The Innovation Hub

for Affordable Heating and Cooling

Design Studio Outcomes Report (100% Milestone)

IDS-12 Illawarra Local Aboriginal Land Council Former Unanderra Police Station Redevelopment – Outcome Report

Project IDS12

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University of Wollongong

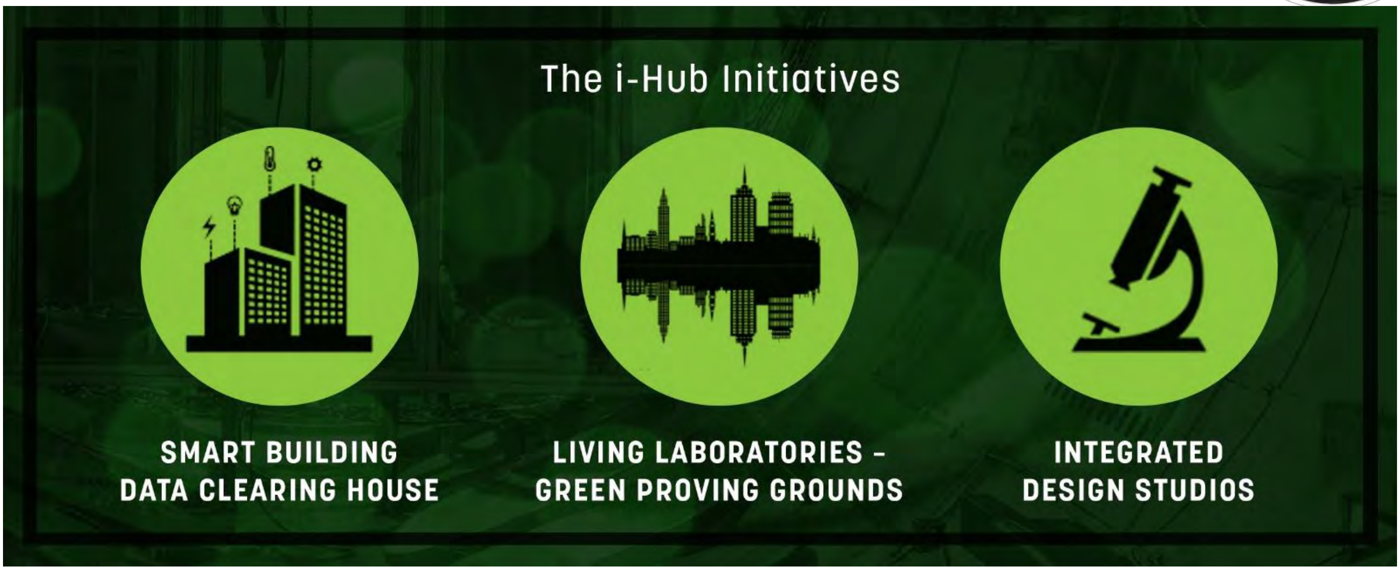
About i-Hub

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.
The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.

Primary Project Partner



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

The IDS-12 Illawarra Local Aboriginal Land Council (LALC) Former Unanderra Police Station Redevelopment Integrated Design Studio investigates design innovation to reduce net energy consumption of a proposed redevelopment of the former police station located in Unanderra. Over a 13-week period, a group of multidisciplinary students, consultants and academics work collaboratively to develop several proposed designs for the client (the Illawarra Local Aboriginal Land Council). These designs will be conscious of the land councils concern of environmental impact and energy usage, while also providing residential or retail opportunities for members of the surrounding community.

The Illawarra LALC is heavily invested in environmental efficiency, being very conscious of the impact construction can have on the surrounding environment, and the ongoing carbon emissions produced through operating inefficient buildings. Any development involving the land council will be required to be conscious of these factors. The proposed redevelopment will be an ongoing asset for the land council, providing opportunities to the surrounding community and supply an ongoing revenue stream to assist with other new and ongoing community initiatives organised by the land council.

Based on the brief provided by the Illawarra LALC, IDS participants explored novel approaches to address the environmental concerns of the land council and aimed to achieve a net-zero carbon solution through inclusion of renewable energy technologies, efficient building strategies and building materials. Considerations were given to the needs of the surrounding community in assessing the recommendations for the redevelopments purpose, and whether this aligns with the objectives of the land council.

Lead organisation	University of Wollongong		
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Report date	25th May 2022		
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1 SUMMARY

1.1. Purpose

This report summarises the findings obtained from IDS12 (Illawarra LALC Former Unanderra Police Station Refurbishment), 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 IDS12 Illawarra LALC Former Unanderra Police Station building 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 provided an introduction to the proposed site location and provided the project participants with a brief on the multi-purpose building as well as with photos and videos from the site. The site was not unfortunately accessible due to the COVID-19 lockdown in NSW.

Outcomes for the IDS have been aligned to focus on producing integrated solutions that target 'Net Zero' design. Due to the impact of COVID-19, the studio activities were held via a fully online platform (Zoom). 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. Energy simulations were undertaken to determine which strategies should be implemented to achieve an annual average REF (renewable energy fraction) greater than 1, analysing results on an hourly basis. It was found that, under a number of pre-specified assumptions, that the majority of baseline designs had an REF between 0.6 and 0.7. These finalised designs and recommendations have been presented to clients, 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 energy demand for specific technological/strategic inclusions

Case	Heating (GJ)	Cooling (GJ)	Lighting (GJ)	Equipment (GJ)	**Total (GJ)**	PV AC Output (GJ)	Site Net (GJ)	**REF**
Base	185.3	92.3	64.8	56.1	**398.5**	311.6	86.9	**0.79**
Insulation	167.3	86.6	64.8	56.1	**374.8**	311.6	63.3	**0.79**
Skylights	143.6	79.2	64.8	56.1	**343.8**	311.6	32.2	**0.89**
Shade + Windows	141.4	62.5	64.8	56.1	**324.8**	311.6	13.3	**0.99**
PV Shade	**141.5**	**62.5**	**64.8**	**56.1**	**324.9**	**342.0**	**-17.1**	**1.08**

Similarly to the findings of prior IDS's, it was reiterated that the integrated design process should include:

- Well defined frameworks to assist less experienced designers through the integrated design process.
- Feedback mechanisms to improve project outcomes.
- An appropriate timeframe that accounts for the professional experience of the participants.
- Detailed client briefs that requests an integrated design and is developed in conjunction with client consultation.

In terms of technical outputs suitable for the building type and climate, design strategies anticipated to be most relevant to abating operational carbon and minimising energy use intensity (EUI) were:

- Two-tone lighting – Reducing energy requirements through zoning of necessary task lighting.
- Passive design solutions (insulation, skylights, shading and rezoning the internal spaces) – Abate operational carbon through lessening the requirements of active solutions
- Modular design and construction – Minimise material wastage and reducing construction efficiency.
- Recycled/sustainable ductwork – Abate embodied carbon through low-process and recyclable material usage.
- On-site renewable energy generation – Optimise rooftop orientation and utilise adjacent rooftop availabilities.

Overall, the IDS process has proven valuable for all participants and is now intended to become a permanent approach in the training of students.

2 PROJECT CONTEXT AND INCEPTION

2.1. Context to the Illawarra LALC Integrated Design Studio

The Illawarra Local Aboriginal Land Council has proposed the redevelopment of the former Unanderra police station into a mixed-use structure for use by the land council and providing commercial, career, social and residential opportunities for the surrounding community. The site encompasses two adjoining blocks (1 and 7 Farmborough Road), with the former accommodating the existing structure. The client is flexible towards development methods and functionality requirements, with IDS participants required to make an informed decision regarding both.

Student designers were to decide whether to retrofit the existing structure (which is in need of substantial refurbishment), or if it is more beneficial to demolish the existing structure and redevelop the site completely. Both options have advantages and drawbacks, however if demolition were to occur, the client would require a complete environmental impact assessment, examining the additional carbon footprint this would cause, and thorough analysis of the end-of-life of all materials removed from site. Either selection is valid providing ample justification. Additionally, the adjoining site could be used to expand the existing structure, or to develop a secondary structure.

Figure 1. Site location for 1 and 7 Farmborough Road, Unanderra

IDS participants were also required to determine the function of the development, with the council open to multiple alternatives. The first option was for use by the land council themselves. Having expanded over recent years, the land council has outgrown its current office spaces, and would welcome additional office spaces suitable for work and accommodating council meetings. The second option available to the students was to develop office/retail/studio spaces which may be privately leased for use by external agents (e.g. small businesses). This option would generate a revenue stream for the land council which would fund new or existing initiatives run by the land council. The third option was to renovate the structure into a residential building, supporting several single-room dwellings which could be leased to indigenous members of the community in need of housing. The client was also open to a combination of these options, based on reasonable justification.

In addition to the options available to the students and consultants, the client highlighted that the interior of the existing structure has very little natural light, which will need to be addressed through the retrofitting process. Additionally, the internal spaces will need to meet accessibility design requirements. Finally, the client is highly invested in environmental efficiency and impact. The inclusion of renewable energy sources and passive design strategies is greatly encouraged.

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 in a design studio. 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 run until 05th November.

The Illawarra LALC Former Unanderra Police Station Redevelopment was one of these two case studies selected to be investigated within the IDS program. A consultation process followed with the Illawarra 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 CEO of the Illawarra LALC, who has extensive knowledge of the site and the regulations surrounding its redevelopment, while also having considerable experience working on economic and regional development, and indigenous community initiatives. The principles of the IDS align with the ideals of the Illawarra LALC in minimising environmental impact, 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 being considerate of the cultural heritage of the surrounding lands and environment.

As no current design proposals exist, the Illawarra LALC will use the designs developed by the IDS participants 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 client has generously 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 client also attended the design studios in week 9 to examine the current state of the student designs and offer any final advice/recommendations before the final detailed design was undertaken. The outcomes of this IDS in combination with an engaged client have great potential to provide a lasting impact for the Illawarra LALC and contribute to the ongoing development of emerging practitioners.

2.4. **Virtual Site Visit**

The Illawarra LALC former Unanderra police station redevelopment is proposed to be developed at 1 and 7 Farmborough Road in Unanderra. A site visit to this location would have given IDS participants the opportunity to interact with the client and provided greater context surrounding the brief, as well as affording students the opportunity to investigate the surrounding environment and community in preparation for developing a site analysis. However, the outbreak of Covid-19 restricted movement for the Greater Sydney region (including Wollongong) and did not allow for the integrated design studio to conduct a site visit. Students instead discussed the site with the representative for the Illawarra LALC through Zoom, with investigation of the surrounding site being completely virtually.

Figure 2. Current state of the former Unanderra police station site (exterior)

In addition to this virtual investigation, the client was able to provide the IDS participants with photographs depicting the current state of the building. Students were also able to participate in a virtual walkthrough of the existing building via a video, providing students with an understanding of the existing space. While these forms of media are no substitute for a true site inspection, they are the best alternative available due to the restrictions that were in place at the time.

Figure 3. Current state of the former Unanderra police station site (interior)

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 IDS12. A particular focus was placed on the findings from IDS10 and IDS11, which identified benefit in exploring design for a 'greenfield 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. While it can be argued that the redevelopment is a 'retrofit', the extent of the refurbishment in addition to the potential to fully demolish the existing structure and the additional block available for extension/additional development class more similarly to a greenfield site rather than a retrofit.

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) to 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 (14 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 has 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 4), 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 4. Select examples of preliminary student work from the Miro workspace

4 DESIGN STUDIO PROCESS FINDINGS

The findings from the Integrated Design Studio IDS12 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 and students give a perspective from those participating in the studio, providing reflection on the studio operations, what alterations could be implemented 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
- Capital cost and feasibility
- Building Regulations and Certification
- Energy Reductions and Carbon Abatement

Table 2: Selected extracts from student work - Evaluation matrix

Proposal Item	Assumptions & Justifications	Brief Description	On-site feasibility	Energy saving potential	GHG saving potential	WELLS impact	BASIX Impact	Capital cost	Operational cost	Technological maturity	Innovation	Adaptability	Client Requirements	Total	Rank
Intensive Green Roof (grass)	[illegible]	[illegible]	★★★ [illegible]	★★★ [illegible]	★★★ [illegible]	★★★ [illegible]	★ [illegible]	★★★ [illegible]	★ [illegible]	★★★ [illegible]	★★ [illegible]	★★★ [illegible]	★★ [illegible]	86	2 & 3
Light Tunnel	[illegible]	[illegible]	★★★	★★★ [illegible]	★★ [illegible]	★★★ [illegible]	★ [illegible]	★★ [illegible]	★★★ [illegible]	★★ [illegible]	★★★ [illegible]	★★ [illegible]	★★★ [illegible]	86	2 & 3
Clerestory Windows	[illegible]	[illegible]	★ [illegible]	★★ [illegible]	★ [illegible]	★ [illegible]	★★ [illegible]	★ [illegible]	★★ [illegible]	★★★ [illegible]	[illegible]	★★ [illegible]	★ [illegible]	50.7	10
Rammed Earth Sound Barrier w/ vegetation	[illegible]	[illegible]	★★★ [illegible]	★★ [illegible]	★★★ [illegible]	★★★ [illegible]	★ [illegible]	★★★ [illegible]	★★★ [illegible]	★★★ [illegible]	★★★ [illegible]	★ [illegible]	★★ [illegible]	83.3	5
LED Lighting replacement	[illegible]		★★★ [illegible]	★★★ [illegible]	★★★ [illegible]	★★ [illegible]	★★★ [illegible]	★ [illegible]	★★★ [illegible]	★★★ [illegible]	★	★ [illegible]	★★ [illegible]	78.7	7
Storing Rainwater	[illegible]	[illegible]	★★★ [illegible]	★★ [illegible]	★★ [illegible]	★★ [illegible]	★★★ [illegible]	★ [illegible]	★★	★ [illegible]	★	★★★ [illegible]	★★★ [illegible]	77.3	8
Deciduous native trees for shading	[illegible]	[illegible]	★★★ [illegible]	★★★ [illegible]	★★★ [illegible]	★★★ [illegible]	★★ [illegible]	★★★ [illegible]	★★★ [illegible]	★★★ [illegible]	★ [illegible]	★★ [illegible]	★★★ [illegible]	83	6

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 incorporating views of the escarpment/Mt. Keira and how the building orientation to incorporate these aspects may impact the buildings thermal performance and alter the efficiency of PV installations. The expertise of the consultants assisted the students with implementing these aspects on a technical level while ensuring that the aspirations of the client were not neglected.

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) if this occurs. 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, electrical, 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 participants 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 accommodated. 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. 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.

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 project's 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. IDS12 was ideal for examining this hypothesis further, due to the site containing an existing structure, though requiring substantial refurbishment. It was observed that students were capable of achieving integrated design proposals, though the existing building footprint did create challenges in achieving the requirements of the brief. The existing structural form imposed restrictions around spatial requirements, though these limitations were overcome with the assistance of the architectural consultants. In this instance, it was found that the structural form did not significantly inhibit potential integrated design opportunities but did create additional challenges.

While the findings from IDS11 are likely still valid, the structure used for IDS12 required substantial retrofitting (unlike the structure used in IDS11). Therefore, the hypothesis may need to be rephrased to outline that integrated design is possible for an existing structure, with greater opportunities becoming available depending on the extent of the structure that is available for alteration.

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 F.

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. This was especially true for the former police station site, given that a floorplan already existed. Students were recommended (by consultants) to evaluate the spatial requirements of the design separate to the existing floorplan, to evaluate if the existing structure would be suitable for the needs of the client, or if a complete rebuild would be more suitable. Additionally, 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 was 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 complete transcript of these interviews can be found in Appendix B, while the discussion of these interviews can be found Appendix C.

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. A complete breakdown of student responses can be found in Appendix D, with the discussion relating to this feedback found in Appendix E.

4.4. Summary

Qualitative data obtained through observations (studio tutors), interviews (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 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.

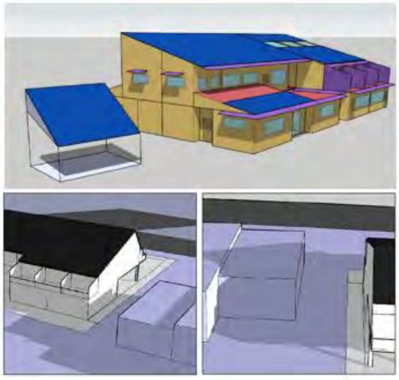
Student survey responses were generally positive for the design studios, with the most beneficial aspect of the studio being the involvement of industry professionals. The student respondents agree that the design studios overall were beneficial to their studies.

5 STUDIO OUTPUTS – SELECT STUDENT EXAMPLES

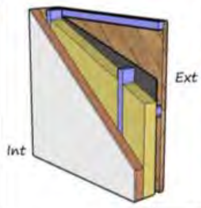
The following section summarises the design solutions identified by participants in the design studios, though does not reflect the entirety of solutions examined by the participants throughout the design studio. For a summary of all reports assessed for this project, please see Appendix A.

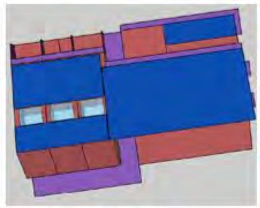
5.1. Passive Design Measures

The client brief for the Former Police Station Redevelopment did not specify a primary focus on what strategies /technologies should be incorporated within the design, though passive strategies did appear to be more in keeping with the clients' aspirations to reduce operational carbon. While passive design strategies minimise thermal losses, and reduce energy requirements and ongoing financial expense (i.e. maintenance), they need to be mindful of embodied carbon through manufacturing. All these factors were considered when assessing the wide range of strategies /technologies which may be incorporated within the building's refurbishment to improve the building envelope, enable a connection with the land, and contribute to the surrounding community.



Case	Heating (GJ)	Cooling (GJ)	Lighting (GJ)	Equipment (GJ)	Total (GJ)	REF
Base	185.3	92.3	64.8	56.1	**398.5**	**0.79**
Insulation	167.3	86.6	64.8	56.1	**374.8**	**0.79**
Skylights	143.6	79.2	64.8	56.1	**343.8**	**0.89**
Shade + Windows	141.4	62.5	64.8	56.1	**324.8**	**0.99**
PV Shade	**141.5**	**62.5**	**64.8**	**56.1**	**324.9**	**1.08**





	Existing Building	
REF Value	No. of Hrs.	% of Year
0	4197	47.9
0 < REF < 0.30	626	7.2
0.30 < REF < 0.95	1121	12.8
0.95 < REF < 1.05	132	1.5
1.05 < REF	2684	30.6

Figure 5: Passive design strategies - Extracts from student work

The following examples were proposed across the student reports, with some examples being highlighted in Figure 5. **Note:** Not all of these initiatives were investigated in detail, though all were considered at least on a preliminary basis via the selection matrix.

- Internal/external green wall/ green roof
- Roof inclination for maximised solar irradiance (improved PV output)
- Natural and artificial exterior shading
- Improved natural lighting conditions (e.g. sky lights, solar wells, etc.)
- Natural cross-flow ventilation
- Reclaimed and low-process material selection
- Air tightness of the building envelope

5.2. Active Design Measures

Student assessments outlined a greater focus on potential active technologies, with a predominant focus on electrified solutions. Many students were unfamiliar with these topics, with most having only a fundamental understanding of building services and energy generation. This (in addition to the client's desire to minimise operational carbon) resulted in students being more favourable of passive strategies. It was still expected that a certain level of active strategies would require implementation (e.g. HVAC, appliances, hot water, solar PV and energy storage) with students examining the numerous active technologies available in an attempt to meet the client (and assignment) specifications.

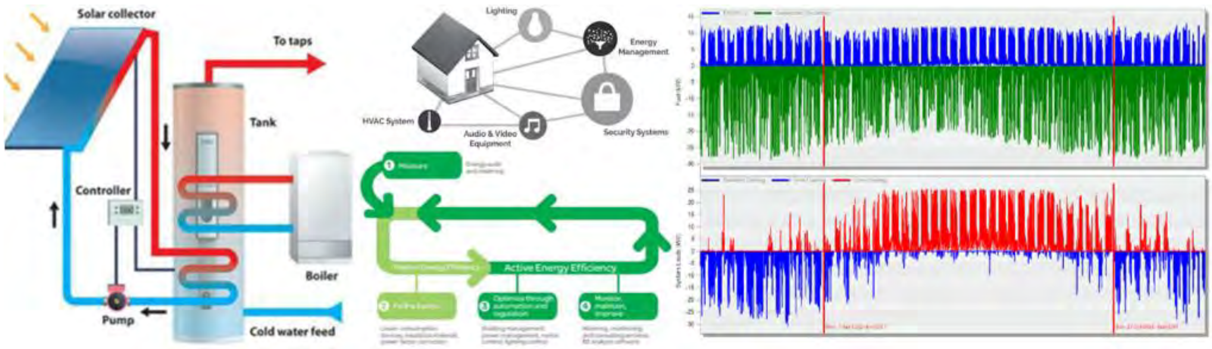


Figure 6: Active design strategies - Extracts from student work

The following examples were proposed, 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 design selection matrix.

- Solar PV systems and energy storage solutions (e.g. battery storage, PCM, etc.)
- Efficient low energy appliances
- Improved lighting and lighting strategies
- Building Management System (BMS)
- Low-cost air circulation (i.e. ceiling fans)
- Efficient HVAC systems and zoning

5.3. Other Design Measures

While the passive and active strategies implemented affect the operation and comfort conditions within the building, an additional focus of the brief was related to the operation of the building, its links to indigenous culture, and the greater impact on the surrounding community. Students were mindful of these aspects whilst undertaking their designs, with the following initiatives being proposed to address these factors:

- Incorporation of indigenous heritage (e.g. views of Mt Keira, recognition of indigenous artistry and culture)
- Community Action Plan/Initiatives (e.g. leasing neighbouring roof space for improved solar PV generation)
- Links to local public transportation networks
- Disability access
- Improved indigenous housing opportunities

Though these considerations do not necessarily align with the aims of the IDS in addressing environmental impact and net-zero energy consumption, these social impacts were a primary focus for the client, and therefore must remain a core principle in driving the final project outcomes.

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, 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 (BAU) 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 G).

6.1. **Existing Opportunities**

The design studio utilised a (mostly) greenfield site affording many potential technological and strategic possibilities for the student designers to investigate, with the primary limiting factors being the footprint of the existing structure and capital expenditure. This resulted in students exploring many different alternatives. Given the scope of the project (and imposed limitations), the list of feasible possibilities was narrowed once they were evaluated (via the evaluation matrix) against various sustainability and cost metrics.

The consultants identified the key opportunities explored by the students, before identifying their own additional strategies which students may not have considered. A summary of the identified strategies can be seen in Figure 7.

Student Ideas
(O) High efficiency HVAC systems
(O) Energy Recovery Ventilator
(P) Natural ventilation and mixed mode ventilation
(R) PV systems
(P) Using PV Systems as Shade
(I) Power Purchase Agreement
(P) Optimising the arrangement of Façade
(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
(P) Cool Roofs
(P) Shading
(P) Thermal mass
(P) Thermal Labrinth
(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) Native Planting below Solar Panels
(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 7: Student and consultant design solutions – Excerpt from vetting report

A considerable number of initiatives were investigated through the combined efforts of the students and consultants, with some of these highlighted within the vetting report. The consultants, while mentioning many of these strategies outlined in Figure 7, highlighted five systems/technologies specifically which could contribute to energy savings and embodied carbon reductions to better meet the desires of the client brief. These systems were:

- Relaxed temperature set-points
- Two-tone lighting
- On-site renewable energy generation
- Modular design and construction
- Recycled/sustainable ductwork

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

Based on the building typology chosen by the student designers (i.e. multi-purpose building, commercial/retail spaces, residential development, etc.) a BAU baseline was developed, incorporating case studies for buildings of similar operation requirements which exist within similar climatic zones. These baseline values (developed by the student designers) varied depending on the operation of the buildings which were chosen by each design team. The calculated values ranged from an Energy Use Intensity (EUI) of 44.77kWh/m^2/year to 247.42kWh/m^2/year, with an assumption being made (by the students) as to what the 'typical' operating requirements would be.

This BAU baseline was developed to establish a benchmark for energy requirements, to which different strategies could be directly compared to measure their success. The key recommended strategies/technologies outlined by the consultants (see Section 6.1) are specific and are recommended in addition to other passive and active/operational strategies. (i.e. insulation, airtight membrane, ceiling fans, energy efficient appliances, etc.). The following is a more detailed overview of the general passive and active strategies, along with more information relating to consultants' primary recommendations.

<u>Passive design solutions</u>

Passive systems such as thermal mass, building layout and orientation, and material were highly recommended to assist in regulating the internal thermal environment, which also assists in reducing the requirements of active systems. Air infiltration also needs to be considered, to maximise the performance of any active cooling/heating systems and minimise undesired air changes when comfort conditions have been achieved.

<u>Operational improvements</u>

HVAC was a primary active technology outlined as being a necessity to assist in regulate internal comfort conditions, particularly during peak seasons (i.e. summer and winter), with various other systems included to support this primary technology (i.e. ceiling fans, HRV/ERV, building management system, etc.). Other minor improvements were also included (efficient appliances, occupancy sensors, daylight dimming, etc.) to assist in reducing typical daily energy usage profiles.

<u>Relaxed temperature set-points</u>

Typical temperature set-points are outdated (according to the consultants), assuming clothing styles and a workforce that is currently antiquated. Through relaxing set-point levels, a more comfortable environment can be created for all occupants (potentially improving work related outcomes) while simultaneously reducing the cooling requirements of the building by approximately 10%.

<u>Two-tone lighting</u>

It was identified that lighting requirements for the building/s could exceed 40% of the total energy requirements. In light of this, consultants recommend the use of a two-tone lighting scheme. While Australian Standards (AS1680.1) mandate 320 Lux within an office environment, this degree of lighting is excessive, resulting in 4.5-5W/m^2 (even with upgraded lighting systems). Ambient lighting within 'simple' task areas (i.e. away from desks and benches) only requires 160 Lux, which can substantially reduce the overall energy requirements of the building if implemented correctly.

<u>On-site renewable energy generation</u>

Maximisation of PV systems should be considered due to their high return on investment and low payback periods. 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. PV installation can also exceed the typical implementation (i.e. rooftop solar), with shade structures and neighbouring buildings also being explorable as locations capable of generating additional solar energy.

Modular design and construction

Prefabricated building techniques are advantageous and are capable of saving time, and reducing waste and embodied carbon. These aspects are in keeping with the aspirations of the client, and also provide potential flexibility in the building layout, allowing for alterations to the floor space as required. Given that the functionality of the spaces may alter over time, modular and flexible design strategies would be an ideal inclusion.

Recycled/sustainable ductwork

Conventional rigid ductwork is a highly processed material, with a high embodied carbon content. To abate these additional embodied carbon values within the structure, the consultant has suggested the use of either recycled 3D-printed ducting or Cardboard ducting. 3D-printing is becoming more sustainable, with the material being recyclable once the product has reached its end-of-life. Additionally, 3D-priting this components allows for more bespoke designs, tailored specifically for the project. Alternately, cardboard ducting (such as Gatorduct) can be flat-packed and cut-to-shape on site, meaning the material is low-process, fully recyclable and completely customizable, with the exterior able to feature customised branding and artwork. This option will diminish embodied carbon values, and minimise potential waste materials. While similar results may be achieved with existing steel ducting, alternative solutions are mor in keeping with the aspirations of the client.

6.3. Key Findings

The strategies outlined by the consultants show that through implementation of commercially available solutions, a reduction of over 25% of building services loads is possible given the various strategies being implemented within a temperate climatic zone. Given the site, it is possible to introduce a sufficient level of PV to achieve a net-zero energy outcome, though this would still require the site to be connected to the grid to allow for energy draw/supply for peak periods and periods of lower than anticipated irradiance. Further savings are possible with additional financial investment, though this would require further investigation.

Many of the suggested technologies and strategies are sympathetic, working in tandem to achieve greater results than they would alone. These synergetic properties may allow for the removal or reduction in of other technologies completely, further reducing energy demands. Given these outcomes, the consultants hypothesise that not only is net zero-energy a possibility, but the building/s may also achieve net-zero operational carbon as well.

7 CONCLUSIONS

7.1. Conclusions and Next Steps

It is clear that the Illawarra LALC Former Police Station Refurbishment IDS is considered to have been a great success, especially when considering the entirety of the project was conducted in a virtual environment limiting potential interactions between studio participants and client/consultants.

Undertaking integrated design in an online working environment creates many limitations within the design process. All parties are effectively working in isolation from one another, creating a challenging environment to share designs and ideas. Some working platforms (such as Miro) allow for designers to share a working space to assist in the development of ideas, though this cannot replicate a face-to-face working environment. Additionally, online communication /conferencing tools (e.g. Zoom) are not conducive to fluid and natural discussions, only allowing a single person to dominate the conversation at any given time, while restricting natural complementary discussions from occurring. This method of interaction effectively mimics the expected way in which architects and engineers would typically interact, working in isolation from one another. These isolated working environments were found to limit creative design, ultimately restricting integrated design opportunities. While it is evident from the design studios that integrated design can work in an online environment, feedback and observations all indicate that this process would greatly improve from face-to-face interactions, to better facilitate integrated design opportunities.

The client brief, while being found to be sufficient by many, revealed its own issues throughout the design process. The initial client brief was found to be very vague by many of the participants and consultants, with additional information being provided throughout the studio. While this swayed opinion, deeming the brief to be more sufficient, additional information was provided after preliminary designs had been completed, making changes difficult to implement. While consultants found a vague brief comparable to industry, further discussions should occur before design commences. It can be surmised that obtaining a more finalised client brief is critical, especially earlier in the design process, to ensure time is not unnecessarily spent on unsuitable design concepts. If clients can commit additional time in the preliminary stages, it would greatly assist the designers and the design process, while also ensuring the client receives a design more suited to their desires.

The technical suggestions of the study include the usual installation of renewable energy generation but also cover three main other 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 greater than 1 (as opposed to the Lightning Ridge IDS where it was more difficult to reach a REF of 1 mostly due to the climate). 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). In addition, some studio teams recommended a residential development next to the existing building structure for which they found that reaching REF of 1 was challenging due to the night-time energy demand.

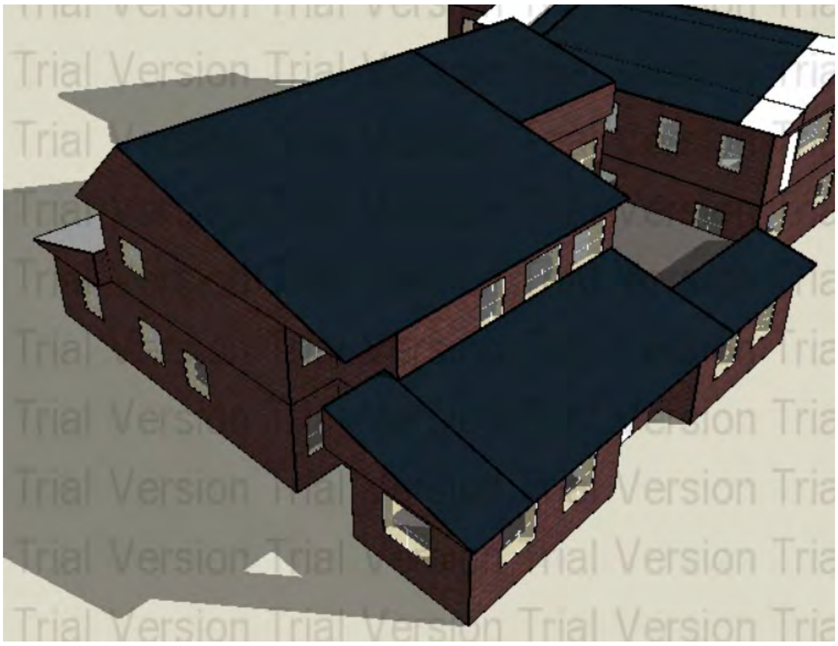
Innovative and efficient technologies may offer greater opportunities in achieving net-zero energy designs, though these technologies should not be evaluated in isolation to other technologies and strategies. The building must be evaluated in a holistic manner, rather than assessing the impact of each discrete component. Cleaner strategies and technologies acting harmoniously will often be easier to implement and achieve better outcomes than a series of disjointed technological solutions assessed in isolation.

Feedback from consultants and participants was highly positive, verifying the benefits that an integrated design process offers.

APPENDIX A – SELECTED STUDENT WORK

ENGG210

Assignment 3 Report
Unanderra Group 2



Improved Existing Building Design

Improved New Building Design

Executive Summary

This report investigated ways to improve the performance and sustainability of two proposed designs for the ILALC, with the intention to reach a net zero energy goal. The two designs were for an existing building (old police station) and a new mixed-use building both to be located in Unanderra, NSW Australia. The initial stage of the design procedure was the development of floor plans for the proposed designs. These floor plans were reviewed and improved upon having received feedback from the clients and consultants. The formation and simulation of a benchmark model, designed to DTS conditions, highlighted key improvement areas within each design. For both buildings, cooling loads were undesirably high. Appropriate insulation in the walls, floors and roof would improve this design flaw. As well as that, the inclusion of reflective external blinds minimises the amount of solar radiation entering both buildings, reducing heating gain through windows. Lighting was another area of concern contributing to between 32-27% of the total annual energy demand. Adaptive lighting, minimising the amount of artificial light produced in the building, reduced this value by 2-3%. The improvements made to each design maintained building functionality, aesthetic appeal, acoustic and thermal comfort and brought costing into consideration. As a result from these improvements, the annual average REF value of the improved existing building was increased to 1.020174, reaching the net zero energy goal. For the improved new building design, the annual average REF value was increased to 0.634716. While this design didn't reach net zero energy status, it was a significant improvement from the benchmark model. The overall energy demand of the improved new building was reduced by 3012 kWh and the solar generation was improved by 102.19 kWh. As well as that, solar generation of the improved new building design was more consistent throughout the day, reducing energy losses with no battery included in the design.

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1. Introduction

With the detrimental effects of climate change threatening the ability for future generations to meet their needs, the construction sector as well as many others must move towards a more sustainable future to prevent this from happening. Numerous energy frameworks within Australia, some mandatory others voluntary, aim to reduce the carbon footprint of the construction sector by rating proposed building designs against benchmarks to determine their overall performance. As Australia moves towards its 2050 net zero emissions goal, frameworks such as NatHERS have increased their benchmark standards, making it harder for newly proposed designs to be approved due to lacking aspects of sustainability.

As a response to these constraints, Assignment 3 focuses on the performance and sustainability of the previously proposed designs in Assignment 2. The target of Assignment 3 is to improve the performance of the existing and new building designs, so that both buildings have an average annal renewable energy fraction (REF) value of 1. Achieving this value of 1 would mean that both buildings are net zero energy designs and consuming as much energy as they produce. The designs of the existing and new buildings were simulated through software, specifically DesignBuilder, and the hourly energy inputs and outputs of the constructed models are obtained.

2. Floor Plans

After receiving feedback on Assignment 2, the floor plans and architectural features of the existing and new building designs were modified. Requested by the client, the existing building would require sufficient garage space for landscaping equipment such as lawnmowers and blowers. To account for this, the professional suites on the ground floor Southern side of the existing building were removed and replaced with a double garage connecting to the rear laneway. The consultants also gave feedback on the layout of the existing building ground floor. The toilets were originally located to the West of the building resulting in a professional suite and the reception to be located in the middle of the office, away from natural light and connections to outside. To resolve this, the ground floor toilets were relocated to the middle of the ground floor, allowing for the professional suites and reception to be moved to the exterior of the building. This not only improved the quality of the professional suites, but also made the ground floor toilets easily accessible for occupants in the existing building. The final floor plans are shown in Figure 1 and 2 below.

Figure 1. Existing Building Floor Plan. Ground Floor (Left), First Floor (Right). (NTS)

Figure 2. New Building Floor Plan. Ground Floor (Left), First Floor (Right). (NTS)

3. Benchmark Model

A benchmark model was developed in DesignBuilder using the floor plans above with the purpose to be used for simulations. The simulations will output the energy breakdowns of each building on an hourly, monthly and annual basis. For the purpose of this project, the hourly energy breakdowns will be focused on. From the 8760 hourly outputs over a year, an average annual REF value can be determined which will be used as the benchmark REF value, where no improvements have been made to the modelled buildings in DesignBuilder.

3.1 Visuals

In terms of visuals, the benchmark models in DesignBuilder are very basic where the software focuses on the function of each building/room over the aesthetics such as furniture and blinds. However, the rendered images produced in DesignBuilder are accurate representations of what the designs would look like taken out of the context of the site.

Displayed below are not to scale (NTS) elevations of the existing building benchmark model.

Figure 3. Existing Building North Elevation (NTS).

Figure 4. Existing Building South Elevation (NTS).

Figure 5. Existing Building West Elevation (NTS).

Figure 6. Existing Building East Elevation (NTS).

Displayed below are the not to scale (NTS) elevations of the new building benchmark model.

Figure 3. New Building North Elevation (NTS).

Figure 4. New Building South Elevation (NTS).

Figure 5. New Building West Elevation (NTS).

Figure 6. New Building East Elevation (NTS).

3.2 Assumptions

To be able to construct a benchmark model of the existing and new building, assumptions had to be made where details such as occupancy schedules and wall compositions weren't specified. Listed below are the main assumptions of the benchmark model.

- **Occupancy Density Existing Building:** 0.11110 (people/m2).
- **Occupancy Density New Building:** 0.11110 (people/m2).
- **Occupant Activity:** The activity of the benchmark existing building model will be similar to that of office buildings stated in the NCC Volume 1 (Class 5 buildings).
- **Occupant Activity:** The activity of the benchmark new building model will be similar to that of apartment buildings stated in the NCC Volume 1 (Class 2 buildings).
- **Equipment Load Existing Building:** 11.77 (W/m2). The activity of equipment is based on the NCC profile for class 5 buildings.
- **Equipment Load New Building:** 11.77 (W/m2). The activity of equipment is based on the NCC profile for class 2 and 5 buildings.
- **Insulation:** Deemed To Satisfy (DTS) insulation values for both the existing and new building.
- **Lighting Existing Building:** 2.5 (W/m2) (LED). The activity of lighting is based on the NCC profile for class 5 buildings.
- **Lighting New Building:** 2.5 (W/m2) (LED). The activity of lighting is based on the NCC profile for class 2 and 5 buildings.
- **Heating and Cooling Existing Building:** COP 4.
- **Heating and Cooling New Building:** COP 4.

- **Mechanical Ventilation Existing Building:** Minimum 10 litres per second per person. (NCC HVAC Schedule).
- **Mechanical Ventilation New Building:** Minimum 10 litres per second per person. (NCC HVAC Schedule).
- **Hot Water Demand Existing Building:** 2 kWh. (Occupancy Schedule 8am – 8pm).
- **Hot Water Demand New Building.** 2 kWh. (Occupancy Schedule 8am – 8pm).

3.3 Results

While the model is to be located in Unanderra Australia, the closest available weather file with the required data was provided by a Sydney weather station. So, results obtained from this simulation, while not exact, are based on very similar climatic conditions to the site. The simulations were run from the 1st of January to the 31st of December 2002, based on the year of the weather file. Listed below in Table 1 and Figures 7-18 are the results from the benchmark existing building simulation.

Existing Building Benchmark (Base)	
Annual Heating Requirements	445.494 kWh
Annual Cooling Requirements	5304.248 kWh
Total Site Energy Demand	39776kWh
Peak Cooling	5.150271 kWh. Occurrence: 4/03/2002 3:00:00 PM
Peak Heating	3.687783 kWh. Occurrence: 29/07/2002 8:00:00 AM
Peak Energy Demand	13.74433 kWh. Occurrence: 4/03/2002 3:00:00 PM
Existing Building Benchmark (With Solar Generation)	
Total Solar Generation	45214.33 kWh
Total Annual Net Energy Requirements	5438.323111 kWh (Produces more solar energy than required)

REF Values Hourly	No. Hrs	% Of Year
0	4197	47.91096
0<REF<0.30	660	7.534247
0.30<REF<0.95	1211	13.8242
0.95<REF<1.05	160	1.826484
REF>1.05	2532	28.90411
Annual REF Value	0.872647	

Table 1. Benchmark Existing Building Results.

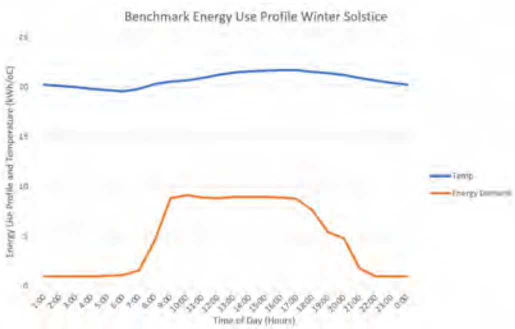

Figure 7. Existing Building Benchmark Energy Use Profile Winter Solstice.

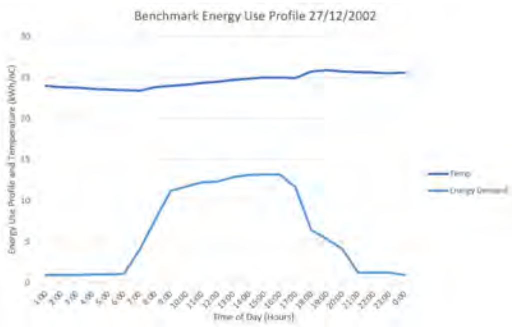

Figure 8. Existing Building Benchmark Energy Use Profile 27/12/2002.

