phase, it is important that clear and well organised management sees that this building is efficient in its implementation of such a design to uphold its sustainability in resources, time and operation upon instalment.
2. **IEQ** – the IEQ of the building is regarded as one of the projects main goals for the final building design. This aims at improving occupant experiences within the spaces through comfort and well-wellbeing which has driven many of the design choices particularly for the interim design and report phase.
3. **Energy** – this report has demonstrated how the building aims at attaining maximum energy efficiency through its design and energy saving modifications. As a result it was possible to attain net zero energy.
4. **Material** – this design has a strong focus on the materials sector of the design using innovative companies such as Infinite R PCM and rammed earth wall technology to assist in maximising

passive design opportunities. This was seen in the individual improvements shown by the simulation modelling for PCM. The building also aims at incorporating locally sourced materials such as mine tilling bricks and Cyprus wood with special attention to the life cycle of such materials involved and its waste impacts.

5. **Land use and Ecology** – this building will be occupying a current vacant, barren and dirt covered block with no natural vegetation or animal inhabitants. Therefore minimal harm to existing habitats and ecology will be done. On completion of the project, it is part of the design package that native, irrigation fed gardens be installed as part of promoting local ecology and boosting IEQ of the building's facade.
6. **Innovation** – extensive research has been conducted (particularly in the interim design report phase) where technologies such as geopolymer concrete, hydrogen battery storage solutions and building integrated photovoltaics (BIPV) are incorporated to increase the operational efficiency of the building.

As a result, it can be seen that through energy efficient modifications in the building envelope, 6 out of the 9 initiatives were achieved with the other 3, namely transport, water and emissions, were non applicable to this particular study. This shows that there is significant opportunity in aiming for government rating schemes where even buildings in challenging environments can obtain high standards and practices toward sustainability and operational efficiency.

8. Appendix B – Assumptions

Table 4 – Assumptions for Zone Scheduling Using NCC Volume 1, Section J Requirements

Zone	Template	Occupancy (NCC Section J)	Heating Ranges	Cooling Ranges
Art Room	Generic Office Block	Table 2f	18.0, 16.0	25.0, 28.0
Commercial Kitchen	Food Preparation Area	Table 2f	18.0, 16.0	25.0, 28.0
Corridor	Circulation Area	Unchanged 8am-8pm in template	18.0, 16.0	25.0, 28.0
Disabled Toilet	Toilet	Unchanged 8am-8pm in template	21.0, 19.0	25.0, 28.0
Female Toilets	Toilet	Unchanged 8am-8pm in template	21.0, 19.0	25.0, 28.0
Male Toilets	Toilet	Unchanged 8am-8pm in template	21.0, 19.0	25.0, 28.0
Elevator	Circulation Area	Unchanged 8am-8pm in template	18.0, 16.0	25.0, 28.0
Entertainment Hall	Hall/ Lecture Theatre/ Assembly Area	Table 2h	21.0, 19.0	25.0, 28.0
Fridge and Freezer	Light Plant Room	Unchanged 8am-8pm in template	00.0, 0.00	0.00, 0.00
Gallery	Gallery	Unchanged 8am-8pm in template	21.0, 19.0	25.0, 28.0
Pantry	Store Room	Unchanged 8am-8pm in template	18.0, 16.0	25.0, 28.0
Restaurant	Eating and Drinking Area	Table 2f	18.0, 16.0	25.0, 28.0
Staff Room	Generic Office Area	Unchanged 8am-8pm in template	18.0, 16.0	25.0, 28.0
Store Room	Store Room	Unchanged 8am-8pm in template	18.0, 16.0	25.0, 28.0
Teaching Room 1	Teaching Areas	Unchanged 8am-8pm in template	21.0, 19.0	25.0, 28.0
Teaching Room 2	Teaching Areas	Unchanged 8am-8pm in template	21.0, 19.0	25.0, 28.0
CEO Office	Generic Office Area	Table 2c	21.0, 19.0	25.0, 28.0
CFO Office	Generic Office Area	Table 2c	21.0, 19.0	25.0, 28.0

COO Office	Generic Office Aera	Table 2c	21.0, 19.0	25.0, 28.0
Common Area	Reception	Unchanged 8am-8pm in template	18.0, 16.0	25.0, 28.0
Lift	Circulation Area	Unchanged 8am-8pm in template	18.0, 16.0	25.0, 28.0
Meeting Room	Generic Office Area	Table 2c	21.0, 19.0	25.0, 28.0
Uni-Sex Toilets	Changing Facilities with Showers	Unchanged 8am-8pm in template	21.0, 19.0	25.0, 28.0

Table 5 – Airflow and Ventilation Schedules

Zone	Floor Area (m^2)	Zone Volume (m^3)	Occupancy Expectations	Fresh Air Supply (L/m^2)	Minimum Supply when Occupied (L/s per person)
Art Room	26.76	93.65	10	9.366	90.63
Commercial Kitchen	31.05	108.69	15	10.87	139.13
Corridor	121.4	424.89	20	42.49	157.51
Disabled Toilets	8.1	28.43	2	2.84	17.17
Female Toilets	28.94	101.28	5	10.13	39.87
Male Toilets	17.81	62.34	5	6.23	43.77
Elevator	4.61	16.14	2	1.61	18.39
Entertainment Hall	182.22	637.79	200	63.78	1936.22
Fridge/Freezer	5.79	20.26	1	2.03	7.97
Gallery	85.54	299.40	30	29.94	270.06
Pantry	3.76	13.15	1	1.32	8.69
Restaurant	97.14	340.00	50	34.00	466.00
Staff Room	13.81	48.33	4	4.83	35.17
Store Room	5.69	19.91	1	1.99	8.01
Teaching Room	24.29	85.01	15	8.50	141.50
CEO Office	15.85	53.89	6	5.55	54.45
CFO Office	10.70	36.39	3	3.75	26.26
COO Office	15.78	53.66	3	5.52	24.48
Common Area	68.97	259.75	4	24.14	15.86

Meeting Room	17.51	59.53	12	6.13	113.87
Unisex Toilets	1.84	18.90	2	0.64	19.36

9. Appendix C – Calculations

In order to ensure client requirements were met, the following calculations were carried out to ensure that no more than 60% of roof space was covered in photovoltaics. This was carefully thought out to consider solar spacing to reduce overshadowing and the number of rows required for each section of roof so that even distribution was achieved. It is assumed a spacing of 0.22m is adopted between each row of PV panels.

$North - east\ roof\ area = 43.48 \times 8.22 = 357.41 m^2$
$Top\ roof\ area = 23.1 \times 7.47 = 163.59 m^2$
$South - west\ roof\ area = 279.05 m^2$
$Front\ roof\ area = 45.06\ m^2$
$Total\ roof\ area = 845.11\ m^2$
$Allowable\ solar\ area = 845.11 \times 0.6 = 507.07\ m^2$

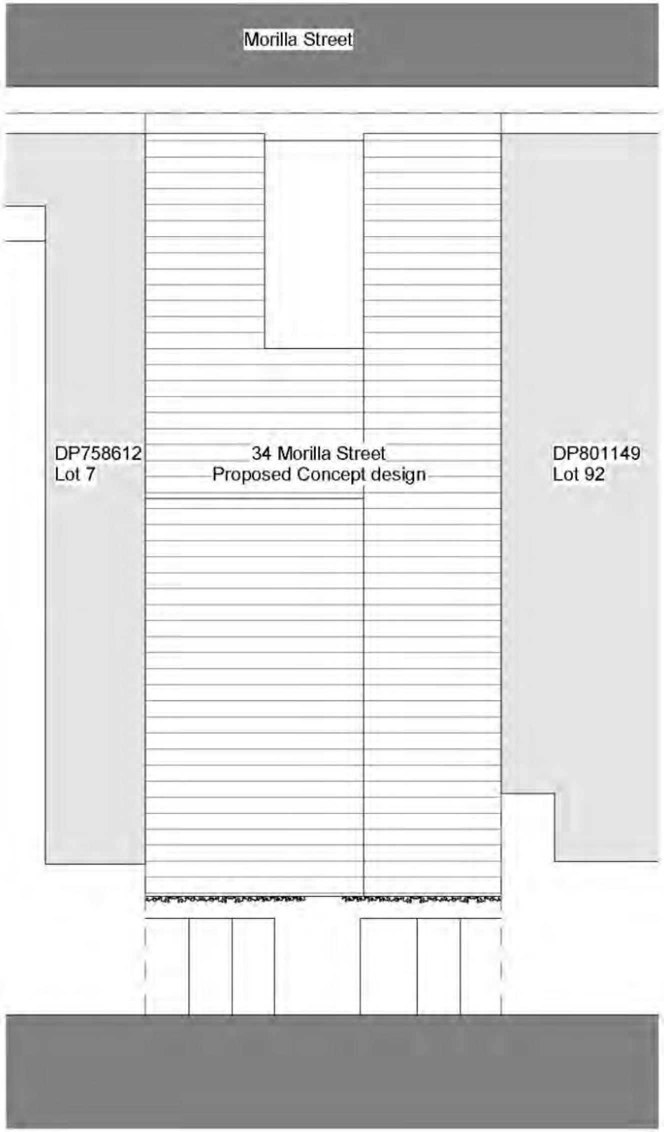
$Solar\ size = 1651 \times 990\ mm$
$Optimum\ tilt\ angle = 29.4^o$ (Sunrise and sunset times in Lightning Ridge, June 2021, 2021)
$Solar\ angle\ for\ roof\ slope = 23.7^o$

$Top\ roof\ with\ PV\ spacing = 180.4\ m^2$
$North - east\ roof\ with\ PV\ spacing = 235.34\ m^2$
$South - west\ roof\ with\ PV\ spacing = 98.4\ m^2$
$Total\ PV\ area = 514.14\ m^2$

The value obtained for the PV is 1.37% over the maximum 60% roof spacing however this roof area does not include the 0.5m eaves that were not included in the model. Therefore the new total roof area would be > 514.14 m^2 and therefore the client requirement holds true.

(Disclaimer: it was brought to attention that from the provided figures, the PV distribution looks to cover 100% of the roof, however this is due to the axonometric views of the model as well as the placement/distribution of each solar row and therefore it can be confirmed that no more than 60% of roof space is occupied by PV)

10. Appendix D – Project Plans



Site

1
1 : 300

Vision Artisans

No.	Description	Date

Vision Artisan's

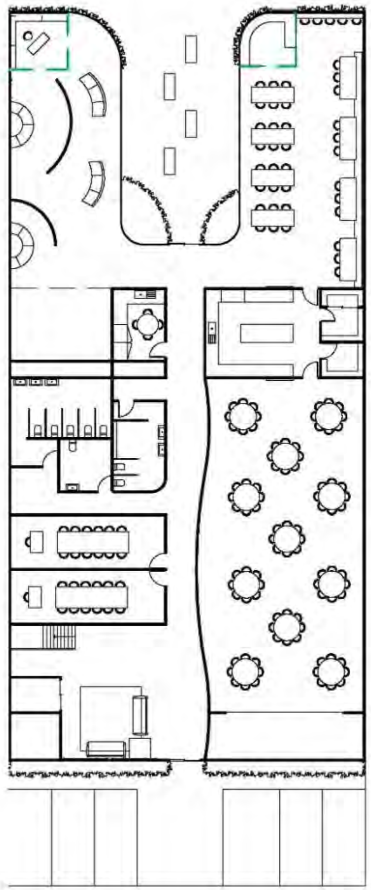
Lightning Ridge LALC

Site Plan

Project number	210922
Date	22/09/21
Drawn by	Vision Artisans

A102

2021 10:33:16 AM



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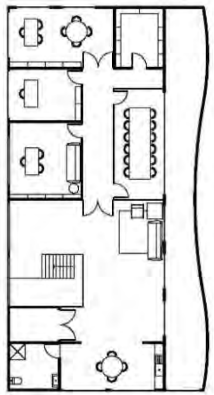

2 **Floor 1**
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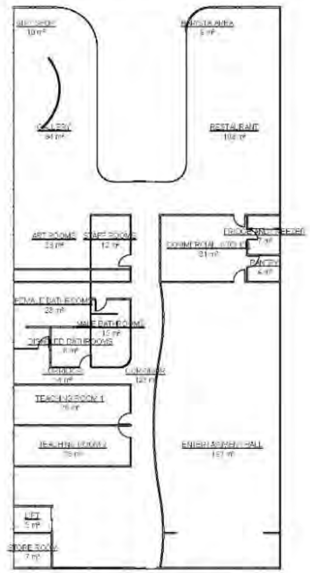
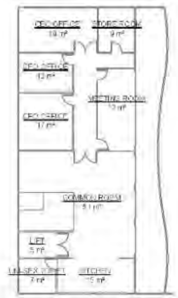


3 **Ground Floor**
1 : 400



4 **Floor 1**
1 : 400

Vision Artisans

No.	Description	Date

Vision Artisan's

Lightning Ridge LALC

Floor and Area Plans

Project number	210922
Date	22/09/21
Drawn by	Vision Artisans

A103

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Interview 1: Integrated Design Studio 09 – Lightning Ridge LALC Multi-Purpose Building – Interview with Client (Dr. Steve Burroughs Foundation)

Q1. What enables successful Integrated Design in the studio setting?

Good question. I think first I should clarify that anything I say or my opinions about what happened during this studio is based on my experience with Czech Technical University, where I have been doing this for about 12 to 15 years, and working with engineering students there who have finished their engineering degree, and now are studying architectural engineering. Most of them are at a master's level or higher, and so their standards are so high, so as I answer questions, I don't want to be really critical, but I just want you to know that's what its based on. The demands that I put on those students, compared to what's happened at Wollongong, are entirely different.

I guess the number one thing is communications. I think with a large group of students, 25 students or whatever it was, and dividing those into groups of 4 or 5, it makes it very difficult for me in this setting. Also, I've never played the role as a client before, so, that was difficult. I'm not quite sure what my expected outcome was or what type of communication was going to be coming my way, but certainly I don't think there was very much in the way of communication. I think communications is important and I think there was a lack of including me in things. Maybe I'm just looking at it from the point of view of giving direction to the students, because I really didn't give direction to the students, or wasn't asked to.

I guess it all comes down to money, and the ratio of students to staff, that type of thing. I mean a large group of students is just really difficult. Smaller groups are better. Not that I haven't myself taught or lectured in a room where I work with different groups of students, but, I'm more used to working one-on-one with students so my experience is having anywhere between 4 to 12 students, so not working individually I see is a bit difficult. I don't know if working in groups is very successful.

Q2. Please tell us about the studio brief's impact on achieving integrated design solutions (considering the way it was written & communicated). Please reflect on the level of detail and the language of the brief.

I know that I wrote a basic brief. I have no idea how that brief was interpreted by the architects, engineers, or the environmental people, or the lectures that were running the course. Did they take my words and rewrite them into a different type of brief? I don't know. What I can say (as far as I'm concerned) in relationship to client, the students didn't really meet my brief. They failed on quite a few things, and again, because I wasn't included or asked. Let me just clarify, well, let me just pick maybe one or two examples which might help.

Number one is that I pushed security. Security is extremely important. I have a lot of years of experience working in remote and very remote locations. Outstations, town camps, and so forth, and security is paramount. I gave examples of the type of door locking systems I wanted, window coverings that I wanted, security for the CEO, security for the board chair. That was never ever mentioned or fed back in any of the presentations that I saw.

There was no sort of in-depth analysis (that I could see) to basically the total amount of power that it (the building) was using, and what was offsetting that power. The students talked about solar, and talked about limiting the amount of solar cells that that went on to the roof of the structure. I'm not quite sure why that (limit) was placed on there.

In relationship say to solar, we have a huge expense. We're spending a lot of money, and the amount of power that we're generating and the money that we're receiving for generating net power versus what it cost to buy power is a very important thing. Just saying that "where we require X amount of power and we're generating *X* amount of power, so therefore, this is how much power we're going to use" doesn't really get into the depth of it. As a client, I can't go to community and say "okay, we're going to build this building. I'm putting *X* number of 350-Watt cells on there and I'm going to generate *X* power. We need *X* power and therefore this is what it's going to cost you", because we know that's not true. So maybe we're being paid 6 cents or 9 cents to feed in, and what we're paying 21, 25, 30 cents to buy back. All these things have to be really upfront with aboriginal people. If you don't, you get yourself into trouble, and there's no work in the future for you. You'll get a bad reputation. There were things that that I ask for as a client, and they definitely weren't delivered.

That's just a couple examples. I think allowing students to look at various types of glazing, yes, that's important, but it's cost prohibitive.

Q3. What were the most critical decision-making points/questions to answer when balancing architectural and engineering input for generating environmentally optimised design solutions? Where did the inspiration for the students' solutions come from? How did the engineering consultant(s) contribute to the authorship of those solutions? What was the impact of engineering and architecture student collaboration on the project outcomes? What impact did the timing of the engineer/architecture collaborations have on the development of the project?

My interpretation of what was delivered was that the buildings were built using green stock and based on a star rating. I asked that we not do that, and that we look to using the building challenge. To me, those two are different, night and day. I saw that the professionals/experts that were used to advise students, they live and work in Wollongong, Sydney, South Coast, etc. That's what they're used to working with and that's what they train the students to do, and that's what the students would most likely do in the future. But it doesn't really hold true in remote Australia. Even though Lightning Ridge isn't that far away, it is classified as remote just because of the population numbers there. It is remote, it's not very remote, it's not an outstation or anything like that, but it is remote. So, I saw things that were good (in the design) and they work, but they're not really necessarily relevant to remote Australia, and can we afford some of those particular items. So that's tough.

I think overall, being their first time, I think they did fairly well. I think they researched and looked at this proposed opal mining museum that is supposed to be built. They researched that, and looked at at climatic conditions, at the terrain and the type of material that was there (water, power, etc.) I think they researched what they could. I'm assuming that some of them would have looked at the at the BOM site to check out weather temperatures and so forth. Overall, I was pleased with what they did. They looked at the local mob of aboriginal people, looked at their values and looked at their totems. They looked at their cultural aspects and that was good, so I'd give him a tick for that for sure. I think that was very well done.

I don't know any of the students backgrounds. I had no idea who was who, or what discipline they came from, so that was very difficult, and had I been eyeball to eyeball with them I would have asked them. I would have made suggestions that this person works with that person, why don't you combine information to do this… There was not of that from my side. I'm used to dealing with engineering students. There are certain things that I would demand of the students from engineering to deliver to me. I am probably a little bit disappointed that more information wasn't given to me from a sort of an engineering background. But, I'm thinking that the course was approached more from an architectural engineering point of view, but I don't I don't quite really know. In relation to corroboration between the two, I can't say. I can't answer that. I don't know.

Q4. What guidance by you was most useful for the students (and why)? How did your input increase their 'level of understanding of' environmental issues and associated solutions? What would you change in order to maximise your input (if anything)?

To be honest with you, I don't think I delivered much of anything to the students. I wrote this brief of things that I expected (as a client) to be in my building, to be resolved and fed back to me in the design concept. I think it (the client brief) was rehashed and redelivered to the students. I was disappointed.

I'm sort of an eyeball-to-eyeball person in the classroom. That must be extremely difficult for all of you (researchers and teachers). It is from me. I think if I could be in front of them, I would certainly have given him a lot more. I would have given them more in relationship to the overall cultural aspects. I would have given them examples of when I talked about security. I would give them examples of places that I've been, things that have happened, that I've seen happen and why I have this big emphasis on security. I would have given that in person which I wasn't able to do. I was just a client, and I was just taking what was given to me. I had a very small, minute role in this whole course.

I think, if there were 25 students, I would have preferred to break them in half. You have a group of 12 and a group of 13. I prefer to break them in half and meet with those students and give them, some background information so that they could then go away and develop some concepts and come back to me, rather than to have a group of 25 students who have been divided into groups of 5, so then you have 5 presentations, all of them sort of being similar.

I realise that having 25 students and breaking them into 2 groups, it would still be hard for me to get feedback to them, having students make a presentation of 15 minutes each. I'd rather give each one 15 minutes individually then having 5 student groups, and give them 15 or 20 minutes as the group.

I don't know what the group's doing, but having each one of them for 15 minutes, I got a pretty good handle on where they are or not, and what they do or don't understand. I also realized that a lot of them have similar designs. That's okay. I just want them to get to know how they come up with a concept for this design, what the delivery is going to be, and so forth.

I think the other thing that really is a very important, significant outcome for them to know, is logistics. It is a nightmare, and with the present-day conditions, of a lack of all building materials, delivery times, and so forth. Canberra, Sydney, Wollongong, or wherever it might be, to think about people, we could add a factor of at least 5 on top of that to remote locations. And these students don't have a clue. I think they need to understand what remote or very remote means, and what the transport is to get there, and what it is to get there. What it is to get the tradespeople on site. Those type of things. That all feeds back to the design and trying to keep it simple, so that more tradesmen can multitask and do various different things, because you just not going to be able, for example, to get a specialist glazier on site. You're not necessarily going to get a painter crew on site, it's going to be the builder and his chippies doing the painting.

What's more important, is that the student understands a type of paint that we're going to use, and how it's applied, and then we (as the person on the ground) determine who does that particular role. None of that type of thing is delivered. It's all about let's just design this building and it has all the bells and whistles, and it's a 5-star building.

To me, we miss all the important stuff, and I see this is the only time that these students they're going to have any information fed to them in relation to building in remote and very remote areas. If they're out there in private practice and they get a chance to tender on a project somewhere out in remote or very remote regions, they are going to go broke. They're not going to be able to deliver. There are just too many things standing in their way that will kill them, and they don't know. And so that's where I should be giving them that information.

I don't think I had near enough time to give them feedback. If I'm the client and you're the engineer/architect delivering a building for me, I'm assuming that you are giving me information quite often, and I'm going to be giving you feedback. I didn't get that. But on the other hand, I'm pretending to be the client, but really I'm not the client, and there's a lot of time involved. I'm not being paid anything for time. I'm a busy man, like a lot of people, like all of us. I'm running several different things, wearing several different hats doing several different things, and yes, I'd love to be giving more feedback, but I don't get paid anything for my time.

Q5. How did students cope with balancing aesthetic/functional design aspects with engineering concerns? What was the impact of engineering and architecture student collaboration on the project outcomes? What impact did the timing of the engineer/architecture collaborations have on the development of the project?

I never really saw all the final results, so that's a bit hard for me.

In relation to engineering, I had suggested in the break, that we use solar powered aircon units, which I have in my home, which I've used in Western Australia. I've used remotely, and cut my energy consumption 90%. I have a project at Halls Creek. I cut the energy consumption by 90% there, in a block of units for aboriginal medical staff. I asked that we employed that in our building concept. As far as I know, that wasn't done. I see that more as an engineering type theme, that wasn't covered, wasn't talked about and again maybe it had to do with the brief being rewritten, and that wasn't an important point outlined.

I didn't see any detailed sectioning, which I think is critical. I really like to see that so that I know they got a handle on how this whole thing goes together. I wouldn't necessarily expect for an architect to understand that. They could just look it up on the internet. For an engineer, I think they should know those things. I didn't see any of that.

Q6. What did students struggle most with when asked to advance their design-thinking with environmental/engineering constraints in mind?