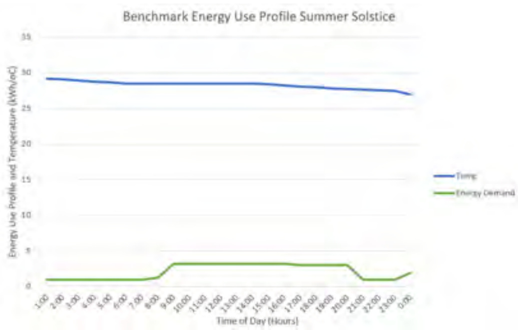

Figure 9. Existing Building Benchmark Energy Use Profile Summer Solstice.

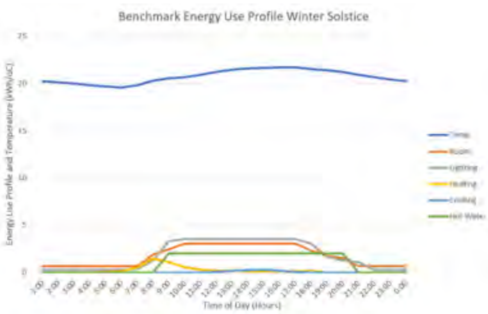

Figure 10. Existing Building Benchmark Energy Use Profile Winter Solstice.

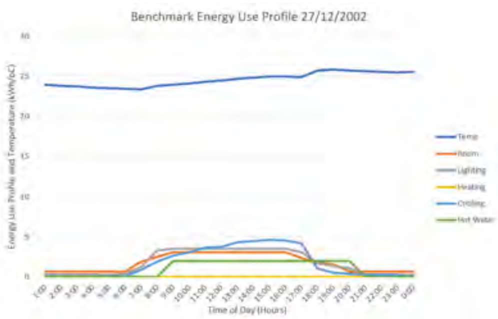

Figure 11. Existing Building Benchmark Energy Use Profile 27/12/2002.

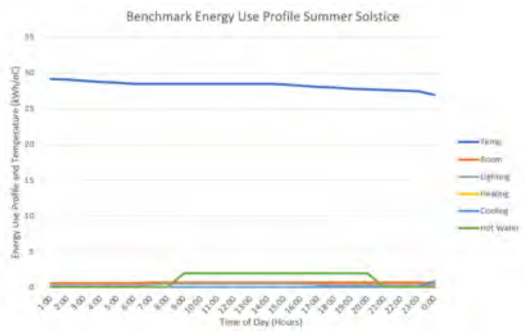

Figure 12. Existing Building Benchmark Energy Use Profile Summer Solstice.

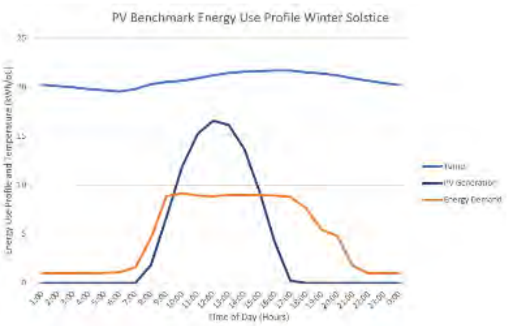

Figure 13. Existing Building Benchmark Energy Use Profile with Solar Generation Winter Solstice.

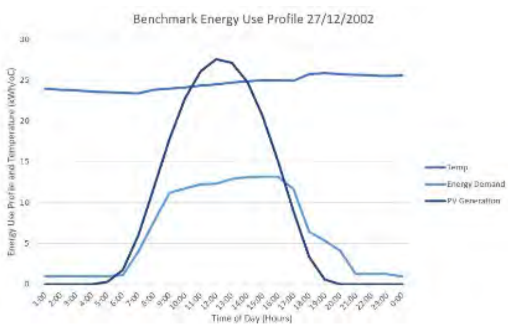

Figure 14. Existing Building Benchmark Energy Use Profile with Solar Generation 27/12/2002.

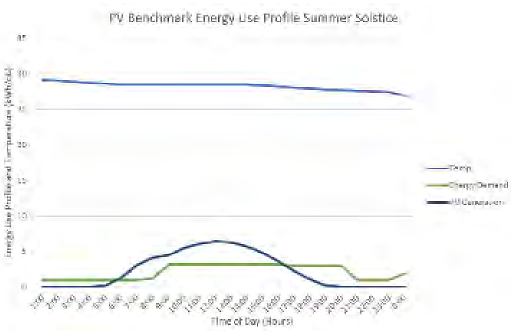

Figure 15. Existing Building Benchmark Energy Use Profile with Solar Generation Summer Solstice.

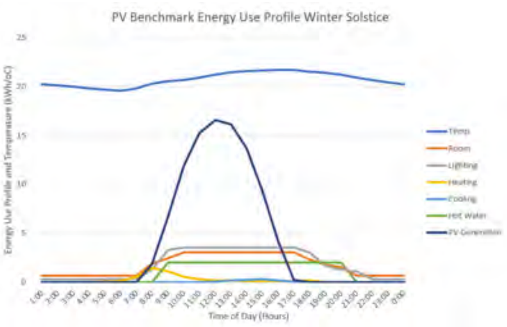

Figure 16. Existing Building Benchmark Energy Use Profile with Solar Generation Winter Solstice.

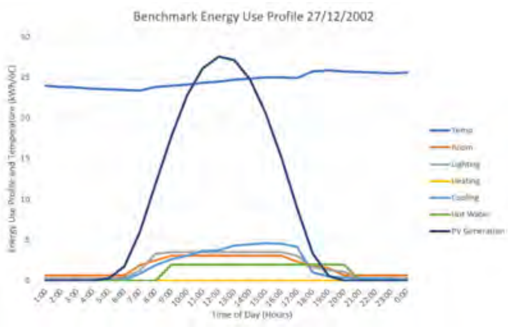

Figure 17. Existing Building Benchmark Energy Use Profile with Solar Generation 27/12/2002.

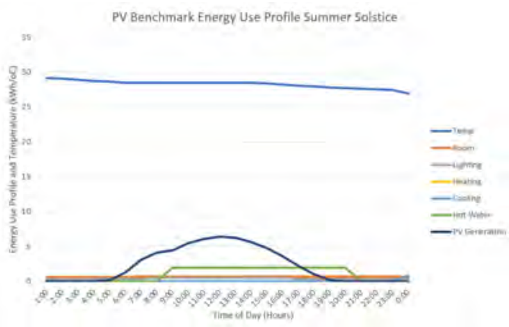

Figure 18. Existing Building Benchmark Energy Use Profile with Solar Generation Summer Solstice.

The results from the benchmark new building energy simulation are listed in Table 2 and Figures 19 – 30 displayed below.

New Building Benchmark (Base)		
Annual Heating Requirements	225.1873 kWh	
Annual Cooling Requirements	5565.597 kWh	
Total Site Energy Demand	32679.85 kWh	
Peak Cooling	3.552513 kWh. **Occurrence:** 4/03/2002 4:00:00 PM	
Peak Heating	1.387377 kWh. **Occurrence:** 29/07/2002 8:00:00 AM	
Peak Energy Demand	9.863922 kWh. **Occurrence:** 4/03/2002 4:00:00 PM	
New Building Benchmark (With Solar Generation)		
Total Solar Generation	25550.97 kWh	
Total Annual Net Energy Requirements	-7128.87 kWh (Produces less solar energy than required)	
REF Values Hourly	No. Hrs	% Of Year
0	4197	47.91096
0<REF<0.30	972	11.09589
0.30<REF<0.95	1407	16.06164
0.95<REF<1.05	175	1.997717
REF>1.05	2009	22.93379
Annual REF Value	0.587865	

Table 2. Benchmark New Building Results.

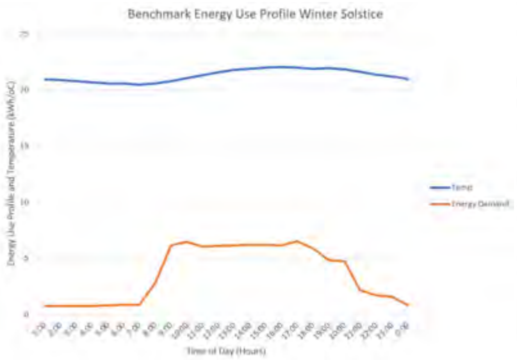

Figure 19. New Building Benchmark Energy Use Profile Winter Solstice.

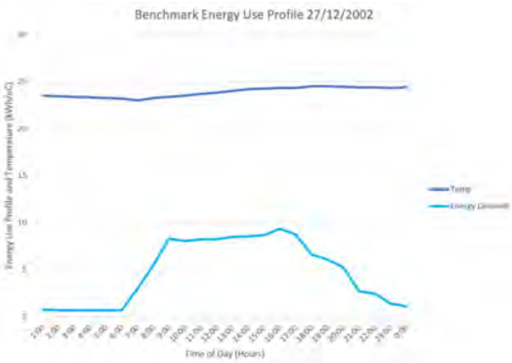

Figure 20. New Building Benchmark Energy Use Profile 27/12/2002.

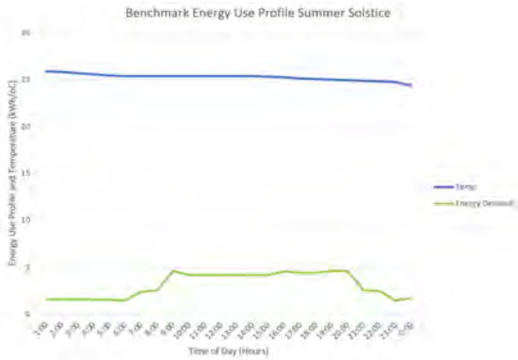

Figure 21. New Building Benchmark Energy Use Profile Summer Solstice.

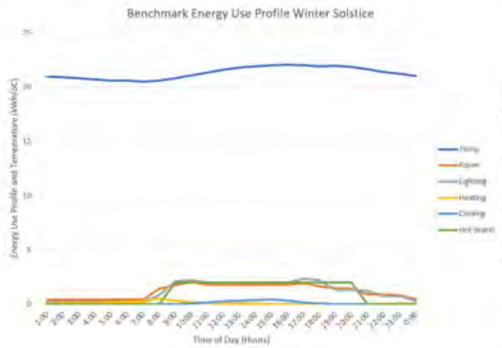

Figure 22. New Building Benchmark Energy Use Profile Winter Solstice.

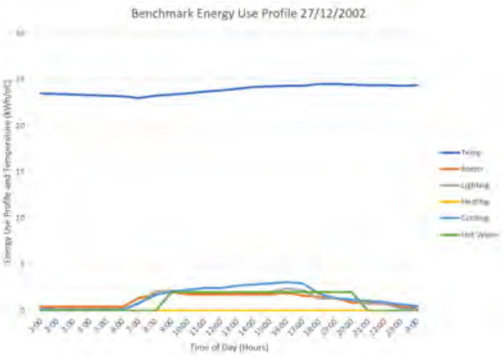

Figure 23. New Building Benchmark Energy Use Profile 27/12/2002.

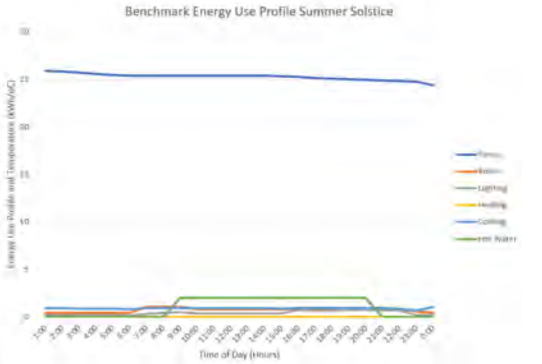

Figure 24. New Building Benchmark Energy Use Profile Summer Solstice.

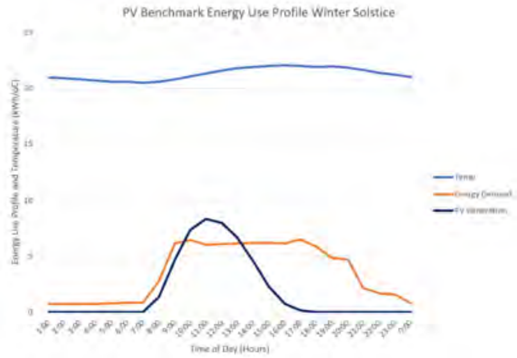

Figure 25. New Building Benchmark Energy Use Profile with Solar Generation Winter Solstice.

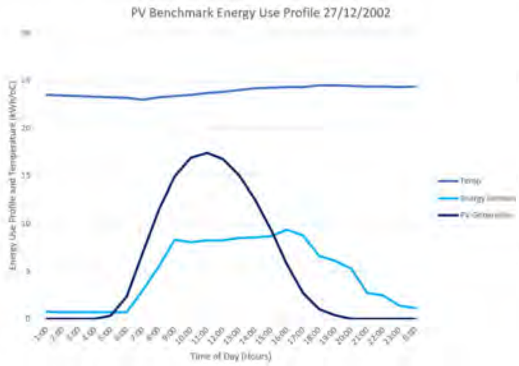

Figure 26. New Building Benchmark Energy Use Profile with Solar Generation 27/12/2002.

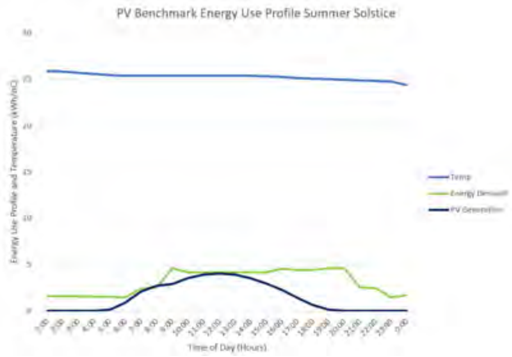

Figure 27. New Building Benchmark Energy Use Profile with Solar Generation Summer Solstice.

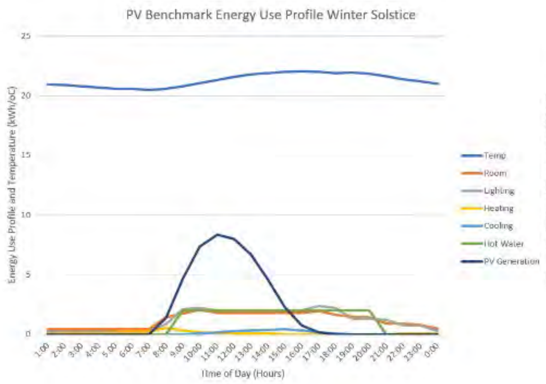

Figure 28. New Building Benchmark Energy Use Profile with Solar Generation Winter Solstice.

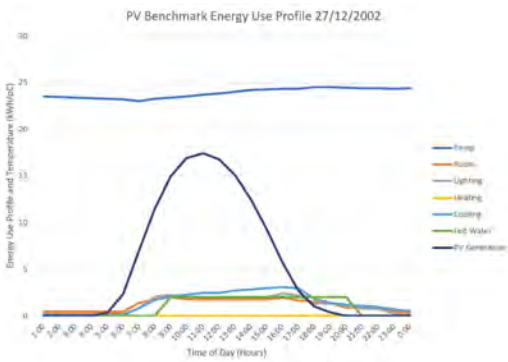

Figure 29. New Building Benchmark Energy Use Profile with Solar Generation 27/12/2002.

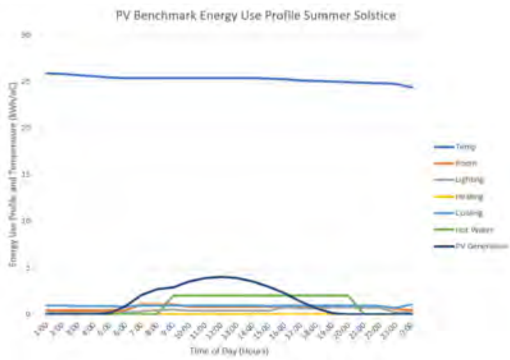

Figure 30. New Building Benchmark Energy Use Profile with Solar Generation Summer Solstice.

3.4 Discussion of Benchmark Results

Seen in Table 1 and 2, the benchmark existing building model is producing 5438 extra kWh of solar energy, while the benchmark new building model has an energy demand 7128 kWh greater than the annual solar energy generation. This is reflected in the annual average REF value for each model, where the existing building has a much greater REF value compared to the new building due to an over production in solar energy. From this, it's apparent that the new building PV system layout must be changed in order to improve the annual average REF value. The intention of improving the layout of this system without changing the efficiency and roof area of the modules, is to increase the annual solar generation.

The cooling loads of both buildings were also much greater than the heating loads. The cooling load of the existing building benchmark is almost 12 times greater than the heating load of the existing building benchmark. The cooling load of the new building benchmark is almost 25 times greater than the heating load of the new building benchmark. This result highlights the importance of appropriate insulation and window shading for both buildings, to minimise heat gain in warmer weather.

Seen in the energy breakdown graphs for the existing and new building, lighting is also a large contributor to the total energy demand of each building. For the existing building, lighting makes up 32.1% of the total energy demand and for the new building, lighting makes up 27.1% of the total energy demand. A larger window to wall ratio (WWR) will increase the amount of natural light in, however, it'll also increase the amount of heat gains/losses throughout the year. Described in Green Building Illustrated, a rule of thumb for WWR is around

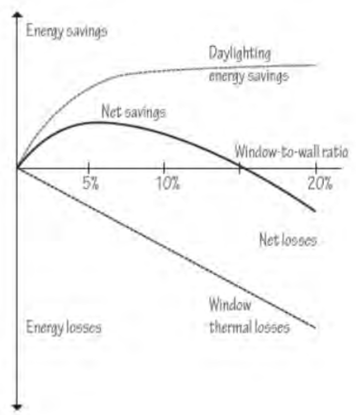

Figure 31. Window to Wall Ratio Rule of Thumb. (Ching, 2014, pg 100).

15%, however, this doesn’t work for all sites (Ching, 2014, pg 100). The WWR of the benchmark existing building is 13.46% and the benchmark new building WWR is 15.06%. The WWR of the 2 benchmark buildings is acceptable where currently they minimise losses/gains and also allow for a strong connection to nature to be maintained.

4. Improved Model

After analysing the results of the benchmark models, immediate areas for improvement were noted and a list of improvements for each building were formed. Specifically, improvements will focus on:

- Insulation
- Window Shading
- Lighting
- Glazing
- PV System Orientation
- Materials (Colours)

4.1 Visuals

After incorporating the design improvements mentioned above into the DesignBuilder models, the architecture of the existing building went under minor changes, however, the roof slope orientation and PV system layout of the new building was significantly changed. This allowed for an East-West facing PV system layout. Materials remained somewhat the same where the brick exterior finish for both benchmark buildings was transferred over to the improved design, however, the roofing material was changed from tiles to custom orb sheeting which greatly affected the appearance of both buildings. Displayed below are not to scale (NTS) elevations of the improved existing building model.

Figure 32. North Elevation Improved Existing Building (NTS).

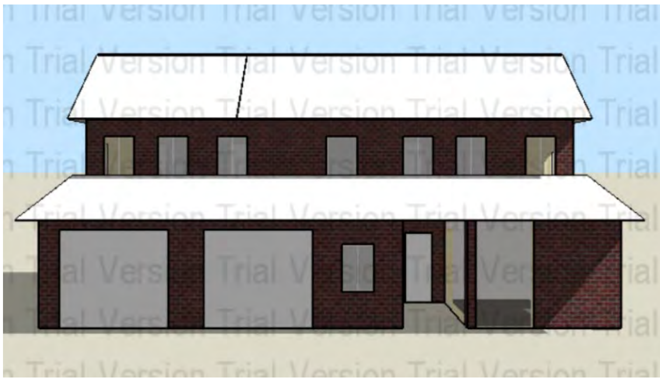

Figure 33. South Elevation Improved Existing Building (NTS).

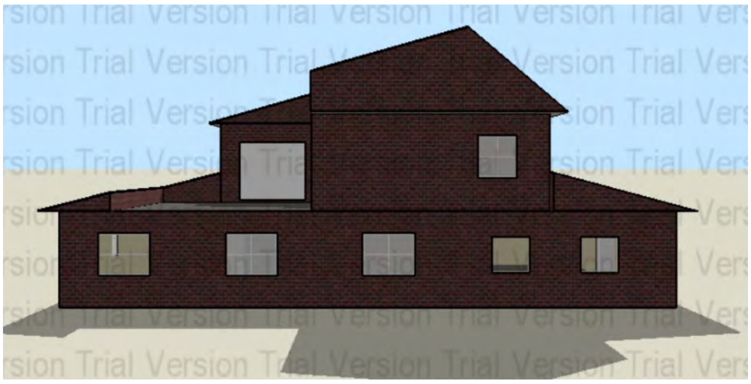

Figure 34. West Elevation Improved Existing Building (NTS).

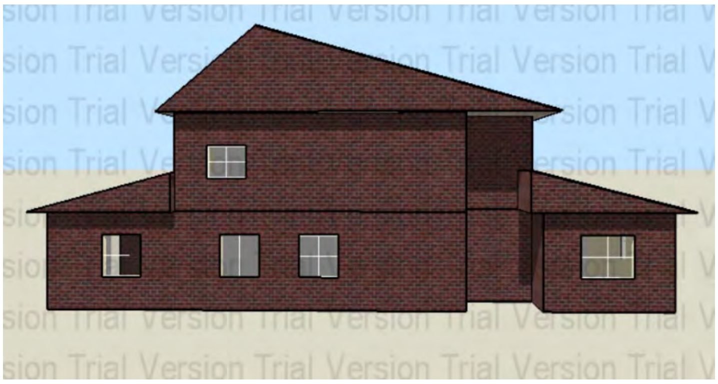

Figure 35. East Elevation Improved Existing Building (NTS).

Displayed below are not to scale (NTS) elevations of the improved new building model.

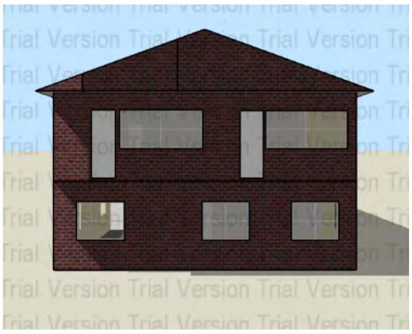

Figure 36. North Elevation Improved New Building (NTS)

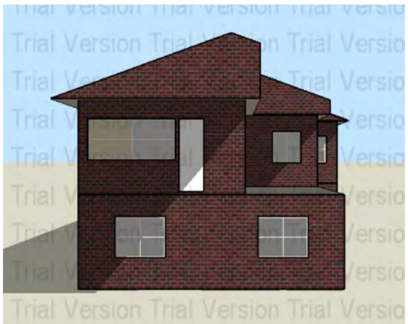

Figure 37. South Elevation Improved New Building (NTS)

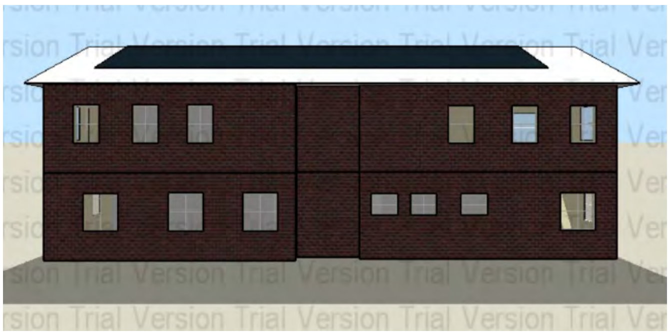

Figure 38. West Elevation Improved New Building (NTS)

Figure 39. East Elevation Improved New Building (NTS)

4.2 Design Improvements

The initial improvement to the benchmark existing and new building design was to increase the insulation values of the walls, floors and roof. The benchmark models had deemed to satisfy insulation values which are minimum requirements, not best practice. Thus, the insulation in the external walls and floors was increased to R3.5 and the roof insulation was increased to R6.5. The reasoning behind these insulation values is that over insulating a building can not only be expensive and result in thick walls, but it may also lead to hidden condensation build up resulting in mould growth and rotting of certain materials (Efficiency Matrix, 2021).

Window shading was also added to each model where external reflective blinds were added to the windows of each building. The reasoning for these blinds being external is based on the heating and cooling loads of each benchmark. With both models have a much greater cooling load, the blinds would be best positioned on the exterior of the building to absorb incoming solar radiation and minimise the amount of heat entering the building. These blinds are also operated with cooling prioritised. So, if the previous hour was undergoing mechanical cooling, the blinds will close, minimising internal solar radiation heat gain. If the previous hour was undergoing heating, the blinds would open to maximise the amount of solar heat entering the building.

With lighting contributing to a large portion of each building's energy demand, adaptive lighting would be beneficial to minimise the amount of unnecessary artificial light in the building. Lighting control was introduced into both the existing and new building, set on a 3-step controller. The more natural light in the building, the less artificial light is required to meet the 2.5 W/m2 condition. The 3-step controller is described in Figure 40 below.

Adaptive lighting control also sets the ‘maximum allowable discomfort glare index’. For office buildings, the maximum glare index value is 22, which was modelled in DesignBuilder (DesignBuilder, 2021).

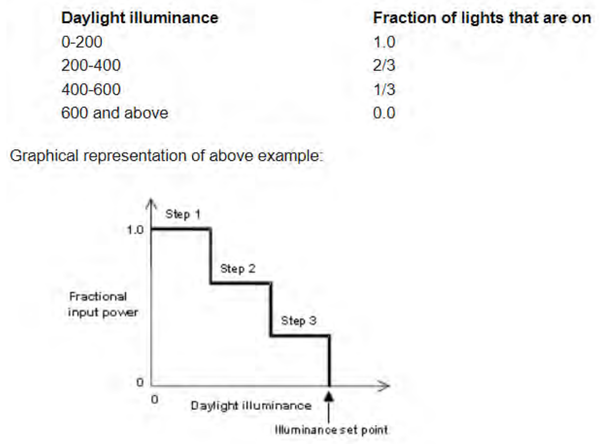

Figure 40. Lighting Control (DesignBuilder, 2021).

Windows account for the majority of heat losses/gains in a building. To account for this, both the improved existing and new building designs will have double glazed windows with argon gas filling the cavity between the 2 glass panels. The total U-Value of the improved windows is U1.680. As well as that, each window will have thicker glass panels, with the exterior panel being safety glass for improved security. The WWR for both the improved existing and new building design was kept the same due to occupant requirements and the need for a strong connection to nature.

The PV system layout for the benchmark existing building was acceptable, however, after analysis of the hourly solar generation data for the benchmark new building design, it was discovered that the majority of solar energy was produced in the morning due to having 100% of panels facing East. If a battery system was not incorporated into the design, this would result in a large loss of solar energy and the remainder of the day would require energy from the grid in order to meet occupant demand. To resolve this, the roof orientation was changed and an improved PV system was modelled for the new building.

This PV system has modules on both the East and West facing roofs, allowing for solar generation to be more consistent throughout the day. This PV system layout can be seen clearly in Figures 38 and 39.

Material selection for both the existing and new building improved designs was also brought into consideration. For acoustic benefits especially within the office spaces, carpet floors will be installed in both buildings and the roofing tiles modelled in the benchmark models for both buildings will be replaced with custom orb sheeting. The intention of light-coloured custom orb sheeting is to reflect solar radiation and minimise the amount of heat transferred into the building throughout the day. As well as that, custom orb sheeting is durable and with nearby trees and PV panel maintenance guaranteed, it's expected the roof of both buildings will undergo unpredicted live loads throughout its lifetime.

All of the design improvements stated above maintain aspects of the design relevant to the client. The function of each building is kept the same as floor area, window layouts and room functions have been kept the same. Other features such as visual comfort, acoustics and aesthetics have also been considered and maintained when implementing new design features to improve the buildings' performance.

4.3 Results

The results from the improved existing building simulation are listed in Table 3 below.

Existing Building Improved (Base)	
Annual Heating Requirements	340.8829 kWh
Annual Cooling Requirements	3881.528 kWh
Total Site Energy Demand	35869.42 kWh
Peak Cooling	3.338134 kWh **Occurrence:** 4/03/2002 3:00:00 PM
Peak Heating	3.112295 kWh **Occurrence:** 29/07/2002 8:00:00 AM
Peak Energy Demand	11.78443 kWh **Occurrence:** 4/03/2002 3:00:00 PM

Existing Building Improved (With Solar Generation)		
Total Solar Generation	45214.33 kWh	
Total Annual Net Energy Requirements	9344.907 kWh (Produces more solar energy than required)	
REF Values Hourly	No. Hrs	% Of Year
0	4197	47.91096
0<REF<0.30	620	7.077626
0.30<REF<0.95	1088	12.42009
0.95<REF<1.05	126	1.438356
REF>1.05	2729	31.15297
Annual REF Value	1.020174	

Table 3. Improved Existing Building Simulation Results.

Improved Existing Building Energy Breakdown		
	kWh	% Of Demand
Room (Equipment)	12382.15	34.52008
Lighting	10504.86	29.28638
Heating	340.8829	0.950344
Cooling	3881.528	10.82127
Hot Water	8760	24.42192

Table 4. Improved Exiting Building Energy Breakdown.

The results from the improved new building simulation are listed in Table 5 and 6 below.

New Building Improved (Base)	
Annual Heating Requirements	235.9509 kWh
Annual Cooling Requirements	4009.759 kWh
Total Site Energy Demand	29667.85 kWh
Peak Cooling	2.50294 kWh. **Occurrence:** 4/03/2002 4:00:00 PM
Peak Heating	1.384358 kWh. **Occurrence:** 29/07/2002 8:00:00 AM
Peak Energy Demand	8.472645 kWh. **Occurrence:** 4/03/2002 4:00:00 PM
New Building Improved (With Solar Generation)	
Total Solar Generation	25653.16 kWh
Total Annual Net Energy Requirements	-4014.69 kWh (Produces less solar energy than required)

REF Values Hourly	No. Hrs	% Of Year
0	4197	47.91096
0<REF<0.30	705	8.047945
0.30<REF<0.95	1448	16.52968
0.95<REF<1.05	165	1.883562
REF>1.05	2245	25.62785
Annual REF Value	0.634716	

Table 5. Improved New Building Simulation Results.

Improved New Building Energy Breakdown		
	kWh	% Of Demand
Room (Equipment)	9190.682	30.97859
Lighting	7471.459	25.18369
Heating	235.9509	0.795308
Cooling	4009.759	13.5155
Hot Water	8760	29.52691

Table 6. Improved New Building Energy Breakdown.

4.4 Shading Diagrams of Improved Buildings

After the completion of the improved existing and new building models, shading diagrams were generated on the Winter Solstice (21st of June) and Summer Solstice (22nd of December) for 2002. These shading diagrams were formed over a 3-hour time interval, from 9am to 12pm. For the purpose of this report, still images will be used taken at 9am and 12pm. The shading diagrams highlight how the buildings interact with one another and display the shading effectiveness of roofing overhangs. These shading diagrams are listed below in Figures 41 to 44.

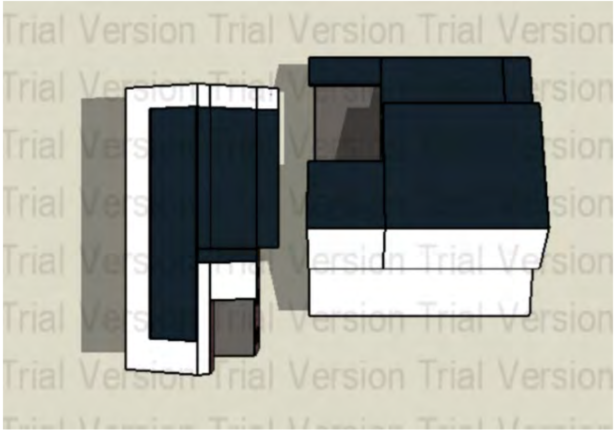

Figure 41. Summer Solstice 9am.

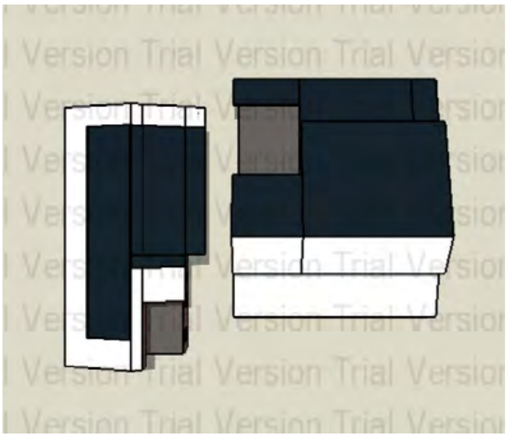

Figure 42. Summer Solstice 12pm.

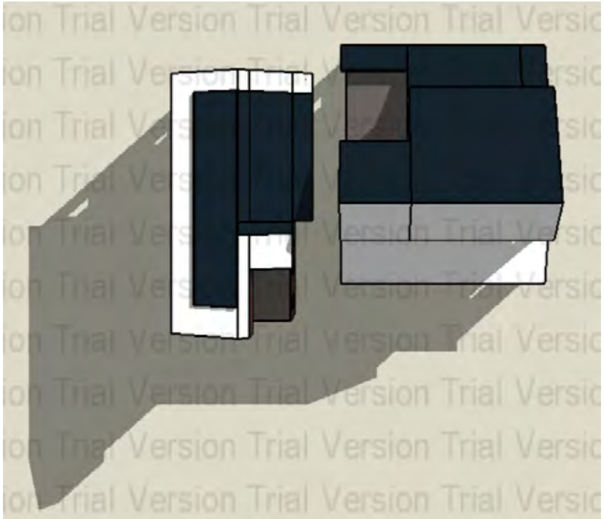

Figure 43. Winter Solstice 9am.

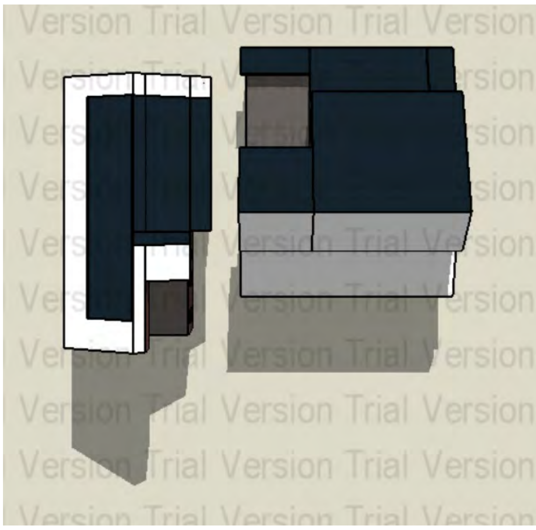

Figure 44. Winter Solstice 12pm.

5. Discussion

Overall, the improved existing and new building designs have been successful. The annual average REF value of the existing building was increased from 0.872647 to 1.020174, which met the target of a REF value of 1. The new building annual average REF value was increased from 0.587865 to 0.634716. After comparing the annual average REF value of the benchmark and improved design of the new building, it was noticed that the benchmark model had a similar REF value to the improved design even though the improved design consumes less energy and produces more solar energy. This was investigated and it was discovered that the benchmark model produces outliers, where only over 1-2 hours of a day the benchmark model produces an hourly REF value which can be a maximum 235.7573 times greater than its annual median (max REF 8.622361, median 0.036573). The improved model produces a maximum REF value which is 154.3125 times greater than the annual median (max REF 6.388504, median 0.0414).

So, the 2009 benchmark hourly REF values over 1, which are 236 less values compared to the improved design, carry a lot more weight, resulting in a larger annual average REF value to be produced. So, the improved model is more consistent at producing REF values closer to 1 throughout the year, with its East-West orientated PV system. If a battery system was to be incorporated into the design, the benchmark PV model would be preferred due to being able to produce more energy in the morning, store it, and then release that store energy when the occupants require it. However, if no battery system is going to be used due to costing constraints, the improved design and its more consistent solar energy production throughout the day would be preferred, more consistently producing REF values closer to 1.

Another attempt to improve the annual average REF value of both designs was to incorporate microinverters into the PV systems. Microinverters were trialled into each PV system to improve inverter efficiency, however, when running the simulations, System Advisor Model modelled the exact dimensions of a realistic solar module, so the overall maximum area of the solar system was 13% less than that of the DesignBuilder solar model. So, the annual PV generation was much less in the microinverter model compared to the traditional inverter model in DesignBuilder. As well as that, it’s estimated that microinverters would add 20% to the total cost of the PV system. Thus, making microinverters undesirable for this project.

When reviewing the energy breakdowns of the improved existing and new building designs, it's still apparent that room equipment loads and lighting are two of the largest contributors to the total energy demand. A simple yet effective solution to reduce these loads is for the occupants to turn lights off in rooms which aren't occupied throughout the day as well as turn off office equipment overnight. Equipment in standby mode still consumes a considerable amount of energy, specifically, 0.434811 kWh.

A key component not modelled in DesignBuilder is the surroundings of the site which the two buildings will be located near. The proposed designs aim to preserve existing nature on the site; thus, trees will be neighbouring the two buildings casting shadows on them throughout the day. This will reduce the cooling load in Summer by absorbing/reflecting incoming solar radiation, however, it'll also increase the heating load in Winter due to shading sunlight from the buildings. Neighbouring buildings to the West of the site in close proximity to the new building will also produce shading from late afternoon sun. Once again this will reduce cooling loads in Summer, but increase heating loads in Winter by reducing the amount of solar radiation entering the building.

6. Conclusion

Overall, the improvements to the proposed designs were effective. The existing building reached net zero energy status while the new building obtained an annual average REF value of 0.634716. From this report, the client can review and understand the estimated energy breakdown breakdowns for their proposed buildings. With this knowledge, the client can go further to reduce the energy demand by doing simple things like turning lights off when not needed and fulling shutting printers/computers down to reduce overnight energy consumption. This is not only cost beneficial, but benefits the environment as well.

7. References

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8. Appendix A

While not mandatory in NSW for commercial buildings less than 1200 meters squared and not being leased out, the NABERS energy rating framework scheme will be used to assess the performance and sustainability of the commercial aspects of the proposed designs. For residential aspects in the new building design, the BASIX and NatHERS energy rating frameworks will be used.

In terms of ratings, each of these frameworks use benchmarks as a comparison. So, if a premium solar system has been incorporated into a design and produces over the top amounts of solar energy, that design will receive a high energy rating due to solar energy suppling the majority of the occupant’s energy needs. Not only does this lack innovation, but it’s expensive as well. The two proposed Unanderra designs are limited to solar energy production, forcing improvements in other areas such as building fabric in order to receive a higher energy rating and reach net zero status. NABERS does acknowledge this issue by excluding solar energy generation in the initial calculation stages, however, seen in the current NABERS ratings, some buildings have reached a high energy rating through solar generation. By constraining the impact that solar energy generation has on these rating schemes, higher performing buildings will result from this in order to reach the minimum mandatory requirements enforced by these schemes to promote sustainability.

While time consuming to determine, embodied energy, water and carbon of the construction materials incorporated into a buildings design should also be brought into consideration to determine the effects the building’s design has on the environment. Embodied energy was only loosely considered for this project, however, if these ratings schemes enforce the determination of embodied energy in designs, the carbon footprint of the construction industry will be reduced astronomically.

9. Appendix B

Simulation Assumptions

- **Occupancy Density Existing Building:** 0.11110 (people/m2).
- **Occupancy Density New Building:** 0.11110 (people/m2).
- **Occupant Activity:** The activity of the benchmark existing building model will be similar to that of office buildings stated in the NCC Volume 1 (Class 5 buildings).
- **Occupant Activity:** The activity of the benchmark new building model will be similar to that of apartment buildings stated in the NCC Volume 1 (Class 2 buildings).
- **Equipment Load Existing Building:** 11.77 (W/m2). The activity of equipment is based on the NCC profile for class 5 buildings.
- **Equipment Load New Building:** 11.77 (W/m2). The activity of equipment is based on the NCC profile for class 2 and 5 buildings.
- **Insulation:** Deemed To Satisfy (DTS) insulation values for both the existing and new building.
- **Lighting Existing Building:** 2.5 (W/m2) (LED). The activity of lighting is based on the NCC profile for class 5 buildings.
- **Lighting New Building:** 2.5 (W/m2) (LED). The activity of lighting is based on the NCC profile for class 2 and 5 buildings.
- **Heating and Cooling Existing Building:** COP 4.
- **Heating and Cooling New Building:** COP 4.
- **Mechanical Ventilation Existing Building:** Minimum 10 litres per second per person. (NCC HVAC Schedule).

- **Mechanical Ventilation New Building:** Minimum 10 litres per second per person. (NCC HVAC Schedule).
- **Hot Water Demand Existing Building:** 2 kWh. (Occupancy Schedule 8am – 8pm).
- **Hot Water Demand New Building.** 2 kWh. (Occupancy Schedule 8am – 8pm).

FINAL REPORT – ENGG210

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EXECUTIVE SUMMARY

After the design of this site was complete, the structures were built in Design Builder to complete an Energy Analysis. The benchmark model was created using the data displayed in Tables 1 and 2 and the initial baseline analysis data was produced for both developments.

For Building 1, the retrofit section of the project, the yearly baseline demand came to close to 40 thousand kilowatts, with the generation total reaching just over 45 thousand kilowatts for the year. The major contributors to the energy usage was the lighting and room electricity with heating loads being significantly lower than cooling loads. By calculating the REF for each individual hour across the year and then averaging those out, the baseline REF for Building 1 is 0.87.

For building 2, the same process was followed and a baseline demand of just under 33 thousand kilowatts was obtained, with a total generation just over 25 thousand kilowatts. Lighting and Room Electricity were again the major energy users, with cooling loads being high as well. The average REF value for this building was calculated to be 0.59

In both instances the distribution of REF values was determined, and the number of hours the REF values of 0, 0-0.30, 0.30-0.95, 0.95-1.05 and greater than 1.05 were calculated. This found that almost 50% of the year the REF was zero for both buildings. An REF value greater than 1.05 was achieved 28.9% of the year for Building 1 and 22.9% of the year for building 2. With 0.95-1.05 occurring 1.8% and 2.0% of the time for buildings 1 and 2 respectively. Meaning that it was very rare that the solar generation matched the usage in the building at the time, it was either too little of too much

In order to improve the performance of both buildings, the building envelope was increased to best practice from deemed-to-comply which gave increased R Values for the walls and roof of 3.8 and 6.3 respectively. The windows were also improved from single glazed to double bronze glazed windows with 13 mm of air between panels, highly reflective internal blinds were also added as well as external awnings to provide shading.

The PV arrangement on the second building was also amended from completely east facing to east and west facing. This improved the generation significantly without increasing the number of solar panels or the efficiency of those panels.

The new arrangement generated just under 30 thousand kilowatts of power. And the improvements to the construction of the building reduced the overall demand to approximately 37 thousand kilowatts for building one and 30 thousand kilowatts for building 2. Obtaining improved REF values of 0.91 and 0.73 respectively.

The REF distribution was still an issue, with only 1.76% and 1.96% of REF values falling between 0.95 and 1.05 for both buildings. However, by treating this system as a whole, the total generation (74542.60 kW) is higher than the total demand (67230.65 kW) meaning that sharing generated energy between both buildings and incorporating a battery system would mean this site would be able to use only power generated by the solar system.

BASELINE MODEL

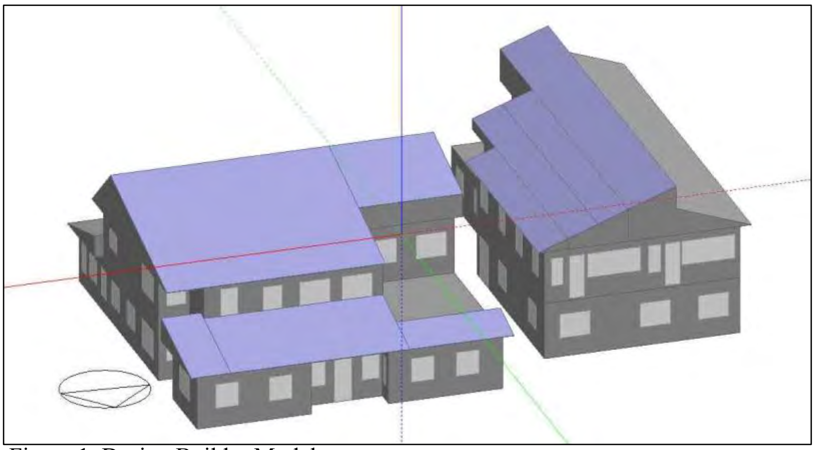

Figure 1. Design Builder Model

In order to develop the benchmark data for this project, the models shown in Figure 1 were constructed in design building, the site data is shown below in Table 1.

Location	Bellambi
Coordinates	34.45940278 S 150.8402361 E
Elevation	21 m
Orientation	355.1°

Table 1. Design Builder Site Data

Table 2 outlines the baseline building details that have been incorporated into the design of both buildings, these details were either given in the assignment brief, assumed or calculated.

Building Fabric	Brick Cavity with Plaster	Assumed
Ventilation	10 L/s/person	Given
Infiltration	0.35 L/s/m^2	Given
HVAC COP	4	Given
Office Occupancy	Building Class 5 NCC	Given
Residential Occupancy	Building Class 2 NCC	Given
PV System Size 1	198 m^2	Calculated
PV System Size 2	125 m^2	Calculated
PV Efficiency	15%	Given

Table 2. Design Builder Model Data

The occupancy data for both buildings was sourced from the 2019 National Construction Code (NCC), as building 1 is entirely an office space a Building Class 5 was allocated with a density of 0.1110 people per square. The schedule details are can be viewed in Figure 2.

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

Time period (local standard time)	Occupancy (Monday to Friday)	Artificial lighting (Monday to Friday)	Appliances and equipment (Monday to Friday)	*Air-conditioning* (Monday to Friday)
12:00am to 1:00am	0%	15%	25%	Off
1:00am to 2:00am	0%	15%	25%	Off
2:00am to 3:00am	0%	15%	25%	Off
3:00am to 4:00am	0%	15%	25%	Off
4:00am to 5:00am	0%	15%	25%	Off
5:00am to 6:00am	0%	15%	25%	Off
6:00am to 7:00am	0%	15%	25%	Off
7:00am to 8:00am	10%	40%	65%	On
8:00am to 9:00am	20%	90%	80%	On
9:00am to 10:00am	70%	100%	100%	On
10:00am to 11:00am	70%	100%	100%	On
11:00am to 12:00pm	70%	100%	100%	On
12:00pm to 1:00pm	70%	100%	100%	On
1:00pm to 2:00pm	70%	100%	100%	On
2:00pm to 3:00pm	70%	100%	100%	On
3:00pm to 4:00pm	70%	100%	100%	On
4:00pm to 5:00pm	70%	100%	100%	On
5:00pm to 6:00pm	35%	80%	80%	On
6:00pm to 7:00pm	10%	60%	65%	Off
7:00pm to 8:00pm	5%	60%	55%	Off
8:00pm to 9:00pm	5%	50%	25%	Off
9:00pm to 10:00pm	0%	15%	25%	Off
10:00pm to 11:00pm	0%	15%	25%	Off
11:00pm to 12:00am	0%	15%	25%	Off

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Energy efficiency

Figure 2. Building Class 5 Occupancy – NCC2019

As the second development is mixed use, with the first floor used for lettable office space, the input data for this space was the same for the of Building 1. However, as the second floor is single bedroom studios, it was classed as Building Class 2 under the NCC. With an occupied density of 0.0237 people per square meter. Figure 3 shows the typical occupancy behaviours which was used for the schedule of this space.

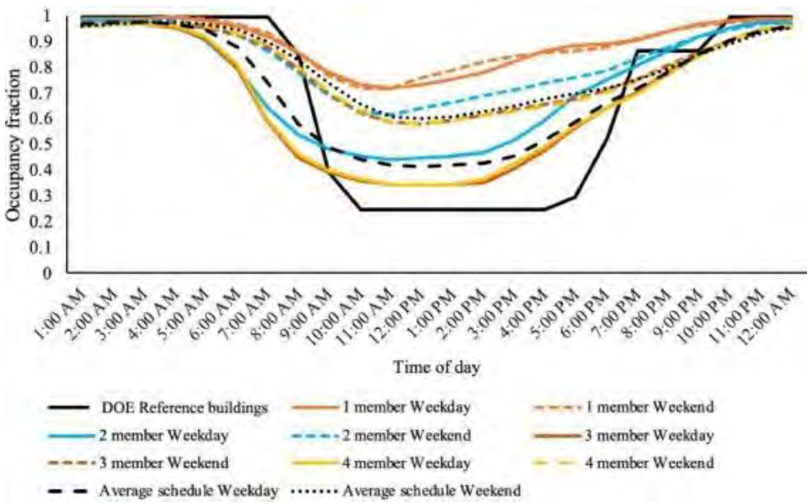


Figure 3. Building Class 2 Occupancy – NCC2019

BASELINE DATA

Building 1 – Retrofit of Existing Structure – 1 Farmborough Road

Demand Totals (kW)		Percentage of Total Demand
Room Electricity	12497.76	31.42%
Lighting	12768.50	32.10%
Heating	445.49	1.12%
Cooling	5304.25	13.34%
Hot Water	8760.00	22.02%
Total Demand	39776.00	
Total Generation	45214.33	

Table 3. Generation / Demand Data - Building 1 - Baseline

REF	Number of Hours	Percentage of Year
0	4193	47.87%
0<REF<0.30	659	7.52%
0.30<REF<0.95	1208	13.79%
0.95<REF<1.05	160	1.83%
REF>1.05	2532	28.90%
Average REF	0.87	

Table 4. REF Data - Building 1 - Baseline

Table 3 shows the demand data produced by Design Builder for building 1, the retrofit section of the project. From this data set it is shown that Room Electricity and Lighting are the major uses of power, with heating loads being very minimal. This is most likely due to the occupied hours of the building, as the space is used during the day when outdoor temperatures are at their peak, the need for heating is very minimal.

The total generation of the North facing solar system is much greater than the demand of the building, however the average REF value is still less than one. This is due to the REF distribution, which can be viewed in Table 4, being very poor. With very few REF values lying in the optimal range of 0.95 – 1.05 and a great percentage of REF values greater than

1.05 and even more equalling zero. Meaning the system is either generating far too much or far too little power in comparison to its usage.

Building 2 – New Structure – 7 Farmborough Road

Demand Totals (kW)		Percentage of Total Demand
Room Electricity	9269.63	28.36%
Lighting	8859.44	27.11%
Heating	225.19	0.69%
Cooling	5565.60	17.03%
Hot Water	8760.00	26.81%
Total Demand	32679.85	
Total Generation	25550.97	

Table 5. Generation / Demand Data - Building 2 - Baseline

REF	Number of Hours	Percentage of Year
0	4193	47.87%
0<REF<0.30	971	11.08%
0.30<REF<0.95	1404	16.03%
0.95<REF<1.05	175	2.00%
REF>1.05	2009	22.93%
Average REF		0.59

Table 6. REF Data - Building 2 - Baseline

The energy analysis of the second structure in Table 5 was very similar to that of the first building. With Lighting and Room Electricity accounting for the majority of the usage. The overall usage of this second structure was far lower due to its reduced size and occupancy with the second floor used for residential purposes.

The generation was also low due to the east-west slope of the roof and the Photo Voltaic (PV) system being placed on the eastern facing roof face. This also presented a similar problem in regards to the REF distribution, shown in Table 6, with a bulk of the values either equalling zero or being greater than 1.05 with very hours of the year having an REF between 0.95 and 1.05, this again is showing that the generation is either far too high or far too low.

IMPROVEMENTS

Building 1 – Retrofit of Existing Structure – 1 Farmborough Road

Initially the construction of the retrofit building was set to a deemed-to-comply standard in Design Builder, the first step that was undertaken to improve the performance of the building was increase the quality of the structure from deemed-to-comply to best practice.

This improvement included the upgrading of Wall and Roof insulation from standard to state of the art, with R Values of 3.8 for the walls and 6.3 for the roof.

Demand Totals (kW)		Percentage of Total Demand
Room Electricity	12425.42	32.67%
Lighting	12546.52	32.99%
Heating	692.04	1.82%
Cooling	3609.01	9.49%
Hot Water	8760.00	23.03%
Total Demand	38032.98	
Total Generation	45214.33	

Table 7. Generation / Demand Data - Building 1 – Improved Structure

REF	Number of Hours	Percentage of Year
0	4193	47.87%
0<REF<0.30	640	7.31%
0.30<REF<0.95	1155	13.18%
0.95<REF<1.05	159	1.82%
REF>1.05	2605	29.74%
Average REF	0.89	

Table 8. REF Data - Building 1 – Improved Structure

Table 7 shows that these improvements to the building structure had a small impact on Room Electricity, Lighting and Heating, however the major reduction was on the cooling load with a decrease of just over 1500 kilowatts across the year, and improving average REF to 0.89 from 0.87.

The REF distribution in Table 8 is still poor with even more hours of the year being above 1.05 meaning that with the reduction of demand the energy generated is not being used effectively.

The model was then reset to the baseline and the improvements on the structure were focused on the windows. The glazing was increased to double bronze glazed windows with 13mm of air between panels. External shading was also provided with 1.0-meter eaves added to the external of the building with highly reflective internal blinds.

Demand Totals (kW)		Percentage of Total Demand
Room Electricity	12497.76	32.60%
Lighting	12768.50	33.31%
Heating	811.87	2.12%
Cooling	3495.77	9.12%
Hot Water	8760.00	22.85%
Total Demand	38333.89	
Total Generation	45214.33	

Table 9. Generation / Demand Data - Building 1 – Improved Windows + Shading

REF	Number of Hours	Percentage of Year
0	4193	47.87%
0<REF<0.30	642	7.33%
0.30<REF<0.95	1164	13.29%
0.95<REF<1.05	164	1.87%
REF>1.05	2589	29.55%
Average REF		0.89

Table 10. REF Data - Building 1 – Improved Windows + Shading

In Table 9 it can be seen that these improvements resulted in an overall demand decrease, the heating load did increase, likely due to the poor insulation and reduced sunlight caused by the shading and glazing on the windows, however this did significantly reduce the cooling load on the building and subsequently improved the overall REF of the building. Again the REF distribution is poor with only 1.87% of REF values being in the optimal range (Table 10).

Building 2 – New Structure – 7 Farmborough Road

For the second structure, similar improvements were made to the model, these included upgrading the structure from deemed-to-comply to best practice, which increase wall insulation to an R-Value of 3.8 and roof insulation to 6.3. Windows were also chosen to be double bronze glazed with 13 mm of air between panels and 1.0-meter external shading was also added to the structure along with highly reflective internal blinds.

Demand Totals (kW)		Percentage of Total Demand
Room Electricity	9221.75	30.35%
Lighting	8752.14	28.80%
Heating	445.63	1.47%
Cooling	3208.61	10.56%
Hot Water	8760.00	28.83%
Total Demand	30388.14	
Total Generation	25550.97	

Table 11. Generation / Demand Data - Building 2 – Improved Structure, Windows + Shading

REF	Number of Hours	Percentage of Year
0	4193	47.87%
0<REF<0.30	925	10.56%
0.30<REF<0.95	1350	15.41%
0.95<REF<1.05	159	1.82%
REF>1.05	2125	24.26%
Average REF		0.63

Table 12. REF Data - Building 2 – Improved Structure, Windows + Shading

These improve results can be viewed in Table 11 and shows a small reduction in Room Electricity and Lighting and a significant reduction in the cooling loads on the building, resulting in an overall reduction of just over 2 thousand kilowatts for the year and bring the improved REF value to 0.63. However, as can be seen in Table 12, there is still a poor REF distribution.

The major modification made to the second structure in this model was rearranging the PV system configuration. Due to the east-west nature of the roof line, the system was initially completely east facing. To improve generation totals the system was split across both the east and west facing roof slopes.

Demand Totals (kW)		Percentage of Total Demand
Room Electricity	9269.63	28.36%
Lighting	8859.44	27.11%
Heating	225.19	0.69%
Cooling	5565.60	17.03%
Hot Water	8760.00	26.81%
Total Demand	32679.85	
Total Generation	29328.27	

Table 13. Generation / Demand Data - Building 2 – New PV Configuration

REF	Number of Hours	Percentage of Year
0	4193	47.87%
0<REF<0.30	649	7.41%
0.30<REF<0.95	1315	15.01%
0.95<REF<1.05	190	2.17%
REF>1.05	2405	27.45%
Average REF		0.71

Table 14. REF Data - Building 2 – New PV Configuration

The demand total of the building was not affected at all from the base level, however Table 13 shows a large increase in the power generated by configuring the PV system across both the east and west roof faces. The REF distribution in Table 14 has improved slightly from the benchmark model with less hours falling between 0 and 0.30 REF and slightly more in the optimal range of 0.95 to 1.05, however there is 396 more hours of the year achieving a REF value greater than 1.05.

FINAL RESULTS

Building 1 – Retrofit of Existing Structure – 1 Farmborough Road

For the retrofit of Building 1, after trialling various methods to improve the structure as shown the previous section, these methods were combined to find the peak performance of the building.

Demand Totals (kW)		Percentage of Total Demand
Room Electricity	12425.42	33.27%
Lighting	12546.52	33.60%
Heating	120.52	0.32%
Cooling	3489.46	9.34%
Hot Water	8760	23.46%
Total Demand	37341.93	
Total Generation	45214.33	

Table 15. Generation / Demand Data - Building 1 – Combined Improvements

REF	Number of Hours	Percentage of Year
0	4193	47.87%
0<REF<0.30	611	6.97%
0.30<REF<0.95	1146	13.08%
0.95<REF<1.05	154	1.76%
REF>1.05	2652	30.27%
Average REF	0.91	

Table 16. REF Data - Building 1 – Combined Improvements

Table 15 depicts the most efficient version of this building after improvements with an overall demand decrease of almost 2500 kilowatts over the year, with the heating loads almost being negated and the cooling load significantly decreased. As through all simulations, Table 16 still shows poor REF distribution with significant amounts of REF values being greater than 1.05 or 0.

Building 2 – New Structure – 7 Farmborough Road

Demand Totals (kW)		Percentage of Total Demand
Room Electricity	9221.75	30.85%
Lighting	8611.12	28.81%
Heating	120.95	0.40%
Cooling	3174.91	10.62%
Hot Water	8760	29.31%
Total Demand	29888.74	
Total Generation	29328.27	

Table 17. Generation / Demand Data - Building 2 – Combined Improvements

REF	Number of Hours	Percentage of Year
0	4193	47.87%
0<REF<0.30	622	7.10%
0.30<REF<0.95	1307	14.92%
0.95<REF<1.05	172	1.96%
REF>1.05	2458	28.06%
Average REF	0.73	

Table 18. REF Data - Building 2 – Combined Improvements

For Building 2, the improved solar arrangement was combined with the more efficient building structure and improved demand totals are seen in Table 17. The overall demand of the building was significantly reduced and the total generation significantly increased. Table 18 shows an increased REF value of 0.73 which is a significant improvement from the base value of 0.59, however still with a poor distribution.

Combined Site – 1-7 Farmborough Road

Demand Totals (kW)		Percentage of Total Demand
Room over Electricity	21647.17	32.20%
Lighting	21157.64	31.47%
Heating	241.47	0.36%
Cooling	6664.37	9.91%
Hot Water	17520	26.06%
Total Demand	67230.65	
Total Generation	74542.60	

Table 19. Generation / Demand Data - Site – Combined Improvements

Combined Average REF	0.82
Total Generation / Demand Ratio	1.11

Table 20. REF / Generation Demand Ratio - Site

Finally, Table 19 shows the combined usage and generation of both improved buildings on the site with a combined average REF of 0.82. However, looking at the total generation and total demand of the site in Table 20, a generation-demand ratio was determined to be 1.11. Meaning overall the site is generating more power than it is using, however this power is not being used effectively.

DISCUSSION

The energy analysis process showed that improving the building envelope by increasing insulation and window types and providing appropriate shading all improve the energy efficiency of a building significantly. However, bigger is not always better, throughout these simulations. 1.5-meter awnings for shading were trialled, along with tripled glazed windows, both of these had over all negative effects on the energy efficiency of the building, cooling loads went down however the lighting and heating loads increased by more.

The comparison of the North facing PV system versus the East-West facing system is one that presents itself throughout this report. The entirely north-facing system on the retrofit building had total area of 198 m^2 which equalled 60% of that building's roof area, it also produced 45,214 kW's of power over the year giving a generation value of 228.4 kilowatts per square meter. Whereas, building 2 with the east-west facing roof had 125 m^2 of its roof covered by a PV system and generated 29,328 kW's for the year. Giving a kilowatt per square meter value of 234.6 which is slightly higher than the north-facing system.

The other major takeaway from the analysis is the distribution of REF values. With both buildings generating either far more or far less power than the building is actually using. The zero value REF's occur during the night when there is no solar power being generated however ambient power is still occurring within the building such as computers left on standby, emergency lighting and other appliances. However, on the other side, around 2500 hours of the year, both buildings are generating more power than required with REF values greater than 1.05, this power is being wasted an going back to the grid.

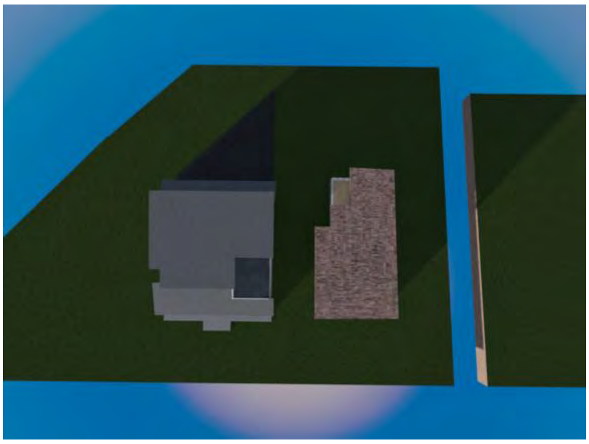
In order to mitigate this, combining the energy use and generation across both sites, is essential, as there will be solar generation occurring from East, North and West facing panels, capturing more sun over the day and creating an even distribution of generation. The installation of batteries will also significantly improve the distribution of power throughout the day, as they will allow unused power in the REF greater than 1.05 range to be stored and used at other times when generation is low and there is still a demand within the building.

CONCLUSION

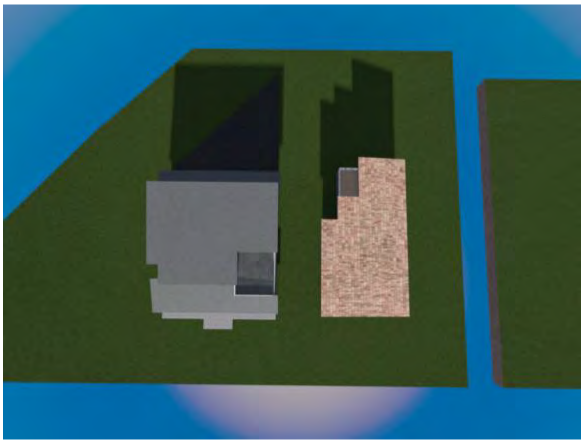
Improving the buildings insulation and ensuring a high quality of construction is key to reducing the energy requirements of the building and in turn reducing the amount of solar energy requiring to be generated.
Whether PV system is entirely North facing or East-West facing, there will be peaks in the generation when not require and lulls when demand is high. Meaning implementing a combination of both systems across the whole site will reduce this effect and the installation of battery technology will allow for the buildings to have more control when it comes to their energy usage and solar generation.

APPENDIX A: SHADING DIAGRAMS

WINTER SOLSTICE 9AM

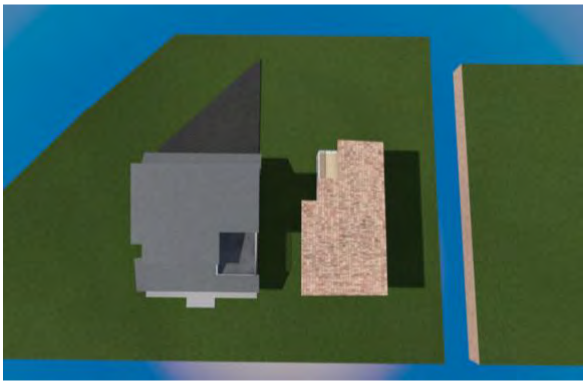


WINTER SOLSTICE 12PM



WINTER SOLSTICE 3PM

SUMMER SOLSTICE 9AM



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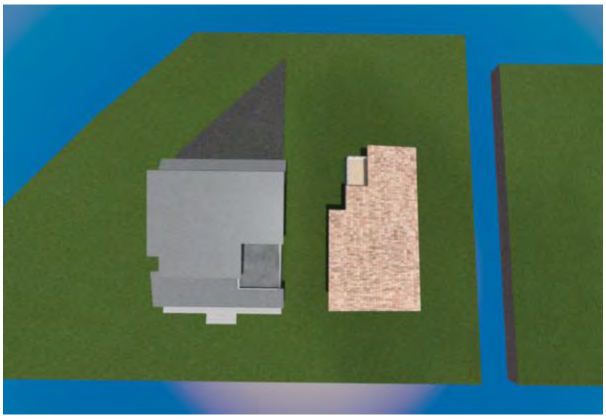

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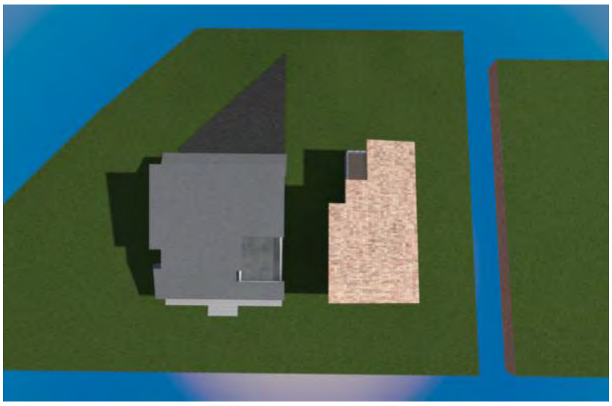


APPENDIX B: REFLECTION

Early in the design process this project set a goal to benchmark against the Greenstar Rating System, which looked to achieve 8 key criteria areas, these are Responsible, Healthy, Resilient and Positive as well as Places, People, Nature and Leadership.

The project has met the responsible category by ensuring a sustainable and net-zero design, reusing the existing structure and sourcing sustainable materials.

To meet the healthy catergory, this project is ensuring high quality of natural light and natural ventilation.

The building is yet to meet the resilient category, as there is no active climate policy and future modelling of changing conditions has not been done.

By modelling the energy usage and generation of the building the positive category has been met, as this development will generate more power than it uses, other requirements such as water re-use will have to be looked at in future

By incorporating bike storage areas, and direct links to public transport, the places category of Greenstar has been met, this has also been done by incorporating views of Mt Kembla into the design to connect the occupants with the indigenous history.

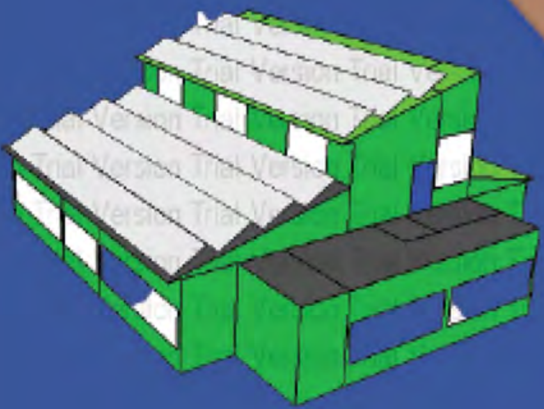
The people criteria is achieved by ensuring both buildings have wheelchair access and it address social health issues in the community by having studio sized crisis housing available to those who are vulnerable.

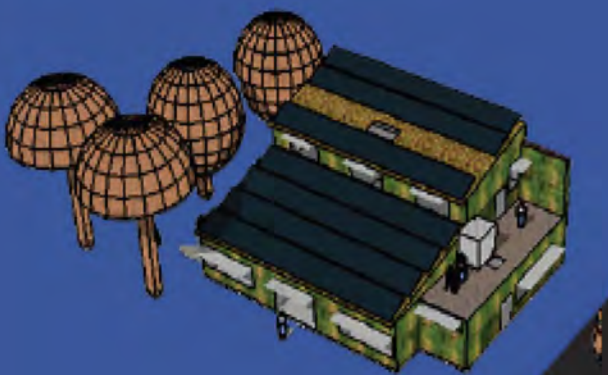
The nature category is yet to be fully achieve, views to the mountains is included however more Greenspaces within the buildings are the site in general are yet to be included within the design.

By incorporating technology into the design such as battery systems and building management systems, this project meets the leadership category by using new and innovating technologies.

Overall the design is yet to hit all 8 criteria for a Greenstar rating however it does meet a lot of the standards and those that haven't been achieved yet are possible to do with further consideration and planning before breaking ground on the project.

Final Design Technical Report
The New ILALC





ENGG-210

Table of Contents

1.0 Executive summary

The purpose of this analysis was to develop an accurate baseline simulation of the updated schematic design proposal for The New Illawarra land Council Building, developed by Team IU1 (see Section 2.3). A benchmark was only developed for the imminent Stage 1 of the design proposal. This benchmark was then used to analyse the performance impact of step-based passive design improvements, with the aim of arriving at a final net-zero design proposal. Results varied for each step based passive improvement (see Section 5), yet a simulation of the last iteration, produced annual site energy savings of effectively half that of the baseline, i.e. 33994 kWh of savings. (See section 5.3 for details). Furthermore, the client's needs were well met (see section 6), yet despite these efforts, net-zero energy was not theoretical achieved using the Renewable Energy Fraction method (REF, see details in Section 4.5), which produced a final calculated reading of REF = 0.897. In other words, the building generated 89.7% of it's hourly energy needs, after the removal of outlying values.

Sections 2-4 describe the construction process and results of the Designbuilder based benchmark model. Section 4 highlights the implementation of solar PV, along with the constraints imposed during this process. Finally, Section 5 details the passive design improvements made and the results. Further model development and simulation research using other software is essential, which would include extending the study to Stage 2 of the development proposal. Although the design did not achieve it's net-zero goal, it has surpassed the BASIX energy goals by 40%. Additionally, many techniques mentioned in Section 6, would boost or stabilise the energy generation, outside the limitations of recently acquired simulation software knowledge. Furthermore, the embodied carbon savings inherent in the design's retrofit nature would very likely off-set the carbon generation required for the remaining 10% of the site's energy needs, however an study is required to confirm this.

2.0 Development of Benchmark Model

2.1 Description of Baseline Model

The Illawarra Local Aboriginal Land Council (ILALC) aims to develop a mixed-use building that allows the entirety of the council's staff to relocate as well as providing retail and office spaces which local businesses can lease. The Unanderra site was once where the police station was located. Through evaluating numerous designs over the course of the project, a final plan has been developed. The baseline 16x19m plan features multiple meeting rooms, a reception, a bathroom for both men, woman and the disabled and storage room on the first floor. On the second floor two large office spaces including managers offices and a roof terrace on the west elevation has been designed. The 2 floor levels are connected by a staircase. The design of the building has allowed for the ILALC staff to relocate as well providing a source of cash-flow for the ILALC through leasing to small businesses.

2.2 Modifications from task 2

The baseline model has since changed from the schematic design due to the feedback received from the clients. The major design change sees the northern elevation roof terrace being change to the west elevation. The reason for this is to allow more solar access on the north roof based on the sun path in Wollongong. Furthermore, the male, female and accessibility bathrooms have been extended into another zone on the eastern elevation. This allows for better access and spatial awareness once ‘Stage 2’ of the design is developed in the future. It is important to note that the baseline model will be analysing ‘Stage 1’ of the project as this is the building that will be built first. Opening the bathrooms into a new zone on the building also provides additional floor plan area which has been used for a technician’s kitchenette, change rooms and a technician’s meeting room which opens to the garage. These new modifications to the design are based on the recommendations from the client and aimed to pursue what was set in the brief.

2.3 Updated Design Drawings

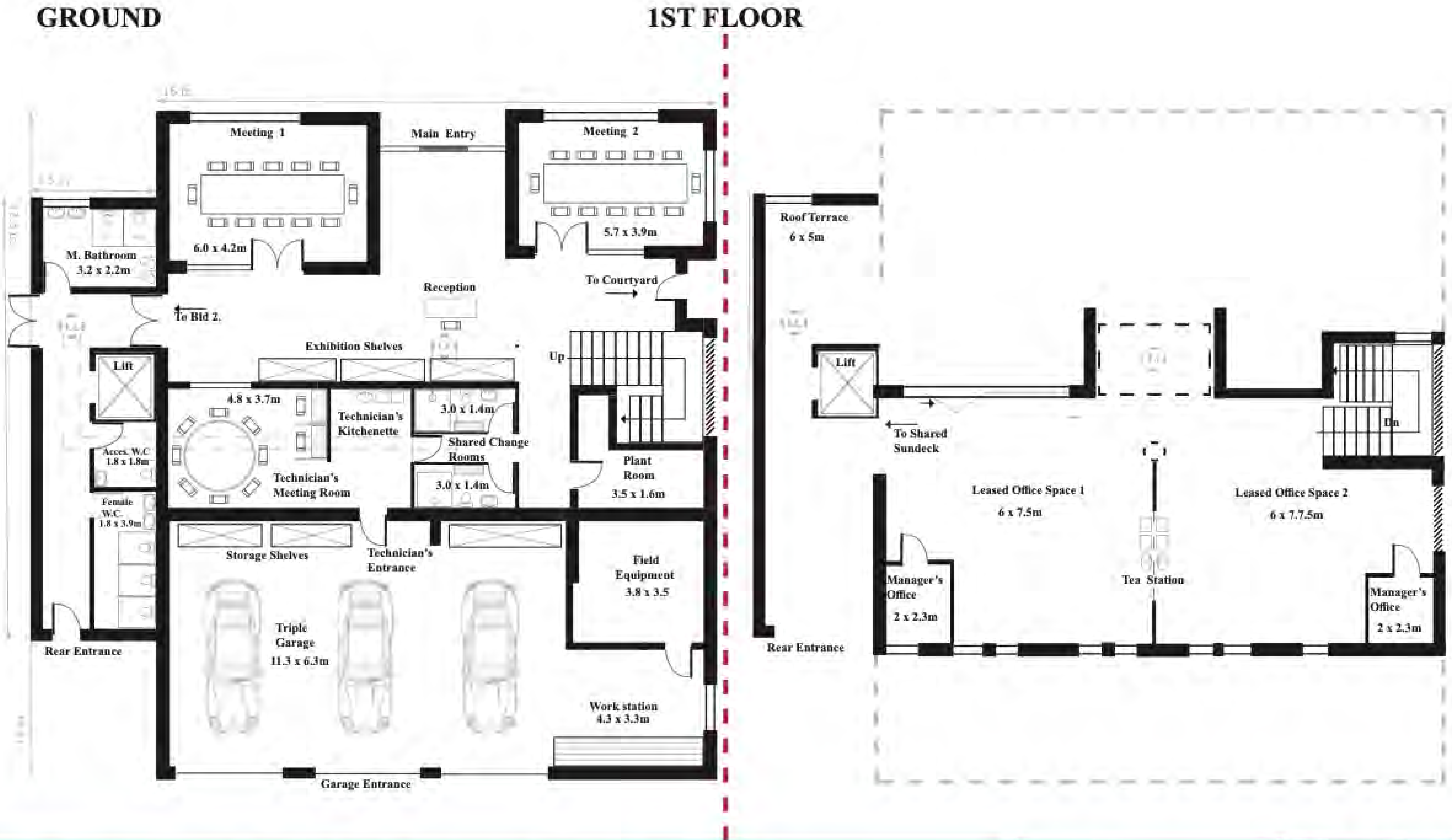
Illawarra Land Council - *Schematic Masterplan*

1 & 7 Farmborough Rd, Unanderra

34°27'33.6"S 150°50'25.1"E

DRAWING TITLE	PROJECT:	001
SITE PLAN	SCALE:	1 : 200 @ A3
	DATE:	21/09/21
	DRAWN BY:	HS
	Drawing No. DA02	Revision: P3

14/09/2021 11:35 AM



Illawarra Land Council - *Schematic Design Proposal*

1 Farmborough Rd, Unanderra

34°27'33.6"S 150°50'25.1"E

N

DRAWING TITLE	PROJECT:	001
	SCALE:	1 : 100 @ A3
	DATE:	21/10/21
	DRAWN BY:	HS
Stage 1 - FLOOR PLAN	Drawing No. **DA03**	Revision: **P5**

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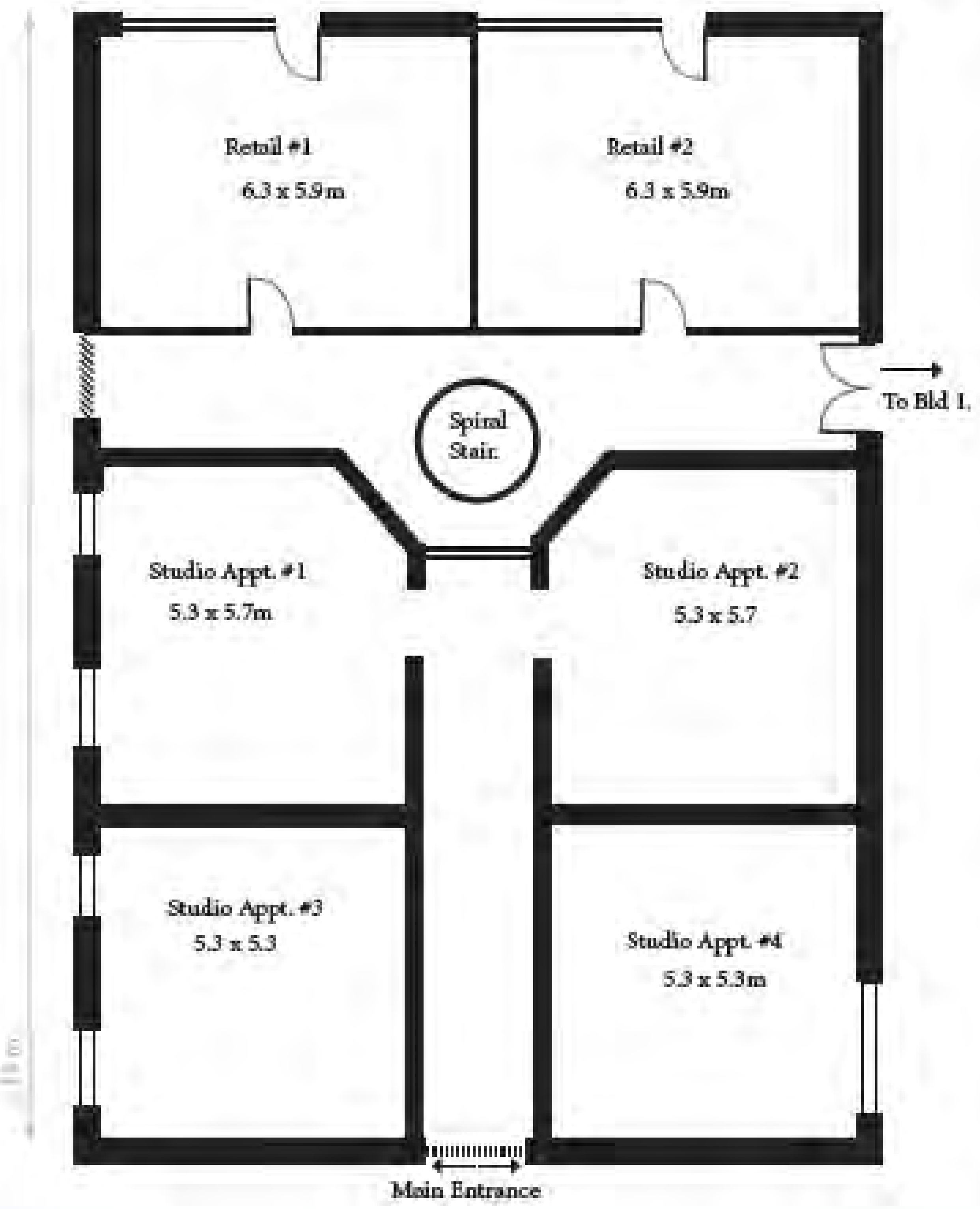
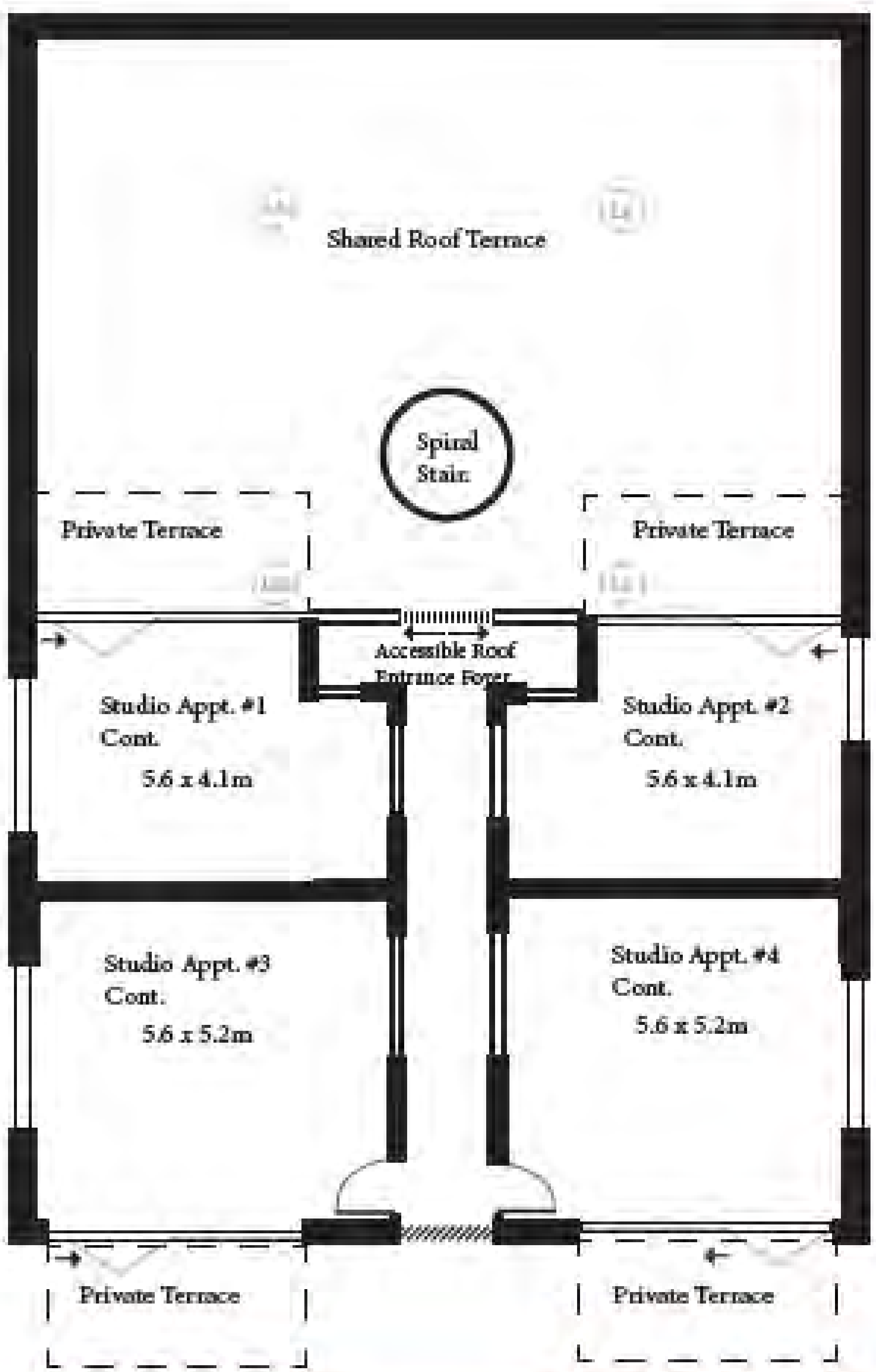
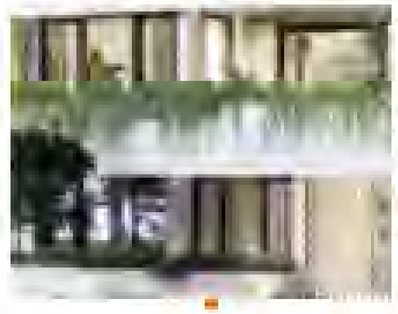
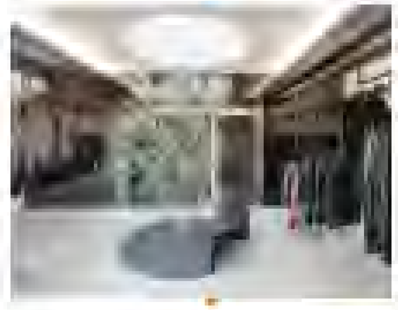
GROUND