The very first presentation, the students had just jumped ahead and done some modelling. They had a structure there, and they were presenting that and what they've done, a little bit of a walkthrough. And I'm thinking to myself "Wait a minute. Where's the brief? What are we addressing here?". As a client, I would want you to be saying, "You asked me to do, x and so therefore I thought about that, and I thought the best way to deliver x for you was for me to do certain things". I don't need to see a building that's been modelled for you to show me that, I just need for you to reassure me that you understand what I want, and you'll give me some feedback on that. That's in the early stages. Then maybe down the road, the next stage, when you do have some type of a model, you ask again. You repeat to me "You asked me to do X. I thought about X, and this is how I'm delivering that within your building". I didn't really see that, and I think that's important.

It looks like I'm blasting architectural students, but again I'm seeing architectural students just jumping in there, getting into CAD and whipping up a model before we sort of refined it. Look at the brief, the detail, talk about how we're going to deliver the brief, develop the outcomes, and then do the modelling. I thought they have got in the saddle, but they forgot about the horse.

Q7. What barriers and constraints to architect/engineer collaboration exist (outside of the actual design process)? Time-poor/fees/contracts/…?

Well, all those (i.e. time poor, fees, contracts, etc.), but I think the number one thing is that, especially architects and some engineers, they come with the preconceived idea that they are the professional, and that they know exactly what the community wants, or what the client wants in that community. They want to build a new store. Well, you know, I just designed a new Coles store in Wollongong, so I know all about designing a store. But the reality is that they know nothing about what a store would look like in Wilpena, for example. We have no idea about how we get deliveries, where those deliveries are stored, what do we have in the way of cool rooms or refrigeration rooms or storage of vegetables or meat. We don't know any of that. We go there, but we don't really know anything about designing this store, so we come back to communications.

You see lot of these professional people, maybe on their website, or talking about how they had all this community consultations. In reality, their community consultation was more them telling the community what they've done, how bright they were, how they knew exactly what the community wanted, and they put their ideas onto the community. The community is sitting there, nodding their head up and down. "Yes, I understand". But in reality, they don't have a clue what they are saying. It is very difficult to develop that communication and that identification with community.

The second thing is that you might have a local person in Wollongong talking about aboriginal culture, and what's going on in Wollongong, but every mob is different. Some are good, some are bad, some are terrible, some are wonderful. You don't know what you're going in to, so you have to know some basic cultural elements, and you have to know who's who in the playing field, which is very difficult to learn. I've been doing this for 45 years and sometimes I still get myself into trouble. I think you have to be very humble. You need to listen more than you talk. They know exactly what they want, and you may realize, as a professional person, that you can't deliver that, but you take that on board anyway, and then you try to work your way around that to deliver what they want.

There are building codes and standards that we have to live up to, which they may not understand. However, I could cite a lot of examples of places in very remote Australia where you think "Why would I bother with a disabled car park?". I mean, would you think about putting a disabled car park at a store in a place like Belga in Western Australia. No. You wouldn't think about that at all, its not even a regional or remote place. Somewhere like Lightning Ridge though, you would. That's remote. But at Belga, very remote. Nope, you wouldn't consider that at all. The point is that you need disabled carparks. You have a lot of people there that might be in wheelchairs wanting that. So those types of standards, you have to comply to, and you must do those things. It all gets confusing because you have to do that. On the other hand, there are things that you would do here that you wouldn't do out there. It's difficult, it is really difficult.

Q8. How would you describe integrated design?

I think to me integrated design would be combining a local totem into the building. Take for example my students in Prague. At Lightning Ridge, I want to build a commercial building on a block that they (LRLALC) own on the edge of Lightning Ridge. They're totem is a long neck turtle. So, I had the students integrate the design of that long nick turtle into the building. They (LRLALC) absolutely loved that.

If you look around Australia, some architectural buildings have been designed exactly that way. They are very high-profile buildings, and the people absolutely love them. A lot of them are built from natural building materials. If you can use natural building materials in your in your design, that works wonderfully, because it's country. It's the things that they have at hand, they see it every day. It comes into the building and it's very important.

I think some communities are really passionate about dancing or singing, or various different things, and so your buildings should include that type of cultural significance for them. I'm not saying that they don't want modern buildings like what we have and Canberra, Wollongong, or Sydney, but try to incorporate some of these other remote things into this modern building, this integrated design. That tends to work very well.

Think of this idea of building something in a warehouse or in a factory and putting it on to a semi and float it to sight and erecting it, using that adage that we are going to hire locals to erect this thing which really is going to take 3, 4, 5 or 10 days. We're going to have this building that was build hear. It wasn't built there. It's steel and corrugated iron which you see everywhere, and then the builder comes back to the east coast and leaves this thing standing there.

These local men or women have maybe had 10 days' work, 2 weeks work, one month's work, and its finished and the building's there, but there's really no attachment to that building. It's not really integrated into that community. It's just something built by a white fella back here on the east coast and delivered.

We can see miles and miles of that in the NT, which is exactly what was done during the Howard Government intervention. Thousands of these things were built, and if you turn on NITV in the evening, probably once a week you'll see a thing come up "We need housing". So here we are, back where we started, another 10 years, and we put3 or 4 billion dollars into housing, and in 10 years we're back there saying "where is the housing". We just didn't try to really integrate anything, we just floated in some metal houses.

Q9. How useful was it for students to experience an integrated design processes as part of their higher degree education?

I don't know. I didn't get anything back from students. It would be very interesting for me to know what they thought, or how things could be better, or what they didn't get that they'd like to have, but I don't I don't know how to answer any of that because I wasn't involved with that. It would be interesting to develop some kind of a questionnaire for them. Maybe you've already done that.

This teaching on Zoom, my hats off to you, it's so foreign. I accept the fact that I do this with the Czech Republic, but that's on the other side of the world. These students are sitting just out there one kilometre away. I mean it's just hard concept for me.

I think it's very important for them to see a different side of design or engineering or delivery of a project. Is it made from mainframe stuff that we deliver here on the east coast? I think it's important for them to realize what's going on out there. I'm not saying a majority of students are never going to be involved in that, but I think it's a thing to teach them. For example, we talk about building code, and we say "Okay, well, we have this this national code that applies". Well, the truth of the matter is it doesn't apply everywhere. One of your students has a project that's, say, in Kintore in Northern Territory, and they designed this building, or they're doing the engineering on this building, or they're doing both. The communities (or the engineer) has engaged a builder and the builders there, and he's building. They might go there and there there's a set of steps, and they're walking up the steps, and they are all different (100 millimeters, 200 millimetres, 150 millimetres, 200 millimetres), and you say (as the engineer or the architect) "Wait a minute, this doesn't mean standard” and the builder says “Well, I deem that satisfied”. You can't do anything about it. Now that's just a simple example, but they need to know there are black spots or areas where building code doesn’t exist. They need to be aware of the fact that they need to stay on top of this builder.They'll never get that information unless we give them some basics, but they can't know everything. They need some examples of problems that come up, and how they can address those problems.

The point is it's all about risk. It's all about mitigating that risk and making sure that that risk does not become an issue. I’ve had a brief conversation with a professor at UOW about this, and they told me, ‘Yes, we we have a class for risk’. That’s great, but (to me) risk is one of the most critical things that we're involved with. Whether you’re an architect, an engineer, or both, when you're in the community, risk means everything. Mitigating those risks is important. If you're at a place where you drive across the river to get to this community, and you don't allow for the fact that that river could rise, you might not be able to get out of that community. You might not be able to get in to that community. Are you going to be able to get any building supplies in there? Are you going to be able to get your crew out of there? Is there a hard surface runway to get a plane in there? What is that going to cost you as the builder? Who's going to pay for that? It's a very major thing. Why would any students back here on the east coast even see that as a risk. They wouldn't. I can't teach them everything, but those are those are just a few examples of things that I think they should be aware of.

Well, I think studios are great, and I think they're a wonderful thing for students. I think they can really be developed. I think it's going to take a while, but I believe that it could come to the point that students are absolutely going to be queued up to get into that studio. They're going to want it, and there's not going to be space for them, because it's in high demand

I’m 75. I've been at this 45 years. Who's going to replace me? I'm actually worried about who's going to replace me, so those studios are a chance for me to find some young spark and see if they take an interest. Then it's a chance for me personally to give them some guidance and to get them on their way if they're keen on that type of thing. There is so much work out there to done, I mean so much. It could be a real career path, not for every student, but it could be a career path for a handful of students, very easily. I think it could also lead to some really great internships. I would love to have one or two students a year that I could take with me and explain things to them, so that they could then come back to Wollongong as an expert.

Interview 2: Integrated Design Studio 09 – Lightning Ridge LALC Multi-Purpose Building – Interview with Consultant 1 (Architectural Consultant)

Q1. What enables successful Integrated Design in the studio setting?

I guess that's a high-level question, and the high-level answer is that obviously a spirit of collaboration with the students, respect for the complementary disciplines. Maybe clear articulation of a brief. The difference between those two projects was a reasonably clear brief in Lightning Ridge and a bit of arm flapping at Unanderra. I think in terms of articulating the requirements, what are the students going to get from it, there's a whole skill set involved in eliciting a brief from a client. If that's one of the outcomes you want for the students, then that process probably needs to be a bit clearer. There was a lot of toing and froing because the brief wasn't clear, testing assumptions, then there is a little bit of push back.

So, clarity about the brief. If that's to be part of the learnings for the students, then that needs to be a succinct stage with some guidance around getting a brief. If it's not, if the emphasis is more on the collaboration of the design disciplines, then it may be that there's work done beforehand to have a clear brief with the respective clients.

Q2. Please tell us about the studio brief's impact on achieving integrated design solutions (considering the way it was written & communicated). Please reflect on the level of detail and the language of the brief.

Well, for both sides, and one less than the other as already alluded to, I don't think the brief was clear enough, so that made it harder probably from an advisor's point of view to test the success of the outcome. If the brief is not clear, then the outcome can be anything. So, the clearer the brief, the more rigid you can be about assessing the success of the outcome.

In an architect's office, and in a conversation that I had on Friday with experienced architects, very much the same. It was just that, a lot of it ran off on a tangent with some inspirational ideas but when you know what the bones of it are, what we are really trying to address, and that wasn't as clear. So this is not new territory, but clarity of the brief is critical. I'm going over old ground, but I think from an outcome's perspective, an educational academic excellence perspective, that is a skill set you're trying to elicit through the process. I think you do need to refine it.

It's not a big amount of time for the task to be done, and I think my suggestion would be that getting the brief is a whole skill set in itself. More work can be done, probably, with the clients up front to do that. Have that clear brief so that students can hit the ground running in terms of what they're trying to achieve, and that can be qualitative and quantitative, in terms of its spatial requirements and more qualitative outcomes that the clients are looking for.

The flip side of the brief is the site analysis. In my view, these two things should be clearly interrogated and articulated before design starts. The brief we've talked about, and that can be something that's handed down and clear, but then the site analysis really is something that they need to get their heads around, but that sort of tended to happen in parallel with the design investigation.

What we find is that, and this is true of fairly sophisticated clients, they analyse, then you look at the site through the lens of what we're going to do to the site, so that becomes quite filtered. Because your analysis happened in parallel with the design investigation, you had the similar things. There wasn't a lot of clarity (I think) around the site analysis before design commenced.

We talk about that as respect for site, particularly when there is an indigenous overlay, documenting all thenuances, climatic, the positioning of your adjacent neighbours, for example, at Lightning ridge, that was a constraint, the boundaries and the position of the [neighbouring] buildings, but it wasn't necessarily clearly identified before solutions were interrogated. Then design happens as a reaction to that, through the process, rather than that being a consideration that drives the design. I think site analysis, again, more guidance there. There's a hold point, would be my recommendation. There is a hold point in the site analysis before design commences. Stop here, show you understood what all the conditions, and learnings across teams. Things such as planning controls, climatic issues, views, a whole range of things that can be interrogated.

Q3. What were the most critical decision-making points/questions to answer when balancing architectural and engineering input for generating environmentally optimised design solutions? Where did the inspiration for the students' solutions come from? How did the engineering consultant(s) contribute to the authorship of those solutions? What was the impact of engineering and architecture student collaboration on the project outcomes? What impact did the timing of the engineer/architecture collaborations have on the development of the project?

This will sound like a broken record, but my pitch would be that if we continue to design big boxes that are ill considered in terms of layout functionality and then throw technology at them, where we're pushing the proverbial

How hard is it to show furniture on plans? and how many bloody times did I say that through the course of the [design studio]? I'm still getting to the final design, and we've got these vacuous spaces, where they've got no idea of how those spaces are being used, for the simple task but actually putting furniture on the plan. And so, some responded to that, but largely that seemed to fall on deaf ears. It's easy. I've been doing this for a few decades, so what's the height of the kitchen bench, what's the size of the dining table, all those sorts of things that are new territory, they're exploring, but these days, it's very accessible on the internet. So, in the final designs, at that point the horse has bolted, there was no point to try and critique at that stage in terms of the final presentations. Even the final presentations, there was some fairly ill-considered spaces, that then were getting some fairly sophisticated analysis in terms of the energy and the rating.

So, I can talk from the architectural perspective. This a balance in with much of what you're doing and projects I have been involved with. This line between getting the engineers generally sympathetic to the architectural input, and understanding the challenges that have associated without necessarily being architects. And we [architects] do the same. I mean as architects we've got our image, and we need to respect the engineers and understand what their drivers are and where they are coming from. So I think there's a whole skill set that is associated with the analysis of space, ergonomics, movement. Things that are… like designing a set of stairs has got a whole lot of constraints about it. So that could take the students a week if not several days just getting around riser heights, what's an efficiency and how's that work. So they're things that they are learning on the run. So that's great, that's an appreciation of the sensitivity. Again, I'm not saying anything new here but a test for me, and it's a test for any project we work on, is to show furniture, and that quickly shows *is it effective use of space? and how is it working?*

I've had clients over the last days where I have had conversations where, first and foremost, I want to understand how you live. How are you actually going to move through the house. Where are you going to have breakfast. You cant tell that if there's no furniture shown. It's just as simple as that. So that's a pretty easy requisite to have there that tests that. And whether an efficiency of the process some of that base data is provided so that you haven't got three teams running off trying to work out the size of a dining room table. I don't know how to actually facilitate that, so it heightens the sensitivity, but it doesn't take a whole lot of time in their research that really should be put into their area of expertise.

This is one example so maybe this is more specific than a generalization, but, I think some became enamoured with a particular material, and that drove a lot of the design. There was some earth walls or rammed earth. Probably, for obvious reasons, was an aesthetic consideration during the course, and even in the final presentations. When pressed with some questions, there were some fairly flimsy answers in terms of its real practicality in terms of building material. At the time, there were comparisons being made to filling tyres with dirt. Rammed earth is very labour intensive unless the soil right. So, it seemed the driver for that was the aesthetics of the material. For one of the designs, the wall was shown to be about 100 millimetres wide, where it's going to be at least 300mm, so there was no sensitivity to actually what that material really was in that investigation.

I think for some it was material, and that probably drove some of the design decisions. For others, the fact that it wasn't as apparent might be telling in itself. I think in the design process, the site analysis and the briefing, the next step is to show your design principles, rather than simply being an assumption or an underlay through the design process. I think if perhaps if we had seen design principles articulated a little bit more clearly then you would have more of a sense of what the inspiration was.

I don't think the inspiration was terribly transparent in the designs. It was the pragmatics of the space. Not one [design] comes to mind where I think there was a strong inspirational design principle driven solution that was very evident in the outcome. I sense it might have been easier for the engineering consultants to offer more specific advice. I found that it was a little bit encumbering from the format. It was hard. If it's more of a studio in a workshop session… we did similar things here with the Solar Decathlon. I sat here [for the interview] because we ran some in the office here. Where you've got people around the table, you've got a task, go and do a little bit of work and let me come back and have a look at it, it was a much more productive process, rather than an hour or two’s conversation, and then away for a week, and then whatever direction that had taken. From the architectural perspective, that was a harder format to be constructive, and perhaps as a result, it was seen more as critical because your reacting to a week’s work rather than seeing something in process and a goal.

Leading question: Did you see any evidence of collaboration between the engineering, architecture students throughout the project outcomes.

No, not through process as much, I dont think that was transparent. I think in the outcomes you can see where there might have been the architectural [input], and the presentations may be an indication of where input might have been guided by the architects. I think each team had one architecture student on, but, I guess the other side of that is there didn't seem to be tensions, they seem to be cooperative teams. I'm hard pressed to think of specific examples where there was an engineering solution modified by an architectural imbibe or visa verse. That probably wasn't a clear, it might well have happened in the process, but not transparent for our involvement.

Q4. What guidance by you was most useful for the students (and why)? How did your input increase their ‘level of understanding of’ environmental issues and associated solutions? What would you change in order to maximise your input (if anything)?

Some of it was fairly pragmatic. We had one of the Lightning Ridge [teams] designing the walls were pitching at about one and a half meters. There was just quite pragmatic thinking in terms of building code or just practicalities of building that gave some guidance. I think just the challenge in how the spaces were being used was probably the most value through it from an architecture point of view. From a passive design perspective, rather than the technology, more just in terms of orientation and solar access. Highlighting those issues and getting right into the building, into the quality of the space. So probably more of a quality of input rather than more the empirical that would be coming from the engineers’ solutions.

In the time frame, coming to terms with the technology and the CAD systems is just a disproportionate amount of time for the outcome. It is a real skill. I've just finished interviewing 15 graduates for new positions, and same thing, we get portfolios. The outputs become so ubiquitous in terms of the CAD presentation, and this is where I think where we got, the jury, at the end. It makes the other jurors impressed, with the walkthrough or the fly-through, but from my perspective, it may actually just be revealing some poor considerations in terms of architecture and design.

I think for all of us, it's very easy to get enamoured with the presentation and the 3D skills, a lot of time goes into that. There's got to be other ways around that so that their time is better spent, that might be limiting. A lot of the planning can be done with paper-mache. I'm exaggerating a little bit there, but it can be done cut and paste and pencilled in. You don’t make a model to assess the sustainability outcomes, so I think there's a point at which both tools should be restricted, because people get very excited about the tools and that becomes the driver rather than the outcome.

I think the architecture inputs seen in some of the projects… the architects on the teams were the ones that have driven the 3D modelling and the CAD. They were drafts people there. A solution might be to outsource that at the end. You have CAD people come in that actually document the design. It becomes a bit of a leveller in terms of output, and then the presentation is more about the content, rather than the image. So what the solution is, it’s worth a bit of a workshop or talking it through, but a lot of the energy certainly did go into the CAD presentation, and in some ways I'd argue that probably obscured the detail of the design rather than necessarily helped to clarify.

The other thing they did, just in terms of presentation skills, is that they get caught in an A4 format, or an A3 format. The drawing becomes a presentation on the screen, and I'm finding that here in the office too as we do more and more by zoom for public meetings and various things. That format is a presentation itself. There's probably really only one of them that comes to mind that actually managed to distil that information down into a presentation format. Maybe one of the workshop series is some guidance around that, so they're not just presenting drawings where it is very hard to see the detail. It's just as a drawing on the screen. That's a fairly basic skill that a lot of people fall into, [not just] students.

Q5. How did students cope with balancing aesthetic/functional design aspects with engineering concerns? What was the impact of engineering and architecture student collaboration on the project outcomes? What impact did the timing of the engineer/architecture collaborations have on the development of the project?

I didn't see an engineering solution driving an aesthetic outcome, which can be the case. Sometimes it's actually the engineering imperative that demands a structures size or positioning, that then drives the architectural aesthetic. I'm not sure there was that. I mean, calculating PV areas, driving an area of roof, that then dictated a roof form, there was that. Collaboration in terms of roof area, solar collection and orientation. Other than a few [groups], they struggled with that, and might have the roofs facing in the wrong way. To be honest, I didn't see the impact of either of engineering or architecture having an impact on that. It's hard to answer. It shouldn't be so hard should it.

Q6. What did students struggle most with when asked to advance their design-thinking with environmental/engineering constraints in mind?

Im sure it will be different for different consultants, but I think the planning issues that was challenging, that then had an impact on design, and I was driving that, very much less from an aesthetic point of view, but more as functionality. You know, *how many people are in that space?*. Coming back to the trope for that was just to show the furniture. I think they struggled when asked to advance the design thinking, and you then you qualify that side of the environmental engineering constraints.

The struggle I saw was understanding spatial requirements and spatial interrelationships. I think that (for me) it comes back to just the base knowledge required and some of the sort of fundamental planning, architectural issues. That wasn't front of mind for them, it was quite dismissive. Great lumps of space were shown and then quite a lot of work was done.

I think what you'd like to have seen more is a broad concept, test, measured, volume, oriented, those design iterations back to engineering input, and I didn't see that. I struggled with the architecture, or the planning, a solution that really didn't vary much despite the commentary, and then the science overlaid that in terms of the engineers, and the metrics that was done at the end. I didn't see the iterative process or the toing-and-froing that I probably would have liked to have seen or expected in an architecture space or with engineering collaboration.

I think it's a little bit tied back to the technology too. We find this in practice too. We come up with a concept, it goes to the engineers. That might be just a structural level without sustainability, but you got the intuitive rule of thumb response, and then you're sort of responded to that designer. What you get is the full computer printout based on the concept, and then you come back and say “Oh, that's good, well let's change this”. “No, no, we have spent our money”. All the engineers are so far down a particular solution, it's not coming back. So that's hard for us really. [They] are looking more for a hand-in-glove approach where the initial idea is loose enough, test the principal, push back on that, and then the design evolves in responds to that.

I think in this case, product of time, product of the technology, limitations of only meeting over zoom meant that… and probably partly too that you've got engineers struggling in a different realm in terms of the architectural planning, a lot of energy going into that probably, I thought without a whole lot of consideration of the sustainability outcomes, design solutions, they're 90% there architectural, and then the overlay of the engineering analysis.

Q7. What barriers and constraints to architect/engineer collaboration exist (outside of the actual design process)? Time-poor/fees/contracts/…?

We covered some of that ground, I think, more of an iterative process. We are looking for engineers to have that lighter approach initially, looking at broader concepts, and the simplest examples but leads more into the structural area. But, before the technology takes over and your so locked into a solution. I think for engineers, and I'm sure there'll be counter comments from engineers regarding architects I can well understand… Look, I'll give you a little example. I had a couple in here, that I have met through other circles and just want a bit advice on alteration in addition. He's in engineering somewhere, and she's not in the university, but is the wife and there is a couple of young kids. So, they bought a house on a plan and in my time I have done a lot of alterations and additions with them, understanding the psychology of space. We just sat here for an hour, and they've clearly struggled with this for some time. It's a house, an alteration, addition, how do we move some walls… and as a good engineer, gone into the *Can we move this wall here? What's the structural point? Will I need a beam?*, and I'm saying *Stop! Stop! Stop talking! Just tell me what you're trying to achieve? What's the fundamentals? How long you're going to be in this house? Five year plan? Ten year plan? How old are the kids? In five years time, the kids, are they going to be in those bedrooms or not?*. After an hour's conversation, the look on their eyes was like, I was Jesus come to life, because I was just saying *You know what? Your master bedroom is on the northern side of the house, it's getting all the sun. Where you're trying to struggle and fit this living room, its not going to see the light of day. Swap the master bedroom and the living room. Minimal structural change. I don't think you need to plan for this*. They're talking about DA approval. You can do this. Somebody told me $50,000 worth of work if your lucky. Really, they are just so into the detail of the minute. They live there. People get into their patterns of behaviour.