1ST FLOOR







Illawarra Land Council - *Schematic Design Proposal*

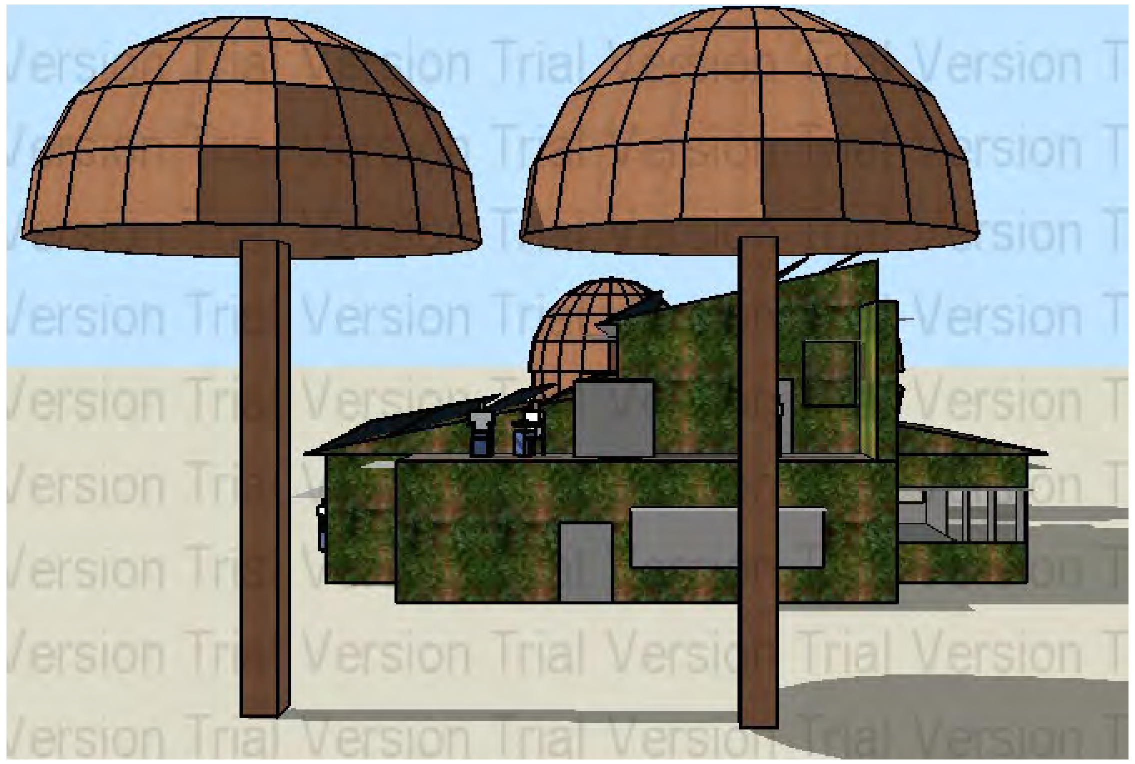
1 Farmborough Rd, Unanderra

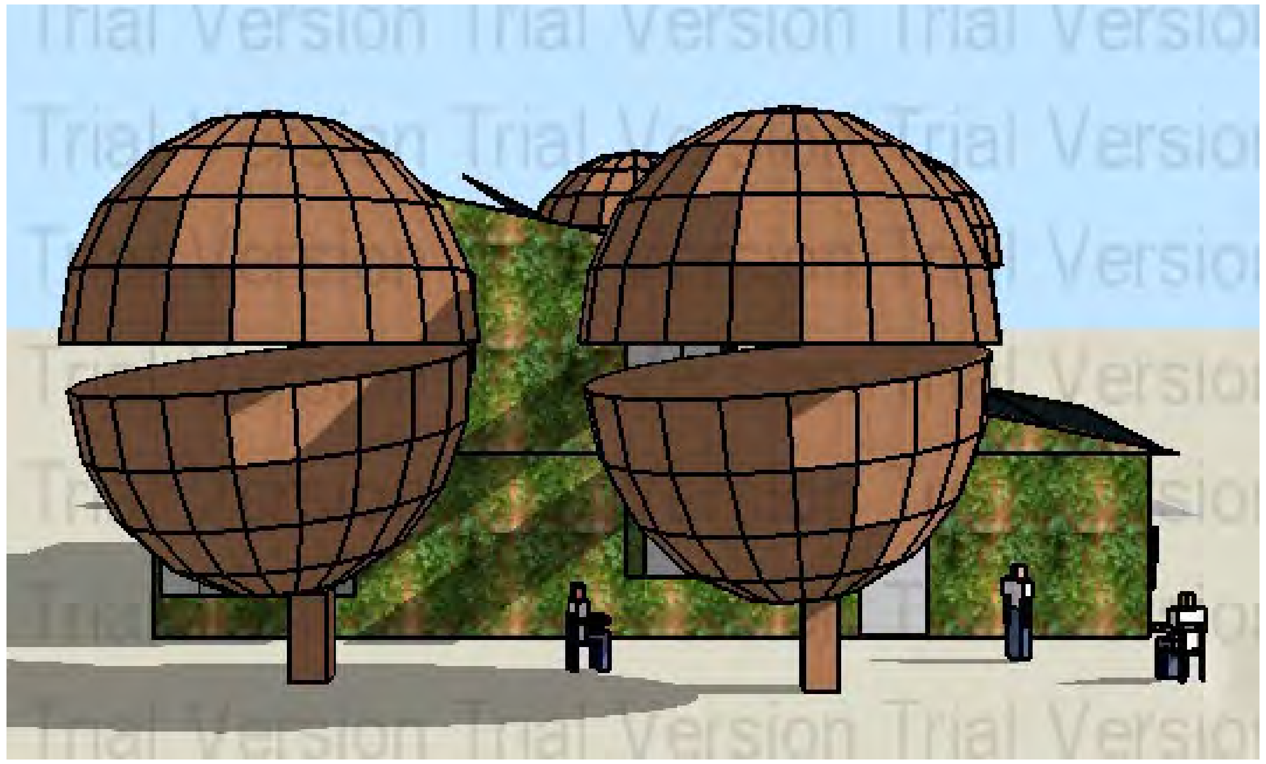
34°27'33.6"S 150°50'25.1"E

DRAWING TITLE	PROJECT:	001
	SCALE:	1 : 100 @ A3
	DATE:	18/09/21
	DRAWN BY:	HS
Stage 2 - FLOOR PLAN	Drawing No. DA04	Revision: P1

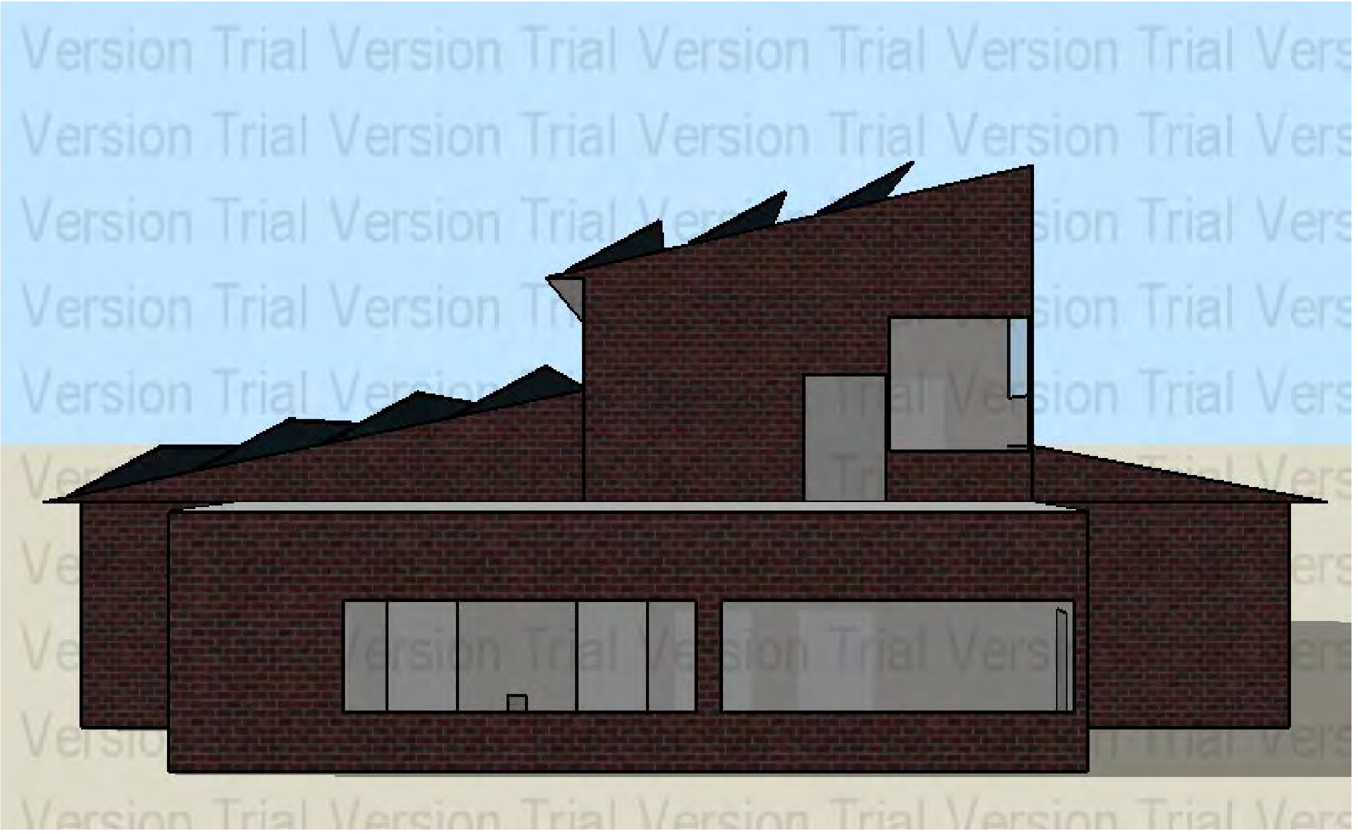
18/09/2021 1:30 PM

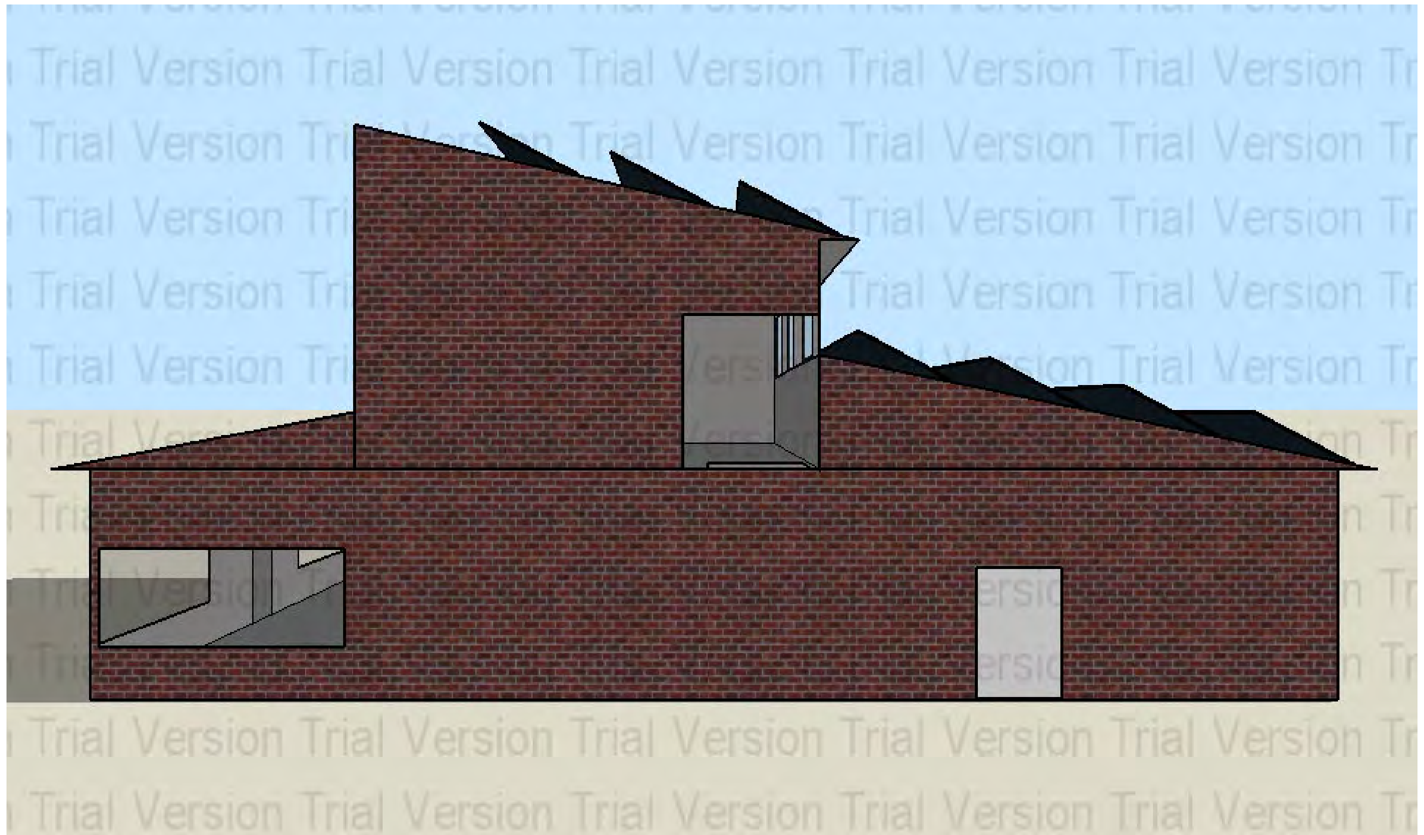
2.4 Post-Modification Design Visualization.

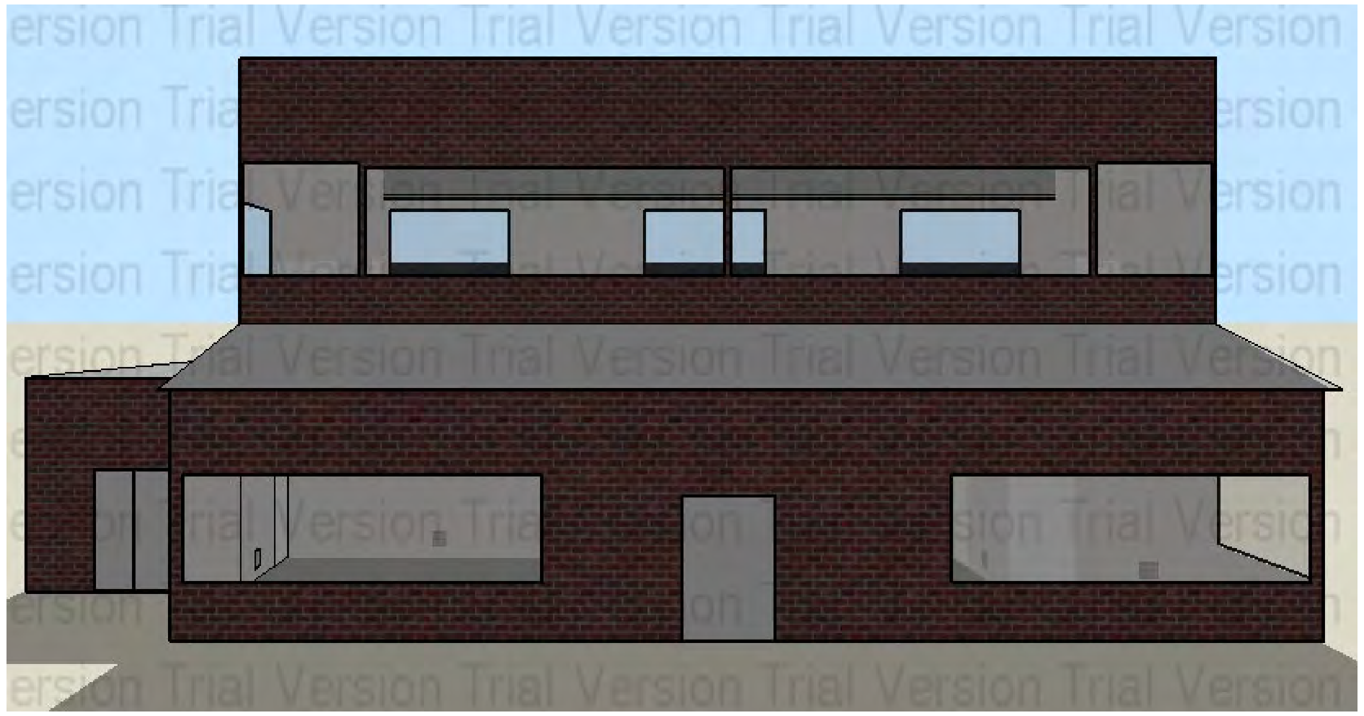




2.5 Baseline Model-Design Visualization.







Southern Elevation

Northern Elevation

2.6 Design Builder

The software application for construction of the baseline model and the analysis is Design Builder. A free, fully functional, 30-day evaluation copy of Design Builder was available and thus did not require licencing. Design Builder allowed for construction detailing, thermal zoning and the addition of PV solar panels. The design builder tool also allowed for building case specific work where functions were altered to match that of the user profile. A medium office space using weather data from Sydney Airport was imported in the program and used for analysis.

2.7 Assumptions for baseline model

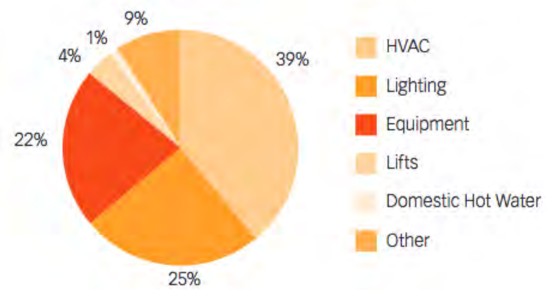
2.7.1 General

The baseline model has used the updated floor plans featured in Section 2.3 – 'Floor Plans of the Model'. The analysis of the building uses a weather file located at Sydney Airport and already found within the software application. Although the site is located approximately 100 km south Sydney Airport, it is assumed that the weather file will provide relevant data for the building. No addition of renewable energy generation will be allocated for the baseline model to identify the net site energy consumption. This baseline will be used as a comparison for when PV solar panels and step modifications are finally added to the building. Although, the building is approximately 15 degrees off from true north, it is assumed that the site is oriented north for simplicity.

2.7.2 Heating and Cooling

Heating, ventilation and air conditioning (HVAC) systems dominate a typical buildings energy consumption, tallying 39% as depicted in Figure 1. HVAC energy use is far greater than other office use appliances such as lighting, equipment or lifts. Thus, efficiency of HVAC systems is vital and can have "radical impact on energy consumption" (Environment, Gov, 2019). While this heating/cooling system is not a realistic one it is the easiest one to define in the simulation tools. Additionally, the thermostat values for the set points and the hours of operations were manipulated to adhere to NCC and SafeWork practices. According to SafeWork NSW, "optimum comfort for sedentary work is usually between 20^0C – 26^0C." and thus the heating and cooling set points were at 20^0C – 26^0C. Since it is also a commercial office space, these set points were only applied from Monday to Friday due to no work being performed on the weekend. Refer to the 'Occupancy' Section to better understand hours of operation.

Figure 1: Typical energy consumption breakdown in an office building[1]



2.7.3 Lighting loads

Lights are the second largest energy consumption appliance in a typical office building, contributing to 25% according to Figure 1. For the baseline model, LED lighting will be used as this is the growing trend in new buildings due to their lifespan, uni-directional light and cost-effective benefits. The lights in the baseline model will reflect typical usage profiles and adhere to requirements set out in National Construction Code (NCC). The information below identifies the Wattage per Square Metre for commercial buildings.

Wattage per Sq/M	Power Density for Specific Area
4.5 watts	Office spaces
4.5 watts	Conference/Board Room
4.5 watts	Common Rooms/Corridors in Class 2 Building
4 watts	Storage Room
3 watts	Toilets

The above requirements set out by the NCC have governed the lighting Watts Per Space Floor area in Design Builder. For example, the storage room in the baseline model has a wattage per Sq/m of 4 which corresponds to the above table.

Furthermore, the simulated usage profiles have been based on real life office lighting usage. For weekdays, office lights will be used 90% of the time from 8am to 5pm and reflects the typical time the users will occupy the space. For weekends, the lighting equipment is less used and thus is represented as a small percentage. In the night-time, the building is hardly occupied and thus only 5% of lighting usage has been deemed appropriate. It is important to note that there are uncertainties around the way ILALC conduct their work as a throughout investigation into staff work-life hasn't been performed. Upon running the simulation, the

2.7.4 Construction

	Construction set	Technical details
Exterior Wall	Brick cavity with uf foam insulation and plaster	R-value: 1.17 Thickness: 248 mm
Interior Wall	Partition – 105 mm single brick with plasterboard both sides.	Thickness: 131 mm R-value: 0.6
Roof	Green roof: • Outermost layer: Sedum layer 200 mm • Sandy soil: 200 mm • Filter layer: 5 mm • UF insulation: 50 mm • Concrete slab: 250 mm	Thickness: 705 mm R-value: 3.98
Floor	• 10 mm carpet • 100 mm concrete slab • Insulation: 123 mm	R-value: 2.7
Intermediate floor	Concrete slab 100 mm	R-value: 0.341 Thickness 100 mm
Windows	Single glazing, clear, no shading	

2.7.5 Equipment usage

The baseline model will account for electricity usage for equipment in the office. Since it is an office space where business will be conducted online, the building is expected to have numerous computers installed in the spaces. The following identifies the assumptions made for computer usage:

- 2 high end computers for the technicians @ 400W
- 10 low end computers for the rest of the office spaces @ 200W each

Upon calculating the energy usage of computers, the following was determined:

- Power Density = (2*400) + (10*200) / 366 = 7.65 W/m^2
- Radiant Fraction = 0.2

Therefore, the computer usage will have a power density of 7.65 W/m^2 and is schedule to be in use from 0700-1800 Monday to Friday which relates to the occupant's office schedule.

2.7.6 Hot Water System

To simplify the model, it was not necessary to model the hot water system. Instead, a miscellaneous electrical demand for hot water for that followed the following daily profile. 8am – 8pm: constant 2 kW demand. The calculations for this electrical demand were as follows:

- *Given: 2kW per 12hr day*
- *2000W / 366m^2 = 5.46* W/m^2
- Therefore, a 5.46 W/m^2 electrical demand was introduced into the building to model the hot water system without over-complicating it.

2.6.7 Occupancy

The baseline model uses an 'Office Building – Open Plan' template that specifies it is a conditioned, non-residential space. According to the clients, approximately 10 ILALC staff will be relocated to this site and will occupy the entire **ground** floor? In addition to this, the second floor will feature leased out office spaces to provide cash flow for ILALC. The second floor will have approximately 10 occupants.

- 10 ILALC occupants on ground floor (250 m^2)
- 10 occupants in upstairs leased office spaces (116 m^2)
- Total occupants for building (366m^2): 20 people
- Occupancy density: 0.054 occupants/m^2

For the baseline model it has been specified that a 'ASHRAE 90.1 Occupancy – Office' schedule will be used. This schedule outlines that throughout the weekdays from 0800-1700 the office will be 95% occupied. On Saturdays the building will be only 30% occupied from 0800-1200 and on Sundays there will be no occupancy in the building. This schedule relates to the working lifestyle of the staff and identifies the normal times and intensity the staff will be using the building. The schedule provides important information for lighting, heating and cooling consumption that will be used for analysis.

2.7.7 Air flow and ventilation

The interaction between air temperature, humidity and air flow determines the thermal comfort of the building. It is important to manage air flow and ensure that 'stale' air is removed and replaced with fresh, clean air. As a minimum, it is assumed a fresh air supply from outside of 0.35 litres/s per m2. It is also assumed that a minimum supply of 10 litres/s per person in all occupied spaces is regulated. Therefore, based on the building's dimensions and occupancy the following calculations were made:

- Background air flow: 0.35 L/s/m^2
- Also supply: 10L/s/person
- Total = Supply – Background
- Background = 0.35 * 366 = 128 L/s
- Supply = 10 * 20 = 200L/s
- Total = 200 - 128 = 72 L/s
- L per person = 72/20 = 3.6

Thus, 3.6 L of air is to be supplied per person in this building for the baseline model.

3.0 Benchmark Model Results

3.1 Annual energy requirements for heating and cooling.

	Annual Energy Requirements (kWh)
District Heating	28833
District Cooling	20097

It was concluded that over the course of a year, heating the building required more energy than cooling as the values were 28833 kWh compared to 20097 kWh respectively. According to the Department of Industry, Science, Energy and Resources, HVAC systems can account for up to 50% of a commercial building's energy use. Upon calculation it is found that for the baseline model the HVAC system accounts for 68% of the buildings energy consumption.

- Heating + Cooling Energy: 28833 + 20097 = 48930
- HVAC Energy divided by total site energy: 48930/71649 = 0.68

This is higher than business as usual cases, however it is expected as it is only a model so miscellaneous electrical usage is hard to calculate.

3.2 Total annual site energy requirements

	Baseline Model (kWh)
Total Annual Site Energy	71649

To analyse the total annual site energy it is best to compare it to the research conducted in the Schematic Design for the business as usual cases. An energy intensity factor was used to create a baseline estimate of energy use for the commercial spaces. The weighted average energy intensity for an office building in NSW was 890 MJ/m2 per annum taken from the Baseline Energy Consumption and Greenhouse Gas Emissions document (Council of Australian Governments 2012, pg. 38). When converted, this is 90,402 kWh annually for the Unaderra building workable floor plan. Therefore, the simulated 71649 kWh falls within close proximation to that of a business-as-usual case and justifies the accuracy of the baseline model.

3.3 Peak energy demand for heating and cooling together with their time of occurrence

	Time of Peak	Peak Energy Demand (W)
Cooling	Jan 2nd @ 1420	24880
Heating	July 18th @ 0810	31004

The peak times for heating and cooling energy demand is in close proximity to the peak hot and cold peaks for the climate in Wollongong, being in summer and winter respectively since it is in the southern hemisphere.

3.4 Peak energy demand of the site

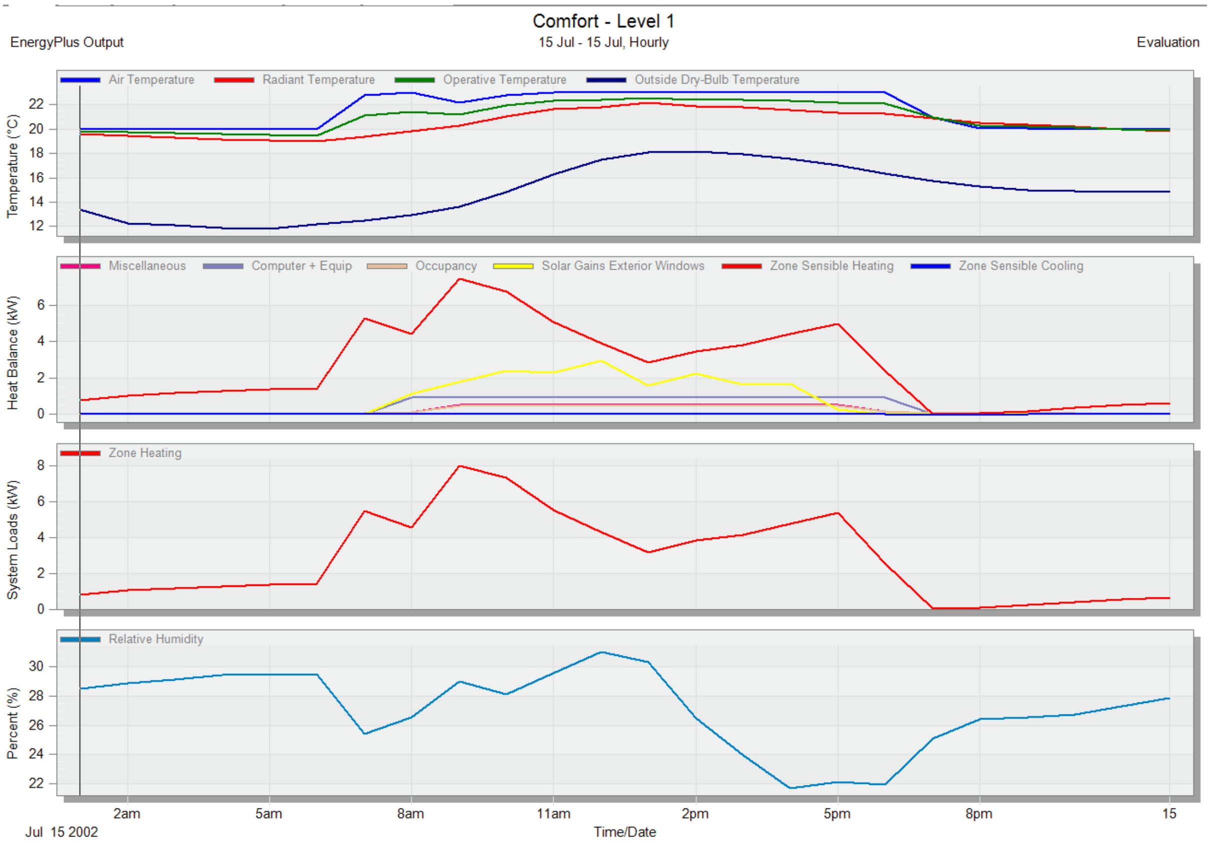
The following is the peak energy demand of the site. This occurred on July 18th in the summer time and is largely contributed by zone heating energy consumption.

	Baseline Model
Peak Energy Demand (W)	35,000W @ July 18th - 0810

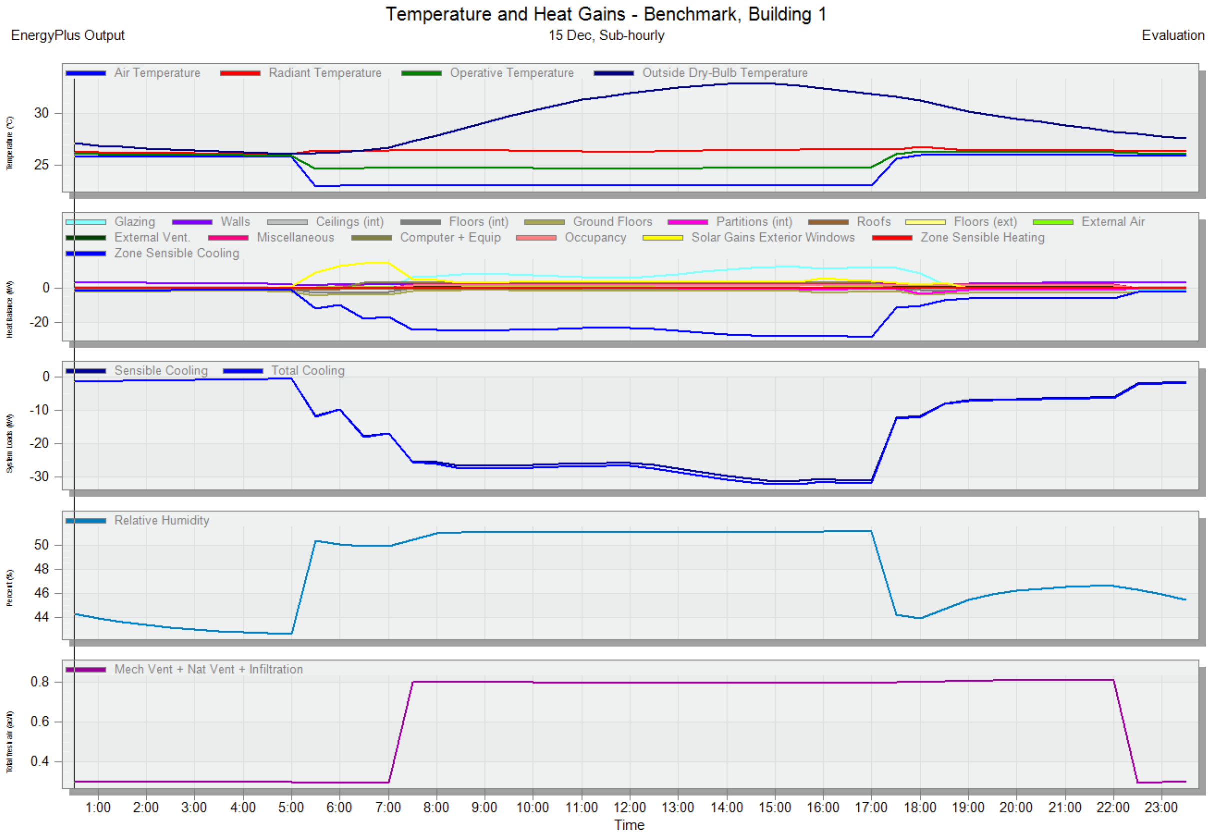
3.5 Winter & Summer typical Daily Energy Use

3.5.1 Winter Design (15 JULY)

The graphical data visually demonstrates to different electrical loads, temperature and humidity on a typical winter's day for the Unaderra site. This is a great method to show the schedules that were inputted prior to running the simulation. When observing the graph, the heating turns on at approximately 0600 which is when it is scheduled to. It is also observable that the heating loads decrease once there is a small amount of solar gains but the simulation always ensures that the inside temperature remains above 20 degrees according to the temperature setpoints. There is no cooling as it is wintertime and thus not required.



3.5.1 Summer Design (15 DEC)



Similarly, the typical summer electrical loads, temperature and humidity are visually conveyed above. However, for this graph since it is summertime there is cooling loads rather than heating loads. The graph shows that although the outside temperature surpasses 26 degrees, the HVAC systems keeps the building within the temperature setpoint of 26 degrees.

4.0 Renewable Energy Generation

4.1 Solar PV Roof placement

The next step of modelling the building involves modifying the benchmark model to include renewable energy generation on site from PV panels. According to the National Renewable Energy Laboratory, commercial building such as the Unaderra building conclude that 60% of commercial rooftop space is suitable for PV. The following calculations outline the allowable area for PV panels based on the size of the roof.

- Northern slope (lower) area: 8.7 x 16 = 139m^2
- Northern slope (upper) area: 7.9 x 16 = 126m^2
- Southern slope area: 4.7 x 16 = 75m^2
- Flat roof area: 12.5 x 3.5 = 44m^2
- Total roof area: 384m^2
- 60% of total roof area: 230m^2

Therefore, the calculated allowable roof area for PV panels, based on the total roof area of 384m^2, is 230m^2. This means that solar panels can be added to 230m^2 of the roof area. Additionally, the nominal efficiency of the panels to be 15%.

To optimise the natural sun path, the solar panels have been placed on the northern elevation of the building, both on the lower roof and the upper roof. The entire lower roof will be covered in PV panels which is 139m^2, leaving 92m^2 available. The remaining 92m^2 of PV panel area will then be utilised on the upper roof (northern elevation) and cover approximately 73% of the roof.

4.2 Solar PV Roof construction

As stated, the solar roofing takes up approximately 230m^2 of roofing space which is 60% of the total roofing area. The individual PV panels are 1 x 1.7m in dimension and have a PV nominal efficiency of 15%.

- The conversion efficiency input mode is set to 'Fixed'
- Fraction of surface with active solar cells: 0.9

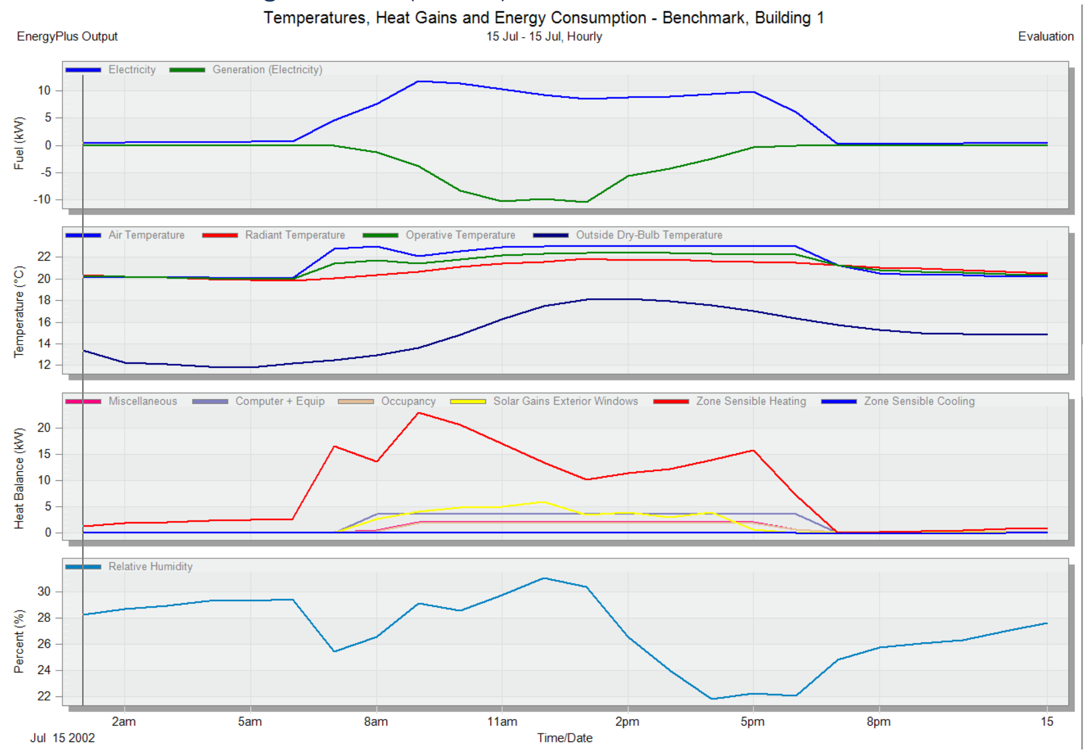
4.3 Total annual net energy requirements on site.

	Simulation calculation (kWh)
Total Annual Net Energy Requirement	26570

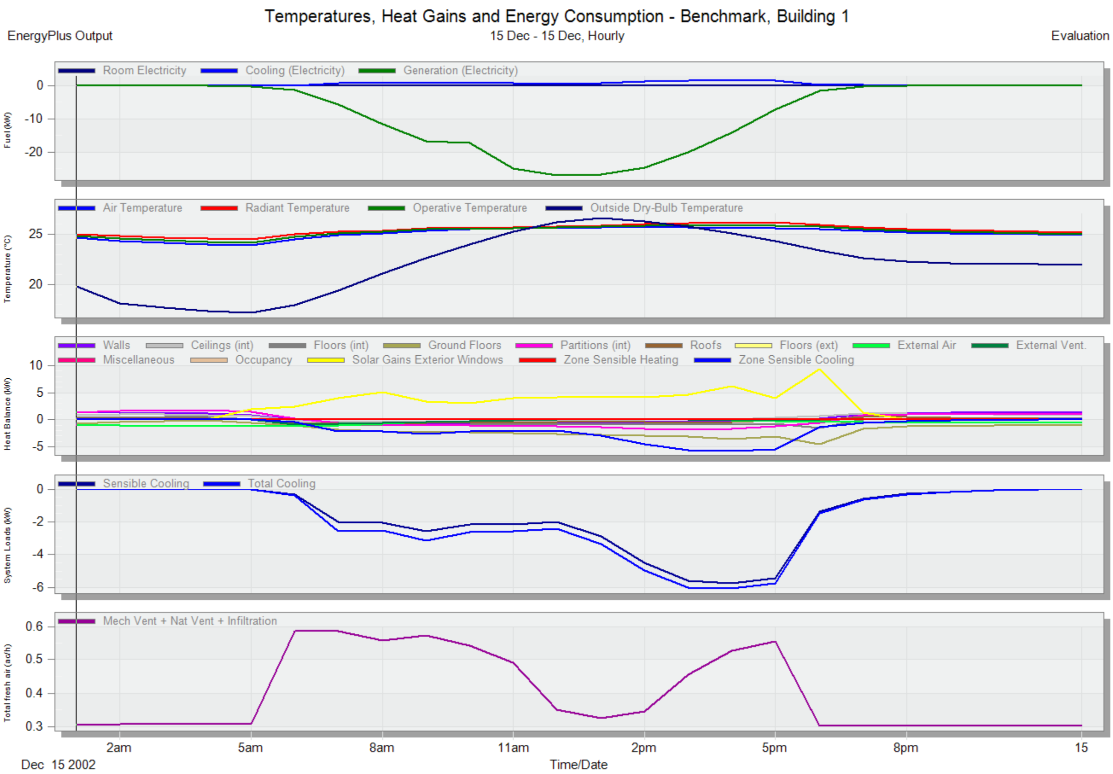
The simulation was rerun after the PV panels for energy generation were added to the model. The simulation calculated that the total annual net energy requirement is 26570 kWh. This concludes that even with PV panels at an efficiency of 15% on 60% of the total roofing area, the renewable energy is not enough to provide off-the-grid living for the occupants. This means that other methods to lower energy consumption in the house must be explored which will be conducted in the next stage of design.

4.4 Winter and Summer Profiles with PV

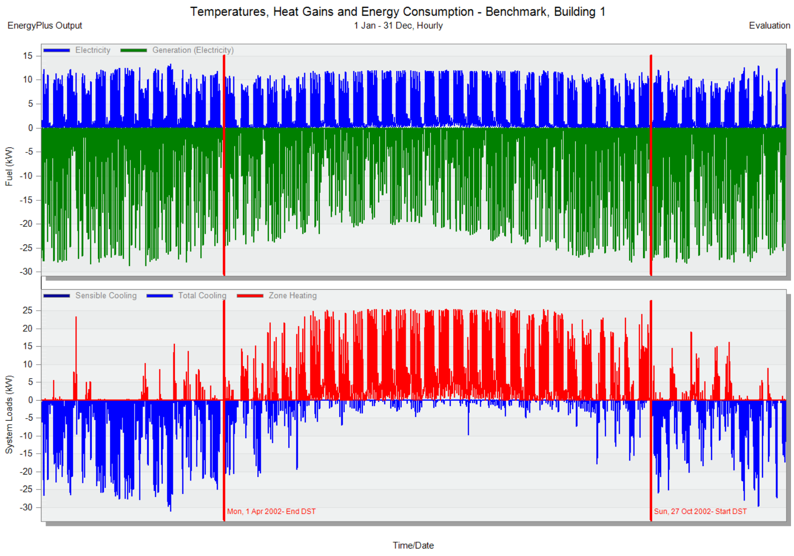
4.4.1 Winter Design with PV (15 JUL)



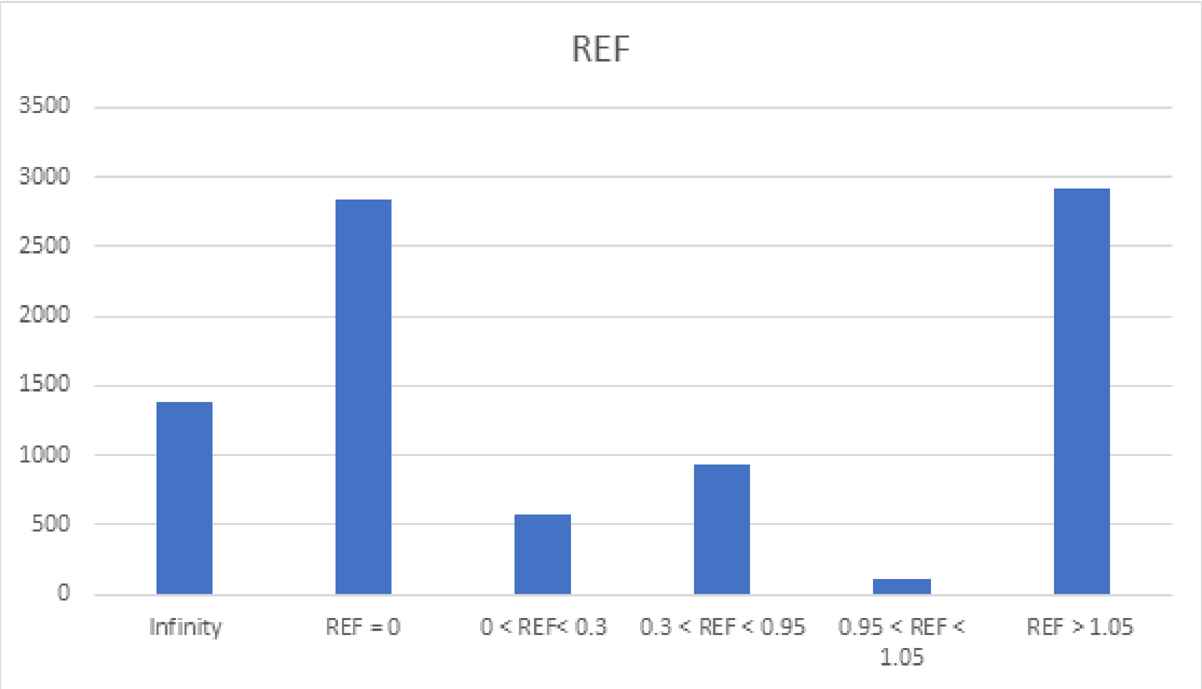
4.4.2 Summer Design with PV (15 DEC)



4.4.3 Electricity Usage vs Generation



4.5 Renewable Energy Fraction (REF) Distribution



The Renewable Energy Fraction is a ratio of the generated electrical energy divided by the electrical energy demand. The aim for a net zero energy strategy is to be able to obtain an REF value above 1.0 as it shows that for every part of the year, renewable energy will completely supply the building with energy. This then demonstrated the self-sufficiency of the building and how much it needs to rely on the power grid. The following indicates with the values mean:

- Infinity: This is not zero as it means there was no electrical energy demand at the instance in time (1hr blocks). Since it is a fraction, this means that the denominator is zero and thus requires an 'infinite' value. This value would be found after work hours and over-night. Since demand for electricity after work hours can become zero, having an infinite value is common, demonstrated in the graph above.
- REF = 0: This means that there is no generation of renewable energy from the PV solar panels. This is likely to be over-night as there is no solar in this time. Since night-time/ low solar intensity is common throughout the year for the climate of Wollongong, a value of zero is very common. Therefore, for approximately 2700 hours of the year there is a value of zero REF.
- 0 < REF < 0.3: These values identify that there was both renewable energy generation and electrical demand. It more specifically shows that the electrical demand was much higher than that of renewable energy generation. For the baseline model, there is approximately 500 hours throughout the year that have values in this bracket. This is a low percentage which is already a good sign for a net zero energy building prior to modifications.
- 0.3 < REF < 0.95: These values identify that there was both renewable energy generation and electrical demand. It more specifically shows that the electrical demand was just a little higher than that of renewable energy generation. This is the range to work on for the modification and making sure these values go beyond 0.95 once adjustments are made.
- 0.95 < REF < 1.05: This is the most important range because it highlights that the PV output has been consciencely designed to meet the building's demand and it is economically better because of the typical electricity tariff structures that favours renewable energy use on site rather than exporting it to the electricity grid. Currently, there is a low percentage of hours throughout the year that fall into this bracket and the modifications in the coming steps will aim to increase this.
- REF > 1.05: Values that are greater than 1.05 convey that the renewable energy has sufficiently provided the building with enough power, however with excess. Although it is good to have a large amount renewable energy, it would be better to meet the buildings demand. These values are most likely to occur in the summer months throughout the day when the solar intensity is high. It is very likely to occur on weekends when there is little to no occupants in the building. For the modification section, exploring the option for energy storage is a good option due to the excess of energy generation.

4.6 Average Annual Renewable Energy Fraction (REF)

	Simulation calculation (0-1.05)	True (all)	**REF VALUE (capping >1.05 at 1.05)**
Average Annual REF	0.46	5.14	**0.52**

Explanation of REF values:

- REF Value (capping >1.05 at 1.05): To exclude the outliers and not have the data skewing to the right, the values over 1.05 were rounded down to 1.05. This is to avoid providing a large REF value like the 'True' value shown in the table.
- True (all): This REF value is the average of all REF values between 0 to infinity. Since there were numerous events were the generation significantly outweighed the

usage, most likely on a weekend, the data was skewed to the right and provided a value of 1.05.

- Simulation calculation (0-1.05): This REF value of 0.46 identifies the average annual REF of values greater than 0 to 1.05.

The REF Value of 0.52 is what was used for the baseline model to improve upon and is shown in bold in the table.

5.0 Building Modifications

The next stage of designing is to make step modifications in the building to improve the REF values that were calculated in sections 4.5 and 4.6 without increasing the area and the efficiency of the PV panels. This will require a rerun of the simulations then documenting and discussing the changes after. The target is to achieve an average REF value of at least 1.

5.1 First Iteration – Further Design Realisation

The following modifications are derived from doubling down on the design ideas, ensuring a strong correlation between the design drawings and the BIM model.

5.1 - Alterations & Reasoning

1. Trees added as component blocks, to simulate shading (Deciduous not possible to model).
2. Manually added doorways – Auto-generation turned off.
3. Manually modified Window size and positioning.
4. Two skylights added, in alignment, through both levels.
5. Raingarden added on sundeck (Component block, R = 0.2).
6. Added lift on sundeck (Walled component block).
7. Failed attempt to add louvres for adjustable shading.

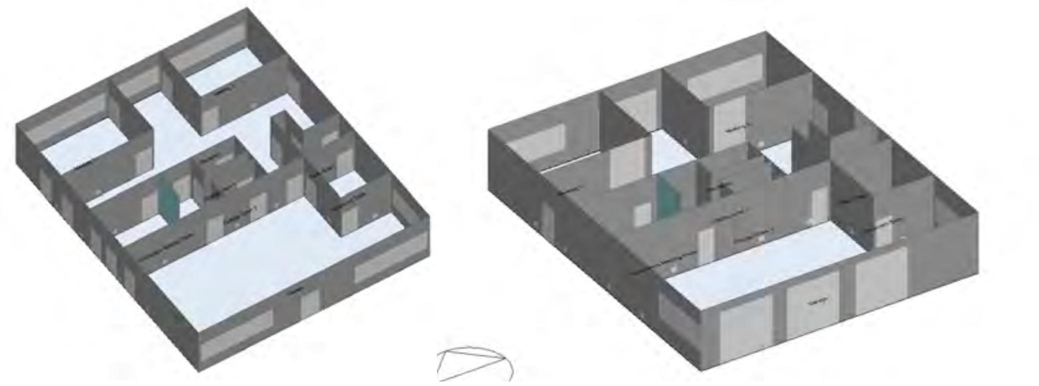


Fig. 5.1.1 – Comparison between Benchmark (left) & Updated versions (right).

Fig. 5.1.2 – Shading diagram, 15th Jan, 8:00am.

Fig. 5.1.3 – Shading Diagram, 15th Jan, 4:00pm.

5.1 - Results & Discussion

Table 5.1.1 – Summary of Results

Annual Load Reductions			Av. REF
Heating: 1169KWh	Cooling: 712KWh	Site Energy: 332KWh	0.516

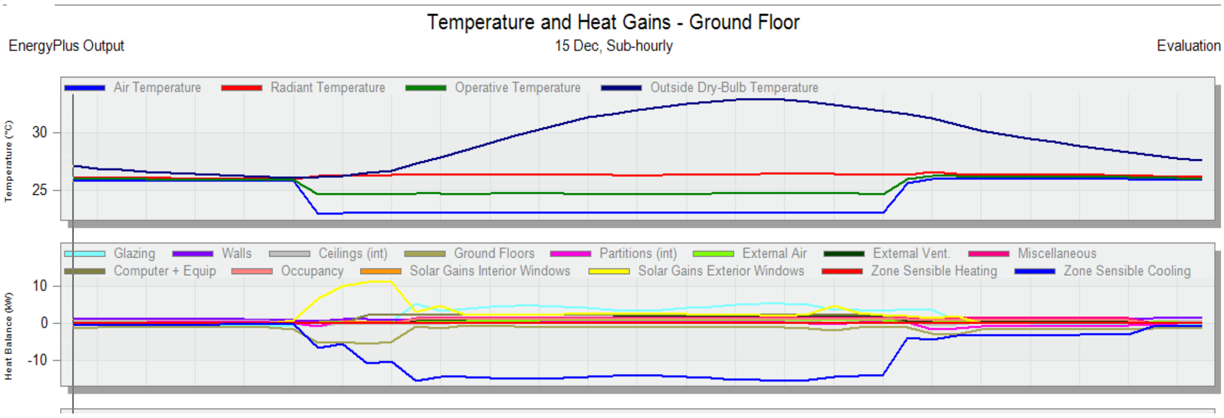


Fig. 5.1.4 – Isolated look at the ground floor.

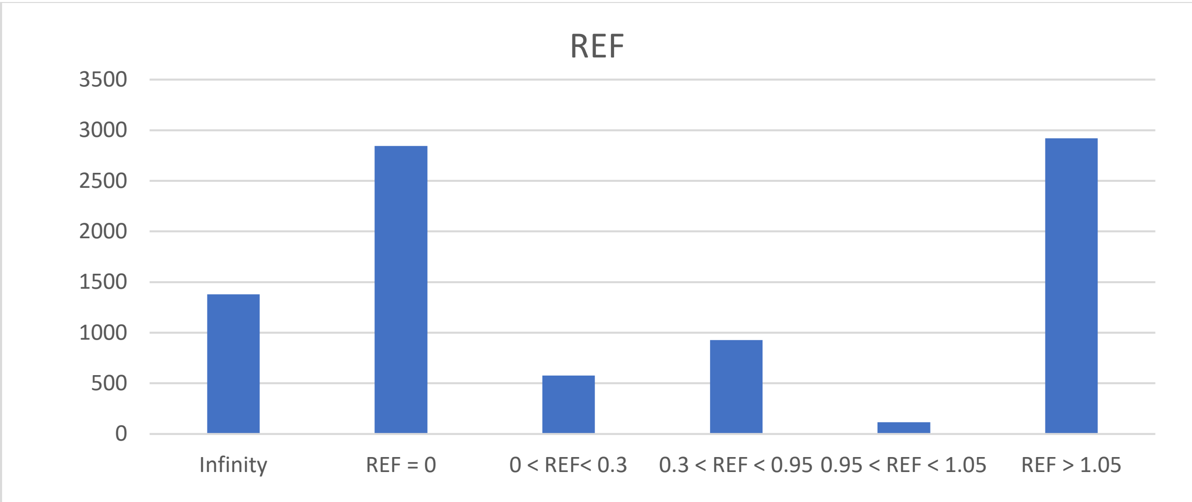


Fig. 5.1.5 – Statistical spread of REF values, excluding infinity values (a constant).

These results indicate certain improvement, yet not the amount of expected improvement. This is likely due to a reduction in solar gains and light in winter due to the annual tree type shading (see Fig. 5.1.2 & 5.1.3) This is further supported by heating and cooling reductions which total to be greater than the annual site energy reductions, indicating a higher lighting load (the only remaining variable).

Finally, it's very possible that the single glazed skylight creates a significant thermal break through the green roof, reducing the insulative capacity of the building and inhibiting performance improvements. This is supported by the quantity of solar gains reaching the ground floor around mid-morning (Fig. 5.1.4)

The REF value distribution has barely improved (see Fig. 5.1.5), and the average value has worsened by approximately 0.05. The aforementioned observations have likely caused this, by producing higher loads during the mornings.

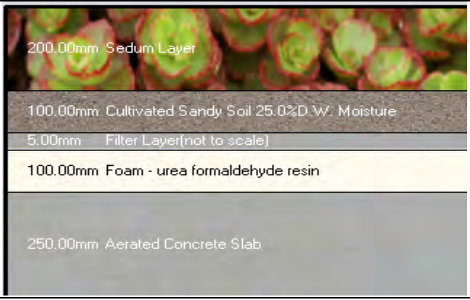
5.1 - Next Steps

Investigate the cause of the early morning solar gains during summer, by referring to the shading diagrams (see Fig. 5.3). Improve building envelope due to high quantities of glazing now present. Attempt to achieve this through innovative means.

5.2 – Second Iteration – Building Envelope Upgrade

Although lacking in innovation, upgrading the building insulation envelope is one of the most tried and tested methods to improve a buildings performance. This is due to lessening the building's temperature fluctuations, by reducing the speed as which a building expels and gains the outdoor thermal conditions. It is all too easy to include the state-of-the-art insulation, when given a soft budget, however, the insulation choices below are within a reasonable economic range.

5.2 - Alterations & Reasoning

	Baseline Construction set	**Technical details**	**Modifications**	**New Tech Details**
Exterior Wall	Brick cavity, open cell UF foam and plaster	R-value: 4.46 Thickness: 370	Replacement of UF with it's closed-cell counterpart. Addition of vine-based green wall to building's exterior.	R-value: 11 Thickness: 390
Interior Wall	Partition – 105 mm single brick with plasterboard both sides.	Thickness: 131 mm R-value: 0.6	No modification As it would reduce usable floor space.	
Roof		Thickness: 705 mm R-value: 3.98	No modification as is already a net zero strategy.	
Ground Floor	• 10 mm carpet • 100 mm concrete slab • Insulation: 123 mm	R-value: 2.7	Unmodified	
Intermediate floor	Concrete slab 100 mm	R-value: 0.341 Thickness 100 mm	Addition of EPS insulation	R-value: 2.3 Thickness 188 mm
East, North & West Windows	Single glazing, clear, no shading		Double glazed windows	Argon filled
Southern Windows	Single glazing, clear, no shading		Double glazing, Fibreglass framed	R -Value: 4.45

5.2 - Results & Discussion

Table 5.2.1 – Summary of Results

Annual Load Reductions (KWh)			Av. REF	Adj. REF
Heating: 3451	Cooling: 3126	Site Energy: 6577	0.494	0.834

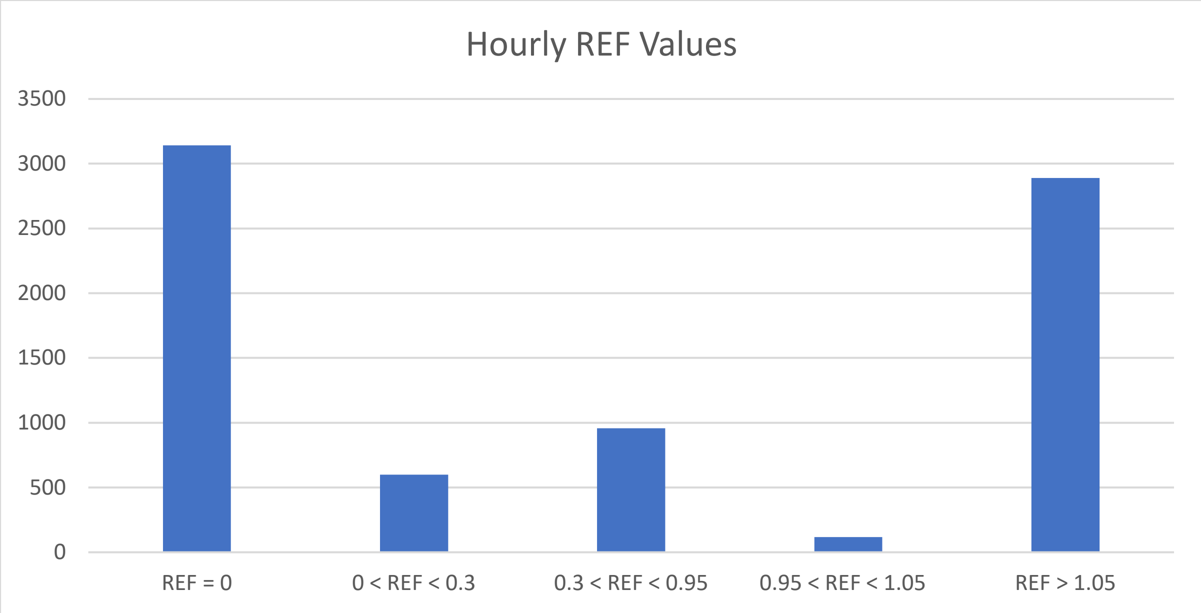


Fig. 5.2.1 – *Statistical Spread of REF Values*

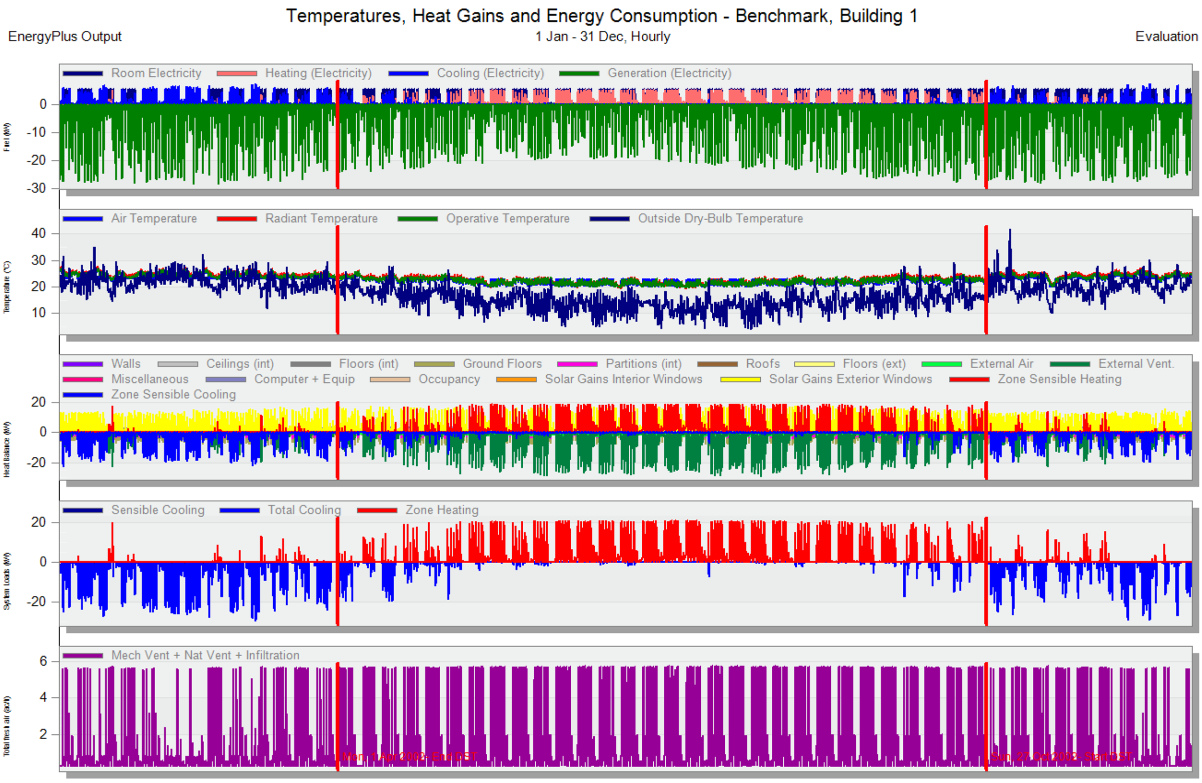


Fig. 5.2.2 – *All Relevant Hourly Data for run period 1 Jan – 31 Dec*

Date/Time	Electricity (kW)	Generation (Electricity) (kW)
1/01/2002 01:00	0.014426	0
1/01/2002 02:00	0.008735	0
1/01/2002 03:00	0.004923	0
1/01/2002 04:00	0.001961	0
1/01/2002 05:00	0.004436	-0.106055

Fig. 5.2.3 – *Extract from the hourly data used for REF calculation*

At first glance (see Table 5.2.1 & Fig. 5.2.2), it is apparent that the building's heating cooling loads and thus site energy consumption have all been significantly reduced. However, upon comparing the REF distribution for this upgrade and the previous one (see Fig. 5.2.1 & Fig 5.1.5), a great deal of similarity is evident. Using the ordinary method of REF value calculation (see), the average REF value is less than previous.

Revision of the hourly time-stamped data used as input for the REF value calculation (see. Fig. 5.2.3) highlights a small-sample size of majority contributors to the 'REF = 0' column in Fig 5.2.1. In fact, the summation of these 3'142 values, totals to only 1172 kW, a mere 1.8% of the annual site energy consumption. Furthermore, these values are largely produced during the very early morning or night-time hours, where no solar power will ever be produced, thus unfairly skewing the data.

Therefore, justifiably removing these zero values, the average REF value increases by 34%. An experiment was made to demonstrate how easily these values could be reduced by crudely installing integrated PV on the Eastern and Western facades. The PV area was borrowed from the roof PV (see Fig. 5.2.4 & Fig. 5.2.5). In summary, this effort proved unsuccessful, as the early morning and late afternoon zero values only constituted a minor percentage of these values, with the majority taking place overnight. Also affecting this result was the subtraction of the majority hour power generation.

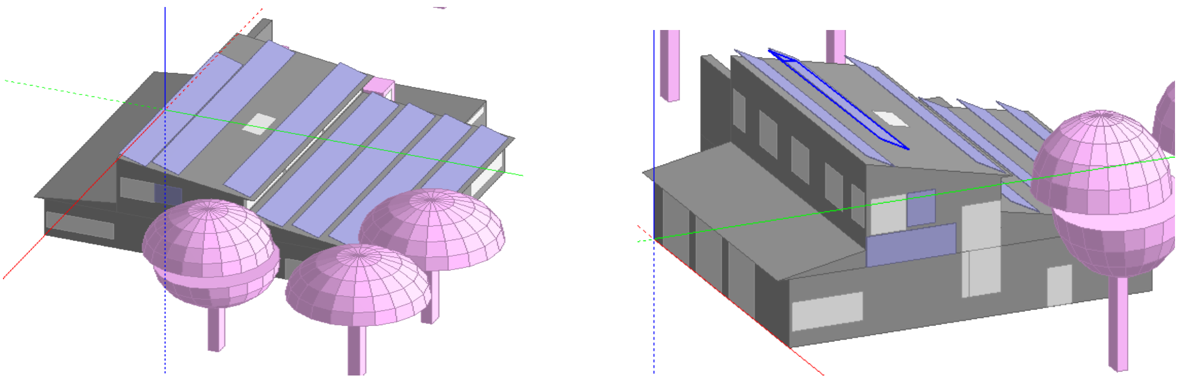


Fig. 5.2.4 & 5.2.5 – *Integrated solar PV on Eastern (left) and Western (right) facades.*

5.2 – Next Steps

Further investigation into the source of night-time power demand which is generating excessive 'REF = 0' values.

Investigation into techniques to reduce the high solar gains in summer (see. Fig. 5.2.2).

Investigation into the continuous heat loss through external ventilation in winter (see. Fig. 5.2.2.)

5.3 – Building Automation & Optimisation

5.3 - Alterations & Reasoning

- Triple garage space switched from conditioned to un-conditioned.
  This large space is only occupied for physical work or car storage by technicians, who are very likely clothed in outdoor wear. Conditioning this south facing, very poorly insulated space is unnecessary.

- External Shading improved.
  Overhangs were added to all eastern and western facades as well as increasing the northern eave length in an attempt to reduce summer heat gains, whilst still allowing for winter solar gains.

- Mix-Mode air conditioning toggled on
  Use of natural ventilation as a priority during summer, with optimised setpoints entered. Furthermore, the **setback points were reduced** as it was uneconomical to continuously heat the building during the night-time hours.

5.3 – Results & Discussion

Table 5.2.1 – Summary of Results

Annual Load Reductions (KWh)			Av. REF	Adj. REF
Heating: 27711	Cooling: 7306	Site Energy: 37655	0.660	0.897

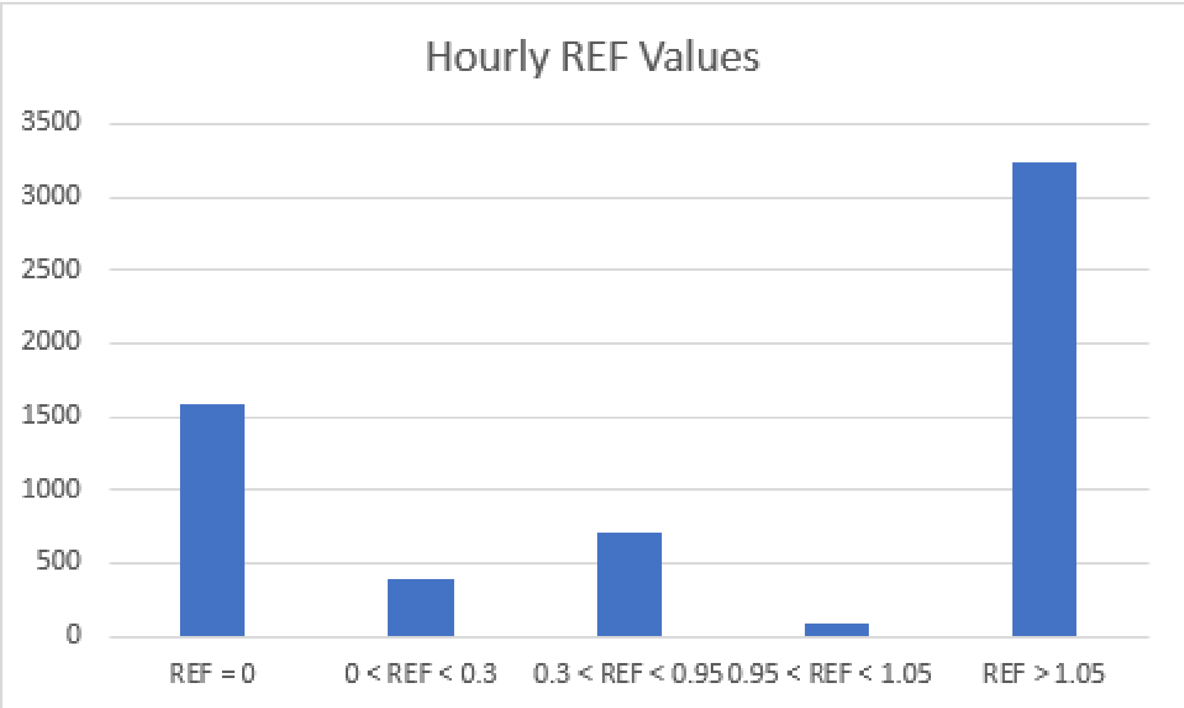


Fig. 5.3.1 – *Statistical Spread of REF Values*

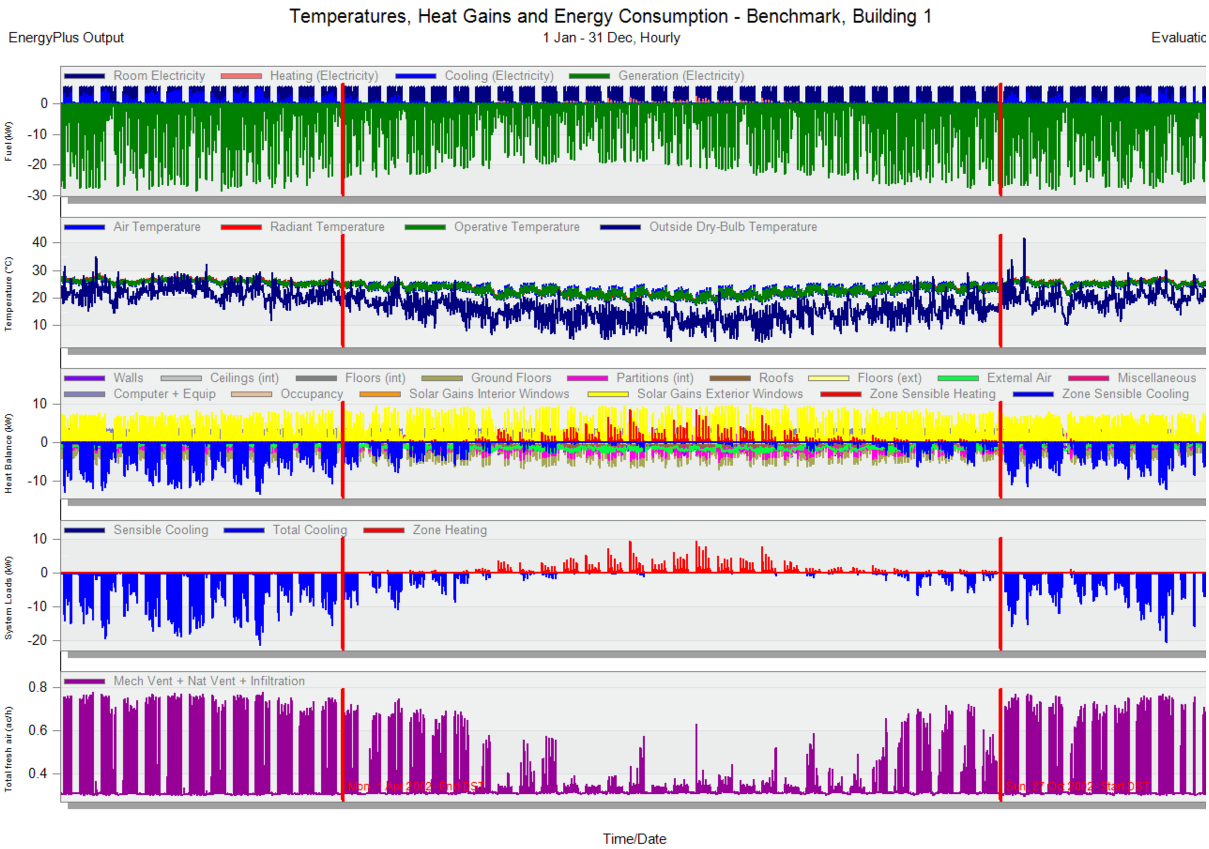


Fig. 5.3.2 – *All Relevant Hourly Data for run period 1 Jan – 31 Dec*

The results detail an incredible improvement to the buildings performance. The energy requirements are effectively halved (see Table 5.3.1), due to the very large decrease in heating load during the winter (see Fig. 5.3.2.).

This is explained by the building having little to no requirement to heat or cool the building during the over night hours (See Temperature in Fig. 5.3.2). Furthermore, switching the mixed mode on importantly reduces the excessive natural ventilation during winter, whereas it is retained in summer to ensure passive cooling. Lastly, solar gains have been reduced by nearly half in summer, due to the added shading. Importantly, significant solar gains are retained in Winter. All of the above result findings contribute to the energy reduction of the building and correspondingly improve the REF value distribution (see Fig. 5.3.1).

The 1588 REF = 0 values now only total to 557kW, effectively half of the previous amount. These requirements will be accounted for in the future implementation of Eastern and Western integrated PV. Negating these outlying zero values, the Average REF value totals to 0.897 or in other words, is able to generate 90% of it's energy capacity without energy retention.

Next steps

If time permits, further reduce solar gains during the summer, re-attempt Eastern and Western PV, seek innovative solutions.

6 Conclusions and discussion

Table 6.1 - Summary of design requirements met

Original design constraints	**Was this still met?**
Facilitates 10 Field Technicians.	Yes, the entire ground floor is designated for the ILALC staff and will comfortably fit 10+ staff. The ground floor features multiple meeting rooms, bathrooms, a garage, storage and a breakroom.
Built to facilitate ILALC employees after growth	Yes, space can cease being leased, unlocking the entire building for the ILALC staff, with Stage 2 replacing the building's revenue streams
Provide a source of cash-flow for the ILALC through leasing to small businesses	Yes, the entire upstairs has been design for external leasing for a small business which will provide cash-flow for the ILALC.
Incorporates sustainable strategies throughout design, construction and use.	Yes, multiple features of sustainable strategies will set in place including the use of a green-roof and renewable energy in the form of solar PV panels.
Innovative strategies are prioritised.	Unfortunately, limited software knowledge translated into limited innovation in the final design. However, most key elements were added into the final design.
Net-Zero status achieved	No, approximately 10% of the energy demand is not generated by renewable energy.
Provides potential crisis shelter/housing for indigenous peoples.	Yes, the apartments in Stage 2 can be used for this cause, while revenue generated through the retail spaces.

Net-Zero Considerations

Although this building has not been able to achieve net-zero status, nor demonstrate cutting edge, innovative technologies, all other key requirements throughout both user and assessment criteria have been met (see Table 6.1). Furthermore, the embodied energy retained within the retrofit of the existing building off-sets a significant quantity of carbon compared to the alternative. Additionally, the design showed significant improvement throughout the

With only 10% additional annual power generation required, there are many methods available for unlocking the net-zero potential of this building. Outside the bounds of limited simulation software knowledge, these methods could include any of the following:

- Integrated Eastern & Western PV with automated shading.
- Greater thermal mass, located centrally in the building to increase solar gains during the winter months.
- Automated shading on the northern façade.
- Integration of phase-change materials to stabilise thermal conditions through the night.
- Replacement of skylight with initially proposed light-tube – with added insulation to reduce the thermal break effect.

- Energy generation through kinetic energy harnessing roof tiles like those recently released by engineering Australia.
- Upgrading all windows to fibreglass framing.
- The addition of a battery to disperse the excess power generation (for all REF > 1.05) to the remaining hours which need additional generation (0 < REF < 1.0).

Design Strengths

Additional to meeting the client's requirements, this design exhibits many strengths from the Client's, local community's and environmental perspective.

- Meets client requirements.
- Meets WELLS priorities.
    - Ample natural light.
    - Natural airflow.
    - Green spaces.
    - Community spaces – adds to local community ecosystem.
- Exceeds BASIX energy requirements.
    - > 50% reduction in typical greenhouse gases.
- Provides flexibility of space utilisation.
- Minimal disruption, embodied carbon as well as retention of history through the retrofit design.
- Staged development provides client with ample time to accumulate funding through immediately available revenue streams.
- Built on tried, tested and successful technologies, which will certainly improve the building's performance.

Next Steps

Once the building has reached a net-zero standard in theory, several steps are required before the design can be implemented:

- Site visit required to confirm site data, such as wall measurements, wall quality, etc.
- Structural plans, particularly focused on supporting the Green Roof weight (est. 65 kg/m^2).
- Further development of Stage 2, including separate simulation and business plan.
- Re-building the simulations in a separate software to compare and conclude on results.
- Embodied energy analysis, to determine the carbon emissions saved by retaining the core of the existing building.
- Finalised drawing package, with complete measurements, elevations and final 3D render.