And so this is coming back to my comment about the briefing process. Unless you're really asking, *What are you trying to do?* and drill down to that and have the principles. And its a lot of fun! So there's probably a good example that engineering thinking as *What we would add* versus an architect. And so there's that really exemplifies these two aspects, and admittedly I'm only looking at a set of plans, haven't walked over the house, but that gives me some objectivity. I'm asking *Let's think about the house separately. You tell me what your desires and aspirations are independent of that house.* You've actually got a brief. The solution might be to sell the house. So you're stepping right back. That's why I've got a sign over the front door down here at the office [that says] "The solution is not always a building". Listened to your clients, see what the outcome is.

So that was just engineering thinking, very fixed solution, narrow down, collaborate, and understand, but get the brief right and understand the site and it's amazing what the solutions can be. But how do you actually snapshot that hour experience into a studio and have that sort of… we work a lot with groups, where you work collaboratively together, and it's not me handing down from on high. It's something we've talked through and got to together. It's not me dictating "I think you should do this and this", and there's a whole lot of resistance. We've actually had a conversation about where it's true. It's not so metaphorical, its what is stuck in their head because it's just so obvious at the end, and you get that obvious solution.

It would be great to capture that in the studio where you do have that toing and froing. And again, they came in with a set of plans, that happened to be in a plastic folder, one of my guys here went up to the whiteboard and grabbed a whiteboard marker, and we just put pen over the top of the acetate. "No, rub that out, that's not working, do something else", and you're not caught in the technology. The solution is accessible and immediate and collaborative. Whereas *stop now, we're going to go away and do a 3D model for you*, now we're invested, we're locked in, thinking is limited. It's just quite a different experience and approach. I think the analogy there was more about, yes their clients, but they're also two engineers. It's the perspective of an engineer in terms of, admittedly, their own home.

Another adage is *good builder, good architect, there's nothing you can't solve*. It's interesting working with builders because they see everything stick on stick. Most builders, either in their nature or their nurture, have no image of the final outcome. They see the next, I say stick on stick, but the next element to go into that. As an architect, we're probably guilty of seeing the vision but not necessarily how the sticks go together, but you get those two mindsets together, and my adage is *good builder, good architect, there's nothing you can't solve* because you bring those perspectives together. So how you do that in a format where there is that mutual respect, and I'm not saying that wasn't there, but the tools in the environment in the current context that we're working in made that more difficult than it usually would be.

I do think technology in the early stages is a limiting rather than enabling factor, depending how to use that. It comes back to what I said at the outset, I think that clarity of brief, and in our two projects there, it didn't come from the client. It came a little more-so from Lightning Ridge, but quite frankly, and im going to give you negative feedback, I know *IDS12 Client*, I've worked with *IDS12 Client* … well I haven't worked with them, but I have had a conversation with *IDS12*

Client. *IDS12 Client* should have been a lot more respectful in the process, frankly. They didn't commit, was late at meetings, didn't contribute, so they didn't get that client feedback through, and that probably needs to be held to account too. They are very much on the run and thinking that this is as far as it goes. That's really hard from a designer's point of view, because you're down at concept and then somebody throws another bit in, then you revisit, or it becomes a bit of a compromise to the process.

I think talking through more and more, the brief is something the organizer could have sorted out and thrash through with the client because the client won't necessarily behave through the process in the limited time. Have that clear, and then let the students concentrate on the site analysis and ask the questions about the brief and understand that sort of process.

Q8. How would you describe integrated design?

Collaborative is obvious, and that's an understatement, but it needs to happen early in the process. I suppose the test is that the outcome is a solution that is optimal, both in terms of the architecture and engineering. You don't have an ideal architectural solution that then is struggling from an engineering perspective or needs to be compromised and vice versa. How you measure that at the end, I think it comes back to the brief. The brief needs to be clear, to be able to see whether you have achieved what was asked for at the beginning.

So, starts early, obviously collaborative, there's respect, and that all parties at the end feel that they've achieved the optimum outcome. There are always constraints, whether its… there may well be an architectural constraint driven by a client, a planning requirement, or something that's outside the clients requirements by planning controls or council. But then how the engineering solution works to address that is probably the test of a good result.

Q9. How useful was it for students to experience an integrated design processes as part of their higher degree education?

The principal I think is fantastic. Obviously the involvement Solar Decathlon was a much more intensive, longer term example of that, but I'm sure those students came out of that, perhaps taking different career paths, and that was from a lot of different disciplines across the University, so I'll come back to the Solar Decathlon as an example of heightened sensitivity to architectural issues through an intensive project, the principles. Right on. That's fantastic.

I think more thought into how you then manage that, take the Solar Decathlon, that's over years, and build outcome. But in a short time frame, what the learning objectives are and how you make the most of that in the time, probably that's where it needs further thought.

Interview 3: Integrated Design Studio 09 – Lightning Ridge LALC Multi-Purpose Building – Interview with Consultant 2 (Structural Consultant)

Q1. What enables successful Integrated Design in the studio setting?

The last semester was a bit different I think to the first semester last year. I suppose it was all online rather than in person, so I guess it was just always going to be very different. I think some of the successful things from last semester that I saw as people were trying to grapple with doing it online was… I think it worked really well when... one answer to that question is finding ways that allow people to share ideas, which is especially hard in the online environment. The architects suggested this Miro board platform. I was in a few of the sessions where they were using that, I think that was really helpful.

One thing that enabled the successful studio was finding those platforms that just encouraged people to share ideas and gave them a collaborative space, so I was pretty impressed with that. Reflecting on it, in some ways I think some of the discussions that happened around that were probably as good as when we were in person. I dug out some of the Miro board stuff, some images of that. I remember it being quite a good tool, people would drop images in and you could actually talk about an image or some text, but as you know, when you're on Zoom and there's a group of people, it's so hard to get people to talk and discuss and share ideas.

So, I guess the idea there, the successful studio thing was finding those platforms or those spaces for people to open up and share, that's true across all the studios. It's a hard nut to crack really. When we're in the room, or when we're online, finding the right format for our studios that gives people the confidence to open up and to share ideas. So the architects were quite helpful bringing that to the last studio.

Q2. Please tell us about the studio brief's impact on achieving integrated design solutions (considering the way it was written & communicated). Please reflect on the level of detail and the language of the brief.

I think we talked about this for the first semester. The briefs, I think they were good, just like in the first semester. They were sort of very open ended, and actually it's good for the students to get these vague, ill-defined briefs because they reflect the real world and real projects and it's not so prescriptive. One thing I've seen all last year is that a big part of the first half or more of the semester is just the students almost trying to figure out what they need to do, because the first assessment is writing a return brief. I think that the brief, it kind of is probably the right level in that it does reflect kind of what a real project would be like.

I think just like first semester, having that client come online, talk about their projects, talk about what they want to get out of the studio, that's a really important part of it. For both of those projects last semester, having the client come on and talk through their project, talk about the information they have, the information they don't have, what's important to them, that's a big part of that brief in a way. That's another sort of real life experience of just hearing a client share ideas from their own head and get a feel for what they want to get out of it. I think it's necessarily messy in that way. And the [architects], they did a really good job with students, helping them to work through that. Just saying, "You've got all this information. How do you take the brief from the university, the client, your own ideas, and get something out of it. Define what you're trying to do".

I don't remember specifically how detailed [the briefs] were, but I think they were reasonably detailed. I think it was the right amount of detail. At the end of the day, you can have as much or as little as you like to reflect a proper design studio. It was fine in that a big part of the design studio was just getting the students to go and figure stuff out, but after we went over it with the clients, there were lots of questions still outstanding. At least everyone kind of knew what they did know and what they did not know, and what information was available and wasn't.

For the police station, there was some drawings but not really anything about the structure. For Lightning Ridge, it was just a blank canvas really. It was just a blank block and they could come up with anything. There was no kind of stimulus in that way like the brief. That one was almost an architectural exercise for them in lots of ways, because they had to invent the shape of the building.

Q3. What were the most critical decision-making points/questions to answer when balancing architectural and engineering input for generating environmentally optimised design solutions? Where did the inspiration for the students' solutions come from? How did the engineering consultant(s) contribute to the authorship of those solutions? What was the impact of engineering and architecture student collaboration on the project outcomes? What impact did the timing of the engineer/architecture collaborations have on the development of the project?

We talked a little bit already about that interview with the client. Whenever the client's going to rock up and you have that opportunity to get their feedback or quiz them, that's really key because that is a point where you really find out if you're on the track or not. On Lightning Ridge, the critical questions to answer were probably around... it's interesting because it was just this blank canvas. I think that question of "just what is this space? What's it used for?". I think once they had decided "All right. We need this much space for this activity, this much space for this activity", and they developed some idea of what this building would look like, that was probably a critical question that all the other discussion around environmental design solutions kind of flows from. So for Lightning Ridge it was that first question of "What is this building?".

The police station was different in that way, because it was fundamentally a different project, the refurbishment of an existing building. For the police station, it would probably... Well, I guess to be fair, it's probably the same question in another way. "What is the use of this building? What are we going to do with this building?" They still had to answer the same question of "What are we going to do in here and what space do we need for this?" And then once they'd sort of answered "How are we going to reuse this building?", then all the other questions about sustainable options and systems are a response to that. Actually, I guess even though they're pretty different projects, that core question of just understanding "What are we doing with this space?" which actually took probably the first half of the semester at least was the key question for that. Once you've answered that question, all the options for environmental design solutions just flow from it.

It was interesting having the Edmiston Jones architects on the studio, because I think did make it a very different sort of tone. The stuff that we talked about was very different to the first semester. It was actually really good to have them there because there was a lot of architecture to think about. In the first semester, the library and the Lendlease project were very defined. They already knew what the building was, and it was just "Here's a building that people want to build. How could you make it more sustainable?", but in these two the projects were "We don't really know what these buildings should be. What could they be?" And then once you figure that out, what's the response?

It was really good to have the architects there, because they were able to help the students through the process of developing a site analysis. Getting them to work through a site analysis which thought about "What's around this building? The sun, the wind. Who are the neighbors? Usage of the space". The inspiration for those solutions, a lot of them were directed by the architectural consultants. But the clients, so on Lightning Ridge, the client directed a lot of that as well in terms of the I guess... Because it needed to respond to lots of Indigenous stuff, a lot of the cultural things. Those specific cultural things that it needed to address; he talked a lot about how to respond to that. I think he was very non-specific, but he reinforced that the building needs to consider the cultural significance of what it's doing.

On the police station one, I don't know if there was much inspiration. When you're developing the technical kind of just solutions that are out there, I suppose the police station was probably more... There wasn't that much opportunity for responding, lots of inspiration in that way. I guess they could be creative with the way they use the spaces. Maybe I'll just say I think the architects contributed a lot in that studio. I think the first semester was fine without them, but when you have these blank canvas projects where you do need to invent a lot of architecture, then, it was really great to have them there.

Q4. What guidance by you was most useful for the students (and why)? How did your input increase their 'level of understanding of' environmental issues and associated solutions? What would you change in order to maximise your input (if anything)?

I think I said this for last semester too. As a structural engineer, I'm a bit of a passenger technically. In the structural world, we've got lots to contribute. But for these studios, there's not a big structural emphasis, which is fine. I think just like last semester, I saw myself as being someone who could be in those discussions and be asking questions as much as providing solutions, trying to be the person who could keep the discussion moving by asking questions of the other consultants, or trying to dig out a little bit of information on this side or the other or sharing ideas.

I'm happy to be there and be involved but I'm not a core part of that process. The role of the structural engineer is to be there for when the structural or a civil thing comes up and people need some direction, but that's not really the emphasis of the studio. I think trying to find a space where you can be a helpful person who moves the discussion along and is enthusiastic and asks questions and sort of... That's what I've sort of figured out, why would you bother having a structural engineer in the studio? I think that is useful, especially in the online world, because a big part of the reason that we have these studios is because everyone recognizes that having these discussions and the process of design is not something that is natural to anyone. It's a learned process, and part of that is, a lot of us as consultants, we're not trying to give them the answers, so much as to model how to design things. Hopefully, part of our contribution is the students hearing and listening and engaging with consultants who are engaging with each other and the students. It's all about learning how to design. No one teaches you that. Most of us just learn it over the years of just sitting with people and interacting, it's this sort of intangible thing that you just sort of learn by watching people. No one can really put their finger on what it is. I don't feel like I'm a passenger, I've sort of realized that just being a part of the conversation is a valuable contribution of a consultant.

At the start of last year, the first time around, we were all figuring out what it means to be a consultant in the studio, So this time around, I definitely had more of an awareness of what we just talked about. I went into this past semester knowing that there wouldn't be a ton of structural content, even though there were certainly some questions on both projects that I was able to respond to. But going in with more of an idea of what I was there to do, and probably because it was so much online, it was helpful just to have someone, especially online, who can try and keep the conversation moving, and ask questions. Especially with architects, you can sort of dart it back and forth with the architects. Maybe I just understood that a bit better this time around.

Q5. How did students cope with balancing aesthetic/functional design aspects with engineering concerns? What was the impact of engineering and architecture student collaboration on the project outcomes? What impact did the timing of the engineer/architecture collaborations have on the development of the project?

I think [the students] did a pretty good job of balancing all that. They had tough job this semester. I think this studio, it must have been a different emphasis on the work for them because they had to develop all this architecture, site analysis, and floor plans and stuff like that, where a lot of that, they probably didn't need to worry about. Considering that, they did a really good job. When I was putting the vetting reports together, there's some really cool renders and stuff that they made. That idea of the site analysis that the architects worked through with them, they did a pretty good job of engaging with all that. I'm no expert on the aesthetics of a building, but I think what they came up with is pretty good. Sympathetic, as they say, to the brief.

It's always hard. No, in the sense that when you're in the studio, you don't really observe the students collaborating that much. I always assume that's because they do that outside the time, and a lot of what they're using the time in the studio for is to interact with [the studio tutors] and us. I guess no. I don't know if that's good or bad. I think it's just, that seems to be how it runs, especially online. In the first semester, you could see a little bit of them chatting to each other. But when it's online, you don't really see that at all.

Q6. What did students struggle most with when asked to advance their design-thinking with environmental/engineering constraints in mind?

It's hard to know what they struggled with. You only see... I don't really know what the answer to that is, because you don't really see them struggling that much in the studio. I suppose the questions they ask might reflect that, and then what comes out in the assignments at the end is, this is what they picked to run with.

I'd say, I think the site analysis and the architectural stuff, again, was maybe a new thing for them, but I don't know that they seemed to struggle with it that much. In terms of the environmental stuff, the environmental solutions, I don't really know because I guess not a practitioner of a lot of the ESD stuff. I don't really get a sense for what they find hard and what they find easy, or what is hard and what's easy. Actually, I did observe the modeling. They make their model, their sketch up model. And then they run them through the analysis to do all their modeling of those buildings. I think there's a pretty broad spectrum of students that find that easy and find that hard.

In both semesters last year, there were students that found that really hard, building the models and then interpreting them. The last half of each semester what I observed was that some students really needed consultants to come and sit with them and help them know how to build the model and then how to analyze it and then how to interpret it. That that makes complete sense. Modeling stuff and analyzing is just hard, especially if you're trying to learn it by yourself. I suspect that a lot of the non-analytical stuff is probably pretty easy, because they're students and you're researching and writing every day. A lot of the solutions that are non-analytical in that way, you kind of know how to do that. That would come from the course content. But building models and then analysis and knowing what it means, it did seem like a lot of people struggled with that.

It's like that in the structural world as well. Like if you build finite element models of buildings, it's hard to build a model properly, and then knowing what you're looking at in a finite element model is very difficult. It's something that takes years and years of making mistakes to get any sort of confidence in. I have no idea what these models are that they're making, but they're very impressive.

Q7. What barriers and constraints to architect/engineer collaboration exist (outside of the actual design process)? Time-poor/fees/contracts/…?

Money is a big barrier, in that the fees that we get paid don't usually allow for the level of collaboration that we would like to have. I think collaboration is harder and more work and people have to be invested in doing something above the minimum standard. It's just easier for people not to do it. You just design the building that you're given and don't ask too many questions, and just do the bare minimum. I think that's probably the default for lots of projects, because everyone's pressed for time, and they don't have the money. It's not always that you have the conditions where you can fully invest lots of emotional energy in making something really good.

Sometimes you get a project where everyone is on their A game and wants to do a really good job and keen to collaborate. That's when it goes well. They're pretty intangible barriers. I guess money is pretty tangible, but I don't know that just throwing more money at it would make people collaborate necessarily. But I guess it's a barrier. We don't really have excuses for technology or anything anymore. In some sort of weird backwards way, almost the ease of video conferencing is a barrier. Meeting in person and physically drawing and having workshops in person, I think there's just something there that you don't get online. So in a weird sense, having the luxury of being able to do video conferencing and video workshops is a barrier to that kind of collaboration. If people can work remotely, then I suspect any sort of collaboration that happens in a design studio sense is just not as good as if people sat down together in the same room. It's like, a barrier of convenience.

Q8. How would you describe integrated design?

When it works well, it's a little bit of what we've just talked about. It's about people being invested in doing a good job and working holistically in the sense that they see their work as part of a bigger picture. To do the job of the structural design, say, you need to do it with regard to all the other parts of the project. Same with the electrical consultant, mechanical consultant. Everyone's invested in having that holistic approach. Making that extra effort to collaborate, rather than keeping your head down and doing the minimum that you need to do.

Whenever that does happen, because there's lots of people out there that want to do a really good job, you just recognize that when it comes up. It probably does manifest itself just in people picking up the phone and talking to each other, or arranging to meet in person. Probably pretty broadly, technically, most people have the same skills. It's not like I can design a beam better than anyone else, or a mechanical guy sizes a duct better than anyone else. You'd probably come up with the same design. But it's about having the appreciation for the bigger picture.

Q9. How useful was it for students to experience an integrated design processes as part of their higher degree education?

It's really useful in the sense that maybe it gives them the feel of what they want to do after university. Some might through the studio and say "This isn't for me, this is like pulling teeth", and some might go through that and say "Oh, this is fantastic. I love working on these problems, with teams of people, and thinking through lots of different options".

It does sort of represent real world projects quite well like that. I think it's useful for the students. I assume it's useful for the clients, I suppose even they're not getting... it's not the same as if they went and paid ARUP or someone to do a report, but I think what they produce is really good and a really thoughtful summary of things that they could do for their project. I hope that at the end, the clients are happy with what they get out of it. As a thing to do at university, I assume it's a good… something different for the students to do where they're not sitting in a lecture or a tutorial. I think it's definitely worthwhile.

Interview 4: Integrated Design Studio 09 – Lightning Ridge LALC Multi-Purpose Building – Interview with Consultant 3 (ESD Consultant)

Q1. What enables successful Integrated Design in the studio setting?

I think what makes it work is you have people coming from different backgrounds and different experiences collaborating on the project. You don't have a room full of architects, or a room full of engineers. You've got a combination of that cohort with a different focus, which allows people to champion their own agenda, and ensure that the outcome considers, not just one element of a requirement, but allows you to consider other people's views, and ensure your design response is sympathetic to more requirements of the project than just your own element.

In both of the studios, the best architecture that gives you the best, whatever best is defined as, in terms of aesthetic or efficiency in the floor plate, is always balanced between what's possible from a structural perspective, what's possible from an engineering perspective. [This] is always one of the challenges that we find in the real world, someone will come in and design a project day one, and they'll do what they want, and it won't consider anyone else's needs. It's good to allow people to witness and experience the different requirements up front. I think that's what makes it a success.

Q2. Please tell us about the studio brief's impact on achieving integrated design solutions (considering the way it was written & communicated). Please reflect on the level of detail and the language of the brief.

This is stretching my memory. I wasn't fully involved at the front end of this. My understanding was the Unanderra brief was written by a client who owned the building, but what he'd written down was kind of what he thought people wanted to hear, and wasn't strictly what he actually wanted to do. That was a really interesting experience, probably a good experience for students, because all of a sudden you learn that what the client says or asks for isn't necessarily always what they mean. And part of the challenge was to understand what is it that you are really are looking to do. What are the challenges?

For example, he was saying, we want a café, we want all these workspaces, and we want this, and this, and this, and when we started to put in all of that, we're like "well, wait a second. This is never going to pass any planning approval. You're never going to get anywhere near the space or the size of all these things". All of a sudden, the cafe was two meters squared because that's all the space that was left. And you sit there going, "Well, the brief was poorly written because he'd set such a big challenge". And it led to poor design outcomes because the students weren't willing to say "You can't have everything in the brief". In the pursuit of perfection, to satisfy everything he had, the quality of the design was reduced.

It was a great lesson to learn that the importance of writing a good brief at the start directs what people will do. Perhaps there needs to be a step in there about challenging the brief and saying how that could be resolved is have that session, sit down with the brief writer and say "You've asked for this, what do you really want? What's critical here? What's nice to happen? What's have to have? What's absolutely mandatory?" Because, all of a sudden we found out we actually don't need that. Or, "Oh, no, that would be nice, but that was kind of an out there idea I had." If we start taking the things out that were a bit over the top, then all of a sudden this actually does work.

From memory, the Lightning Ridge [brief] was a little bit less specific on what was required. This gave great flexibility, but also meant that you wouldn't necessarily get everything. The designs could have more flexibility in them because they weren't being directed in the same way.

One element was being too over prescriptive, and the other was being not prescriptive enough. Simple methods of communication, like a table that says "Office space - 3x 60m^2" are things that the project team can start to work on. Have the mandatory spaces and the ideal spaces, and start to judge them. So, there was a bit of the element of too much flexibility on that [brief].

Q3. What were the most critical decision-making points/questions to answer when balancing architectural and engineering input for generating environmentally optimised design solutions? Where did the inspiration for the students' solutions come from? How did the engineering consultant(s) contribute to the authorship of those solutions? What was the impact of engineering and architecture student collaboration on the project outcomes? What impact did the timing of the engineer/architecture collaborations have on the development of the project?

What was really good was having the architects involved quite early, particularly on the assistant side, because they could at least point [the students] in the direction, to say "These are the things the project must have". Obviously we want to design it from environmental principles from the get go, but we have to comply with DDA. We have to comply with access, have minimum amenities, and the structure and that. They can say, "Yes, we really want to achieve that, but the building doesn't work without these elements". I think that was really good for everyone to understand. "I want to achieve the greatest sustainable outcome; however, I know I have to provide these other elements".

Having that architectural input from the get-go for the students was incredibly beneficial, as well as having combined workshops. Particularly early on, so that they can get professional advice before they go off on their own tangent and get a little bit lost. As well as working at the same time, and having two people in the room so they could hear the conversations and understand the philosophy from where the engineer would come from, to say, well, give them a chance to challenge the architecture, make the architecture work harder. Which worked well.

The students had their own ideas, and they were pretty good at coming up with ideas. They looked at other buildings for precedents, which is good. They were good at going out there and trying to find sustainable buildings that had been done either locally or nationally, or internationally, and assess what elements of those designs could work, and which ones couldn't, and bring those ideas to the project.

As a consultant, we tried of avoid spoon feeding them ideas, but at the same time, when they were drawing blanks, what we try to do is ask directed questions, or suggestive questions. Sometimes down the wrong path deliberately, to send them on the trip to work out that that's not a real solution, but also to spark their interests and get them excited about what's going on.

The engineering consultants were responsible for a few ideas, as well as making sure the students, what they were suggesting was a real practical idea. Sometimes the students would say, "We're going to follow Green Star", and you go "Why are you going to do that? What does that mean? Do you understand what that means for this project? What's the benefit for the project?". There's a lot in that, but what's the benefit to the client? How does it change the outcome? What does it mean? And we can educate them so that they can go away and make an informed decision, and go, "Oh, actually, we don't really need to do X, Y, and Z. It would be more relevant for this project to go and pursue these two or three initiatives that came out of that and benchmark these concepts, but not necessarily follow that specific thing", or "that's not appropriate for the project, and I know why it's not appropriate".