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12.0 APPENDIX A: Government Certification Schemes (WELL)

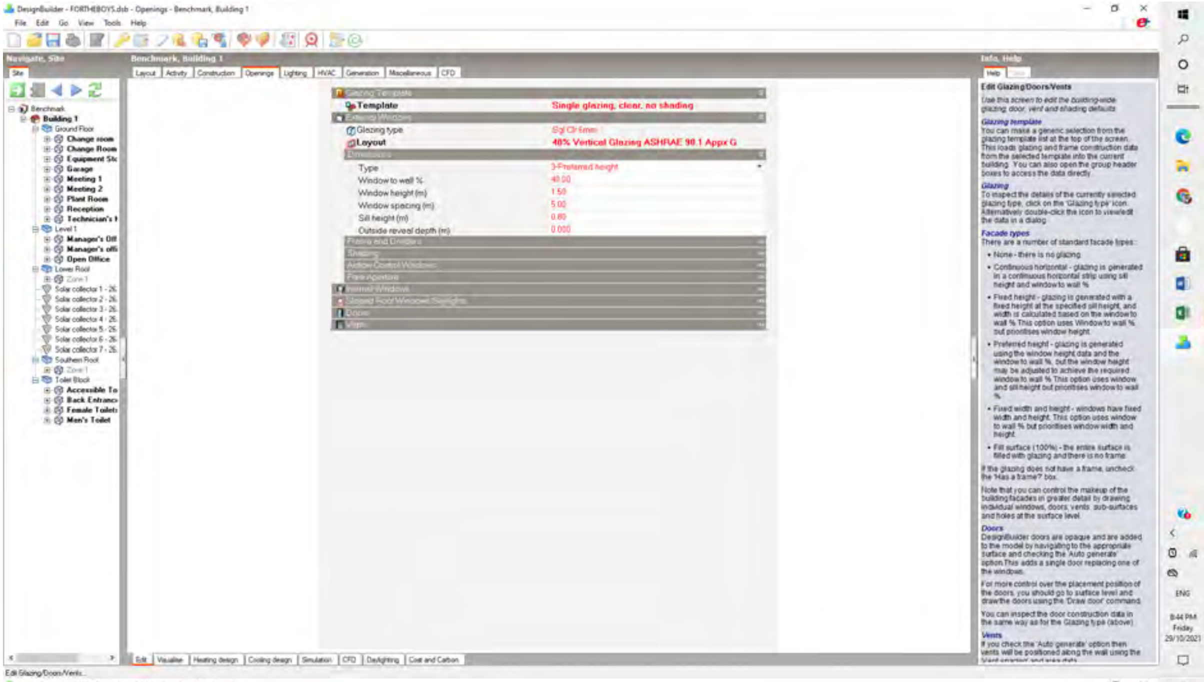
Human health and well-being is the top priority when designing new buildings and the WELL Building Standard offers insightful, scientifically backed information in order to achieve this. The main strategies to improve the home's atmosphere, physically, emotionally and physiologically are on concepts including air, water, light, mind, movement, thermal comfort, sound materials, and community. WELL offers performance standards for designing buildings to enhance the life of the occupants, some of these standards include:

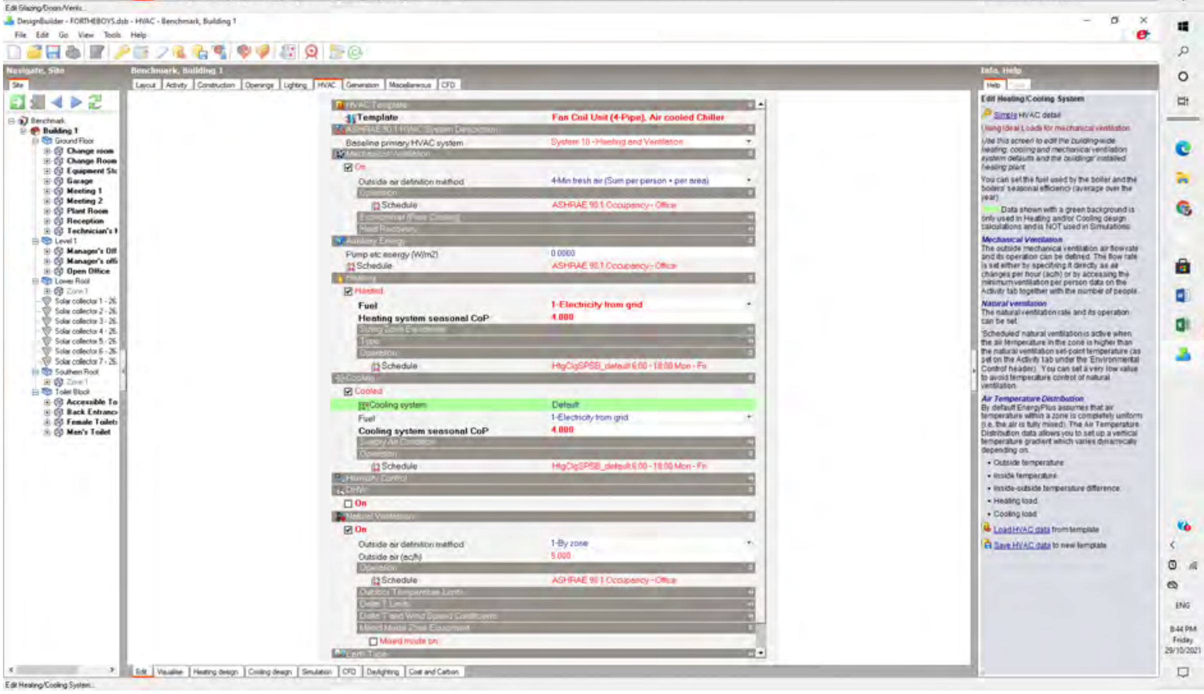
The WELL Building Standard	How was it achieved at Unanderra
Mind: Address and support these drivers of mental health with the goal of improving the cognitive and emotional health and well-being of those living, working, learning and spending time in built spaces.	This was achieved through fostering natural features into the design such as a green-roof. The spatial were designed to relate to each other effectively such as locating the accessibility toilet on the ground floor.
Air: Implement holistic design strategies to promote clean air and minimise human exposure to harmful contaminants.	As a minimum, it is assumed a fresh air supply from outside of 0.35 litres/s per m2. It is also assumed that a minimum supply of 10 litres/s per person in all occupied spaces is regulated. Thus, 3.6 L of air is to be supplied per person in this building for the baseline model. A smoke free environment and not using harmful materials such as asbestos was a must.
Water: Increase the rate of adequate hydration in building users, reduce health risks due to contaminated water and excessive moisture within buildings.	Provide quality drinking water and sanitation spaces such as bathrooms for hygiene support.
Movement: Promote movement, foster physical activity and active living and discourage sedentary behaviour, by creating and enhancing opportunities through creating active spaces.	The roof terrace was an open space for ‘fresh air’ and encourage limited outside activities. Rooms were designed to relate to each other like having a manager’s office located nearby to the main offices or the breakroom being close to all rooms downstairs.
Thermal Comfort: Provide a maximum level of thermal comfort among all building users through improved HVAC system design.	Use high quality insulation materials and HVAC systems and use quality doors and windows to limit gaps between the exterior and interior for air tightness and minimise heat loss. Double glazed windows and a green roof was used to retain the heat. Thermal comfort was kept

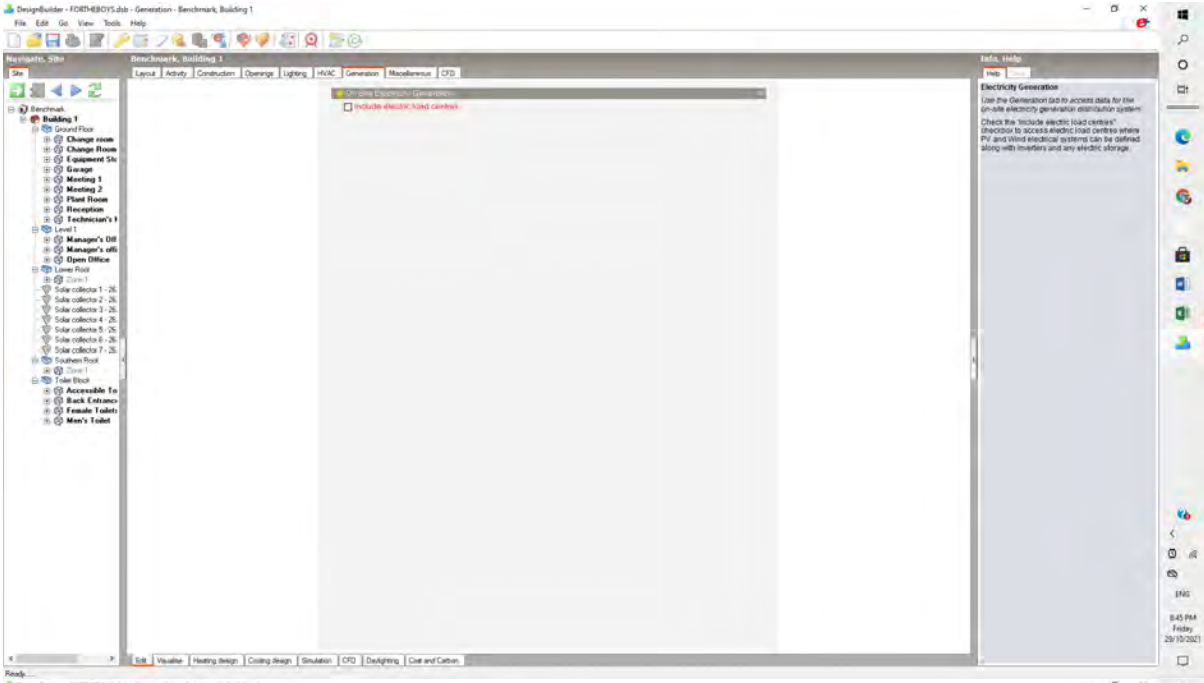
	between 20-26 degrees according to SafeWork NSW.
Barriers to be removed/changed if on a large scale:	• Creating a green-roof for mass production is too difficult and simple, effective roof would replace it such as a Colourbond Coolmax roof which reflects 77% of the suns rays. • Double glazed windows: The simulation only allowed for ‘all or nothing’ for double glazed windows. If continued with the design, adequate research will be performed to see which elevations and/or windows should be double glazed. • The exterior wall would be re-designed. This is because for the Unanderra building the current double-brick construction was continued for use rather than knocking down the building.

13.0 APPENDIX B: Assumptions

13.1 Baseline Model Assumptions:



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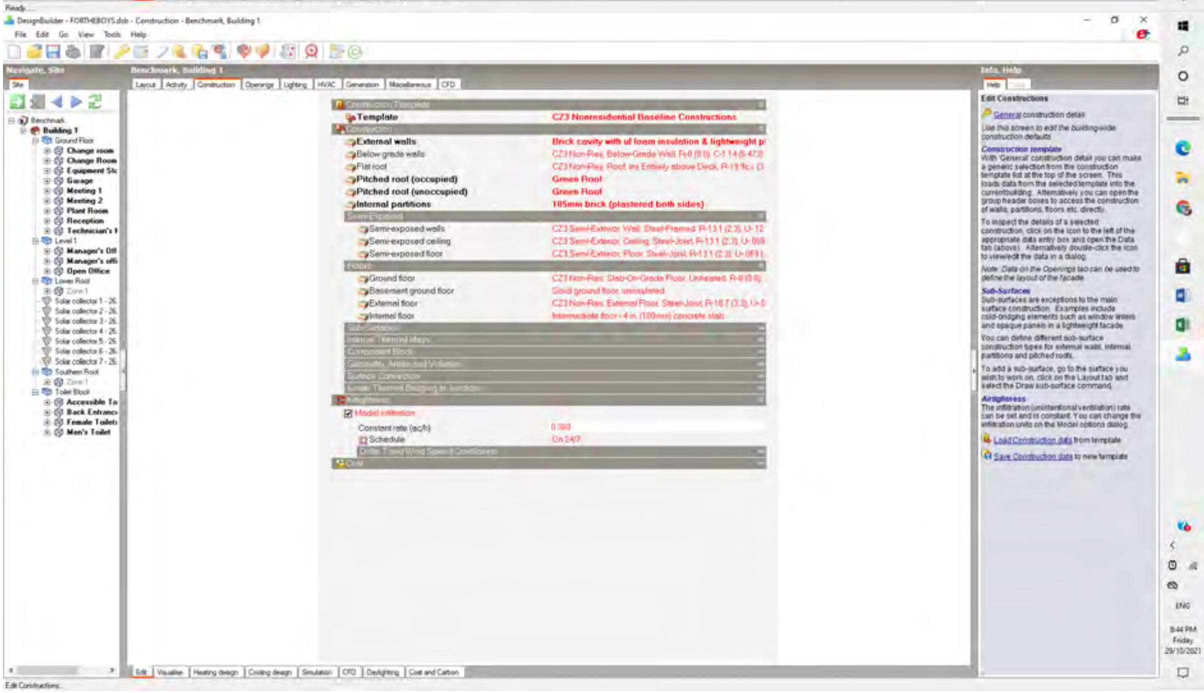
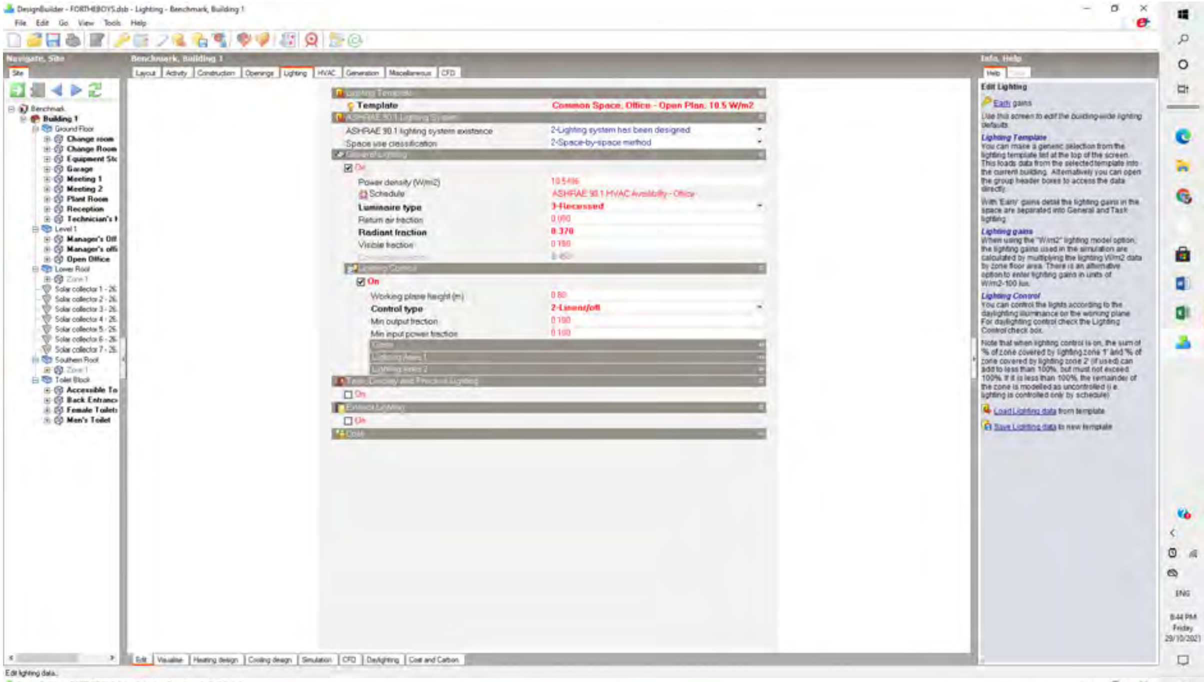
Benchmark, Building 1
Info, Help
Electricity Generation


DesignBuilder - FORTHEBOYS.dsb - Construction - Benchmark, Building 1
Benchmark, Building 1
Info, Help
Edit Constructions
Template
CZ3 Nonresidential Baseline Constructions
External walls
Pitched roof (occupied)
Green Roof
Pitched roof (unoccupied)
Green Roof
Internal partitions
105mm brick (plastered both sides)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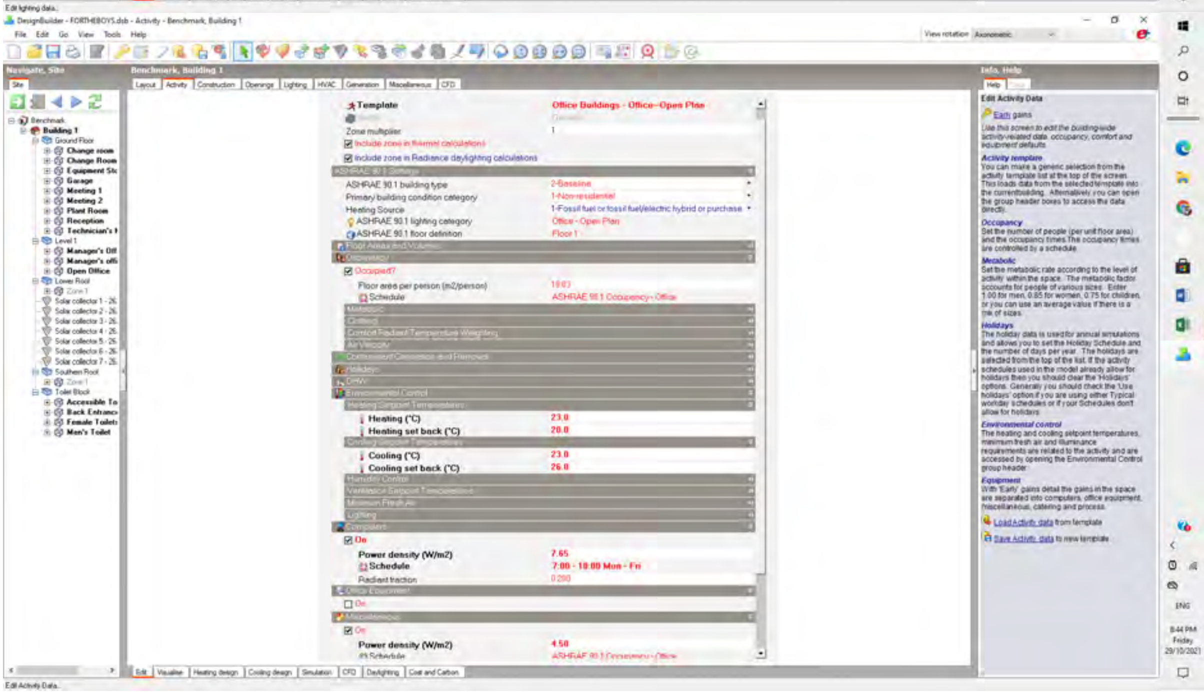
Template
Common Space, Office - Open Plan, 10.5 W/m2
ASHRAE 90.1 lighting system existence
2-Lighting system has been designed
Space use classification
2-Space-by-space method
Power density (W/m2)
Luminaire type
3-Recessed
Radiant fraction
Control type
2-Linear/off
Edit Lighting


DesignBuilder - FORTHEBOYS.dsb - Activity - Benchmark, Building 1
Template
Office Buildings - Office - Open Plan
Heating (°C)
23.0
Heating set back (°C)
20.0
Cooling (°C)
23.0
Cooling set back (°C)
26.0
Power density (W/m2)
7.65
Schedule
7:00 - 18:00 Mon - Fri
Edit Activity Data

ENGG210 LALC Final Report

Executive Summary

This report will aim to meet the requirements set by the Illawarra Local Aboriginal Land Council in producing a net zero energy retrofit for the existing police station located on the corner of Farmborough Road and Princes Highway, Unanderra. It will analyse the performance of the existing building by modelling the existing footprint and materials in Design Builder which will simulate the interaction of the building with its surrounding environment. It will then use this simulation data to characterise an effective means to achieve net zero energy for the structure in which improving the insulation, glazing, lighting and HVAC achieved this. It will analyse the thermal performance, energy performance and the REF of the corresponding design to determine the effectiveness of solutions through design iterations. The resulting is a net zero energy structure that may be utilised by the ILALC as a head office or leased out to provide revenue.

Table of Contents

1.0 Introduction

In 2019, the Illawarra Local Aboriginal Lands Council (ILALC) acquired ownership of Lot 101, and 102, Farmborough Road through the premise of a title claim. Located on the corner of the Princess Highway and Farmborough Road in Unanderra, the existing building was previously utilised as a police station which has stood, mostly unused, since its decommissioning in the 1990s.

Following their acquisition, the ILALC propose the development of a mixed-use building that can provide office, retail and potential residential space. The ILALC plan to relocate their staff to this location in which then opens significant potential for the land. The ILALC also specified a total cost of less than $1 million whilst maintaining a low environmental footprint. This then opens up the options for potential retrofit for the existing building, or the demolition with a new construction on both premises.

The existing police station resides on Lot 101, whilst the adjacent lot, Lot 102, contains no structures apart from a brick fence stretching around its perimeter. The former police station is a double story building constructed of masonry and consisting of a pitched tiled roof. It was noted that the existing building was structurally sound, however the aging nature of the internal partitions cannot be salvaged due to updated fire and safety compliance requirements.

It was discussed with an ILALC member that retrofit for the existing building would not require a Development Application (DA) and would prove to be the preferred option. Although the poor performing nature of the existing structure may prove to be a challenge in achieving net zero energy as the ILALC aim to align with future goals of Australia in an attempt to reach a net zero 2050.

2.0 The Project for the ILALC

Initial brainstorming and planning towards the creation of a mixed-use development was then conducted with various iterations being produced. This involved the creation of bubble diagrams to understand the complex spatial relationship of a mixed-use building. It proved difficult as it is important to maintain confidentiality of the spaces in which some were proposed to be leased out to differing organisations to produce income for the ILALC. As seen in Figure 2-1, an early bubble diagram, an attempt is made to isolate spaces such as amenities whilst also separating spaces that would be shared by different organisations.

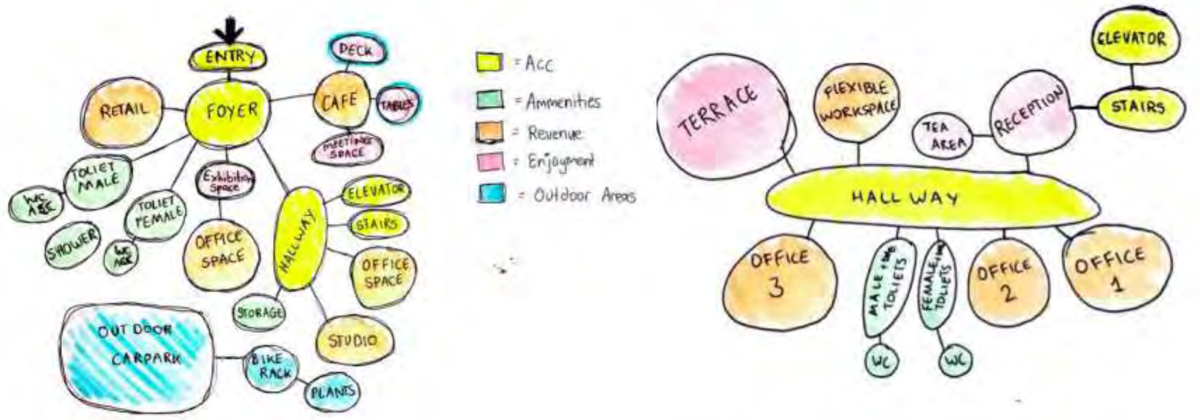


Figure 2-1 Initial Bubble Diagram

The bottom floor is to accommodate 4 offices in which may be leased out to potential clients to provide an income for the ILALC. It will also include various amenities including toilets, a kitchen, storage and a foyer at the entrance of the building from Farmborough Road. The bottom floor is to occupy a total of 260 square metres. The top floor will consist of 3 offices that is for proposed used for the ILALC in which also provided an open flexible work area and outdoor terrace in which will accompany a total of 120 square metres of the building's footprint. Based on the floor plans, as seen in Appendix C1 and C.2, it was estimated that a total of 25 occupants would utilise the structure on an average day and resulted in an occupancy density of 0.066 person/m^2. The full floor plans and elevations are seen in Appendix C.

3.0 Benchmark Model

Following the final design for the retrofit and the construction of a new mixed-use building, the two could be modelled in a program called Design Builder in which utilises the Energy Plus engine to enable the simulation of building performance. In saying this, to develop a somewhat accurate representation of the how the building would perform in real life, many assumptions were made. The full list of assumptions, materials and schedules used in the initial simulation can be seen in Appendix B, however this section will explore the basic assumptions used.

As seen in Figure 3-1, the building was modelled to scale which included internal zones, windows, openings and simplified construction materials that closely represented that of the existing building. Figures 3-2 and 3-3 also represent the internals of the baseline model.

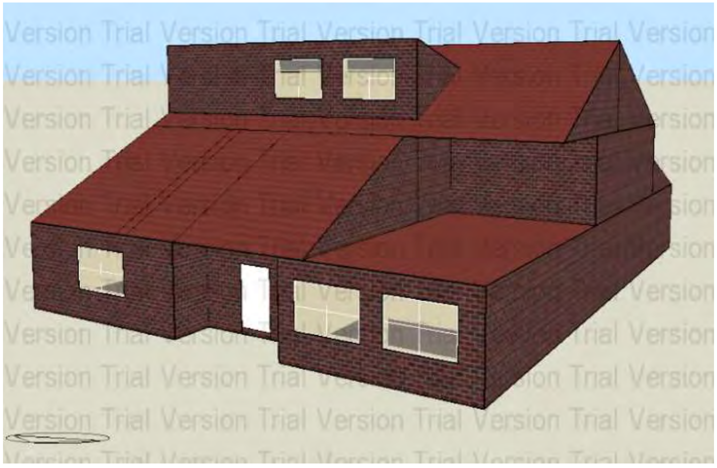


Figure 3-1 3D Render of Baseline Model

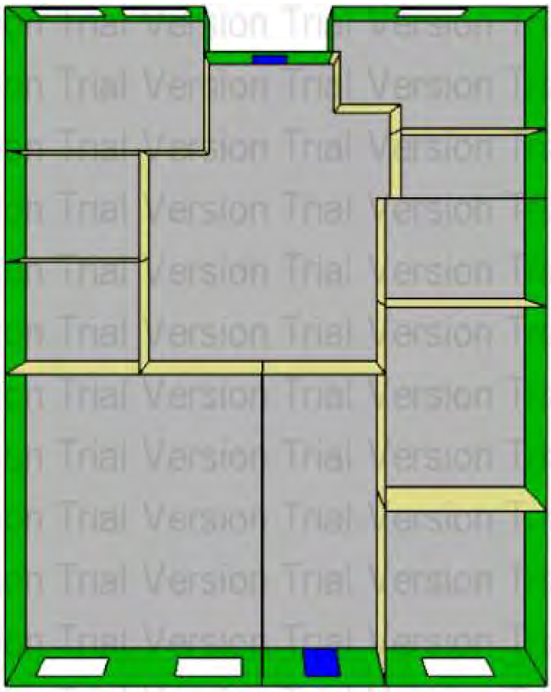


Figure 3-2 Baseline Ground Floor

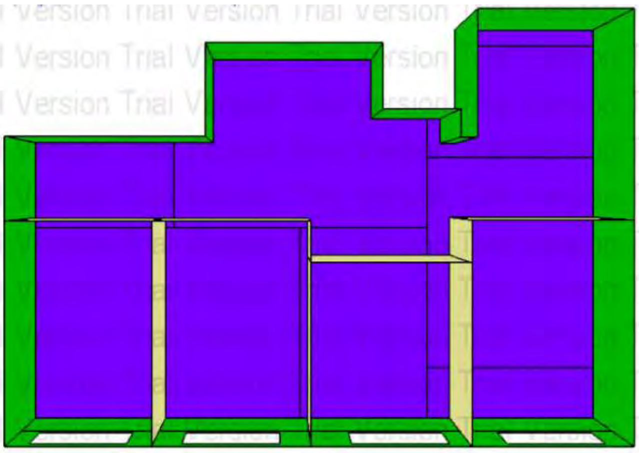


Figure 3-3 Baseline First Floor

3.1 Designing the Model

Once the initial case had been modelled, the construction materials and occupancy usage could be generated. This included specifying the construction materials of the buildings, the environment and location of the structure, lighting and equipment used, occupancy, heating and cooling requirements as well as hot water demand.

3.1.1 Construction Materials

It was assumed that the existing masonry of the structure exhibited properties to the uninsulated, heavyweight templated listed by Design Builder and shown in Appendix B.2. This template modelled the exterior and exterior walls, pitched roof and flooring as seen below:

External Walls – Uninsulated Heavyweight Double Brick Wall
Internal Walls – 115mm Single Leaf Brick with Plaster on Both Sides
Pitched Roof – Uninsulated Heavyweight
Ground Floor –300mm Concrete Slab
Internal Floor – Uninsulated Heavyweight

The construction component of design builder also requires the input for air tightness in which air changes per hour was calculated. To do so, the background ventilation was first calculated, followed by the occupancy requirements. The full calculation can be seen Appendix B.6 which resulted in a value of 0.45ACH. This represents some degree of accuracy as the NCC, Section JVb, recommends a value of 0.7 air changes per hour where no mechanical ventilation is provided (NCC,2019).

3.1.2 The Buildings Environment

As Design Builder allows the user to specify a location for the building, the closest location was Nowra, Australia. Through some research it was established that a weather file for Kiama could be attained from http://climate.onebuilding.org/. The weather file for Kiama would provide a more accurate representation of the Unanderra weather patterns as no weather file for Wollongong could be established. The building is also rotated 8 degrees from the north to the west in order to represent the buildings true orientation during the simulation.

3.1.3 Occupancy Loads

The systems loads are dependent on the occupancy profile and usage within the building. To determine the energy load using the Energy Plus Engine, the simulation must account for the lighting and equipment loads to maintain comfort for the users. To ensure accuracy in modelling, the NCC (2019) was used to determine the final normalised power density.

Table 3-1 Maximum Illumination Power Density (NCC, 2019)

SPACE	MAXIMUM ILLUMINATION POWER DENSITY (W/M^2)
OFFICE - ARTIFICIALLY LIT TO AN AMBIENT LEVEL OF 200 LX OR MORE	4.5
COMMON ROOMS, SPACES AND CORRIDORS IN A CLASS 2 BUILDING	4.5
STAIRWAYS, INCLUDING FIRE-ISOLATED STAIRWAYS	2
TOILET, LOCKER ROOM, STAFF ROOM, REST ROOM AND THE LIKE	3

As seen in Table 3-1, extracted from Table J6.2a from the NCC 2019 Volume 1, each area of the building can be multiplied by its corresponding space type factor to produce a weighted average. This resulted in a final normalised power density of 4.068 Wm^2 in which the full calculation can be seen in Appendix B.7 and its implementation exemplifies in Appendix B.4.

On top of the lighting loads, a mixed-use office building will require equipment loads that reflect the occupants use of computers, lamps, chargers, printers etc. This is also complemented by an occupancy schedule to ensure the program does not simulate these devices running 100% of the time. This occupancy schedule is modelled from the NCC (2019) Table 2C (Appendix B.8) which the schedule 'Copy of Office_OpenOff_Occ' was created to reflect the usage and can be seen in Appendix B.1. The energy requirements of the office equipment were then determined to be 11.77W/m^2 by using a template in Design Builder.

The occupants of the buildings will also generate energy loads as well as heat. The resultants are dependant on the amount of the people withing the building in which can be an unpredictable parameter for day to day use of the building. For the purpose of the model and using an educated guess, it was assumed that 25 occupants would occupy the building on an average day. As given in Section 2, the occupancy density can be calculated by dividing the total occupant number by that of the total floor space in which 0.066 people/m^2 was used for the model. This was then also complemented with the aforementioned schedule 'Copy of Office_OpenOff_Occ' to realistic simulate their interaction with the building and its appliances.

3.1.4 Heating, Cooling and Water Loads

A hot water system was also to be modelled in the baseline. As hot water consumes a significant amount of energy it was though that it would produce the greatest energy loads. It was assumed that the occupants would consume a continuous 2kW of electricity between 8am and 8pm in which, by dividing by the total floor area, 5.263W/m^2 was established. The consumption rate was also calculated by using Table 3-2, by converting Gallons to litres, multiplying by the occupant number and dividing by the total floor area which resulted in a total of 0.243L/m^2-day.

Table 3-2 Hot Water Use by Building Type (NREL, 2011)

Building Type	Estimated Hot Water Use Gallon/Person/Day
House	15.8
Hotel/Motel	20.0
Hospital	52.0
Office	1.1
Restaurant	2.4
School	0.5
School with Showers	1.9

Design Builder also implements the possibility to integrate a HVAC system in to the model in which will be used to determine the total annual energy requirement of the building. The HVAC often plays a significant role in improving thermal comfort a may produce a significant energy load if the system is highly inefficient and uncontrolled. To determine a reference for these annual loads based on a simple, inefficient HVAC system, a natural ventilation system was used with natural gas utilising a COP of 4 as seen in Appendix B.5.

In saying this, it is important to specify comfortable temperature levels for the occupants in which NSW SafeWork (2018) specifies a temperate range of 20 to 26 degree Celsius. As seen in Appendix B.1, a temperature of 23 degrees was set with heating to start when the building drops to 20 degrees and cooling to begin when the structure hits 26 degrees. The dehumidification and humidification setpoint were also set to 40% and 70% respectively in alignment with the recommendations by NSW SafeWork (2018). The schedule 'Copy of Office_OpenOff_Occ' was also used on the basis of NCC Table 2c as it represents the most probable times in which the occupants will be using the temperature controls.

Airflow and Ventilation are also an important aspect for liveable structures. The factors impact the internal air temperature, thermal comfort and humidity levels. As given in the client brief, it was to be assumed that the background ventilation of the existing building was to be 0.35 L/s/m^2 and that the minimum fresh air supply per person should be 10 litres in all spaces. The calculations in Appendix B.6 exemplified the need for an additional 4.3 L/s/person was required and included in the simulation

Following these assumptions and calculations based on the minimum requires governed by the NCC (2019), NSW SafeWork (2018) and the client brief a baseline simulation was run to determine the annual energy requirements, peak heating and cooling demands as well as a typical summer and winter day.

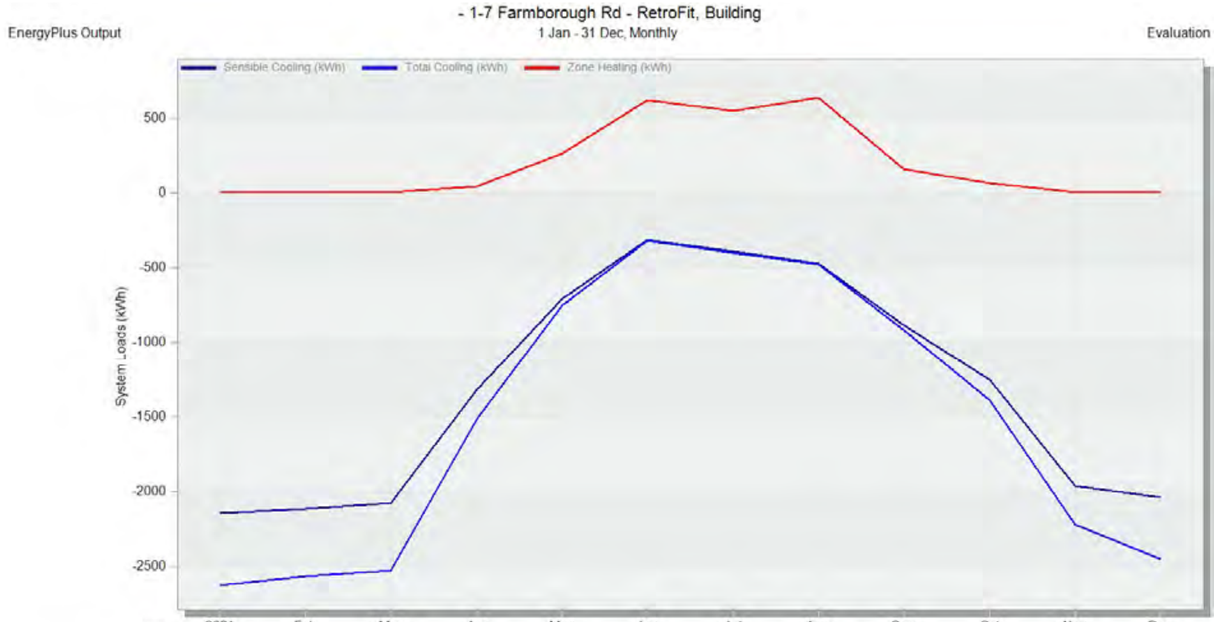
3.2 Baseline Results

The initial simulations ran smoothly with no errors and enabled the identification of the aforementioned data plots. Initially the annual energy require for heating and cooling were extracted and can be seen in Figure 3-4. The Figure shows how the heating and cooling loads are distributed through out the year with minimal heating during the summer months. The cooling however, shows the significant cooling required to keep the building withing the thermal comfort range specified by NSW SafeWork (2018) which a peak of 2625.94 kWh was produced in January,2021. Contrasting this, the maximum heating load was 634.19 kWh and was experienced in August,2021. The initial design simulated a total cooling load of 18175.46

Table 3-3 Total End use Loads

Load	kWh
Electricity	38798.23
Cooling	18175.46
Heating	2342.88

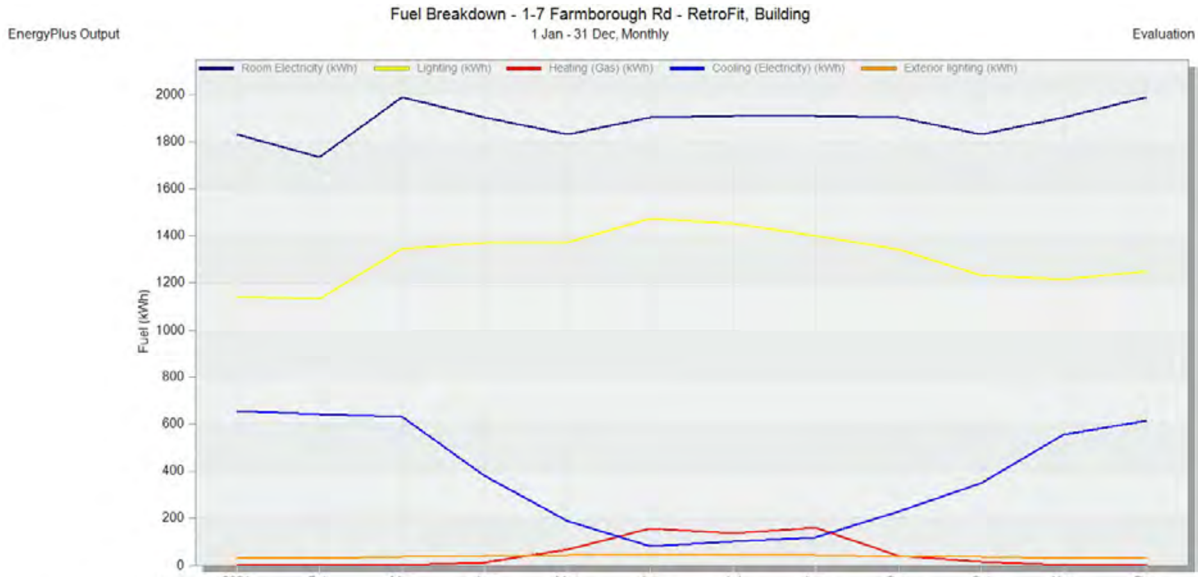
kWh whilst the Heating was 2342.88 kWh as seen in Table 3-3. A full break down of loads can be seen in Appendix B.9.



Month	2021	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sensible Cooling (kWh)	-2143.30	-2114.00	-2077.19	-1318.17	-708.42	-313.65	-392.85	-471.51	-886.63	-1253.31	-1962.59	-2041.23
Total Cooling (kWh)	-2625.94	-2567.97	-2527.09	-1516.75	-754.52	-322.55	-401.26	-478.12	-917.63	-1390.72	-2220.13	-2452.78
Zone Heating (kWh)	4.42	1.62	3.17	41.71	263.57	620.99	545.66	634.19	155.92	62.37	4.20	5.06

Figure 3-4 Yearly Heating and Cooling

This can be furthered by Figure 3-5 which analyses the total monthly loads of the building including the energy required for lighting as well as office equipment which both follow the occupancy schedule set by NCC (2018).



Month	2021	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Room Electricity (kWh)	1830.03	1734.10	1987.30	1902.90	1830.03	1902.90	1908.67	1908.67	1902.90	1830.03	1902.90	1987.30
Lighting (kWh)	1142.68	1131.32	1346.83	1371.01	1372.39	1471.62	1453.68	1400.63	1343.91	1234.04	1213.95	1248.63
Heating (Gas) (kWh)	1.11	0.41	0.79	10.43	65.89	155.25	136.42	158.55	38.98	15.59	1.05	1.26
Cooling (Electricity) (kWh)	656.49	641.99	631.77	379.19	188.63	80.64	100.31	119.53	229.41	347.68	555.03	613.20
Exterior lighting (kWh)	30.45	30.30	36.70	38.60	42.75	43.40	44.00	41.30	36.75	34.85	30.55	30.15

Figure 3-5 Individual Fuel Breakdown

Figure 3-5 exemplifies the significant lighting loads that has resulted from the inefficient lights selected in the initial program which resulted in a total annual load of 15730.69 kWh. In saying this, room electricity can be seen as the most significant monthly load experienced by the building resulting in a total of 22627.74 kWh. Similarly, as previously mentioned, heating and cooling can be seen and contribute to approximately 35% if the buildings total annual energy consumption of 59316.57 kWh.

The simulation was also run to model both a typical winters day as well as a typical summers day. Figure 3-6 examines a typical summers day, particularly the 1/12/2021 as recommended by Design Builder. Whilst Figure 3-7 examines a typical winters day, particularly the 22/6/2021 as recommended by Design Builder. The comparison of the total loads can also be seen in Tables 3-4 and 3-5.

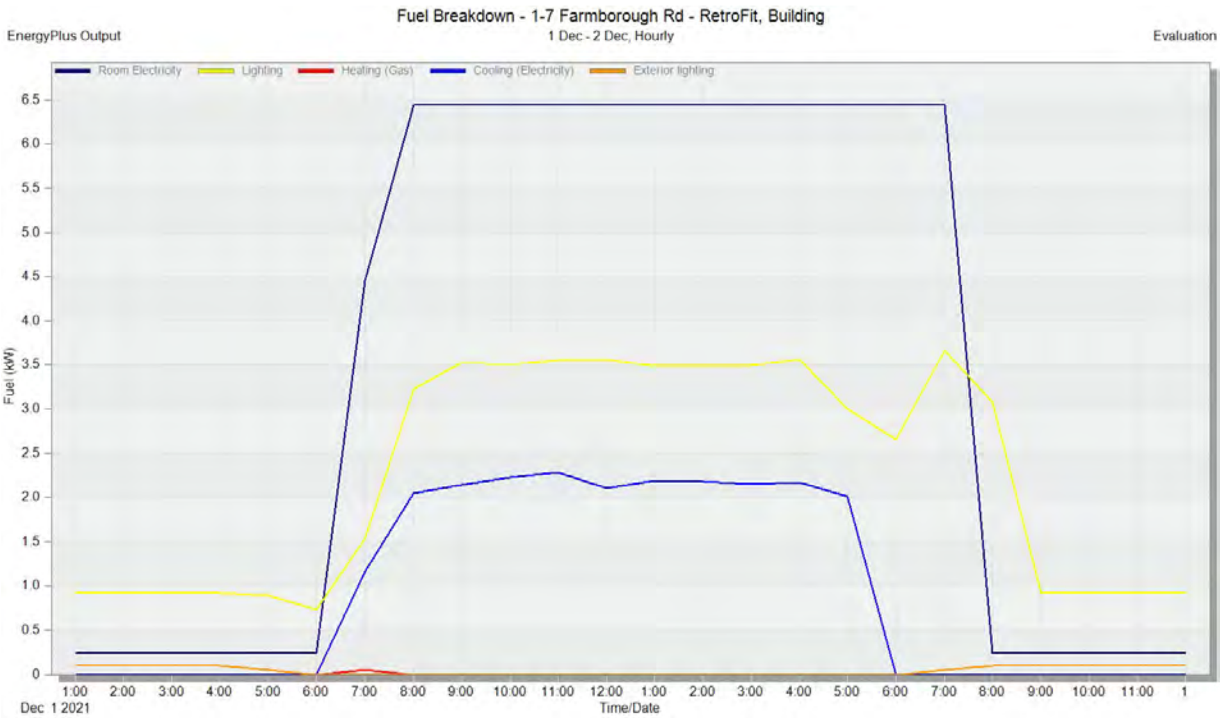


Figure 3-6 Typical Summers Day Fuel Breakdown

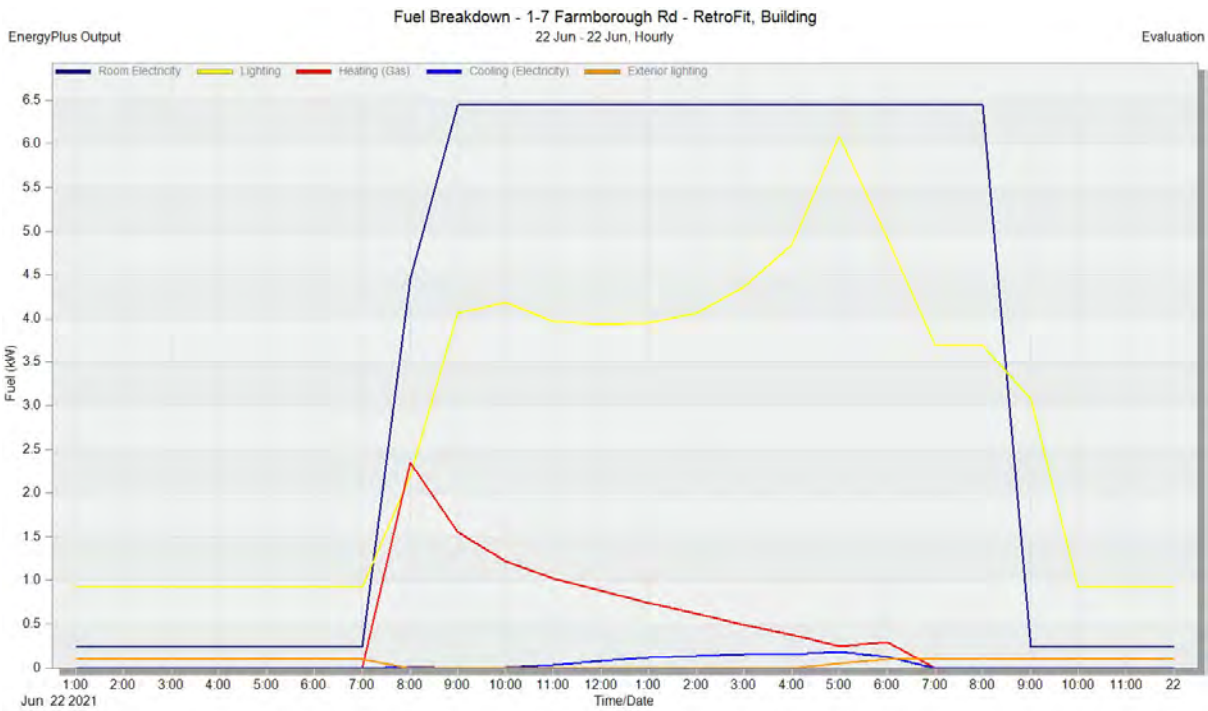


Figure 3-7 Typical Winters Day Fuel Breakdown

Table 3-4 Typical Summers Day Total Energy

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	463.03	1.22	1.22
Net Site Energy	463.03	1.22	1.22
Total Source Energy	1080.36	2.86	2.86
Net Source Energy	1080.36	2.86	2.86

Table 3-5 Typical Winters Day Total Energy

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	195.31	0.52	0.52
Net Site Energy	195.31	0.52	0.52
Total Source Energy	627.56	1.66	1.66
Net Source Energy	627.56	1.66	1.66

The Tables exemplify the comparison between the two extremes which seen a decrease of 42% of total energy use in the Winter. This is a direct result of the climate of Wollongong, or Kiama rather, which the temperature does not deviate significantly. However, the large amount of thermal mass modelled in the initial simulation may be holding significant thermal energy during the summer months and hence, requires significant cooling loads during the summer months. The temperatures of the building for both typical days can be seen in Appendix B.10 and B.11 and further show how the building heats and cools to maintain the 20–26-degree range.

4.0 Strategies to Achieve Net Zero

Once the baseline model had been created, it then becomes of how to achieve net zero energy by changing the existing building materials and design. Net zero can be achieved by balancing energy generation with consumption by utilising efficient technology to reduce loads. As seen in Section 3, besides the office equipment, the largest loads were the lighting and cooling which can be greatly reduced by more efficient technology.

4.1 Energy Generation

The first task was to generate as much solar energy as possible. As set in the client brief, solar panels were limited to 60% of the total roof area which were to operate at a maximum of 15% efficiency. It was determined that a total roof area of 298.12m^2 was available in which resulted in a total of 178.17m^2 of possible solar. In saying this, only a total of 115.64m^2 of north facing roof was available to achieve maximum solar generation in which resulted in south facing solar panels. This is not ideal in terms of solar efficiency as they produce 25% less solar energy than their north facing counterparts, it is proposed to use polycrystalline solar panels that are more sensitive to solar rays (Wright, 2015). Although, it is argued by NREL (2018), that south facing PV may actually be beneficial for commercial buildings as they are able to generate power early in the morning and late in the evening during summer (Wright, 2015). However, they fall away in the winter and hence it is proposed to use polycrystalline panels for the south facing roof to maximise solar generation. In saying this, only monocrystalline panels have been modelled in Design Builder, seen in Figure 4-1, covering a total of 79.158m^2 of north facing roof and 96.3m^2 of south facing roof. Although the total area of the solar panel specified by Renogy was taken into account when determining the number of solar panels, only the effective area was model in Design Builder to ensure accuracy. The solar panel of choice was a simple 100W Monocrystalline Solar Panel supplied by Renogy and modelled as seen in Appendix D.1.

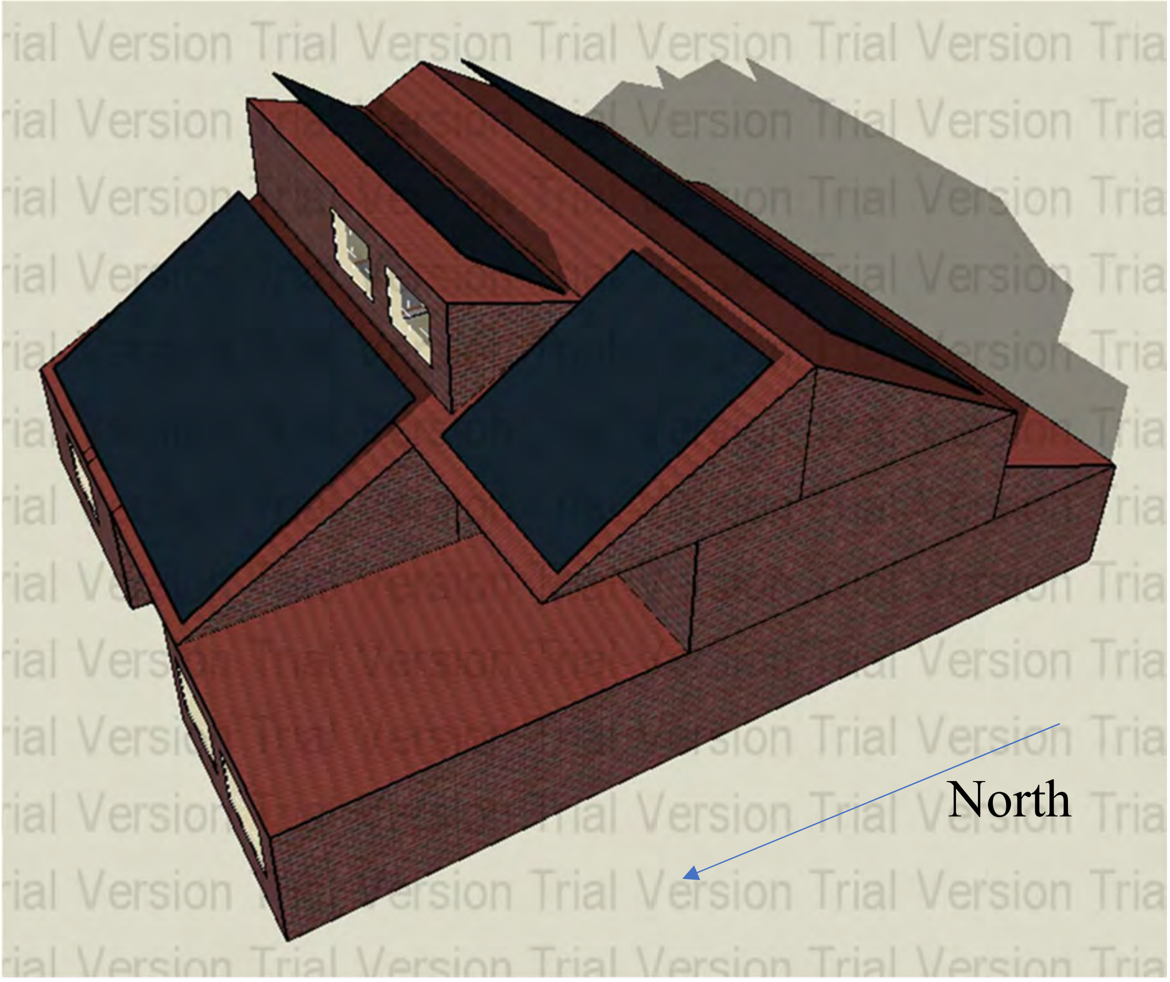


Figure 4-1 Renogy PV Modelled in Design Builder

The simulation was then run and produced the results seen in Table 4-1.

Table 4-1 Annual PV Generation

Electric Loads Satisfied

	Electricity [kWh]	Percent Electricity [%]
Fuel-Fired Power Generation	0.000	0.00
High Temperature Geothermal*	0.000	0.00
Photovoltaic Power	46064.419	118.72
Wind Power	0.000	0.00
Power Conversion	-2303.22	-5.9
Net Decrease in On-Site Storage	0.000	0.00
Total On-Site Electric Sources	43761.198	112.78
Electricity Coming From Utility	16397.364	42.26
Surplus Electricity Going To Utility	21357.564	55.04
Net Electricity From Utility	-4960.20	-12.8
Total On-Site and Utility Electric Sources	38800.998	100.00
Total Electricity End Uses	38800.998	100.00

The Table shows the impact the inverter has on usable energy which an efficiency of 0.95 was assumed. This resulted in a total usable energy of 43761.19 kWh which the monthly generation can be seen in Figure 4-2.

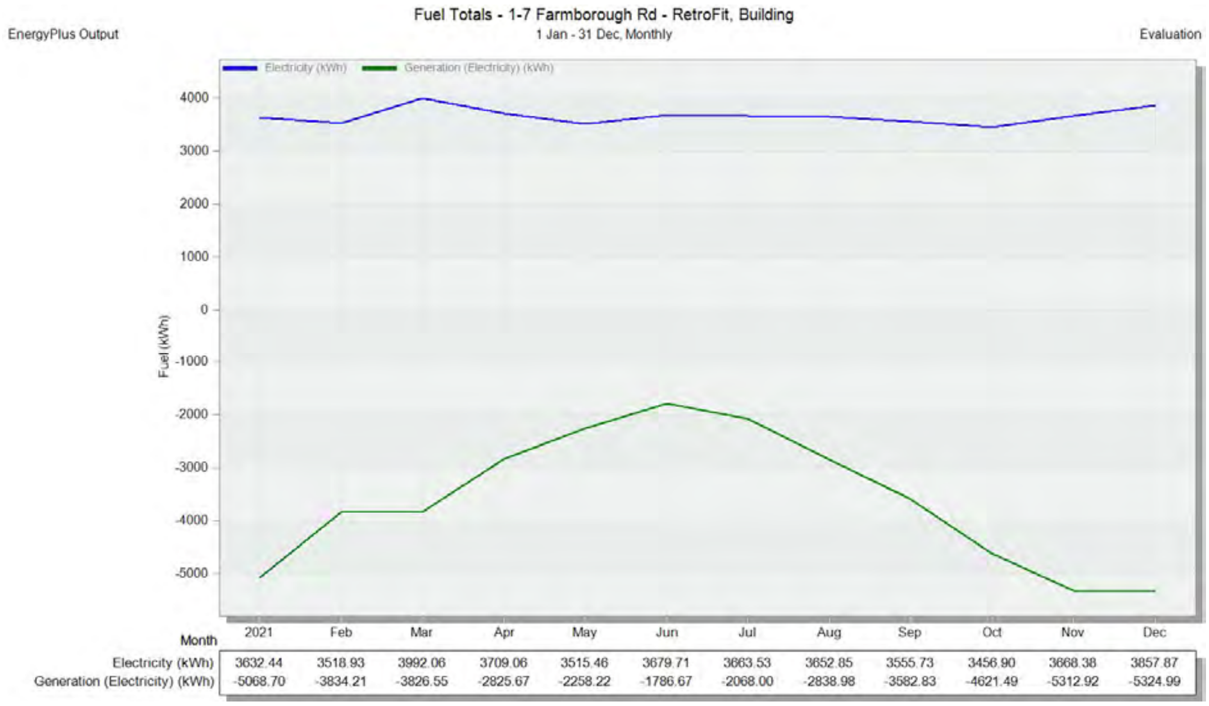


Figure 4-2 Monthly PV Generation vs Building Loads

The graph reinforced the views of NREL who discussed the possibility for south facing solar panels to aid sufficient energy consumption during the summer which is satisfied in this simulation. However, generation falls to consumption between March and August which results in the difference of 15472.943 kWh, as seen in Table 4-2, that must be reduced to achieve net zero energy.

Table 4-2 PV Offset to Total Building Loads

Site and Source Energy

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	59208.74	156.52	156.52
Net Site Energy	15447.54	40.84	40.84
Total Source Energy	154739.68	409.06	409.06
Net Source Energy	16147.97	42.69	42.69

Similar graphs were produced to those in Section 3 for the iteration that solely introduces PV and can be seen in Appendix D.

An REF was then calculated for the model in which proved to be difficult as often consumption, or generation, were so significant that the numbers were either extremely large or small. This can be seen in Appendix D.10 in which Table 4-3 exemplifies the 3 different REF values calculated.

Table 4-3 Data from REF Calculations

REF = 0	0<REF<0.3	0.3<REF<0.95	0.95<REF<1.05	1.05<REF	Check Sum	Avg. REF Value
29	1259	2451	3852	1169	8760	4.582775027

REF = 0	0<REF<0.3	0.3<REF<0.95	0.95<REF<1.05	1.05<REF	Check Sum	Avg. REF Value
29	1259	2451	3852	0	7591	0.76541093

REF = 0	0<REF<0.3	0.3<REF<0.95	0.95<REF<1.05	1.05<REF	Check Sum	Avg. REF Value
0	977	2451	3852	0	7280	0.797999322

Initially the entire data column was averaged to determine the REF which was noted to be significantly inaccurate to a building that was a deficit for energy consumption. Following this, the large outliers were removed with both large and small outliers being removed in the last example to produce an REF of 0.80. After some research no accurate means to determine outliers could be found so it was a personal judgement to remove those above 1.05 and below 0.01. Figure 4-3 is comparing how the removal of these data points effected the results.

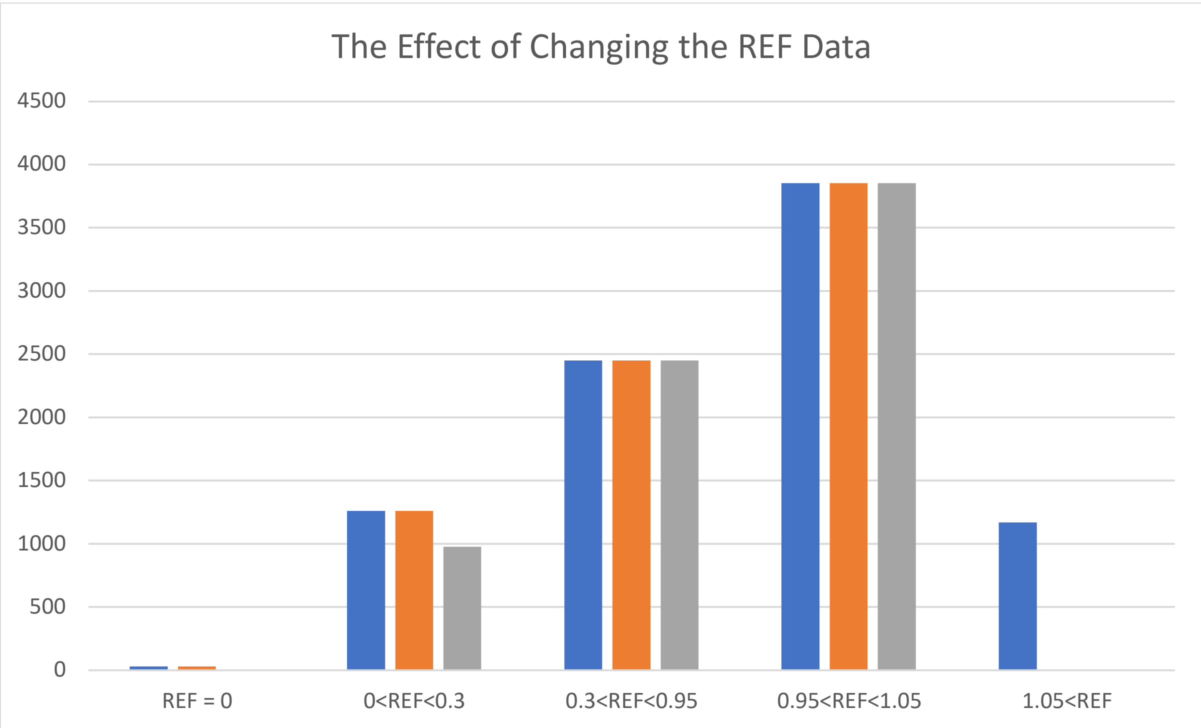


Figure 4-3 The Change in REF Data

4.2 Reducing Consumption

Once energy generation had been introduced into the model, the focus then shifted to reducing consumption of the building. As seen in Section 2, significant loads including the lighting, heating and cooling play a vital role in maintain thermal comfort of the building. However, these loads can be reduced through s variety of strategies including glazing, building material or simply more efficient systems.

4.2.1 Construction Materials

The first factor in reducing the consumption of the building was to greatly improve the insulation of the walls in which the template 'Best Practice, Heavyweight' was used in Design Builder. The external walls were updated to 'state of the art' having properties seen in Figure 4-4 having an R value of 3.979 m^2K/W, as calculated in Appendix D.4, compared to 0.668 of the original external walls. This resulted in an improvement of 596% at an additional cost of $1/$m^2$ according to Design Builder. Similarly, the pitched roof was also change to the design seen in Figure 4-5 which resulted in a R value of 6.321 m^2K/W as seen in Appendix D.5. This resulted in an improvement of 1854% at a cost of $6/$m^2$ according to Design Builder. Following the change in materials, glazing was adjusted to allow for more solar gains to be achieved by the building.

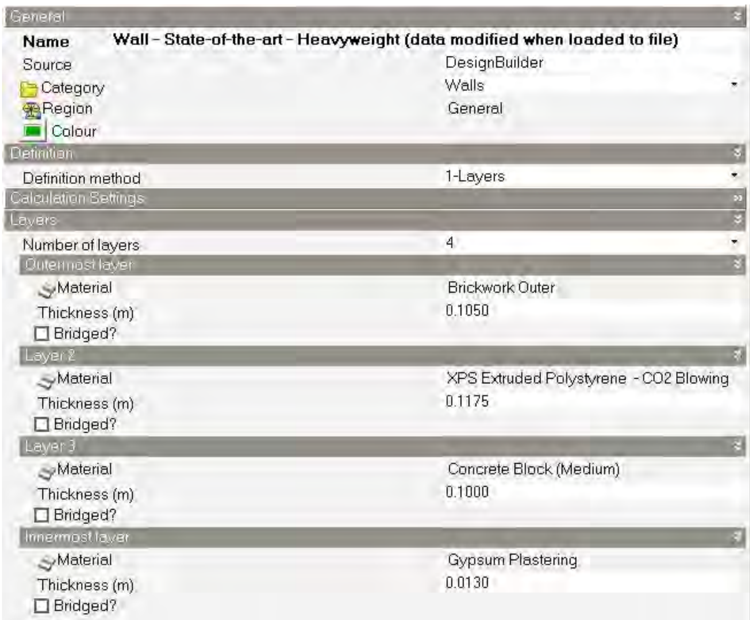


Figure 4-4 External Wall Design

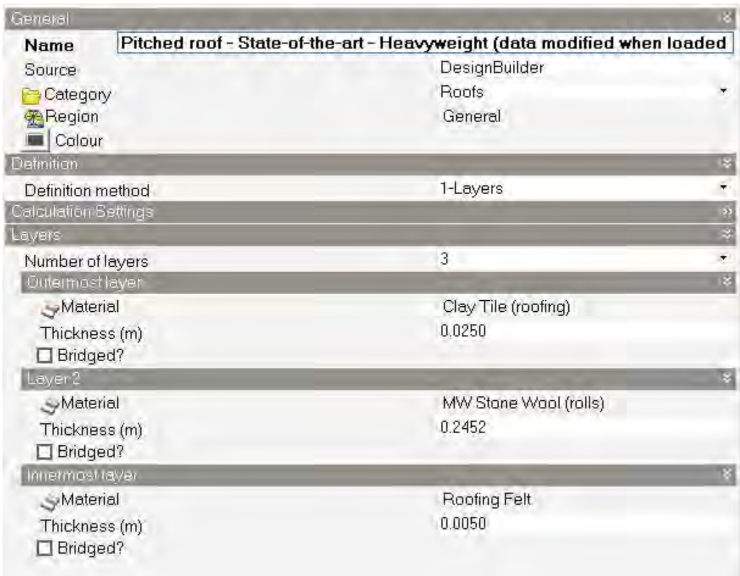


Figure 4-5 Pitched Roof Design

4.2.2 Glazing

In the initial simulation, only single glazing was used to represent the current windows of the existing structure. Double glazing is seen as a significant means to boost internal temperatures and retain heat withing a structure. as seen in Figure 4-6, the new glazing consisted of 6mm panes of glass with a 13mm air gap. These were preferred to triple glazing, low emissive glazing or argon filled glazing due the price difference in which double glazing is economically affordable and will adhere to the budget of $1 million set by ILALC.

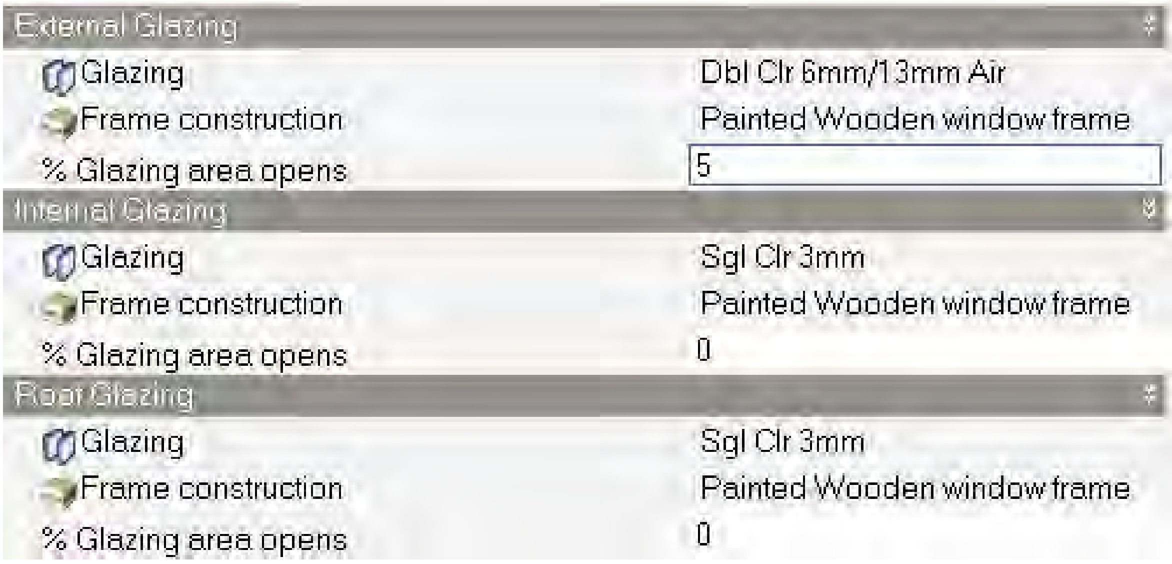


Figure 4-6 Double Glazing

The double glazing was also fitted with internal micro louvres and 1 metre external awnings that have been modelled to be adjustable to allow let in when the building requires it. Through various iterations it was noticed that with more glazing, the less energy the building was consumed and hence, as seen in Appendix D.6, the windows were increased to a height of 1.5m and encompass 40% of the external cladding. The new windows generated by Design Builder can be seen in Figure 4-7 and acts only as a representation for window placement which will require further detailing in future designs.

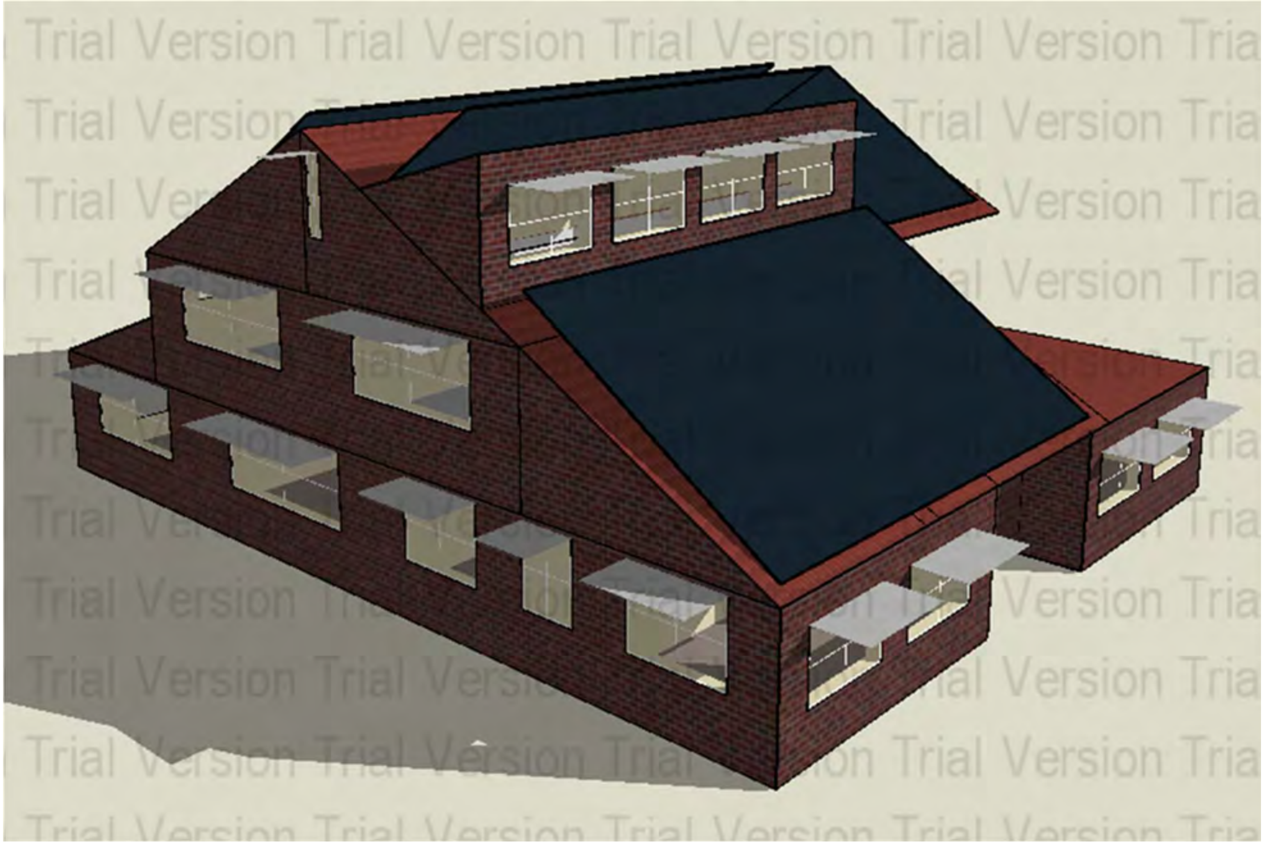


Figure 4-6 Additional Glazing to Achieve NZE

4.2.3 Lighting

The lighting of the building was then adjusted to reduce the 15730.69 kWh produced in the initial simulation. Through the optimisation program in Design Builder, it was established that LEDs with linear controls were the most effective to reducing the consumption in which only cost approximately \$183/m^2 compared to \$128.1/m^2 of the original lighting system.

4.2.4 HVAC System

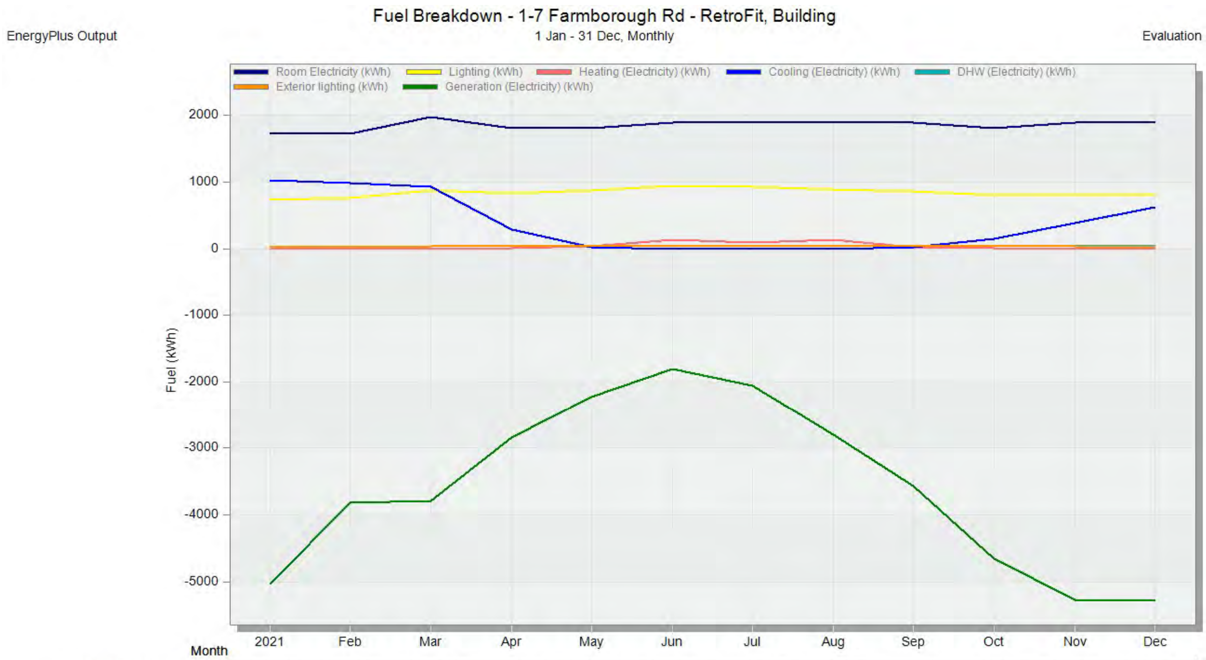
As seen in Section 3, a simple natural ventilation system was used that used significant cooling loads to balance the temperature in the buildings. By upgrade the HVAC to a more efficient system, in conjunction with the glazing and insulation, the system was able to easily improve the thermal comfort for occupants with significantly less loads. As seen in Appendix D.8, a Constant Air Volume (CAV) with water cooled chiller and electric heating system was adopted with additional natural ventilation to further reduce the loads.

5.0 The Net Zero Design

After the implementation of the strategies mentioned in Section 4, the structure was effectively able to achieve net zero energy across the year 2021. Table 5-1 exemplifies the overall annual usage whilst Figure 5-1 graphs the monthly energy usage of individual loads.

Table 5-1 Annual Energy Usage

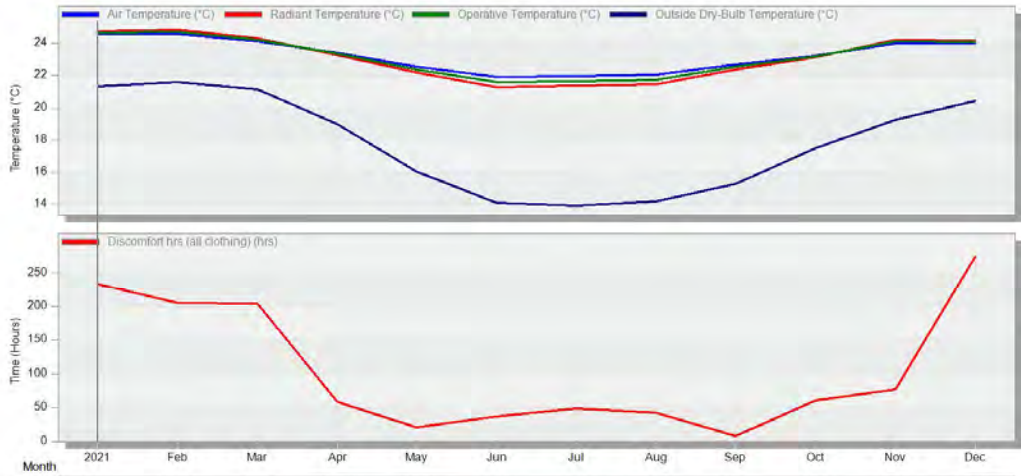
	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	42712.01	113.76	113.76
Net Site Energy	-441.9	-1.2	-1.2
Total Source Energy	119270.96	317.67	317.67
Net Source Energy	-17397.5	-46.3	-46.3



	2021	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Room Electricity (kWh)	1738.34	1721.18	1972.49	1810.67	1816.39	1888.72	1894.44	1894.44	1888.72	1816.39	1888.72	1894.44
Lighting (kWh)	736.08	765.20	876.33	837.03	874.50	949.17	924.66	895.63	866.16	802.06	801.45	810.15
Heating (Electricity) (kWh)	0.13	0.01	0.01	3.49	36.46	128.69	96.54	130.23	19.21	6.52	0.03	0.02
Cooling (Electricity) (kWh)	1024.04	991.98	926.54	287.25	27.39	0.00	0.00	0.45	23.77	146.60	384.39	623.18
DHW (Electricity) (kWh)	29.16	29.13	33.50	30.59	30.59	32.05	32.05	32.05	32.05	30.61	32.05	32.05
Exterior lighting (kWh)	30.45	30.30	36.70	38.60	42.75	43.40	44.00	41.30	36.75	34.85	30.55	30.15
Generation (Electricity) (kWh)	-5029.89	-3820.52	-3791.22	-2839.99	-2230.59	-1802.34	-2062.08	-2805.15	-3564.82	-4651.80	-5277.40	-5278.14

Figure 5-1 Annual Fuel Breakdown

The total end use breakdown is also examined in Appendix D.9 which exemplifies the effectiveness of the changes made. The changes resulted in a 15% improvement of total electricity use in which within that, the LED lighting with linear controls contributed to a 36% improvement in lighting efficiency. This is also furthered by the effectiveness of the glazing, insulation and HVAC system which resulted in a 56% and 18% improvement for heating and cooling respectively. The building maintained an average temperature ranging between 21.67 and 24.75 degrees Celsius as seen in Figure 5-2.



	2021	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air Temperature (°C)	24.59	24.60	24.17	23.42	22.56	21.95	21.97	22.05	22.71	23.25	24.04	24.01
Radiant Temperature (°C)	24.80	24.90	24.34	23.31	22.18	21.30	21.37	21.48	22.39	23.14	24.26	24.18
Operative Temperature (°C)	24.69	24.75	24.26	23.36	22.37	21.62	21.67	21.76	22.55	23.19	24.15	24.10
Outside Dry-Bulb Temperature (°C)	21.35	21.61	21.14	18.97	16.04	14.10	13.88	14.18	15.27	17.48	19.26	20.43
Discomfort hrs (all clothing) (hrs)	233.30	205.10	204.69	58.46	21.01	37.11	48.72	42.92	7.63	60.72	77.32	274.44

Figure 5-2 Average Temperatures

However, due to the lack of experience using design builder, the total comfort hours appear to be significantly high. This is a result of temperatures outside the occupancy hours in which the heating and cooling loads are disable to reduce energy consumption and is evident in Figure 5-3.

Figure 5-3 Discomfort Hours

The sun that hits the external walls and glazing plays a significant role in maintain thermal comfort which can be aided by building systems, like the microlouvres, that are programmed to enable maximum light. Figure 5-4 analyses how the summer sun hits the structure and how it enters the ground floor now with the addition of new glazing.

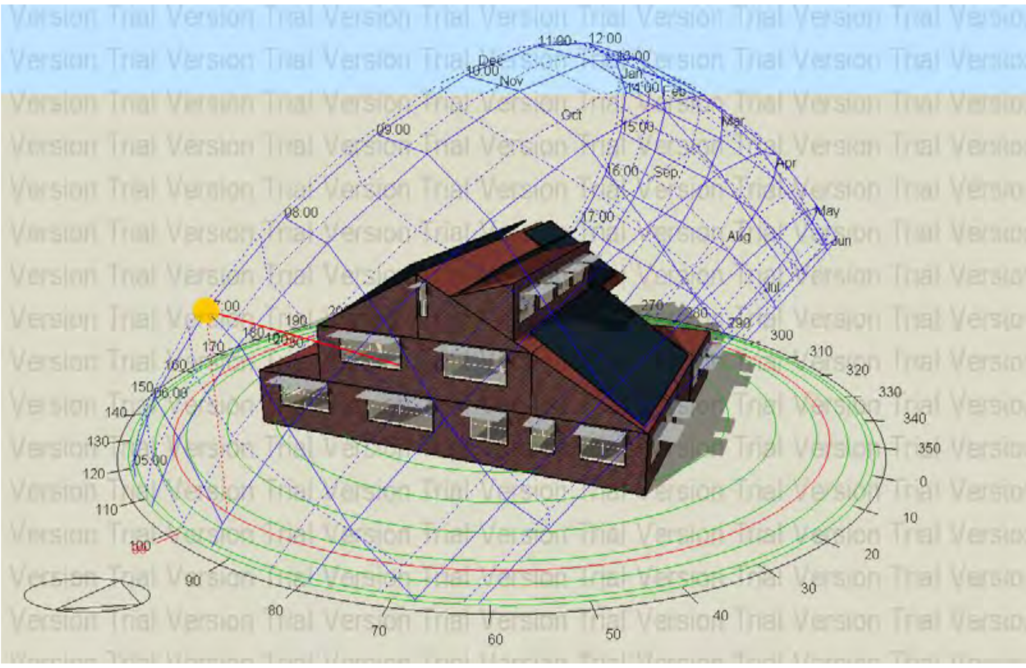


Figure 5-4 Summer Sun Entering Eastern Facade

In contrast to the initial design that incorporate no windows on the eastern façade which resulted in the loss of significant solar Gains the importance of the louvred and northern windows are also exemplified in Figure 5-5.