What I witnessed was less about the students collaborating, which I know they did, we did see that. What was positive to see was the way in which they collaborated. They were adopting technologies, and new ways of working together that are quite cutting edge. So, things like Moodle and screen share, the way they have continuous chat, they basically set up a WhatsApp group or whatever it is and have that chat going so they can constantly be sharing information and ideas across disciplines.

The other thing that works quite well is how they would divide tasks along engineering-architecture lines. They can say "Well, that's an architecture thing, so you can focus your energies on that, but I'll pick up the engineering side of this", Which is really good division of labor. They can both go away and study it, work out what's important, then come back and bring their learnings back to everyone, as opposed to what I would say a more traditional way of tertiary education, which is everyone goes and works out the same thing. You can learn for each other's study as well as your own.

Q4. What guidance by you was most useful for the students (and why)? How did your input increase their 'level of understanding of' environmental issues and associated solutions? What would you change in order to maximise your input (if anything)?

One of the things I really enjoyed was when we often got off on a tangent and stopped talking about the project, but it started questioning all things sustainability, and talking about industry experience, how things work, and start to explore more novel technologies, and work through the process of how those technologies work, and apply onto the project. So, a student's like, "Hey, what about this? What if we do that?" And I go, "Well, let's work through that example."

For example, on Unanderra someone suggested to look at thermal labyrinths to provide free conditioning. We weren't just saying "that doesn't work here" or "that's a great idea, go and do it", but talk about how that works, why it works, and what climate it would/wouldn't work in. What's almost appropriate for the project, and start to explain the physics in an example that they can understand. It's less of a lecture and more of just a discussion about a project that they are familiar with, it's a good opportunity to collaborate and understand that, and really get that message across in a way that they can understand. As opposed to just talking about a principle, they've already got the building in their mind. So you can talk about the building, as opposed to a foreign concept in a theoretical building.

I think one thing that would've been better would be to try and physically get people around the table. I think the whole Zoom thing worked really well, as far as it can, in terms of being able to come together and do something, and then back into rooms. And being based in Sydney, it was very convenient for myself being able to do that rather than making the trip down to Wollongong, but I do feel that ideally it would've been more time in the classroom together. I do think there is benefit in that face to face in particular at this this level of learning, and ensuring that everyone's collaborating around the table. There is something lost in the message when it's not face to face. It's tough. We made it work and it was good, but it is tough.

Q5. How did students cope with balancing aesthetic/functional design aspects with engineering concerns? What was the impact of engineering and architecture student collaboration on the project outcomes? What impact did the timing of the engineer/architecture collaborations have on the development of the project?

Through the process, the students were quite encouraged to start at a high level. Start by mapping out what they want in the space, and how it connects, and what the space looks like. Really mind map and blurred line space and say this is how the space works. We don't necessarily need have the walls in place and all that. But let's start with, with what goes where, and that meant that you could start to think about how the engineering would work around those spaces. They weren't setting the architecture and then putting the engineering in on top, which is what happens 99% of the time in the real world of design.

It was nice to see the architect saying "This is how the space will kind of go together, and this is how it work", and then the other students have the opportunity to come in and engineer that and say "We need to think about how this gets here" and, for example, "If you want this to be the break out space, how do we get the most light, and let's design the facade and the system so that this breaks out to an outdoor space. This part is covered so we don't have the heat loads". Start to think about how we place the building, not just for the layout of the optimum architectural connection space, but also giving a weight to what the most appropriate space is from a sustainable design perspective.

Making sure that the facade that's facing north is letting light in, but the ones that have the heat load but not the views are solid, and are allowed to reduce the energy use of the building through sustainable design practices. The students were quite good at good at that, saying "This is what we need to put in the building", and then compare that to "These are the site constraints, this is what's happening around the site. Micro climate, macro climate. These are the prevailing winds, and where we're getting too much heat from". [They let that] influence the architecture through that vernacular design, and move the general spaces around.

Q6. What did students struggle most with when asked to advance their design-thinking with environmental/engineering constraints in mind?

There's probably two things there. One is they're looking to apply single technologies, or specific solutions to buildings, rather than use sustainable design philosophy throughout each element of the building. It was quite common to say "Here's our building, we need to increase the window performance, add solar, add photovoltaics". Add things, as opposed to start by looking at the building as a whole, and saying let's start the question how this building should work. What the most sustainable way to make this building operate, and work holistically around the building. I think that was one of the challenges students often faced, going to the checklist of things that a sustainable building would have and doing that rather than considering the building as a whole, and how the building works as an organism, as a system.

The other [thing] where they struggle is to consider the flow-on effects to design considerations. It's not due to lack of care or concern, it's just due to lack of experience. They'd be good at saying “What if we add a technology in?”, but not don't necessarily consider the implications that could have. For example, suggest deciduous trees to allow enough light in in summer, and low lighted in and winter, but without thinking of the water impacts, or time impacts, or how to get those trees, or what does it look like from the street. Have you block the views to the mountains and the horizon. They're considering each element discreetly, but not necessarily holistically about the overall building and how it will go together.

And I guess that was what the role was as the consultants, to help them when they say “Hey, we've got this idea” and we can start asking questions. “Okay, that's great, what are the benefits of this? Okay, you've got the benefits, what are the drawbacks? What are the follow-on effects where this will slow you down?”. All of a sudden. “Well we've said we'll do this, but it's going to take five square meters of internal space. Now we can't have that studio. So is that design solution worth getting rid of the studio? Yes? No? Maybe? Can we afford that much space? What's that space worth to the client? Five square meters is worth, put on whatever rate you want, 400, 500 bucks a square meter per year. Let's look at the cost benefit and consider the overall challenge here.”

Q7. What barriers and constraints to architect/engineer collaboration exist (outside of the actual design process)? Time-poor/fees/contracts/…?

One of the things we often see is the architects will go “Here's our building, this is what we've designed, now make that sustainable”. Now, tell me how that's sustainable. And a part of that comes from the required personality traits of an architect, which is to be used to be proud, and right, and really be quite headstrong to say “This is what the right solution is”.

That integrated design philosophy doesn't necessarily always occur at a stage where the building is still up for grabs. Oftentimes there's no engineering given, or no sustainable engineering given, prior to the building even being through town planning, or development applications. A mechanical or an electrical engineer, or a structural engineer might come in and say “For you to build this building, you need to have 10 square meters of riser space in the core so we can lay it out”, but no one's sat down and said, have you really considered how this building's working, is the core in the right place to maximize this daylight, but reduce energy? Those opportunities are lost before the project is really past concept. That's one thing that we struggle with in the real world.

A couple of other [issues] are client aspirations. Some clients won't push it and dont value it. That's okay, it's their money. Ultimately it's their project, but part of our role as sustainability consultants is to educate and to upskill, and to ensure that everyone understands where the industry's going, and why it's going where it is, and what that means for them in terms of their responsibilities. To frame it in a way that speaks their language.

For example, if I know a client's cost driven, and doesn't care about the environment per se, which is their right, it's up to me to talk a language that explains to them why sustainable design will save them money, or increase the value of their asset, or de-risk their asset, or speak a language that fits into their philosophy around development.

Q8. How would you describe integrated design?

When it happens well it means everyone's around the table and thinking about, and working together on how the building and the development is going to come together before anything's set in stone. It's best done by workshops run by one party, it'll always be led by one party, but everyone's got the opportunity to come in and challenge that design, and give parameters from the get go. Everyone comes together with the logic that everything's negotiable. There's a sweet spot somewhere where everyone's equally unhappy about the final design. It's a weird way to describe it, but if the architect wanted something, they had to give something up, so they’re unhappy. The sustainability consultant had pushed for all these things and got enough of what they wanted, but that they couldn't get the last couple of things, so they’re slightly unhappy. And the developer wanted to have none of it all together, and wanted the cheapest box possible, but they had to give up something to architecture. If everyone's equally unhappy with the outcome, then it's probably the best outcome.

I don't mean unhappy, but you know what I mean? Integrated design is where everyone is suitably compromised to a point where the need for sustainability has been balanced, everyone's pure drivers have been negotiated and met to a level that works for everyone. If everyone's 96% happy, that means they're all equally unhappy.

Q9. How useful was it for students to experience an integrated design processes as part of their higher degree education?

I think it's really good. It's one of the first things that we really try to get graduate engineers to experience when they come into our companies. You'd sit there and say “Hey, we really want you to experience how the architect thinks, how the developer thinks, what the drivers are outside just the sustainability world”. It's all and good for us to push this agenda, we want to drive these things, you need to understand that. You also need to understand who you're talking to, who you're working with, and how they're thinking about things. The IDS process, integrated design studio's really giving its students the opportunity to experience why people are making the decisions they are.

For the first six years of my career, I thought architects were useless and horrible designers, and it took me and took me that long to realize that, actually, they're looking at things from a completely different way. They start from a completely different point from where I am. We're trying to meet in the middle. It always looks horrible from where I'm sitting, because they haven't considered what I wanted them to consider. The IDS then gives [students] the opportunity to do that from the start, and appreciate someone else's perspective, someone else's philosophy, which gives everyone a leg up.

It makes them understand the design comes from many hands, and it does consider many elements, not just the ones that you care about, and it's great for them to work through [that]. What we do day in, day out with work is go back and forth on points. We'll work with the architect to get something to work, and then it won't work with the mechanical engineer, and it won't work with the access person, and we'll move things around and keep juggling it and juggling until we can find a solution that works, that meets everyone's needs. That process, integrated design, gives people a quicker chance to get there, rather than going through the slower process of speak to everyone one at a time, that taking a year. It could happen in a short course and they can get that experience, which will set them up well for the next stage of their career, going into the professional world. I’d definitely continue to look to hire from the students through this degree.

There's a lot there. I think you're doing a great job, and it's working really well. What's really refreshing to see is how engaged the students are. Obviously there's a few that will always speak more than others, and there's always going to be a few that sit back and don't do much. But, I've felt that most students are engaged, and working, going through the process, and I think they're getting a fair bit out of it, which is good.

Interview 05: Integrated Design Studio 09 – Lightning Ridge LALC Multi-Purpose Building – Interview with Consultant 4 (Architectural Consultant)

Q1. What enables successful Integrated Design in the studio setting?

Having a diverse range of people, meeting up early, and I think also enabling somehow all of them to speak so that somebody doesn't dominate, one particular view doesn't dominate. So yeah, being able to actually get everyone's different views as well as get them in the same place at the same time.

Q2. Please tell us about the studio brief's impact on achieving integrated design solutions (considering the way it was written & communicated). Please reflect on the level of detail and the language of the brief.

They're different briefs in, not just their direction, but the way they were written and in the information that was presented. Maybe I'll start with the Lightning Ridge one. It was pretty scattered ideas and language that did make it quite difficult to get started. What ended up happening was we just went through as a group and tried to analyze the brief and work out which bits to target. That was probably just myself and Mark and Georgios. I'm not sure if the other consultants had much input on analyzing the brief in that way. And we had very limited contact with the client, which made it tricky as well. The Illawarra situation was a lot better because we had good chats with the client, so we could really understand what the brief was and I think we end up, too, rewriting the brief ourselves. Well, Georgios did.

That meant that we could focus a bit more in terms of sustainability outcomes. The make-up of the group of students that we had wasn't really diverse in terms of their academic background, they were all engineers of a certain type. There weren't even any service engineers and there weren't any architects in our group of students. So, the questions that were about aesthetics and things were pretty low priority on this bunch of students. For these particular projects, as well, I think from looking at some of the past projects, past years, some of those were a lot more architecture focused. These ones were real functional focused projects that the aesthetics were not a huge priority for us, even as architects.

Q3. What were the most critical decision-making points/questions to answer when balancing architectural and engineering input for generating environmentally optimised design solutions? Where did the inspiration for the students' solutions come from? How did the engineering consultant(s) contribute to the authorship of those solutions? What was the impact of engineering and architecture student collaboration on the project outcomes? What impact did the timing of the engineer/architecture collaborations have on the development of the project?

It's tricky for me to remember but they were all a bit slow getting started. All teams were quite slow getting started. But then [they] are expected to do a lot, in terms of output. So, the specific points ... Like, I don't know, I find it a bit difficult to answer this question. In retrospect to be asked. There was a ... I mean, the studio thing is what aspect that is if it's working well there's points all the time, every week obviously, but even in each session. Hence, there's various times when you're given feedback that you're guiding constantly. It's not necessarily seeing it once. This is the point where something clicks from the architecture point of view, anyway.

We tried to let them have a crack on their own and I don't know where they got their ideas from. But then we would give precedence, so some projects that we know have got some of the ideas that they're talking about. We would follow that direction and try to help them find a more resolve, sort of, example of something along those lines. And the engineering consultants had similar ideas as well, and that's how they work, too. They… have been done in the past. Well, it's just a certain feature of the project, the process of a project, or it's the whole thing. It's difference process but were all ideas that can help students progress their thinking.

There weren't different background students, so that's the tricky thing there. There's certainly lots of different opinions and approaches, but as far as the architecture and engineer thing, we didn't have any architecture students.

Q4. What guidance by you was most useful for the students (and why)? How did your input increase their 'level of understanding of' environmental issues and associated solutions? What would you change in order to maximise your input (if anything)?

I think I would like to be more involved in the brief making before we got started, because when you're in practice, in the real world, you don't get briefs that are so vague. It's such a short amount of time, in a three-month studio, to try and tackle what was asked of the client and also of the uni. I think that some of the outcomes for learning could have been better if things were a lot more focused in specific areas. So yeah, that's answering the last part of the question. But the value I added was ... I think I tried to be a facilitator and to try and get as many of the students involved. I couldn't ... they were consultants but I ended up, in a lot of sessions, being the tutor, myself. Trying to run the sessions and get the students talking and explain to them what was expected of them and what they should do by next week and things like that. So, that's one thing, because architects have experience in that whole studio experience, I've tried to do that part. I think my value was in guiding the group, getting all the students to talk, and also the consultants. I would often be like, "Oh, what do you think about this, consultant?"

Content-wise, the whole site analysis, we spent quite a bit of time on that, and I think that's quite valuable. That helped them, that was like a base for the rest of their decisions, was really having a good look at the site. So that's one thing. The other main thing is just looking at that planning for how people move around buildings and the site.

Looking at dimensions of rooms and looking at furniture layouts and things helped them a lot. Realizing what could actually happen in different spaces. We spent a good amount of time on that. I didn't spend much time at all on what the buildings looked like, and partly that's because of the project type but also, just, my interest in architecture. I'm less about what things look like and how they perform and how they're working for people. Focused on things like light and space and windows and aspect, ventilation., as well as the science on energy efficiency and thermal comfort, and tried to explore options for those things. I tried to bring out Passivehaus projects at being an approach that had benefits for both sites.

Q5. How did students cope with balancing aesthetic/functional design aspects with engineering concerns? What was the impact of engineering and architecture student collaboration on the project outcomes? What impact did the timing of the engineer/architecture collaborations have on the development of the project?

It was pretty limited. There weren't pretty things that were being designed, except for one project at the Lightning Ridge project. There was one group that did draw up some illustrations and things and a lot about what the street front would look like and things like that. They kind of fell into it, to see what sort of trap an architect would do with just north facing glass because it had an aesthetic function. It's tricky because the approach was to push the innovation and their answer to that having too much glass question was to use fancy glass. Which is what an architect would expect in a space. I would say this whole question is pretty limited, and the way that I focused them was definitely not aesthetics at all. I don't know what Mark, the other architect involved, was like, but I suspect we both focused on the floor plan and the way that the buildings worked rather than the way they looked, for both projects.

I think we actually worked pretty well as a group of consultants because we're all in the same room at the same time with students. Sometimes that doesn't happen in the real world. You might just have dealings with one consultant and then another day you'd have another meeting with another consultant. It's always a huge benefit to have those collaborative meetings, especially early on. But there was a greater effort than normal, I think, to really encourage the other consultants to think about giving input on the spot.

Q6. What did students struggle most with when asked to advance their design-thinking with environmental/engineering constraints in mind?

I think the unlimited options that they had was a potential problem. And that's because we were still pushing them to be innovative and just come up with whatever ideas they could, with how wacky they could be. Understanding how realistic the design was, that was an issue in some regard. I think the whole space planning, the things an architect does, it's very difficult to teach a bunch of students how to do that in a few weeks. That didn't get done as well as it could have. We tried as hard as we could but we understand the complex situation. That was tricky. We're not getting to a certain point, and even though that one is great, we just have to leave it here because the next assignment deals with something completely different. Whether it be the environmental modeling and things like that. The limited time meant things couldn't be as resolved as they would be in the real world, obviously.

Q7. What barriers and constraints to architect/engineer collaboration exist (outside of the actual design process)? Time-poor/fees/contracts/…?

Yeah, meetings are expensive. Having lots of meetings, they're really expensive and often they're not as useful as they could be. One of the barriers is actually scheduling meetings and running the meetings so that they're efficient and you get your value for the money early on, so that there is true collaboration and input and iteration, rather than using consultants just at a certain point (usually at the end) to tick boxes and things like that. It seems to be the way things go in most situations that I've been involved in.

Q8. How would you describe integrated design?

That's tricky because it depends on who is defining what. What needs to be integrated I suppose. It's like a collaboration where you want to use the skills of all the people that you can. Diversity of skills, and that gives you a greater knowledge to work with. But also, the benefit of integration and collaboration is, you can bring people along, because they feel involved in the process. So, there's two parts to that integrated designs that both lead to better outcomes.

Q9. How useful was it for students to experience an integrated design processes as part of their higher degree education?

I think it's really great. I think the students got heaps out of it, actually. I think that if I was provided the opportunity to do more of this stuff it would've been a great benefit to the way that I work. You can get these habits ingrained as a student and there's more chance that [integrated design] will actually happen in the world. People will be able to feel confident in putting their hand up, to get these things happening, to be involved in it when the do happen.

There was a couple of thoughts I had during the studio. One, is because of the funding, a fair bit of funding came from ARENA (I think). There was a focus on trying to come up with ways to ... I think it was even phrased that, ways to use more renewable energy, it wasn't focused on using less energy. For a project like this there really isn't much you can do apart from just whack solar panels on your roof, to use renewable energy. In an innovative way, there weren't very many options. So, that was one small thing that was a bit weird. I think it was good to have the diversity of consultants, but having a range of students from all different schools would be a massive benefit to everyone. Its just that that didn't happen in this particular studio. So, I don't know if there's an ability to pair up different uni's or some way to get that happening. That would definitely be better than just a bunch of engineering students from one uni.

I had heaps of fun doing it, it was really cool. I don't know if you have had much feedback on the briefs. But I really enjoyed it. The students were amazing and the amount of output that they were able to produce, I was so impressed. But, like I was saying before, if I were a bit more focused or a bit more constrained in certain areas they would've been able to do some deeper thinking on certain topics or certain parts of the project that were would have enabled them to learn more than just trying to do a million things in one super short semester.

APPENDIX C – TRANSCRIPTS OF STUDENT RESPONSES

The following is the questionnaire and student responses from a voluntary survey provided to consenting students participating in the Design Studio. Where there is a selection of responses to choose from, a breakdown is given outlining the percentage of student responses for each of the given options. For written responses, all student responses have been transcribed.

1) Have you had any experience with Environmental Design prior to this Integrated design studio? Please select one option.

Response options	Frequency of response selected
Not familiar at all	17%
Slightly familiar	0%
Somewhat familiar	17%
Moderate familiar	67%
Extremely familiar	0%

2) What are the key design-drivers that affect the success of environmental design to achieve renewables/zero carbon goals on a community centre project? Please select all that apply.

Response options	Frequency of response selected
Level of existing expertise of individual contributors	67%
Imagination and creativity	100%
In depth knowledge of technology for collaboration	67%
Time assigned to the dialogue between Architects and Engineers	67%
Software skills to simulate and analyse building performance	83%

3) Did the client's brief support you in achieving a balance between architectural and engineering design? Please select one option.

Response options	Frequency of response selected
Not at all supportive	0%
Slightly supportive	50%
Somewhat supportive	0%
Moderate supportive	33%
Very supportive	17%

4) Please tell us about the impact the brief had, and the way it was written/communicated? Was it adequate? (if not, what could be changed?)

- It was very informative in considering building requirements in terms of design, spacial requirements, valued features, etc. It also outlined key structural/engineering features important to the client and the local area. Whilst it held many valuable points to consider in the building's design, a lot more information was needed to be gathered from the client in regular consultations that could have easily been included in the client brief. To change this so that more targeted and necessary information is included in the brief, it could be structured in a Q+A layout. For example, what rooms/spaces are necessary and how important are these to the client. Then include more in-depth questions like how many people are likely to use the space, etc. That way students can read the brief and understand what information the client is addressing, allowing for more room to ask more detailed questions in consultations later on.
- There could have been more details for the space uses and requirements.
- I felt the brief was quite restrictive with what could be achieved, with not much focus on sustainability which was what the subject was about. There was also little feedback on the overall design, rather focussing on small sections of it.
- I think the client brief needed to match with the the client values. There were some differences which made it harder to design the facility

5) What were the most critical decision-making points/questions to answer when balancing architectural and engineering input for generating environmentally optimised design solutions? Describe in your own words.

- Choice of materials - is the client okay with spending extra money on locally-sourced and more environmentally-friendly materials in achieving a more net zero design? Also, are there any materials preferred or not wanted? Again in terms of money, how far the client is willing to go on paying for more efficient glazing without becoming impractical or impacting aesthetic requirements. What architectural features were the main goal of the project that needed to be included and then practical ways to ensure they could be incorporated into the building's structure, etc., without impacting the environment negatively but instead optimising energy efficiency. Critically, the building's structure, materials, appearance, spaces, uses, etc., impacted energy efficiency, requiring well thought-out solutions both architecturally and structurally. For achieving these solutions, it was necessary to follow codes and standards to aim for net zero design, which made considerations more targeted.

6) Where did the inspiration for your solutions come from?

- The client brief. Design software offering inspiration, both architecturally and structurally. Base case designs used in similar regional and climatic settings and looking at how they dealt with climate and culture in a similar sense. Knowledge of materials and building services mentioned in lectures or researched as part of group assignments. Consultation with clients and other architects/engineers who had further design input or improvements to provide.
- Researching new innovative designs and following current practices around the world.

7) What guidance by the consultants was most useful for you (and why)? Describe in your own words.

- Physical changes to make to the design and reasons why - such as references to specific codes and standard practices. Input on what sustainable options would work more effectively, particularly in terms of design solutions already formulated and the climate conditions. Consultants introduced online resources valuable to the design making process, as well as offering their own personal methods of conducting this process. Consultants gave clear questions on what we should ask the client to achieve more targeted ideas or design answers necessary in the process of forming the design.

8) What would you change in order to maximise their input (if anything?)

- My experience with consultants wasn't maximised as well as it could have been due to fear of asking the wrong questions or jumping in at the wrong time whilst they were talking to other groups online. More individualised time spent with consultants, particularly in singular groups, would have given greater time to ask questions more targeted to my group's design solutions. Taking notes of what input they give in answering questions from other groups or my own group would have removed the need to ask the same questions multiple times, particularly across different groups.
- I think more 1-on-1 with the groups would have been more beneficial to gain more in depth feedback, but as they are working on their on times that is understandable that it was more group based.

9) Did the input by the consultants increase your 'level of understanding of' environmental issues and associated solutions? Please select one option.

Response options	Frequency of response selected
Not at all supportive	0%
Somewhat supportive	20%
Moderate supportive	60%
Very supportive	0%
Extremely supportive	20%

10) Were aesthetic and functional design aspects compromised when balancing architectural and engineering concerns?

Response options	Frequency of response selected
Not at all compromised	40%
Slightly compromised	0%
Somewhat compromised	0%
Moderate compromised	60%
Very compromised	0%

11) If you agree that aesthetic and functional design aspects were compromised when balancing architectural and engineering concern? Do you think this can be avoided? If so, please explain how.

- It can certainly be avoided by not designing for a more detailed solution earlier on, as certain assumptions are made that aren't so easily changeable later on. Instead, creating what the consultants gave as a good layout of bubble diagrams, a design specifications sheet, etc., could provide clearer ideas for design aspects earlier on without permanently setting on a design straight away.

12) What did you struggle most with when asked to advance your design-thinking with environmental/engineering constraints in mind? Describe in your own words.

- Coming up with solutions that could work around these constraints, if not optimising the design itself to become more energy efficient. Net zero constraints gave for a huge struggle when trying to come up with environmental solutions that could work, especially within the design already formulated beforehand. With these limitations, it was hard to come up with many solutions/modifications and required more understanding of the building's processes in terms of energy performance in order to achieve solutions that could work.

13) Please list the barriers/constraints (outside the actual design process) that exist in architects/engineer collaboration? Please select all that apply.

Response options	Frequency of response selected
Knowledge gaps	33%
Time constraints on projects	100%
Education in isolation	66%
Contractual/fee barriers	66%
Inability to define joint goals	33%

14) How would you describe integrated design.

- Integrated design involves bringing together different groups of people with different knowledge and understanding of a particular topic, aiming to achieve a design that incorporates ideas from all parties involved in aiming for a more optimised design solution. This solution must address as many concerns as possible, brought up by all groups of people, and must involve regular consultations between these groups. Integrated design works best when everyone gets involved and when the needs of the client are being met on all sides. Different groups necessary in achieving more optimised design solutions for building projects involve both architects and engineers to address aesthetics, functionality and durability of a design. A third group - the client - needs to be regularly consulted to ensure no design considerations are compromised and that more personalised values, particularly regarding culture, are included within the design.

15) How useful was it for you to learn about integrated design processes as part of your university education? Please select one option.

Response options	Frequency of response selected
Not at all useful	0%
Somewhat useful	0%
Moderate useful	0%
Very useful	33%
Extremely useful	66%

APPENDIX D – OBSERVING RESEARCHER NOTES

This semester was undertaken entirely online with all workshops conducted virtually. This posed difficulty in getting observations as well, as only one workshop could be viewed at any one time, and the discussed was a lot more limited than it was in the previous IDS. However, there was more sharing of the progress by students and specific guidance given by the consultants.

The early classes mostly revolved around identifying the requirements for the project and how to evaluate potential design solution. Discussions included challenges of renewable energy technologies – such as bang for buck for solar, and difference between renewables on site/off site. Also discussions around the green star system and how that could be used to identify areas to develop in. Overview of green star ratings scheme was shared by the consultants – not easy to come by unless a GBCA member.

Discussions around CAD modelling early on in the project had the consultants trying to highlight the dangers of getting caught in 3D modelling too soon, and the need to first consider the 2D layout and include furniture, dimensions, use of space and functionality. Whilst this was pushed heavily, there were will models that still did not consider these aspects later in the course, so the message was not taken on board. The students struggled with the concept of understanding layout and impacts of design choices early on and the concept that the functionality should drive the footprint rather than the building size – this may be from a lack of architectural understanding.

The Client in Lightning Ridge expressed a desire to ensure designs focused on how the space will work with planned activities and events, and to consider the balance between aesthetics and security issues.

As the studios progressed, more technical questions were raised including green walls and the structural requirements and thermal impacts of these. Consultants also highlighted aspects of designing to the national construction code and shared explanations and tools that would assist in designing to code, such as the façade calculator, diagrams for communicating designs etc. There was a lot of conversation between consultants and where multiple consultants were present in a studio, they would ask questions of each other to help keep the discussion in the classes going. The consultants also provided a realistic assessment of design considerations such as the maximum number of steps, energy consumption etc.

Towards the end of the semester, there was an openness between the groups, with students noticeably keen to work with each other, share their work and help each other out. However, some groups still seemed to be lost in the modelling detail and focused on trying to get a finalised design rather than looking at and assessing alternate solutions. This limited their ability to fully explore integrated design.

APPENDIX E – CONSULTANT VETTING REPORT

IDS09 – Lightning Ridge Community Centre

Lightning Ridge Aboriginal Land Council (LRALC)

Vetting Report 26th April 2022

Image: Student 1 Assignment Submission, IDS09

Document Verification

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Peter Jameson

The report presented is a collaborative effort of the above noted authors.

Overview

The iHub Integrated Design Studio (IDS) ran during the second semester of 2021 and included Engineering major students from the University of Wollongong supported by the engineering faculty and consultants from industry.

The students investigated sustainable design options for a new Aboriginal Land Council community centre in Lightning Ridge. The studio explored concepts and solutions to achieve net-zero carbon in during operation through the use of both passive and active measures and on-site renewables.

This summary report documents the vetting process undertaken by the supporting consultants following the studios. The aim of this report is to summarise the process of the IDS and capture the key recommendations developed by the students, faculty, and consultants over the course of the semester.

The analysis and design undertaken during the studio demonstrated that the goal of net-zero carbon is possible to achieve by adopting a number of considered sustainability strategies.

Image: Group 3 Assignment Submission, IDS09

Image: Group 2 Assignment Submission, IDS09

Introduction

I-Hub is a program run by the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) alongside the University of Wollongong and supported by the Australian Renewable Energy Agency (ARENA). It aims to facilitate the HVAC industry's transition to a low emissions future, stimulate jobs growth and showcase HVAC innovation within buildings.

The Integrated Design Studios are a part of this initiative and explore innovative solutions for achieving net-zero carbon on complex design projects.

University of Wollongong students in the IDS09 design studio were given the task of designing a sustainable, net-zero, new Local Aboriginal Land Council facility in Lightning Ridge. A range of feasible opportunities for minimising the project carbon footprint and energy usage were to be considered including active and passive solutions.

Weekly studios were held over the semester, supported by the engineering faculty and industry consultants from Edmiston Jones Architects, Northrop, E-Lab Consulting and MIEngineers.

Net-Zero Carbon

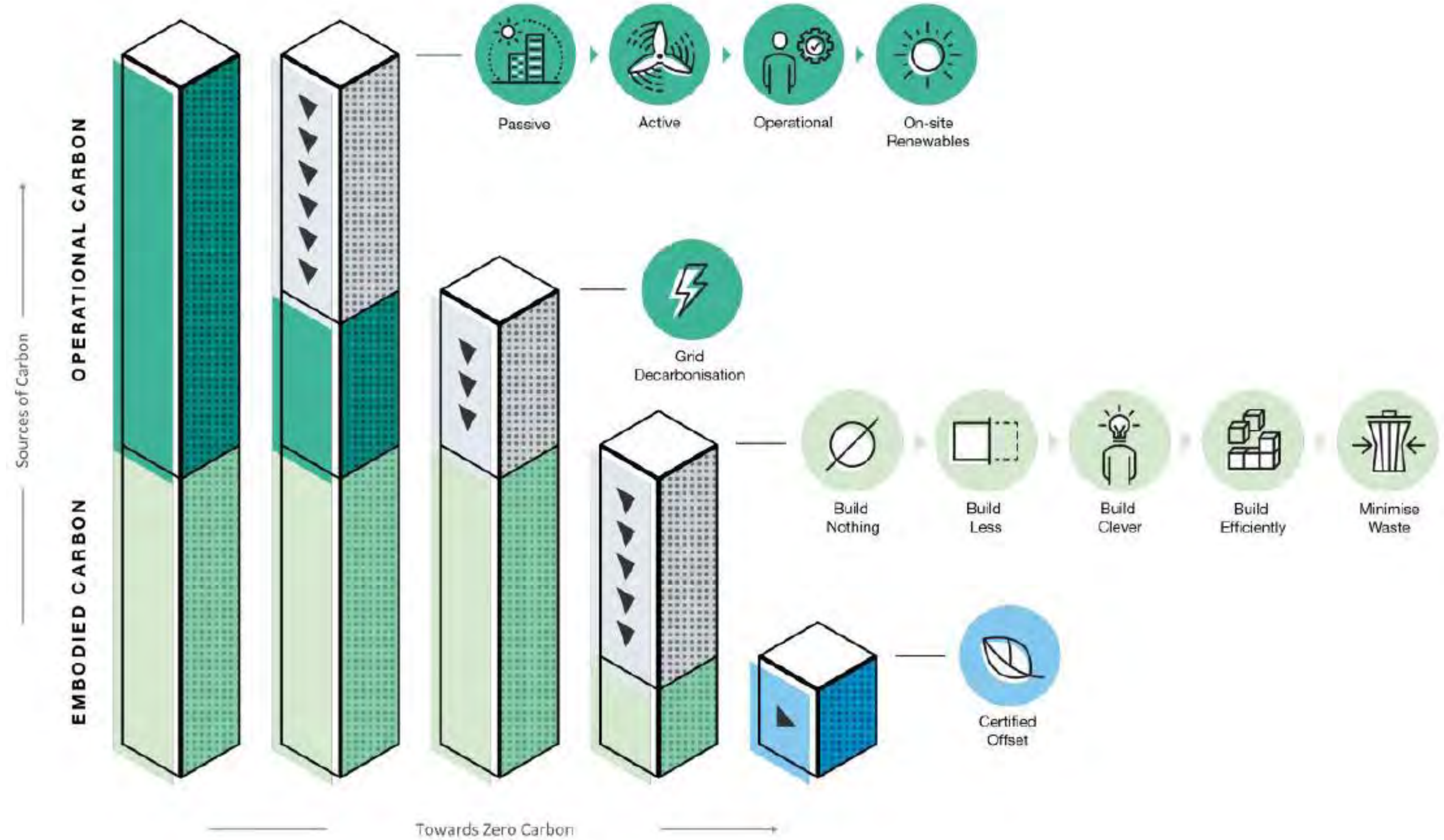
This term is commonly used across industry but its definition varies due to a lack of consensus on where the boundary for assessment is defined for a given building or system.

For the purposes of this studio, the term 'net-zero carbon' encapsulates both the operational carbon emissions and embodied carbon emissions.

Operational carbon emissions are those that are generated over the service life of the building.

Embodied carbon typically refers to carbon emissions generated by the construction, maintenance and demolition of the building with a particular focus on the construction phase as the most understood and quantifiable metric.

A truly net-zero building considers the whole lifecycle, with the emissions associated with building materials, construction, operation, and end of life all quantified and accounted for. Thus any emissions generated by embodied carbon during to construction must ultimately be offset during the operation of the building to achieve an overall net-zero.



Source: Arup - net-zero carbon buildings: three steps to take now (2020)

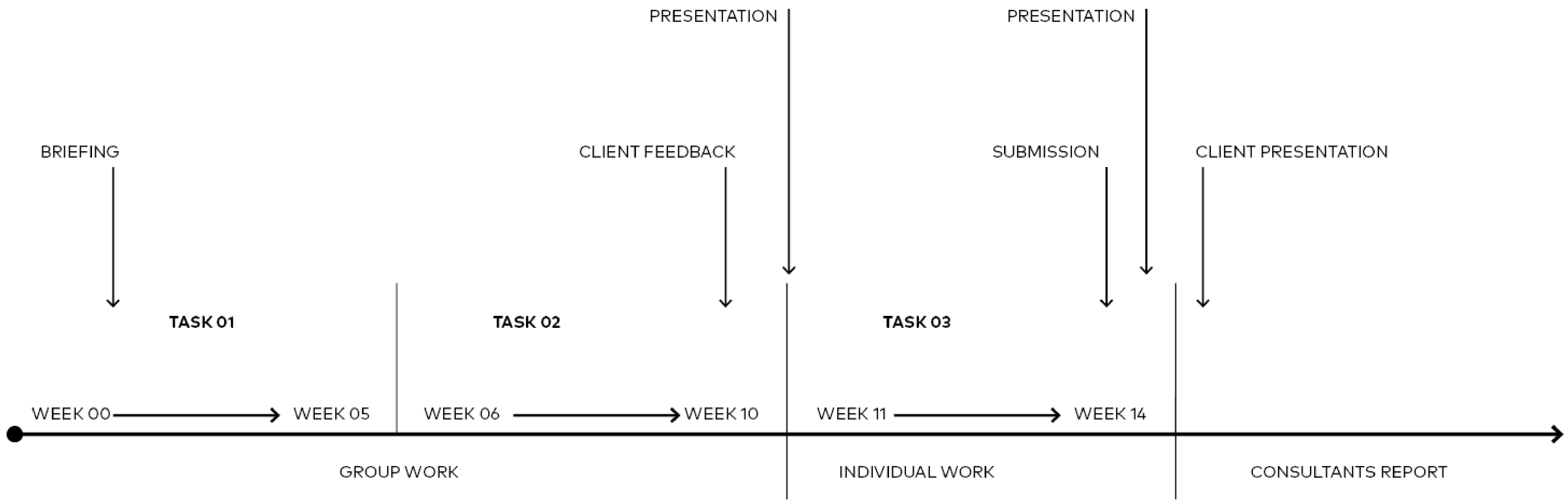
Studio Structure

The students met weekly throughout the semester to workshop and discuss ideas with the engineering faculty and industry consultants.

In the first few weeks, students were provided with a written design brief and video conference with Dr Steve Burroughs from the Dr Steve Burroughs Foundation representing the Lightning Ridge Local Aboriginal Land Council to direct the avenue of inquiry.

Following this, a range of initiatives were developed in the form of a return brief and site analysis. The initiative were subsequently assessed in a detailed matrix which included feasibility, cost, constructability, and a number of other criteria. These options were refined over the course of the semester to identify key changes that would have the most impact towards moving the building to net-zero.

The studio was structured around three assessment tasks where students presented their written submissions to the class and the clients. The first two tasks were developed in groups that required collaboration between a 'design team' of students from different engineering majors. For the final assessment, each student selected one or key initiatives to research in more detail and explore with computer modelling and analysis of building performance.



Studio Interactions

IDS09 was undertaken during a period of intermittent lockdowns due to the COVID-19 global pandemic. Consequently, the studio sessions were conducted in online environments rather than the typical face-to-face interactions preferred for these collaborative exercises.

Weekly *Zoom* sessions with breakout rooms were used to facilitate the interactions between students, the faculty, and consultant. Assessment presentations were also delivered through this platform.

A number of online collaboration tools supported the development of the designs. The university's *Moodle* platform provided a central location for shared studio information and resources. The online collaboration tool, *Miro*, was used during studio sessions to provide a communal, collaborative digital whiteboard for sharing text, images, and ideas in real-time.

Image: UoW Moodle Platform for IDS09

Image: Miro online collaboration environment from IDS09

Image: Miro online collaboration environment from IDS09

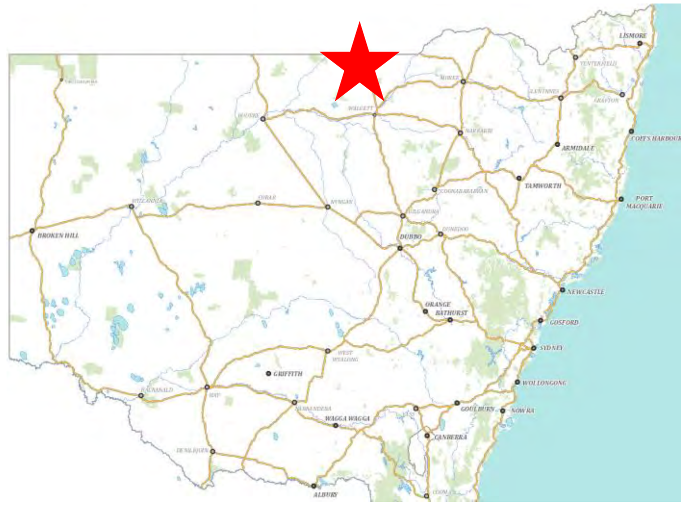
Location and Site

The site is located in Lightning Ridge, NSW in Walgett Shire, approximately 70km north of Walgett.

The site is currently vacant with an approximate area of 900m^2. The site is bound by Morilla Street to the North, and a slip street to the South providing two access points. The site has a central position in Lightning Ridge and the design was to consider the context of the surrounding area that included shops, a bowling club and cafes.

Geographical considerations such as the proximity to nearby mining facilities and the remote location were also considered in the development of initiatives.

As a facility for indigenous peoples, the consideration of cultural heritage and the history of the Gamilaraay people (also known as the Kamilaroi people) was also important for understanding the usage of this building and the development of materials and spaces.



Source: NSW SixMaps

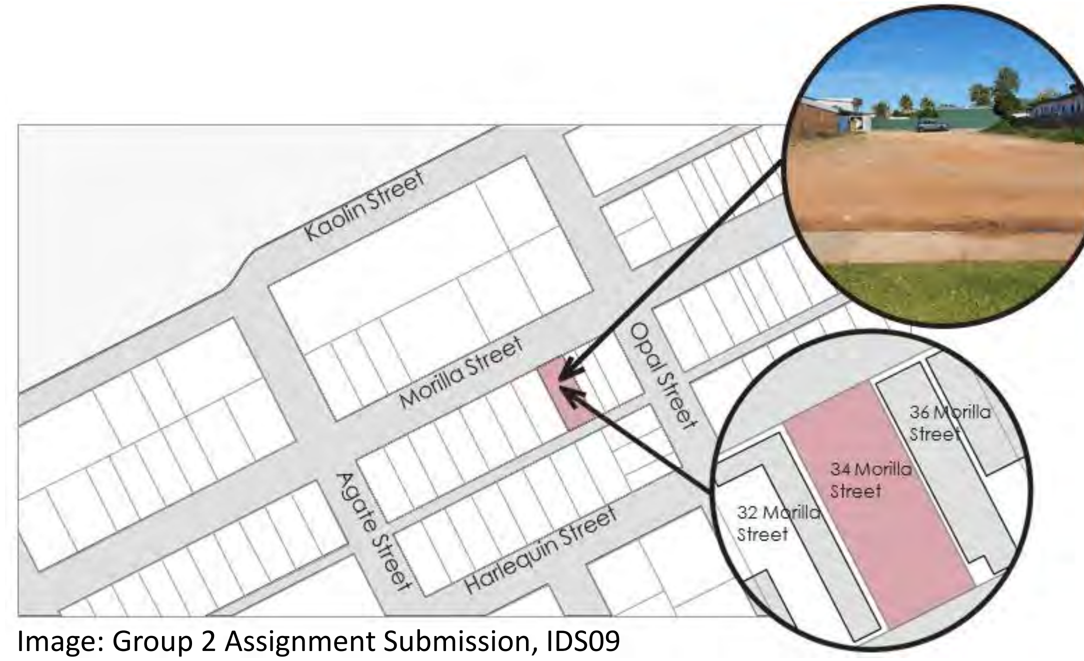


Image: Group 2 Assignment Submission, IDS09

Image: Dr Steve Burrows Foundation

Introduction

The Local Climate

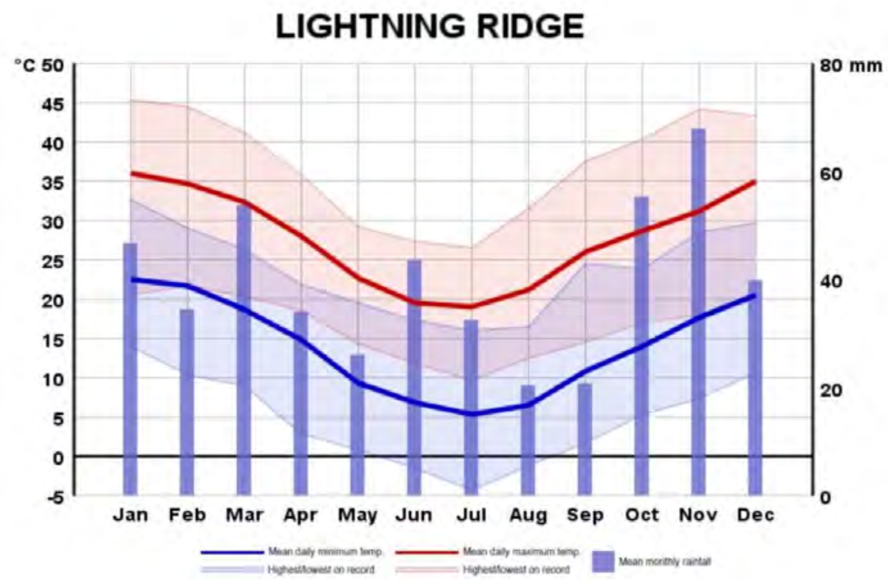
This region experiences hot dry summers and cool winters and has distinct seasons with low humidity all year round.

The annual rainfall is low with the area only receiving approximately 431 mm on average of precipitation per year.

The site is prone to extreme hot weather, the climate is semi-arid with mostly dry weather. The weather can get up to 45 degrees in the summer and drop below 0 degrees in the winter. The area is quite dry, so humidity is seldom an issue. There is a significant shortage of water, but a prevalence of sunlight.

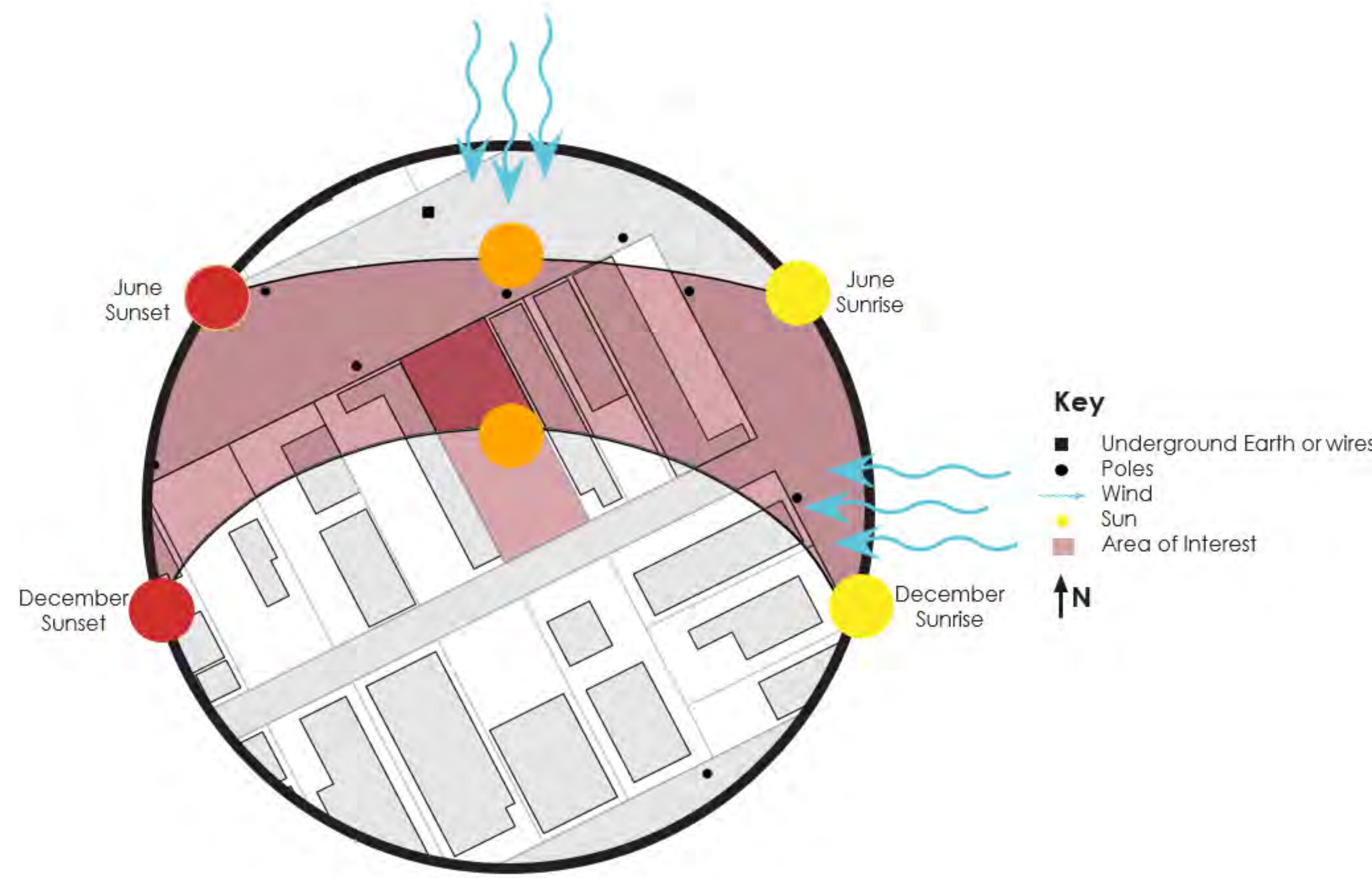
Solar is quite is accessible, as the nearby buildings to the site or only one story and the weather is rarely cloudy.

Prevailing Winds are from the east, however the site is well protected by the neighbouring properties.



Source: Mean Monthly Rainfall and Temperature in Lightning Ridge (FarmOnline 2021)

Source: Rainfall and Relative Humidity at Walgett Airport between August 2019 and 2021 (Willy Weather 2021a)



Source: Group 2 Assignment, IDS09

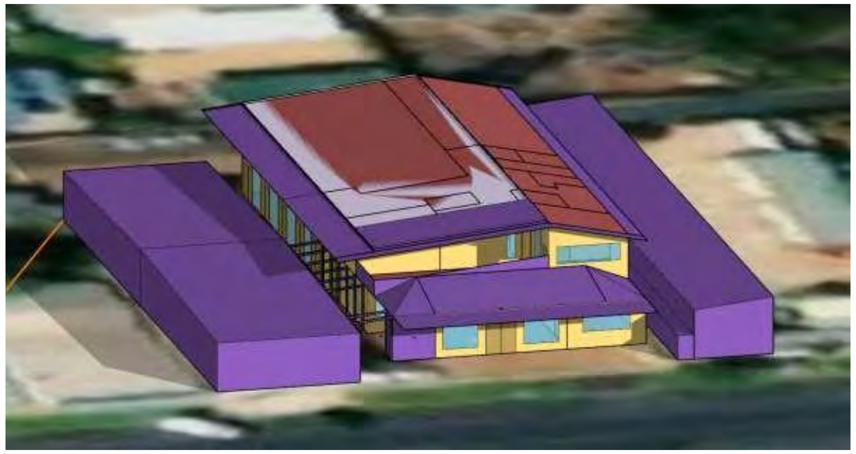
Integrated Design Studio

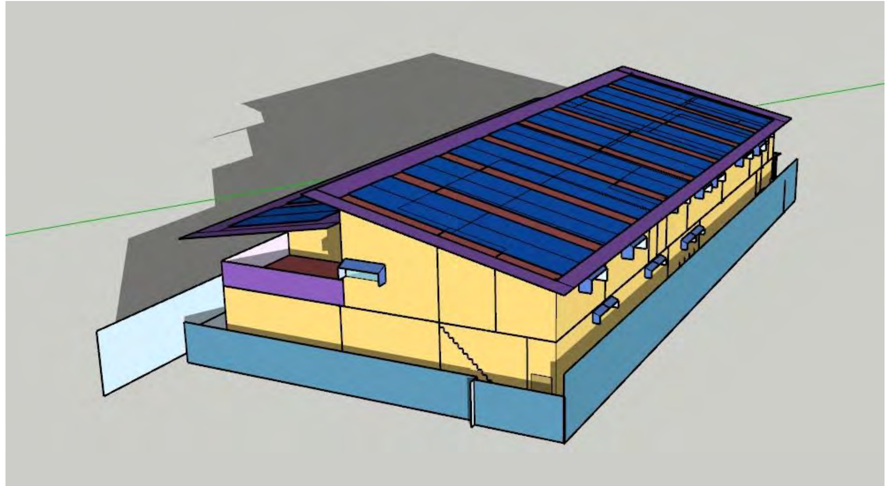
Through the IDS process, the students and tutors worked to explore alternate design elements and positive actions that could be taken to improve the current performance and help the building move towards net-zero carbon in operation.

Students would suggest ideas within the context of the Lightning Ridge Function Centre, and together teams would assess the viability of these options in the context of the project.

These were tested through literature reviews, exploring the site-specific restraints and modelling the performance improvements in programs used in industry to assess thermal and overall energy performance.

The following pages show examples from students work where they have addressed the key tasks set out for them in the studio.





Images: Group Final Assignments, IDS09

Studio

Task 1 Site Analysis and Return Brief

To better understand the building requirements, the students developed a site analysis and return brief. This brief detailed such items as; the existing condition of the building; the local environmental conditions; and end user requirements which would inform the direction of their investigation of sustainable initiatives.

In the initial brief, examples of the areas of consideration were:

- Natural features
- Indigenous heritage
- Heritage
- Transportation & connectivity
- Needs Analysis
- Character of built environment
- Services – existing and new
- Climate/microclimate, solar access, predominant wind direction
- Constraints & opportunities

Bubble diagrams were developed to explore the interactions between internal spaces and the possible options for usage.

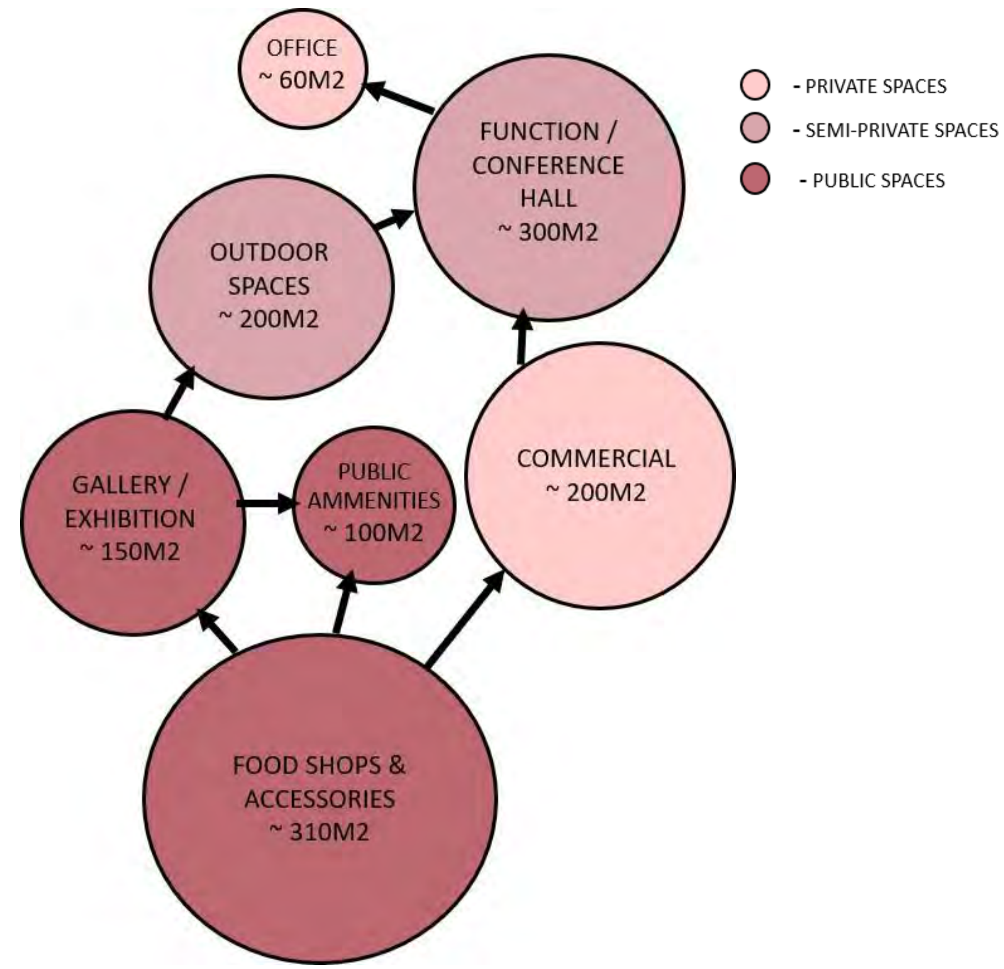


Image: Group 2 Assignment, IDS09

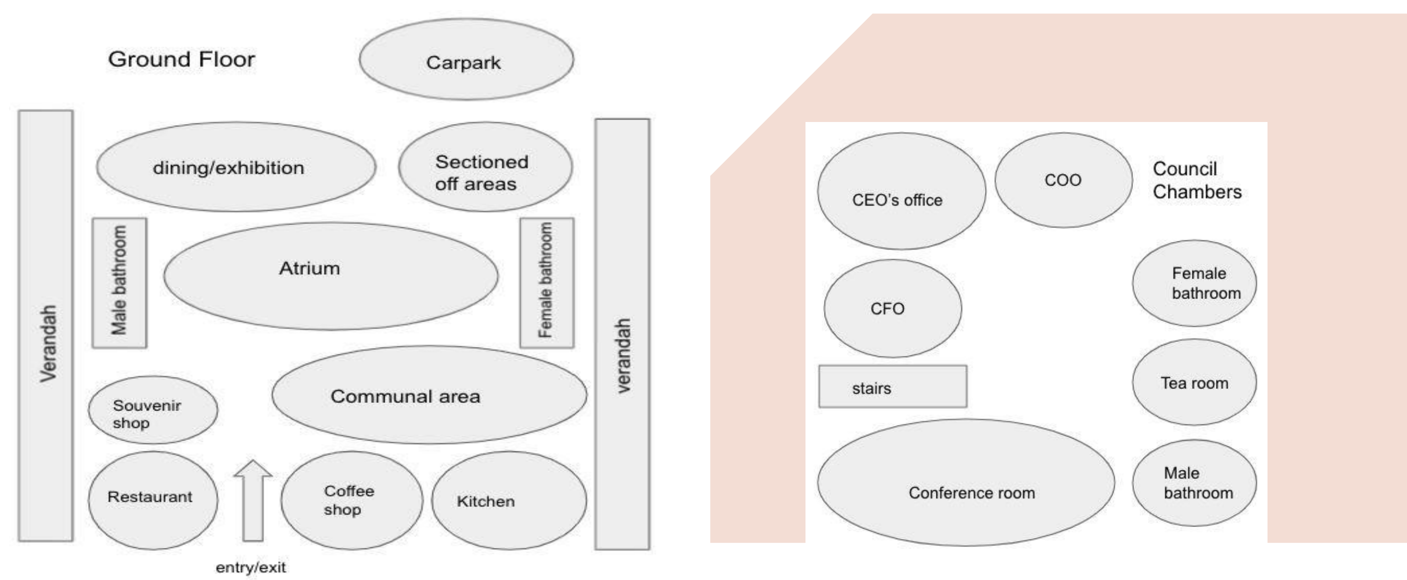


Image: Group 1 Assignment, IDS09

Task 1 Site Analysis and Return Brief

Students were also challenged to explore sustainability benchmarks that may be appropriate to the site. Students developed standard practice benchmarks for performance for water, energy and thermal comfort.

They also explored third-party standards that could be applied to the development to drive the design decisions forward.

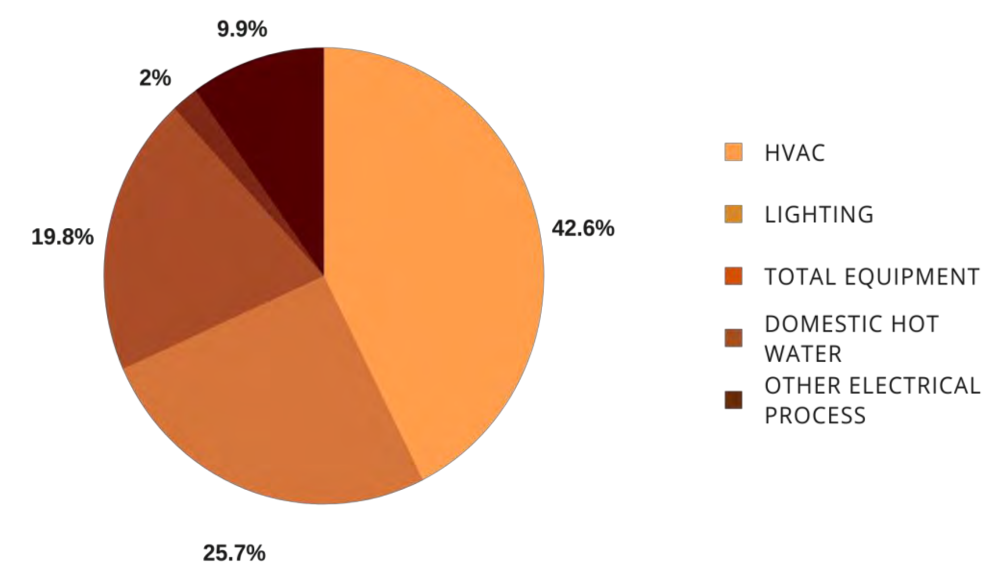
This encouraged design to meet holisitc sustainability approaches, while simultaneously focussing on the energy and water consumption reduction targets.

Rating	Benchmark with cooling towers	Benchmark without cooling towers
Best practice	0.77 kilolitres/m^2/year	0.40 kilolitres/m^2/year
Efficient	0.84 kilolitres/m^2/year	0.47 kilolitres/m^2/year
Fair	1.01 kilolitres/m^2/year	0.64 kilolitres/m^2/year

***Figure 1**: Water usage ratings for office building (Sydney Water)*

Rating	Benchmark
Efficient	<35 litres per food cover
Fair	35 to 45 litres per food cover
Inefficient	> 45 litres per food cover

***Figure 2**: Water usage ratings for cafe/fast food building (Sydney Water)*



Task 2 Research

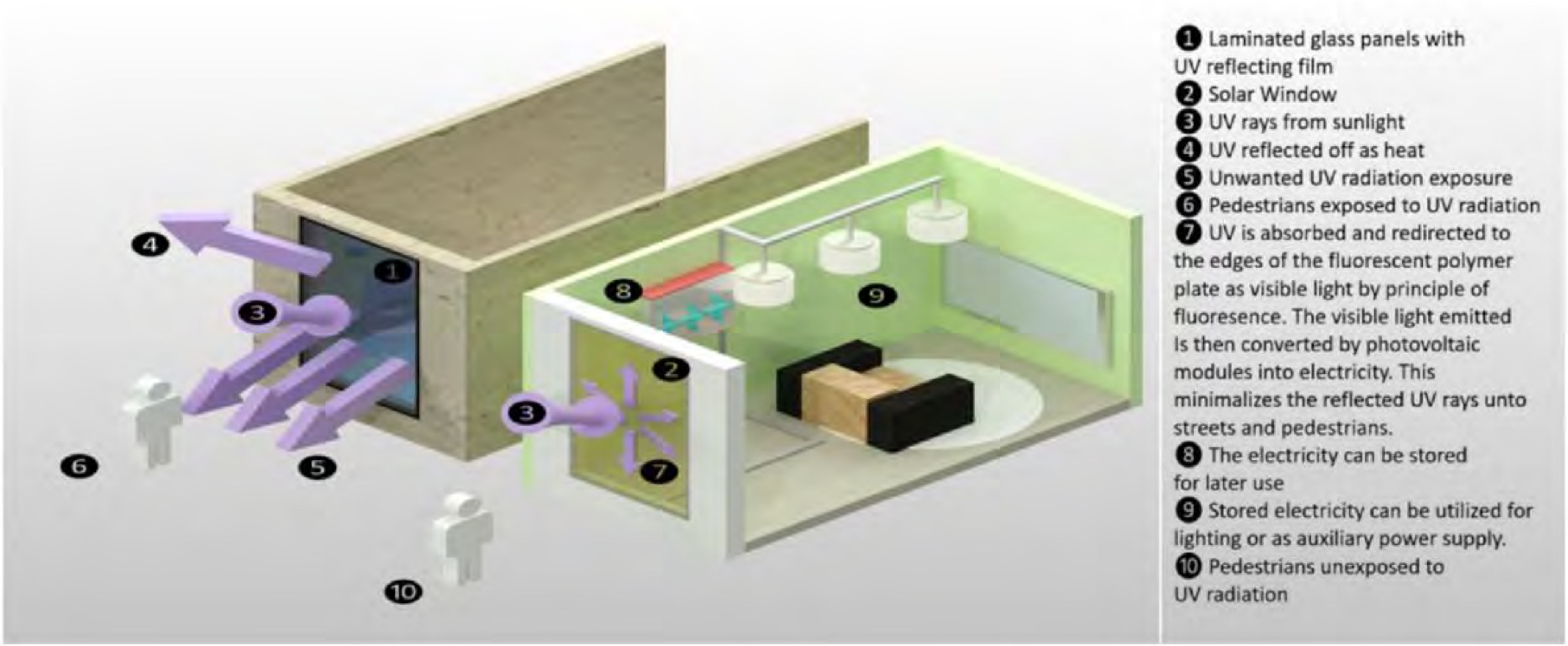
With the brief defined, and the facility details confirmed, the students reviewed technology and processes that may address any perceived any energy efficiency issues. Examples of the items reviewed and shown below and on the following page.

The students were encouraged to review critically each process and assess their potential contribution to the overall site goals.

Although primarily focused on reduction in carbon intensity, students were also encouraged to review other potential benefits such as water efficiency and contribution to wellness.

The approach adopted was primarily to develop a scoring matrix to assess their ideas.

Students explored a range of technologies from standard design improvements such as LED lighting and solar hot water, all the way up to electro-chromatic glass to find the most appropriate, project-specific applications.



[Figure 4. Borealis window compared to conventional window]

Studio

Task 2 Research

Matrix example

The below is a small snapshot of a full feasibility matrix produced by the students to assess the feasibility of concepts in the project.

Design Measures	Business-As-Usual Case	Measure Description	Feasibility 0.17	Innovation 0.03	Green Star Impact 0.08	WELL Impact 0.11	Energy Savings Potential 0.22
Solar Panels	Fossil Fuels (Petroleum, Natural Gas and Coal)	Solar panels (also known as PV panels) are small photovoltaic (PV) cells that convert sunlight into energy. These cells are often made up of silicon, a semi-conductive material, which conducts electricity while maintaining the electrical imbalance required to create an electric field.	High feasibility, as solar panels are a source of renewable energy, reducing carbon emissions and the dependence of fossil fuels. They require low maintenace once installed, with the benefit of paying less for electricity depending on the size of the chosen solar panel system and daily electricity usage. **Value: 3/3**	Low innovation, having been used for around 100 years. Solar batteries allow for energy that is produced by a solar panel system during the day to be stored and distributed to appliances that require ongoing energy consumption to be utilised during the night. Solar battery storages have the potential to almost double a households self-consumption of solar energy. **Value: 1/3**	Credit 15.0: Greenhouse gas emissions Credit 16.0: Peak electricity demand reduction **Value: 2 credits**	I06B.3 Carbon reduction (3 points) L03.1 Meet lighting for day-active people (3 points) **Value: 6 points + 0 requirements**	High energy savings potential. Installation of solar panels reduces energy bills by approximately $400/year/kW of solar. Energy savings also varies with the size of the solar panel system and how much energy the building uses. **Value: 3/3**
Transpired Solar Collector	Heat Recovery Units (Heat Pump System and Heat Exchanger types)	A Transpired Solar Collector (TSC) is a type of Solar Air Heater (SAH) that works by reducing the overall load on a building's heating system. This is done by drawing in warm air heated by the sun, which will then flow to the top of the building where it is circulated throughout the building. This can be done by using a mechanical ventilation system, such as a HVAC system, where it heats up the heating system or the warmed air can flow directly into the building.	High feasbility, as a TSC is 80% efficient, with low maintenance once installed. They are durable, having a long life span of about 30 years. Installation is simple, as it does not need to operate off of existing heating systems in a building. TSCs are quiet, with little impact on daily living and can act as a rain-screen, which allows for proper drainage and evaporation, also collecting heat that attempts to escape the building through the air cavity. TSCs can be connected to a HVAC system where the heated air heats up the heating system. A TSC was found to have a SIR of 1.86 and an IRR of 5.59%. **Value: 3/3**	Low innovation, as TSCs have been used for over 20 years. Payback for TSCs is 3-7 years, shorter than any other technology using renewable energy. They also have a high GHG emissions savings potential by replacing fossil fuel energy sources with solar energy. Unglazed TSCs (UTSCs) have a perforated metal cladding used to preheat fresh air through a cavity (15cm) between the metal and the building's wall. UTSCs are being tested for optimal geometries and perforation positionings that give greater thermal efficiencies. **Value: 1/3**	Credit 14.0: Thermal comfort Credit 15.0: Greenhouse gas emissions **Value: 2 credits**	T01.1 Provide acceptable thermal environment (required) M01.1 Provide mental health and well-being (required) I06B.3 Carbon reduction (3 points) **Value: 3 points + 2 requirements**	High energy savings potential. TSCs can reduce energy consumption by 10-50% of conventional heating loads. This only takes into consideration the building's distribution system, as distribution grids and other external systems do not affect the amount of energy generated. A 25m2 TSC was found to have saved about 14000kWh/year, though energy savings will vary depending on climate conditions and differing locations. Higher thermal efficiencies have been achieved with UTSCs of up to 40%. **Value: 3/3**

Task 2 Research

Matrix example

The full matrix assessed 20 initiatives across 8 categories – far too large to present here. The below is included to show how the matrix appears.

Net Zero Energy Design Strategy

Design Measures	Business-As-Usual Case	Measure Description	Feasibility 0.17	Innovation 0.03	Green Star Impact 0.08	WELL Impact 0.11	Energy Savings Potential 0.22	Carbon Savings Potential 0.19	Capital Cost 0.06	Operational Cost 0.14	Weighted Value (Higher is Better Practice)	Overall Ranking (1 = Best Practice)
Solar Panels	Fossil Fuels (Petroleum, Natural Gas and Coal)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.07	6
Transpired Solar Collector	Heat Recovery Units (Heat Pump System and Heat Exchanger types)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.02	8
Power Purchase Agreement	No Power Purchase Agreement and Purchase of Electrical Generating Equipment	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.3	4
Hydronic Radiant Floor Heating	Forced Air Heating	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.44	15
Electric Radiant Floor Heating		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.61	13

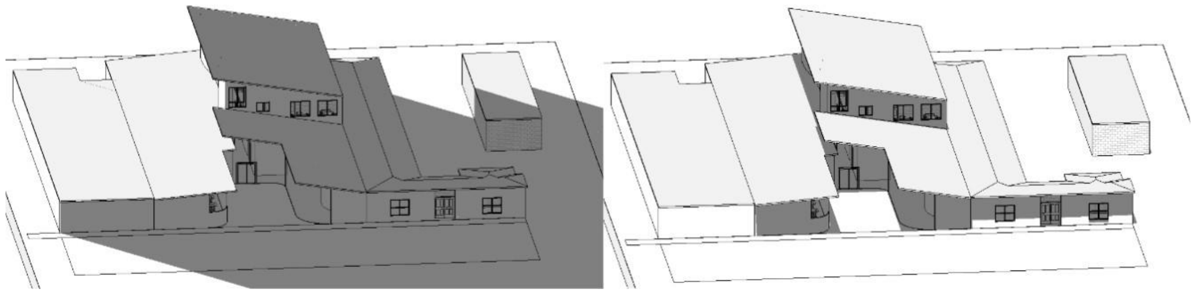
Studio

Task 3 Proposals

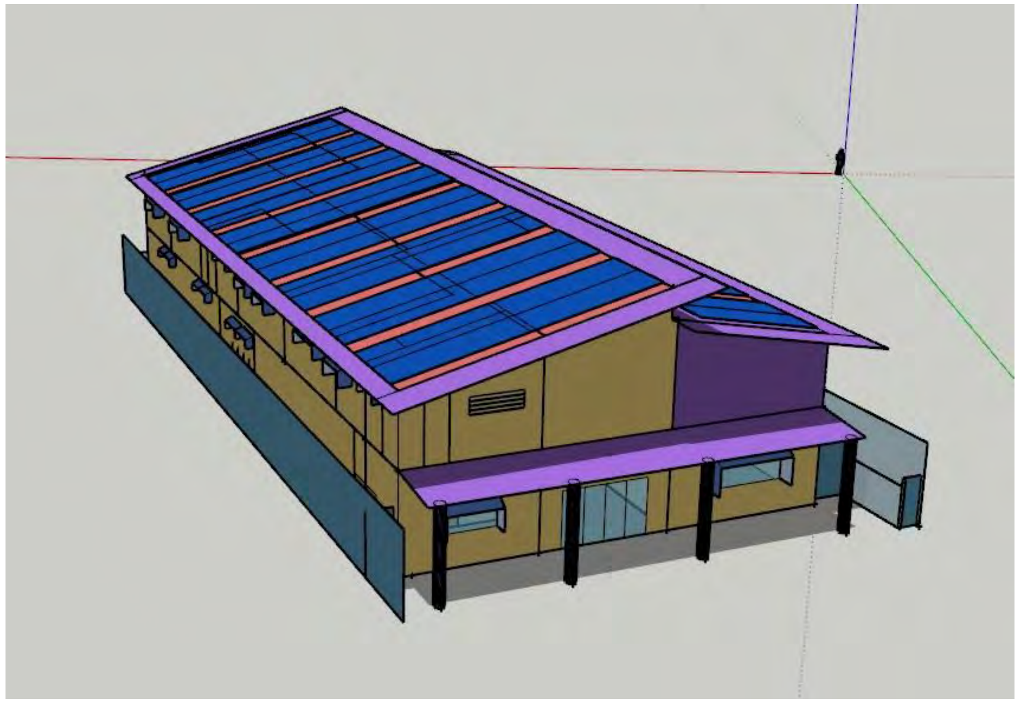
The final assignment had each student working on assessing in detail their proposed initiatives. This included where appropriate energy modelling of the facility to identify the potential carbon saving benefit.

The example shown here is a statistical analysis of the impact of different glazing on HVAC load across the year and a relative impact.

The students' final reports summarised the findings of their analysis and allowed them to provide their assessment of the achievable savings associated with specific technologies. As the task was focussed on specific initiatives, there is no overarching study which shows the total carbon savings.



Glazing Type	Annual Energy (GJ)				Average REF Value
	Heating	*Cooling*	*Net Site*	*Total Site*	
Clear	24.47	674.30	660.04	1096.45	0.396027
Low-E Clear	23.25	670.60	655.11	1091.52	0.397549
Green Tint	24.97	667.06	653.30	1089.71	0.398922
Bronze Tint	24.98	666.94	653.19	1089.59	0.398970
Blue Tint	24.98	666.90	653.15	1089.56	0.398984
Grey Tint	25.02	666.28	652.57	1088.98	0.399234
Low-E Spectrally Selective Clear	23.37	665.10	649.74	1086.15	0.399793
Low-E Tint	23.73	663.68	648.68	1085.09	0.400384
EC Ref Coloured	24.42	654.99	640.68	1077.09	0.403890
Low-E EC Abs Coloured	24.19	653.97	639.43	1075.84	0.404321
Low-E EC Ref Coloured	24.19	653.97	639.43	1075.84	0.404321
Low-E Spectrally Selective Tint	24.22	653.64	639.13	1075.54	0.404451
EC Abs Coloured	26.77	652.79	640.83	1077.24	0.406490



Task 3 Proposals - Summary

Throughout the IDS, multiple ideas were presented by students. These were tested and modelled to calculate the overall improvements that were expected to be realised. The lists below highlight some of these ideas, as appropriate to community facility.

In line with the noted net-zero carbon approach noted previously, the features have been collected into categories and are reviewed as noted in the following section.

The key focus is applied to passive design techniques and opportunities

Student Ideas
(O) High efficiency HVAC systems
(O) Energy Recovery Ventilator
(P) Natural ventilation and mixed mode ventilation
(R) PV systems
(I) Power Purchase Agreement
(O) High efficiency appliances and systems
(P) Double or triple glazed windows
(P) Increased insulation performance
(P) Use of phase change materials (PCM)
(O) Thermal zoning (thermostat control)
(O) Indoor Breathing Wall
(O) Battery Storage for excess PV production
(O) Use of Biogas plant
(P) Shading
(P) Rammed Earth Walls
(P) Thermal mass
(P) Trombe Wall
(P) Solar Chimney w/ Earth Tube

Additional Ideas Explored
(O) Automated blinds
(O) Occupancy detection
(O) Daylight Dimming
(O) Relaxed setpoints
(O) Adaptive comfort through ceiling fans
(O) EC Plug fans
(O) Centralised, efficient heating/cooling plant
(P) Improve quality of window/door seals beyond business as usual

Feature categorisation
(P) – Passive design
(O) – Operational efficiency
(R) – On-site renewables
(I) – Innovation/other

Energy Modelling

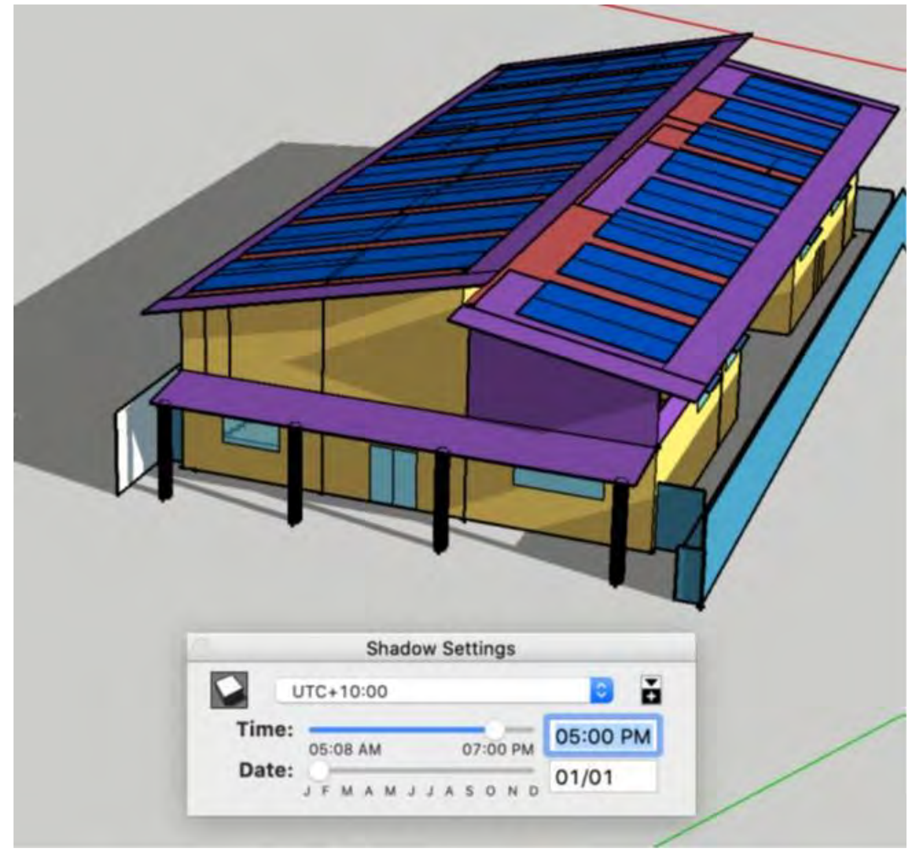
Energy models were developed by the students to assess their proposed improvements across the year. This design stage of verification allows the support of the development of the technology.

This was typically completed in either Google Sketchup and assessed using OpenStudio through the EnergyPlus energy modelling engine, or using DesignBuilder with their built-in engines which runs on EnergyPlus.

Students took on this task to develop the models themselves, but were guided by the Tutors and approached in a cross-discipline collaborative sense.

This allowed them to investigate how technologies could be applied and where the savings would come from. This is a critical step as it mimics how projects achieve this in a construction environment.

The common language used for all students was to achieve a Renewable Energy Fraction (REF) of at least 1.0 - indicating the overall development had achieved net-zero



$$REF\ Value = {}^{Renewable\ Energy\ Generation}/_{Total\ Site\ Energy\ Requirements}$$

Table 1: Renewable Energy Fraction values

REF Value	REF = 0	0 < REF < 0.3	0.31 < REF < 0.95	0.96 < REF < 1.05	1.05 < REF
Number of REF Hours	5	4263	2215	184	2093
Annual REF Value	0.67				

Passive Design

Students identified early on that there are significant opportunities to integrate passive design for new build designs.

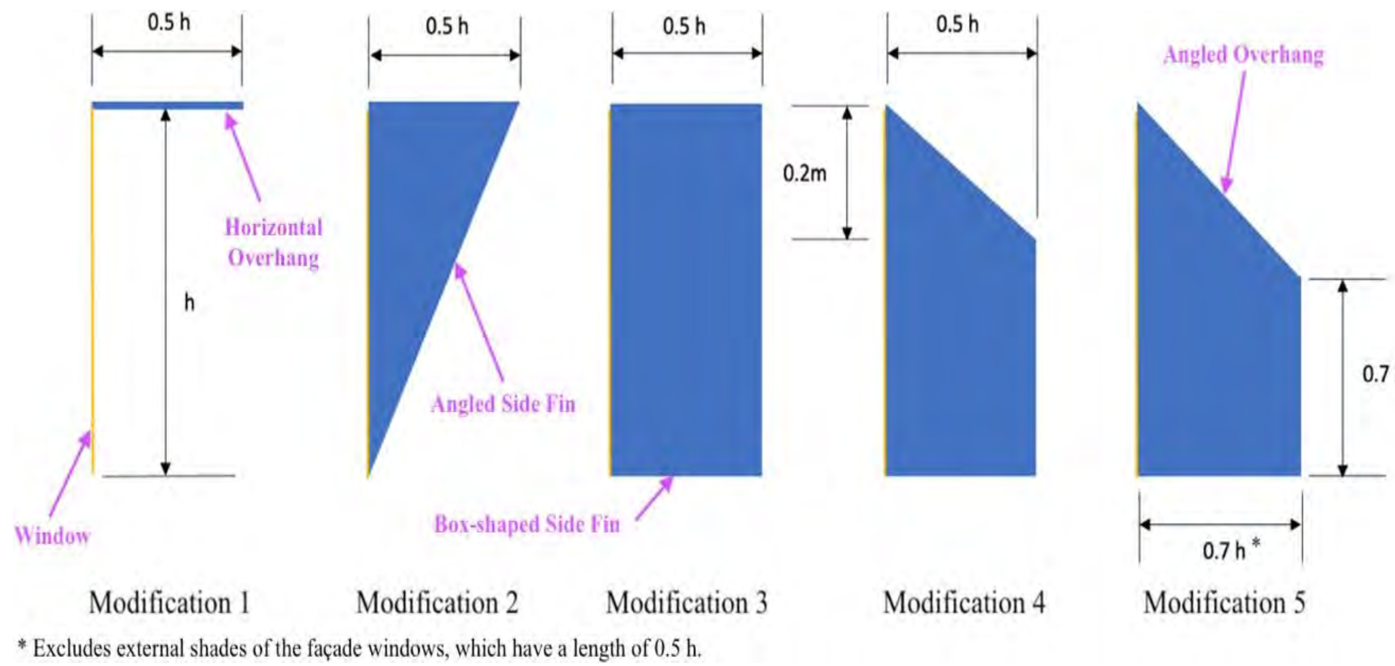
Massing of the building can be adjusted to optimise solar load for both cooling and heating, which offsets the need for actives systems.

Reduction in loads through increased façade or envelope performance were assessed.

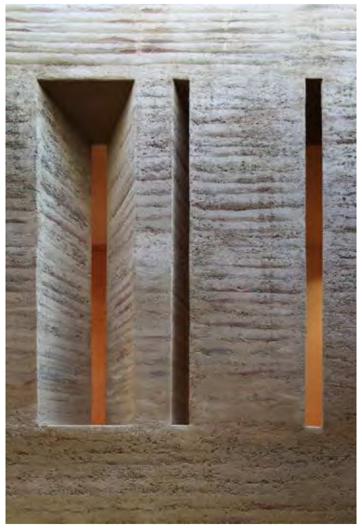
Given the significant heat profiles in Lightning Ridge, emphasis was provided on shading, quality of construction and high-performance facades.

Students concluded the best element to produce the best REF was to negate solar gains through shade.

The students were challenged with coming up with local material solutions that were available, possibly taking inspiration from Aboriginal culture and building techniques. Students explored novel traditional construction techniques such as using rammed earth which has excellent mass and provides great thermal protection from outdoor temperatures. It also provides stability.



A range of different shades were tested to find out which provided the best overall performance.



Rammed Earth is a sustainable construction material with great thermal properties
https://www.wsj.com/articles/rammed-earth-luxury-homes-1427989394 (left hand image)
https://www.archdaily.com/933353/how-rammed-earth-walls-are-built (right hand image)

Passive Design

The student's desire for passive concepts also explored clever design solutions and known technologies. This included phase change materials, enhanced window performance systems, utilising thermal mass and exploring ideas such as solar chimneys.

The students were quite keen to explore how passive solutions could affect an outcome. Significant research was completed and modelling of techniques to improve overall energy consumption without system integration was key.

Key passive solutions focussed on the geometry, but also took inspiration from nature to cool air. Ideas such as thermal labyrinths were explored, given the cool winters and warm summers. These systems, while expensive and not a full conditioning solution, could provide an element of heating/cooling to the overall design.

This passive attempt at reducing greenhouse gas emissions is the key first step to any design and is critical across both architecture and engineering.

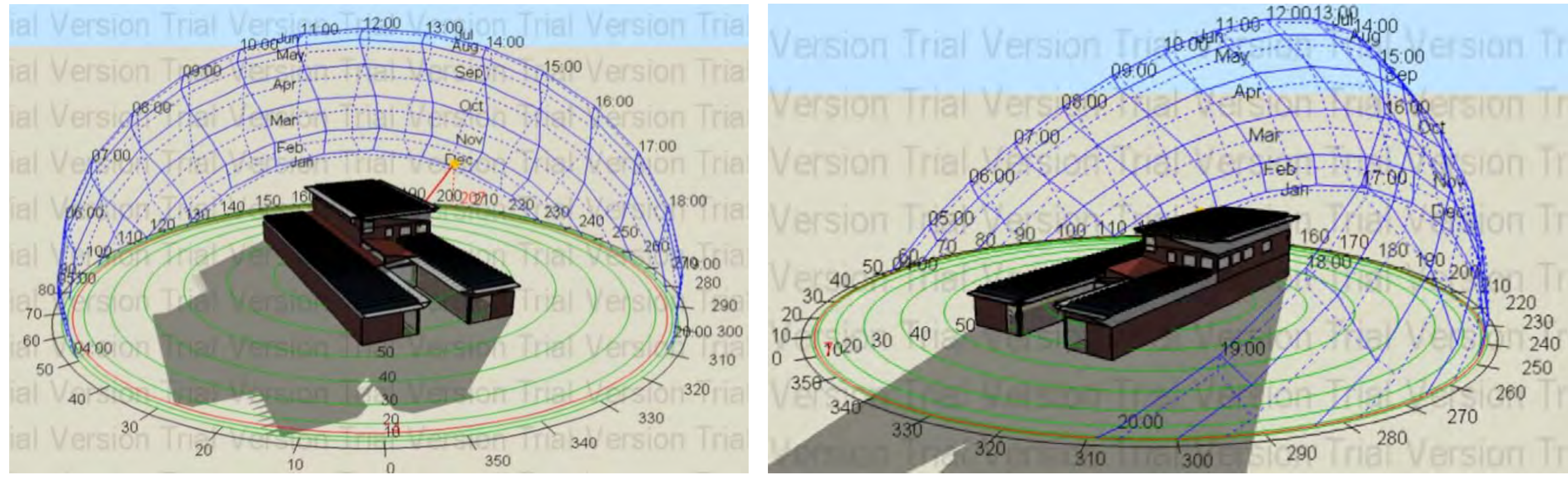


Image: Student 6 Assignment Submission, IDS09

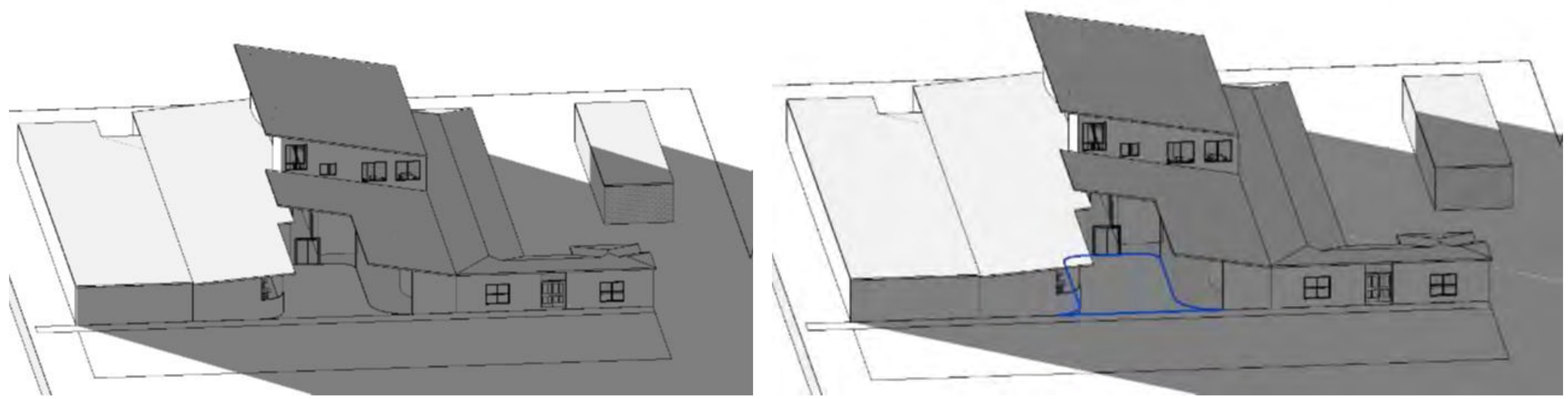


Image: Student 1 Assignment Submission, IDS09

On-Site Renewables

On-site renewables offer a simple and incredibly effective way to offset electricity consumption within the built form. All buildings providing amenity will consume energy. Once the building's energy consumption has been reduced as far as possible, the next step is to offset it through renewables.

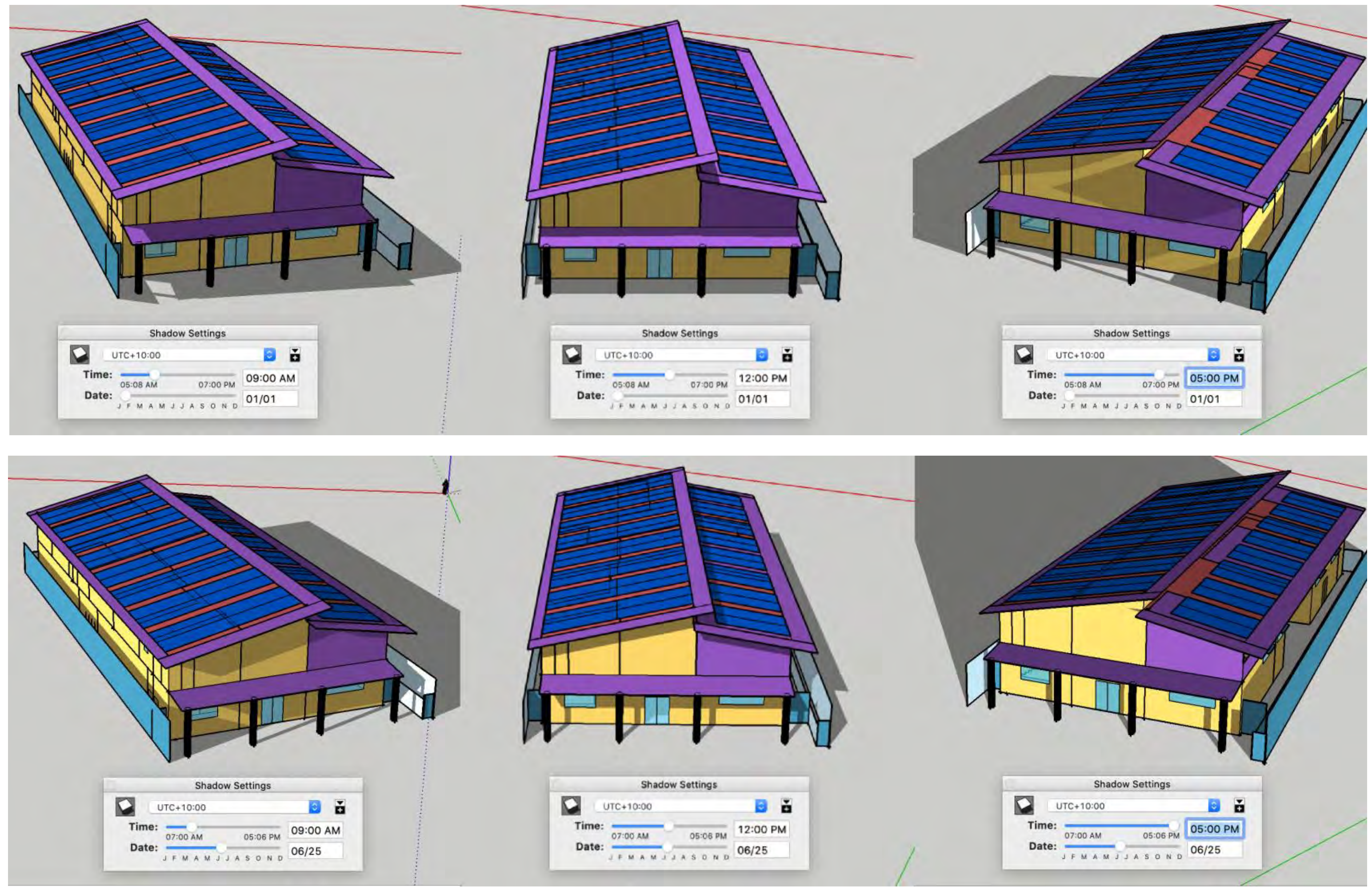
The return on investment is typically high with relatively short payback periods, making it an attractive option.

All new developments should aim to maximise PV, as it provides excellent payback, works towards net Zero and is the single best technology we have.

Most students found that PV had the largest jump in performance when aiming to improve their building performance.

PV systems design should be integrated into a larger site-wide energy strategy which should consider storage to maximise on-site usage of generated power.

A 60kW system was found to reduce the overall building annual energy consumption by 40% compared to a reference case building.



Operational Initiatives

Operational efficiencies are key to driving sustainability and moving towards net-zero. There was a strong focus from students on this area – initiatives associated with operational efficiency provide good opportunities to analyse carbon benefit, compared to passive examples where occupant behaviour may impact effectiveness.

At a high level, the operational measures fell into the following high level categories:

1. High efficiency systems
2. Energy recovery systems
3. Energy management systems

High efficiency:

Given the climate zone, students explored relevant solutions to maximise efficiency. This included designing climate-responsive systems, such as installing windows that meet both the hot summers and the cool winters.

Finding the right technology was pivotal to maximising efficiencies. Students considered the impacts of lighting, including daylight dimming, LED's throughout and pushing what was possible in terms of system choices.

Similarly, students were keen to explore alternates to active heating and cooling. Items such as high volume, low speed (HVLS) fans and thermal labrinths/Trombe Walls were discussed but not analysed – this may require changes to the project brief to enable inclusion.

EC Plug fans and newer technologies are now able to drive higher efficiencies, but the key element is the design of these systems to operate to their full capacity. These systems will always be limited by the underlying technologies.

Energy recovery:

Energy recovery includes the capture of waste energy from required processes to provide inputs and/or offsets for other processes.

Energy recovery ventilators were reviewed by students as a means of capturing heat from exhaust air streams to preheat/cool ventilation air required for code compliance. This reduces the amount of conditioned air being rejected into the atmosphere.

Relaxed Setpoints:

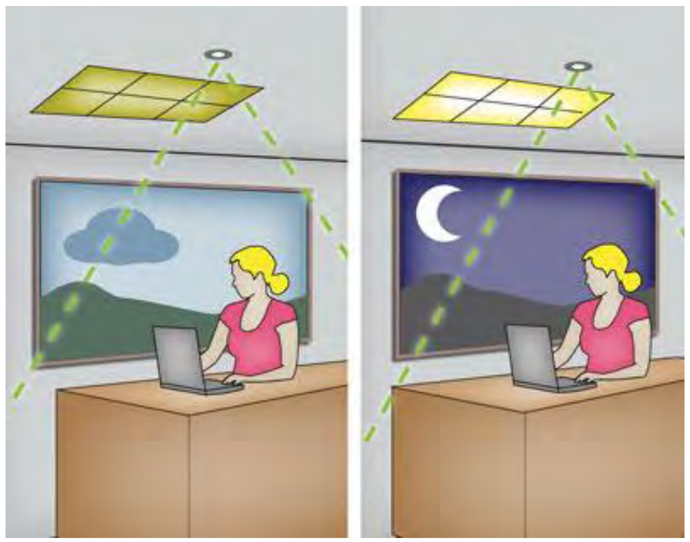
Typical offices are designed to an arbitrary 21-24degC. The students discussed with the tutors the opportunity to increase this temperature band beyond the range. Benefits include a significant saving in energy in both summer and winter, as well as achieving gender equity. The office space is designed for a 60kg middle-aged man in a three-piece suit. It is no longer relevant to the current climate, dress or population.

Students and tutors alike explored the opportunities to save energy by relaxing archaic temperature ranges, as well as designing for people whose clothing choices match the climate (I.e. warmer dressed in winter and cooler in summer.

https://www.abc.net.au/radionational/programs/greatmomentsinscience/freezing-in-office-because-air-conditioning-standards-sexist/8300132

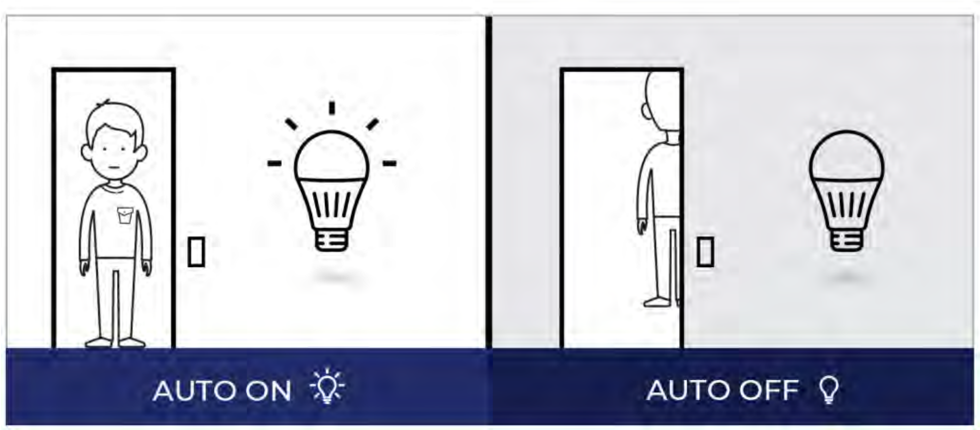
Operational

Daylight Dimming



Daylight Dimming is a method to reduce output of artificial light when ambient light is sufficient. This light is wasted and exceeds the required minimum provisions. It can also lead to glare, so this initiative will ensure adequate light, but reduce waste in energy and assist glare

Occupancy Sensors

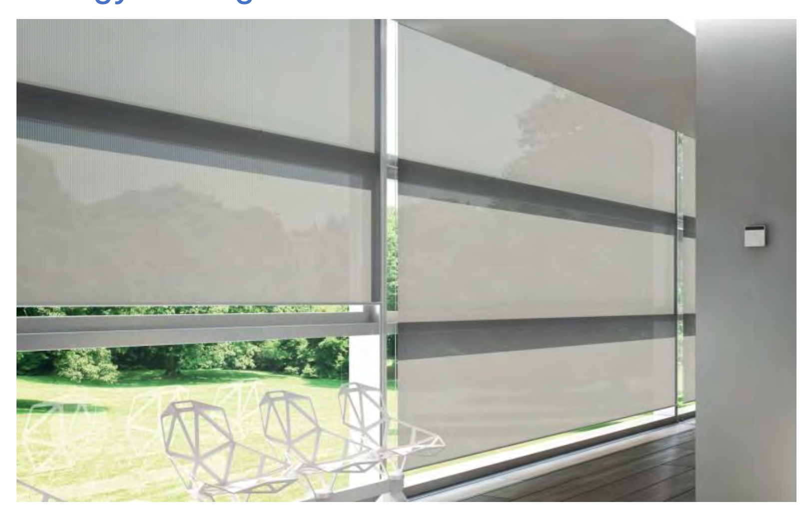


Occupancy Sensors are a tried and trusted technology that allows buildings to only use lighting or equipment when the space is in use. Mechanical systems and lights can turn off and on as required in the space

Air Tight Facades

Exploring Air Tightness is a key consideration in extreme climate zones. Controlling the internal air temperature and movement of air is critical to this. This can control energy, comfort and reduce losses.

Energy management



Automated blinds to control solar loads automatically without user intervention – blocking heat in cooling conditions, allowing solar in heating.
https://www.digitalhomesystems.com.au/about-smart-home/nice-blind-shutter-and-awning-automation

Studio

Embodied Carbon

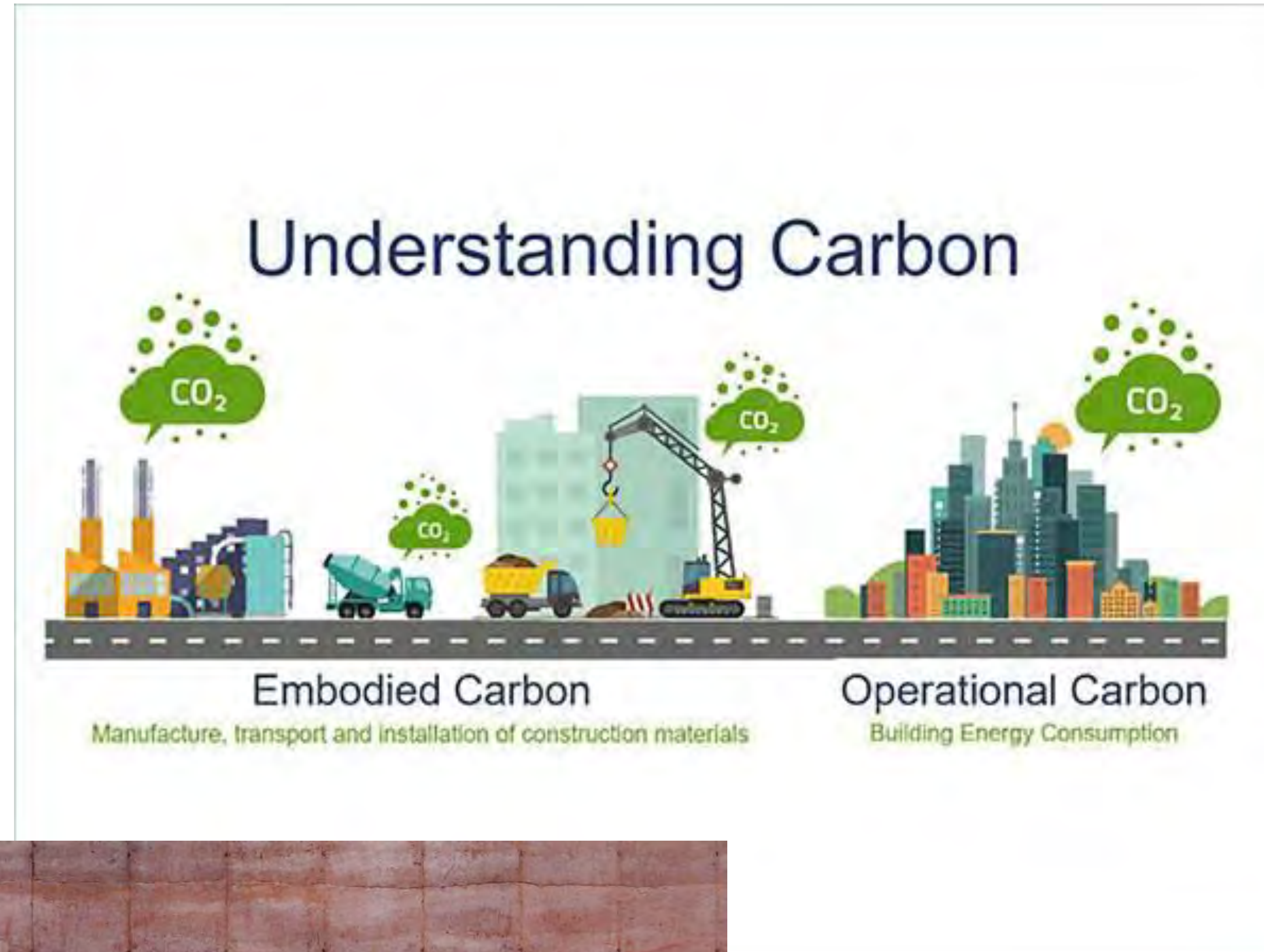
As the grid decarbonises, the importance of embodied carbon within the design continues to increase. In time, embodied carbon and materiality will be the most important metric in sustainable design.

Selection of low-process and low-carbon materials, minimisation and optimisation are key design elements within embodied design. Structural design efficiencies are key as building more with less has an immediate reduction in carbon.

Using alternate materials such as timber, muds, clays, or recycled/repurposed/ upscaled or reused products will reduce the embodied carbon of any development.

An option at Lightning Ridge could be to explore locally-sourced natural materials that can be used for construction. Performance solutions in structural and architectural designs can also reduce construction cost and embodied carbon.

Alternately, waste products locally sourced such as mining tailings could be used in a Rammed-Earth Wall construction. This could assist with multiple problems at once



Rammed earth construction using local soil/clay with timber framed roof – low embodied carbon building materials.
https://www.archdaily.com/894341/rammed-earth-construction-15-exemplary-projects

End of life

Planning the end of life and deconstruction of a building starts in the design phase. The best technique is to ensure the structural life of the building is as long as possible, so the building can have many lives in its existing form.

Specific to the Lightning Ridge Site, it must be considered that there is likely no realistic recycling option for building material. As such, planning building elements to have an extended life, reducing material in construction and planning for how the building will be disassembled is more important than ever.

One concept that has not been explored in this report is the potential benefits of modular construction or prefabrication of façade elements. Considering the location, this could significantly reduce waste during construction, and put in place a stewardship (take-back) option at the end of the project to remove a vast portion of embodied carbon from the construction process.

Timber is also a fantastic material for pre-fab, being quick, accurate and light to bring to site.

Timber construction – designed properly for deconstruction can then be repurposed of recycled easily at end of life
https://givingcompass.org/article/mass-timber-construction-is-about-more-than-just-storing-carbon

Prefabricated units could significantly reduce the end-of-life waste issue, transport, speed of construction and cost.
https://medium.com/autodesk-university/integrated-bim-workflows-in-modular-prefabricated-construction-concept-to-fabricate-2cff9b3573e1

Improvement on Business as usual

Unlike commercial buildings which have NABERS or Residential developments that have BASIX, the variability in design of the size and usage of similar facilities means there is no single, definitive benchmark available for end of use energy. Similar buildings are necessarily normalised for climate zones, as Lightning Ridge is in itself an atypical site.

The students through their work have developed assessments of potential savings within their proposed scope of study. The combined savings associated with these end use energy components, combined with renewable energy potential would result in a significant reduction in the building operational energy compared to business as usual design.

Students have aimed to demonstrate a REF value as close to 1.0 as possible. Most students have found a REF Value to be possible in the range 0.6-0.7, suggesting up to 70% of the site's operational carbon can be abated.

This is typically achieved through a combination of operational and passive measures, complimented with compromise on operation and renewable sources

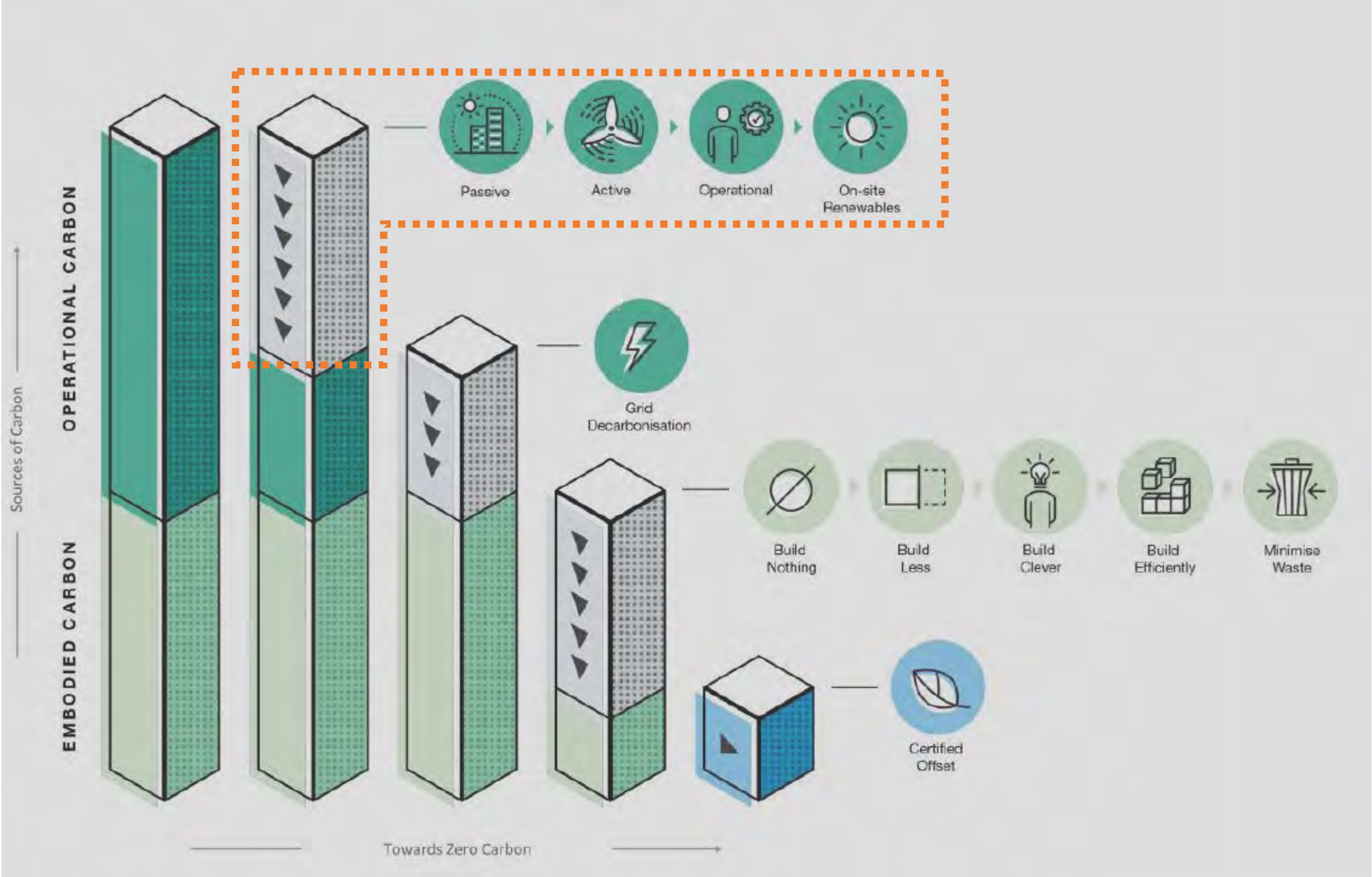
The options reviewed as part of the studio would be capable of achieving a reduction of well over 25% of operational carbon.

Minimal analysis was completed on economic effectiveness of the proposed measures – this may impact the adoption of specific initiatives which have lower return on investment.

While the scope of the studies were limited in parts, there were significant works undertaken to demonstrate opportunities across engineering and architecture to affect real change.

A range of design improvements, combined with onsite and offsite renewable the development could achieve net-zero operational carbon.

This is achievable with whole-of-life, whole-of-process thinking through design.



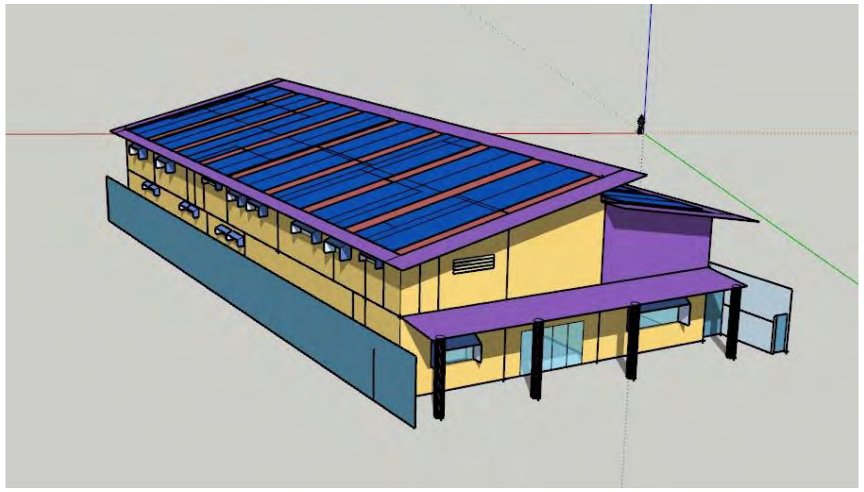
Adapted from: Arup.com - net-zero carbon buildings: three steps to take now (2020)

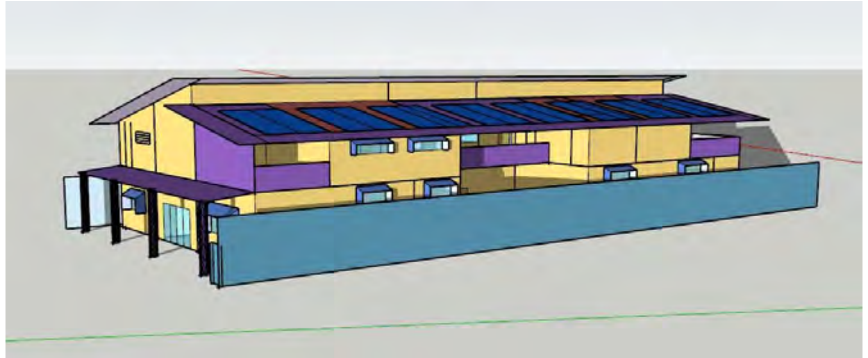
Conclusions

This studio concluded that there are many opportunities to reduce this building's carbon during construction and operation. The focus of this vetting report has typically been on operational carbon and drawn primarily from the students work. It is not exhaustive, and we note that there are other net-zero pathways available for community facilities such as this.

Building design should look to minimise energy use first through passive design minimising the building requirements. This may include adjustment to the user amenity, e.g. nominated thermal comfort requirements. Where energy use is still required, energy recovery and efficiency should be prioritised with management of the energy use playing a key role in optimising the environment. Renewable energy can then offset the remaining energy, looking to maximise this onsite first and potentially integrating energy storage. Where a shortfall still exists, there may be potential to combine this with an offsite renewable energy scheme.

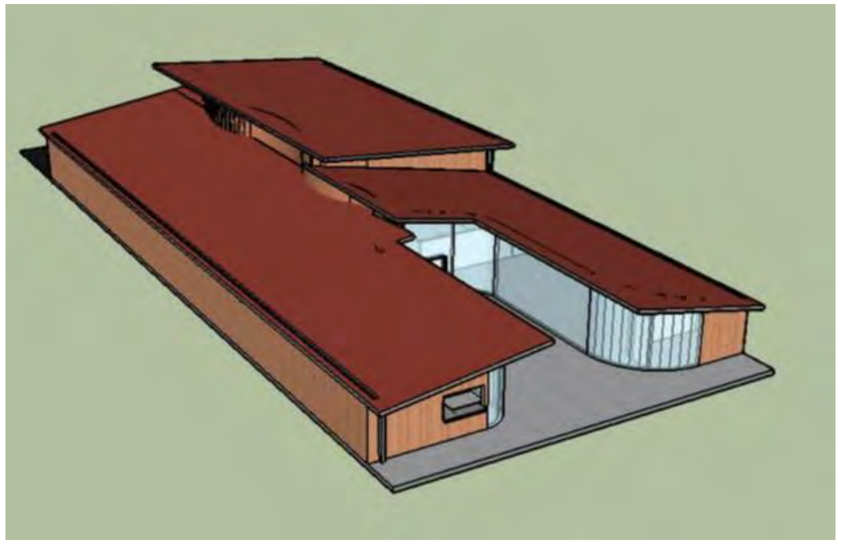
As a facility which focusses on communal spaces, consideration should be given to features which can also have other more intangible benefits such as natural daylight providing both carbon reduction and a positive contribution to wellness of the facilities' users.





Images: Student 4 Assignment, IDS09

No overarching pathway for net-zero has been presented in the students' work, however, the individual reports do show a high level of savings is available. Design optimisation, higher minimum standards and renewables will continue to play a major role in any net zero strategy.



Images: Group 2 Assignment, IDS09