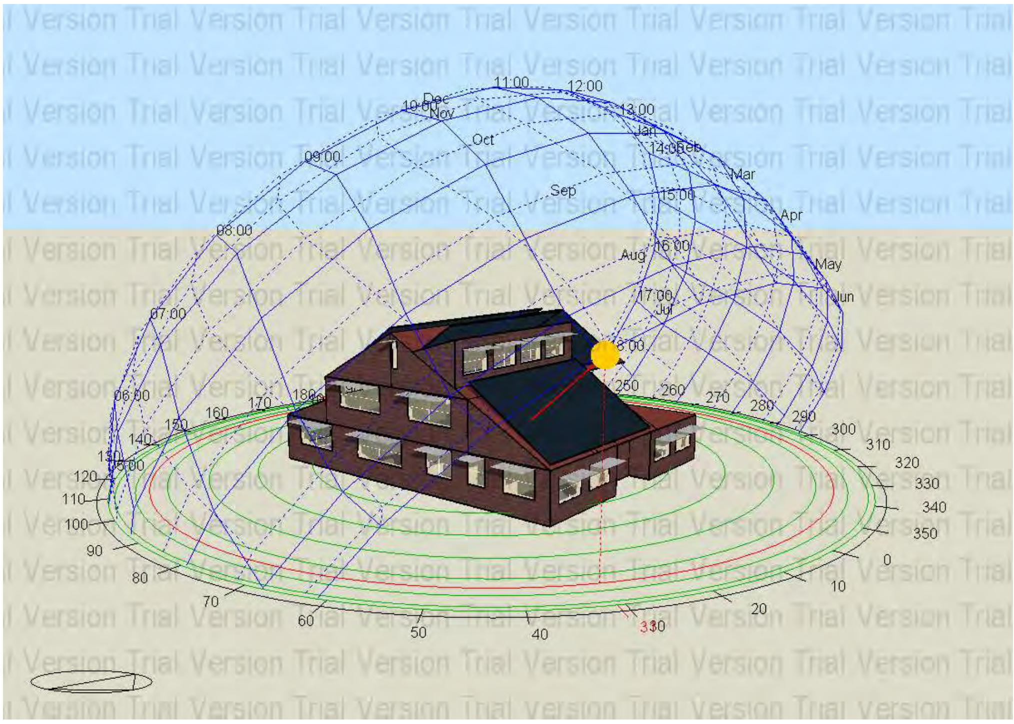


Figure 5-5 Winter Sun Entering Eastern and Northern Facade

The differing Figures analyse the difference in the summer and winter sun. As seen in Figure 5-4, minimal summer sun is able to enter through the glazing on the northern façade which limits internal thermal gains for the structure and limits cooling requirements. In contrast, the winter sun, depicted in Figure 5-5, allows the sun to penetrate through both the northern and eastern glazing which significantly improves the thermal gains during the winter. However, during the winter, very minimal sun will be absorbed by the south facing solar panels which is exemplified in the Section 4, as minimal PV energy is generated during the winter months.

Data to Calculate the REF was then extracted and a snippet visible in Appendix D.11. As seen in Table 5-2, the REF was calculated for initially all values, then with large outliers above 1.05 removed and final with smaller outliers below 0.01 removed.

Table 5-2 REF Calculation NZE

REF = 0	0<REF<0.3	0.3<REF<0.95	0.95<REF<1.05	1.05<REF	Check Sum	Avg. REF Value
20	822	1206	5340	1372	8760	5.072935834

REF = 0	0<REF<0.3	0.3<REF<0.95	0.95<REF<1.05	1.05<REF	Check Sum	Avg. REF Value
20	822	1206	5340	0	7388	0.836545751

REF = 0	0<REF<0.3	0.3<REF<0.95	0.95<REF<1.05	1.05<REF	Check Sum	Avg. REF Value
20	404	1206	5340	0	6970	0.887001169

This issue is further discussed in Section 6 however a final REF of 0.89 was determined even though the structure had proven to generate more energy than it consumed.

6.0 Discussion

Various Issues arose when adding the sustainable technology. The first resulted in the reduced privacy of the building due to the significant increase of glazing around the buildings. Although it significantly increases the thermal performance, it may have resulted in a design that is outside the scope of the ILALC as all rooms have solar access.

To reduce the number of windows required, thought should be put towards the implementation of plug-in load controls as the office equipment contributes to 52% of the total energy loads of the structure. The schedule created reflects the occupancy usage however, by using smart plug-in appliances, this load can be drastically reduced. Decreasing usage such as chargers, fridges, printers and alike when they are not in use will provide a significant reduction in the end use load for office equipment and can either open the opportunity to decrease the number of windows, or improve the HVAC system. This may be implemented in conjunction with a Building Management System (BMS) to effectively control the technology in the building and even learn when to store excess solar energy in the battery based on the weather.

Another issue that occurred during the simulation is calculating the REF. The REF should in fact be an accurate reflection of the building's hourly energy usage which, as specified in the client brief, it was required to achieve a rating of at least 1.0. Although the REF increased through the iterations, its accuracy is questionable as seen in Figure 6-1.

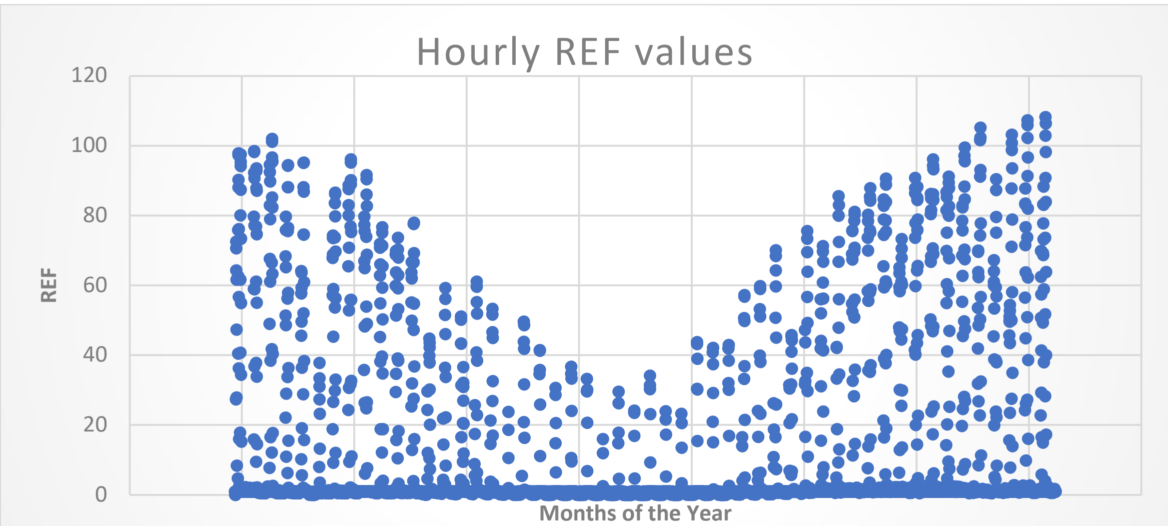


Figure 6-1 Total REF Value

For this example, the net zero energy design has been used in which significant outliers are depicted. As seen in Figure 6-2, the total hours sum to 8760 although the data is significantly skewed and results in an REF of 5.07.

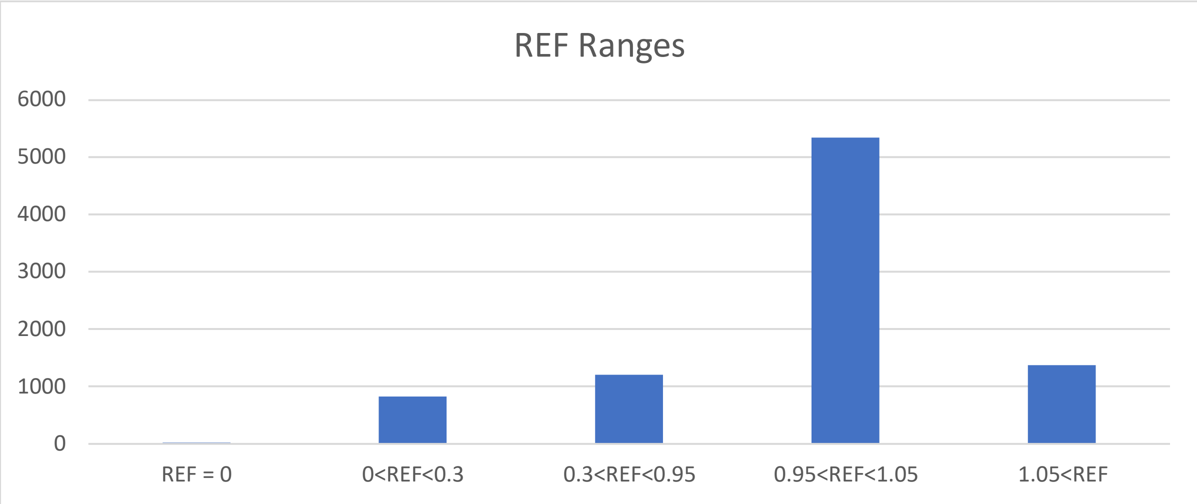


Figure 6-2 REF Data Ranges

By removing values larger than 1.05 and smaller than 0.01 the new dataset appears in Figure 6-3, however only represents 6950 hours of the year. As no research could be found on the topic assumptions were made based on personal judgement to remove this range of outliers.

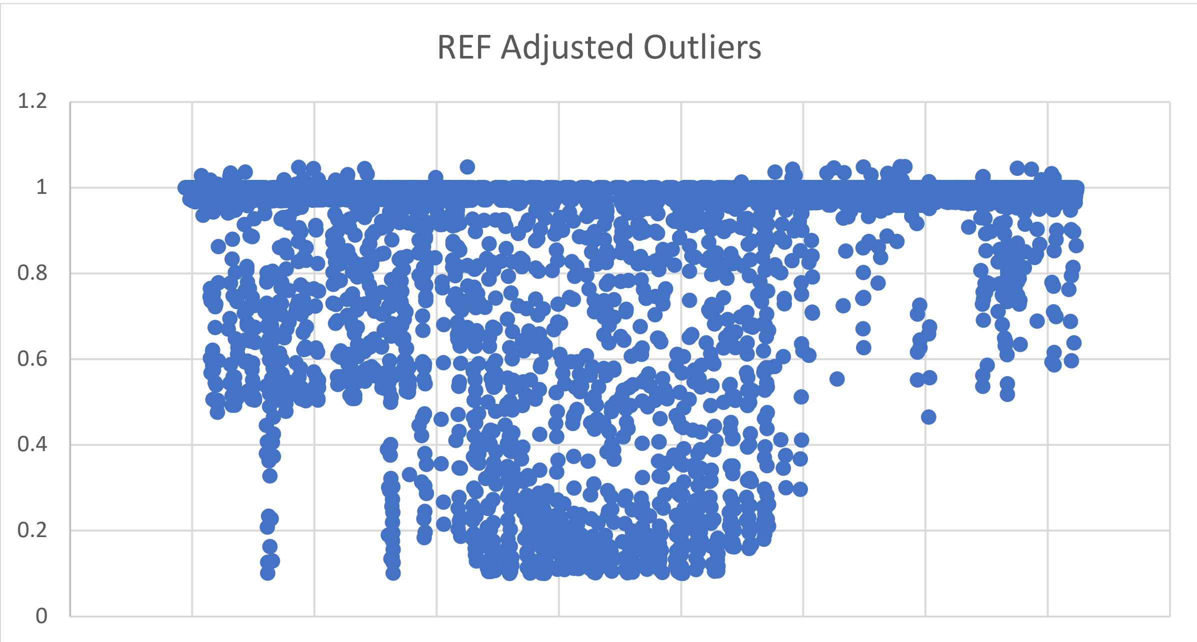


Figure 6-3 Adjusted REF without Outliers

Even with the adjusted outliers, the building only achieved an REF of 0.89 which does not reflect accurately when the end use is in fact, net zero. This occurred on all simulation however, the final design is used to exemplify the issue.

7.0 Conclusion

The report aimed to meet the requirements set by the Illawarra Local Aboriginal Land Council to produce a net zero energy retrofit for the existing police station located on the corner of Farmborough Road and Princes Highway, Unanderra. A design was developed utilising industry feedback and modelled in Design Builder to analyse the performance of the existing building. The simulation emulated the interaction of the building with its surrounding environment and how it would perform from an energy standpoint. Following the development of the baseline, it was retrofitting with strategies such as improved insulation, double glazing, efficient HVAC system and LED lighting with controls. These technologies enabled the net zero retrofit for the structure whilst maintain thermal comfort during the operating hours of the office. This proposal analyses a cost effective means to achieve net zero for the existing building and further explores methods that can be used by the ILALC to improve energy efficiency for the office retrofit.

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Appendices

Appendix A Reflection Towards Government Certification Schemes

There are many barriers facing the implementation of sustainable design which a significant issue that is faced, is how it is incorporated into government policy. Hankinson and Breytechback (2012) characterise three key barriers that that may prevent the implementation of sustainable design through use of rating tools such as Green Star, Nabers and Alike.

The first barrier is cost. As exemplified in Section 4, all the sustainable solutions were more costly than their counterparts and may be difficult to tender for if the client is not sustainably orientated. For clients to adapt a sustainable design approach towards their buildings either policy must be enforced to meet minimum requires set by the rating institutes, or incentives offered to attract more clients to adopt sustainable design in their structures.

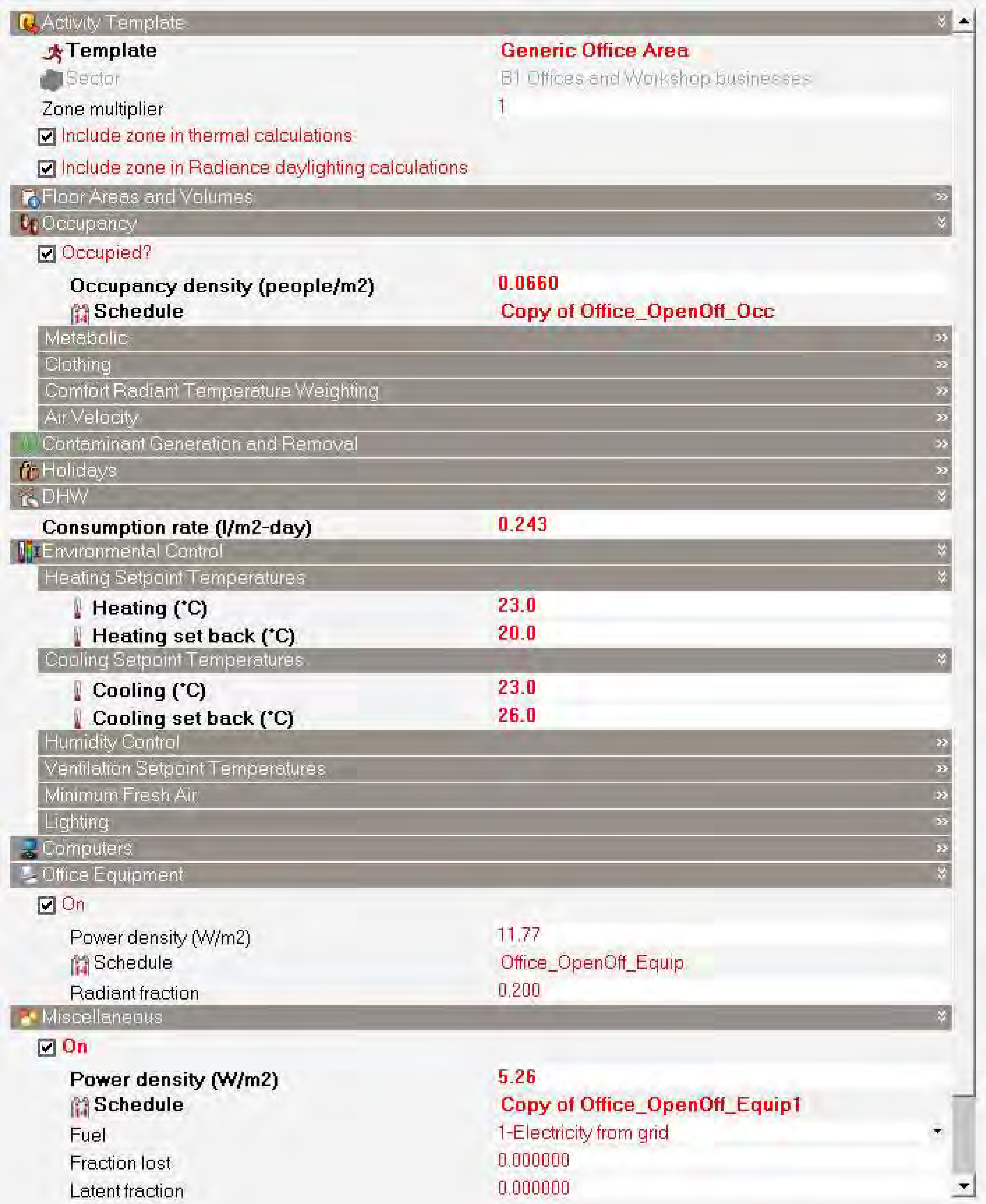
The second barrier is education. Improving the awareness of construction organisations, builders and the wider community is essential to furthering the knowledge for the need for sustainability. A lack of education and inexperience towards sustainable building design may also result in firms disabling the potential to produce them. The downfall of education however, is who will pay for it. If it is provided for free, the firm still may lose out on productivity and may result in the only effective stemming downward from government policy.

The third barrier is the client. As mentioned previously, if the client is not sustainably oriented or aware for the need of for sustainable designs, their tender requirements may not reflect the pricing of these technologies. The contractor and/or designer will have no ability to tender for a sustainable design as requirements set by the client do not reflect this scope and will neglected due to the increase in price.

In saying this, it is important not only to educate employees in the green industry but also the enforcement of government to collaborate with green rating institutes such as Nabers and Green Star to develop a code that enforces sustainability requirements and incentives the adoption of the technology utilised in this report to achieve net zero energy.

Appendix B Baseline Model

Appendix B.1 Baseline Activity



Activity Template	
Template	Generic Office Area
Sector	B1 Offices and Workshop businesses
Zone multiplier	1
☑ Include zone in thermal calculations	
☑ Include zone in Radiance daylighting calculations	
Floor Areas and Volumes	
Occupancy	
☑ Occupied?	
Occupancy density (people/m2)	0.0660
Schedule	Copy of Office_OpenOff_Occ
Metabolic	
Clothing	
Comfort Radiant Temperature Weighting	
Air Velocity	
Contaminant Generation and Removal	
Holidays	
DHW	
Consumption rate (l/m2-day)	0.243
Environmental Control	
Heating Setpoint Temperatures	
Heating (°C)	23.0
Heating set back (°C)	20.0
Cooling Setpoint Temperatures	
Cooling (°C)	23.0
Cooling set back (°C)	26.0
Humidity Control	
Ventilation Setpoint Temperatures	
Minimum Fresh Air	
Lighting	
Computers	
Office Equipment	
☑ On	
Power density (W/m2)	11.77
Schedule	Office_OpenOff_Equip
Radiant fraction	0.200
Miscellaneous	
☑ On	
Power density (W/m2)	5.26
Schedule	Copy of Office_OpenOff_Equip1
Fuel	1-Electricity from grid
Fraction lost	0.000000
Latent fraction	0.000000

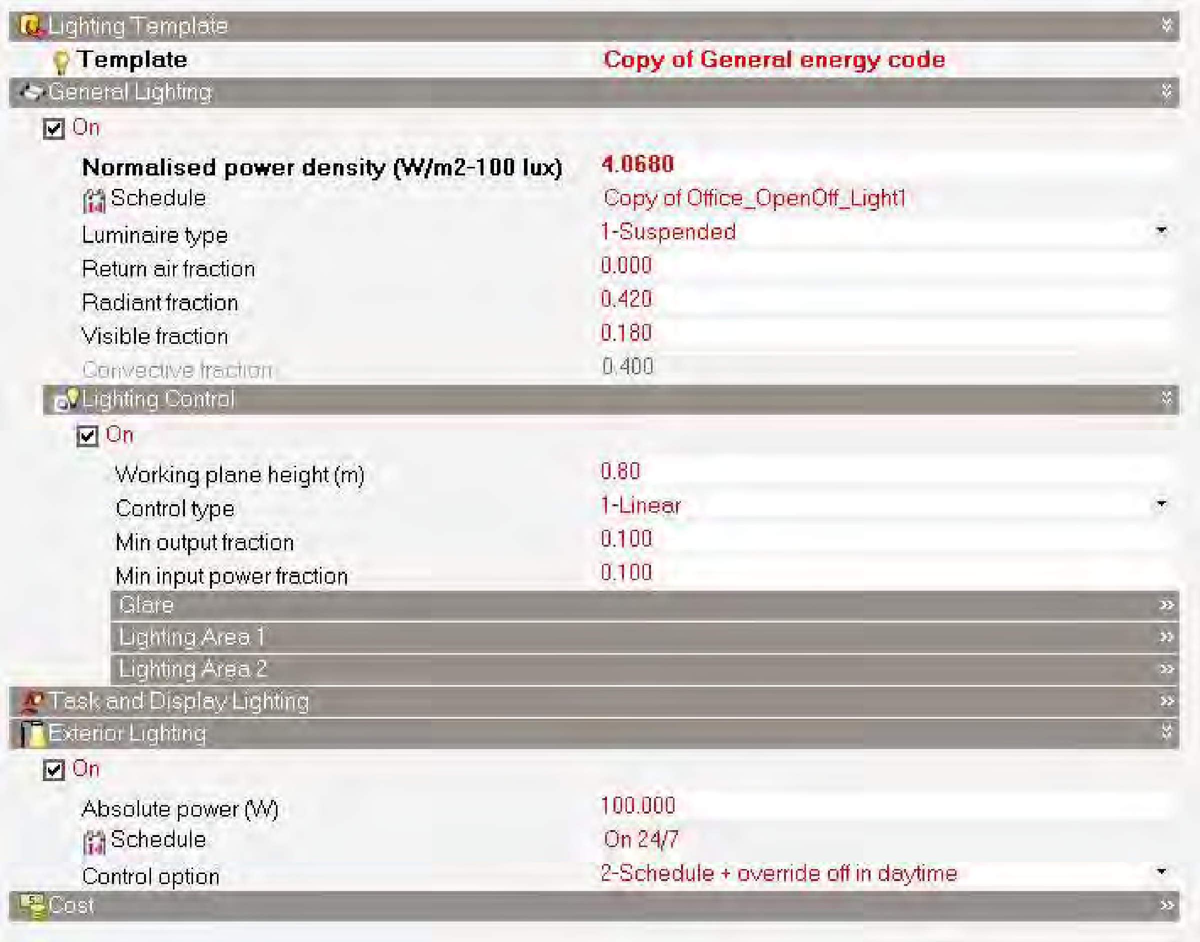
Appendix B.2 Baseline Construction

Construction Template	
Template	**Uninsulated, Heavyweight**
Construction	
External walls	Wall - Uninsulated - Heavyweight
Below grade walls	Below grade wall - Uninsulated - Heavyweight
Flat roof	Combined flat roof - Uninsulated - Heavyweight
Pitched roof (occupied)	Pitched roof - Uninsulated - Heavyweight
Pitched roof (unoccupied)	Pitched roof - Uninsulated - Lightweight
Internal partitions	115mm single leaf brick (plastered both sides)
Semi-Exposed	
Semi-exposed walls	Semi-exposed wall Uninsulated - Heavyweight
Semi-exposed ceiling	Combined semi-exposed roof - Uninsulated - Heavyweig
Semi-exposed floor	Combined semi-exposed floor Uninsulated - Heavyweigh
Floors	
Ground floor	Combined ground floor - Uninsulated - Heavyweight
External floor	Combined external floor - Uninsulated - Heavyweight
Internal floor	300mm concrete slab
Sub-Surfaces	
Internal Thermal Mass	
Construction	**Ground floor slab - Uninsulated - Heavyweight**
Zone capacitance multiplier	1.00
Component Block	
Geometry, Areas and Volumes	
Surface Convection	
Linear Thermal Bridging at Junctions	
Airtightness	
☑ Model infiltration	
Constant rate (ac/h)	**0.450**
Schedule	On 24/7
Delta T and Wind Speed Coefficients	
Cost	

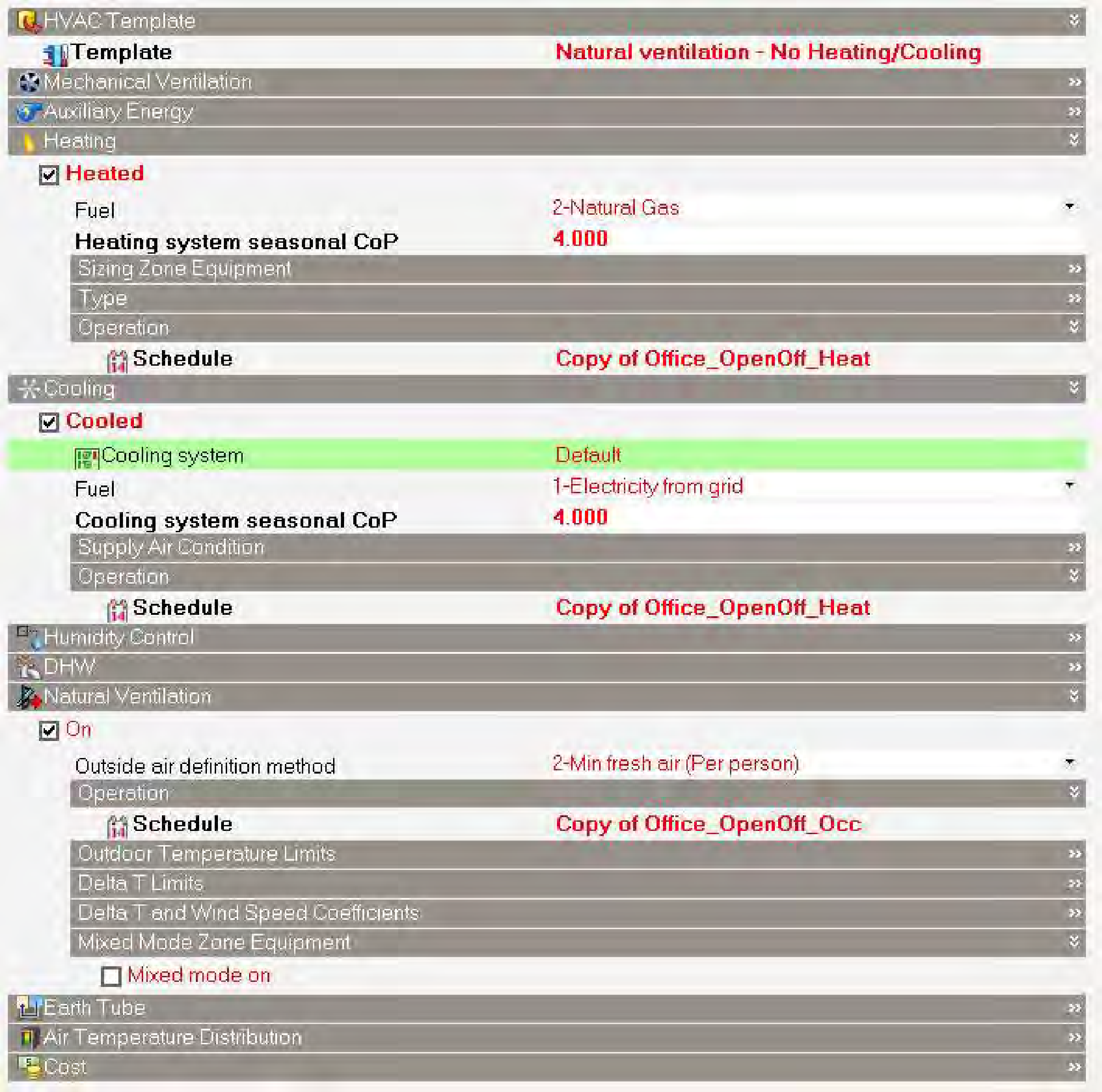
Appendix B.3 Baseline Windows

Glazing Template	
Template	**Single glazing, clear, no shading**
External Windows	
Glazing type	Sgl Clr 6mm
Layout	**Preferred height 1.5m, 30% glazed**
Dimensions	
Frame and Dividers	
Shading	
Airflow Control Windows	
Free Aperture	
Internal Windows	
Sloped Roof Windows/Skylights	
Doors	
Vents	

Appendix B.4 Baseline Lighting



Appendix B.5 Baseline HVAC



Appendix B.6 Air Flow Calculation

Calculations
120m^2 x 0.35 = 42 litres/s
Background ventilation (ILALC upstairs office area) = 42 litres/s
10 people x 10L/s per person = 100 L/s
Therefore 100 - 42 = 58 l/s for 10 people present

260m^2 x 0.35 = 91 litres/s
Background ventilation (downstairs office area) = 91 litres/s
15 people x 10L/s per person = 150 L/s
Therefore 150 - 91 = 59 l/s for 15 people present

= 108.25 L/s
Minimum Fresh Air = 108.25/25 people = 4.3 L/s per person
Mech Vent per area = 108.25/380 = 0.3

58 l/s

122.8950384200626 cfm

Convert

Enter Room Length in Feet *
49.2126
Please enter a number from 1 to 500.

Enter Room Width in Feet *
26.2467
Please enter a number from 1 to 500.

Enter Ceiling Height in Feet *
8.85827
Please enter a number from 1 to 25.

Enter the CFM of your air filtration device. *
122.8950384200626
Please enter a number from 1 to 10000.

Our Pure Breeze HEPA Air Purifier has a rating of 550 CFM.

Total Number of Room Air Changes Per Hour
0.6

To increase ACH (Air Exchanges Per Hour) increase the number of Air Filtration units.

59 l/s

125.0139183928223 cfm

Enter Room Length in Feet *

49.2126

Please enter a number from 1 to 500.

Enter Room Width in Feet *

56.75853

Please enter a number from 1 to 500.

Enter Ceiling Height in Feet *

8.85827

Please enter a number from 1 to 25.

Enter the CFM of your air filtration device. *

125.0139183928223

Please enter a number from 1 to 10000.

Our Pure Breeze HEPA Air Purifier has a rating of 550 CFM.

Total Number of Room Air Changes Per Hour

0.3

To increase ACH (Air Exchanges Per Hour) increase the number of Air Filtration units.

Air changes per hr = (03 + 06)/2 = 0.45

Appendix B.7 Final Normalised Power Density Calculation

CALCULATIONS:

Section areas

Office = 168.1 m^2

Stairs/lift = 35.4 m^2

Common Area = 126.1m^2

Toilet = 50.4m^2

Total = 380 m^2

Average Power per room W/m^2 (According to NCC)

Office = 4.5 W/m^2

Stairs/lift = 2 W/m^2

Common Area = 4.5 W/m^2

Toilet = 3 W/m^2

Power For Room Sizes

Office = 756.45 W

Stairs/lift = 70.8 W

Common area = 567.45 W

Toilet = 151.2 W

Total = 1545.9 W

Total W/m^2 divided by total area *= 1545.9 W / 380 m^2*

Final Normalised Power Density: *= 4.068 W/m*

Appendix B.8 Weekday Occupancy Schedule for Office Buildings

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

Time period (local standard time)	Occupancy (Monday to Friday)	Artificial lighting (Monday to Friday)	Appliances and equipment (Monday to Friday)	*Air-conditioning* (Monday to Friday)
12:00am to 1:00am	0%	15%	25%	Off
1:00am to 2:00am	0%	15%	25%	Off
2:00am to 3:00am	0%	15%	25%	Off
3:00am to 4:00am	0%	15%	25%	Off
4:00am to 5:00am	0%	15%	25%	Off
5:00am to 6:00am	0%	15%	25%	Off
6:00am to 7:00am	0%	15%	25%	Off
7:00am to 8:00am	10%	40%	65%	On
8:00am to 9:00am	20%	90%	80%	On
9:00am to 10:00am	70%	100%	100%	On
10:00am to 11:00am	70%	100%	100%	On
11:00am to 12:00pm	70%	100%	100%	On
12:00pm to 1:00pm	70%	100%	100%	On

Time period (local standard time)	Occupancy (Monday to Friday)	Artificial lighting (Monday to Friday)	Appliances and equipment (Monday to Friday)	*Air-conditioning* (Monday to Friday)
1:00pm to 2:00pm	70%	100%	100%	On
2:00pm to 3:00pm	70%	100%	100%	On
3:00pm to 4:00pm	70%	100%	100%	On
4:00pm to 5:00pm	70%	100%	100%	On
5:00pm to 6:00pm	35%	80%	80%	On
6:00pm to 7:00pm	10%	60%	65%	Off
7:00pm to 8:00pm	5%	60%	55%	Off
8:00pm to 9:00pm	5%	50%	25%	Off
9:00pm to 10:00pm	0%	15%	25%	Off
10:00pm to 11:00pm	0%	15%	25%	Off
11:00pm to 12:00am	0%	15%	25%	Off

Note to Table 2c: The occupancy profile is expressed as a percentage of the maximum number of people that can be accommodated in the building. The artificial lighting profile is expressed as a percentage of the maximum *illumination power density* permitted under Part J6. The appliances and equipment profile is expressed as a percentage of the maximum internal heat gain in Table 2l. The *air-conditioning* profile is expressed as the plant status.

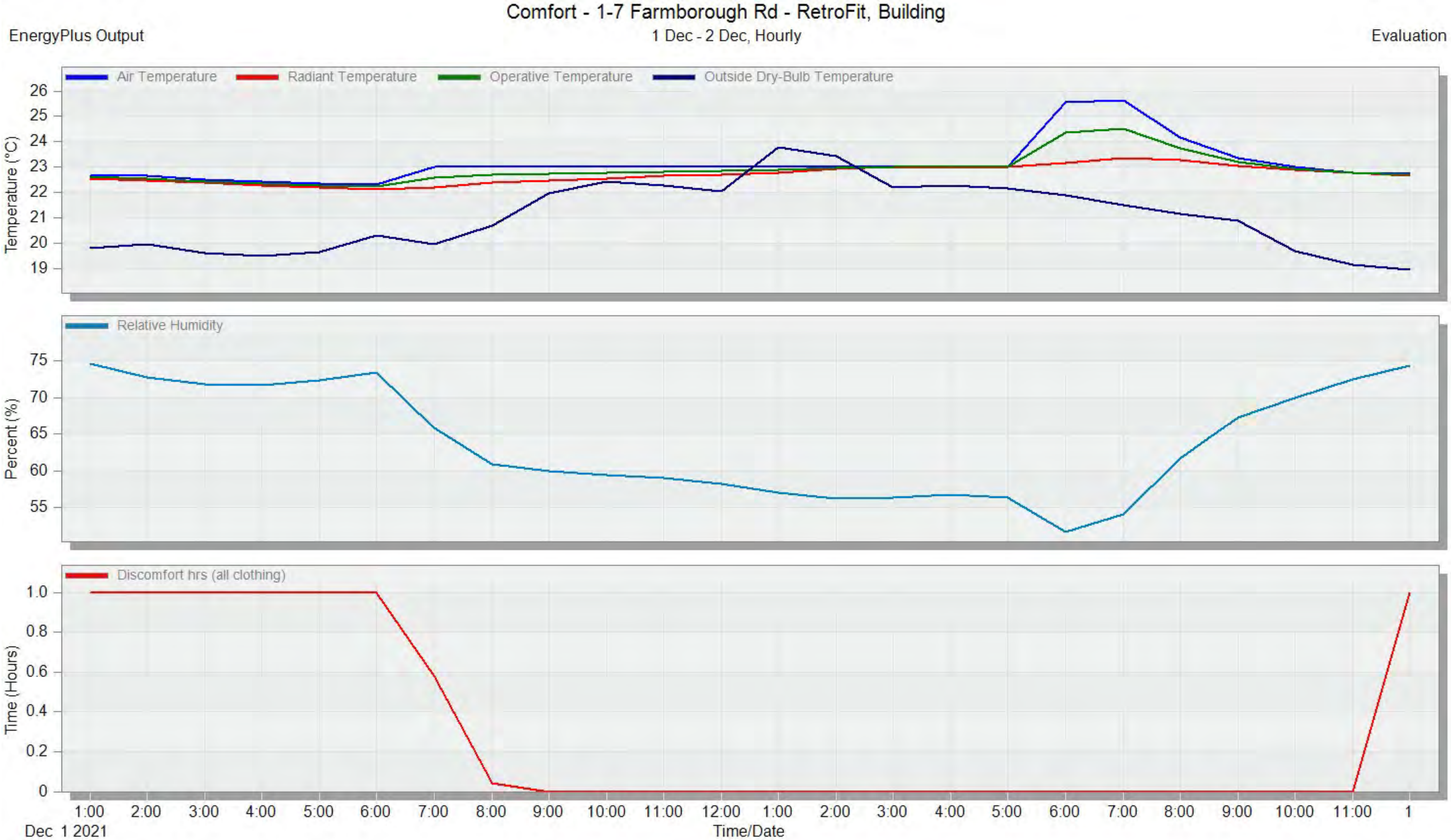
Appendix B.9 Baseline End Use Loads

End Uses

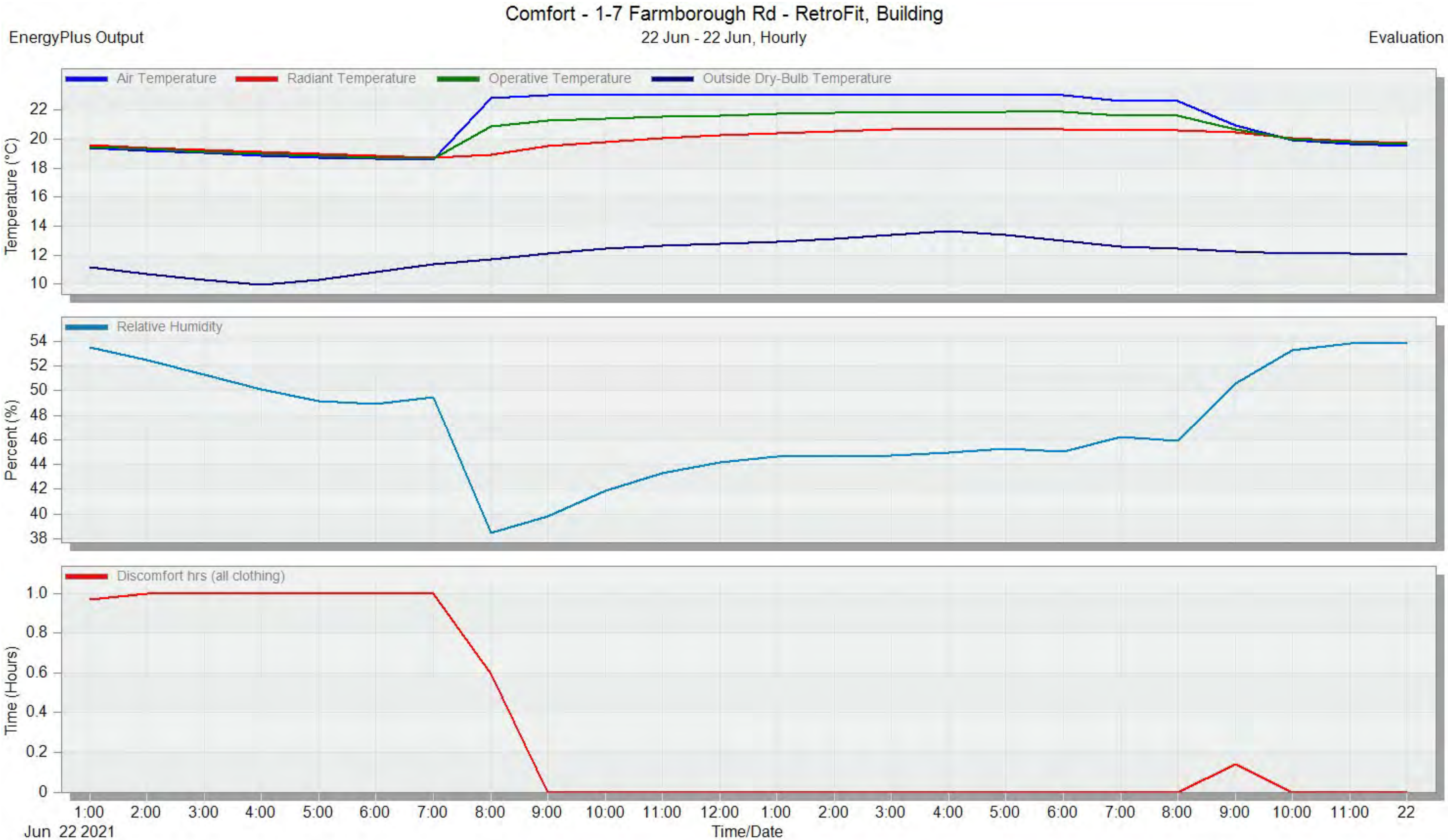
	Electricity [kWh]	Natural Gas [kWh]	Gasoline [kWh]	Diesel [kWh]	Coal [kWh]	Fuel Oil No 1 [kWh]	Fuel Oil No 2 [kWh]	Propane [kWh]	Other Fuel 1 [kWh]	Other Fuel 2 [kWh]	District Cooling [kWh]	District Heating [kWh]	Water [m3]
Heating	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2342.88	0.00
Cooling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18175.46	0.00	0.00
Interior Lighting	15730.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	439.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	22627.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	38798.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18175.46	2342.88	0.00

Note: District heat appears to be the principal heating source based on energy usage.

Appendix B.10 Typical Summer Days Thermal Performance

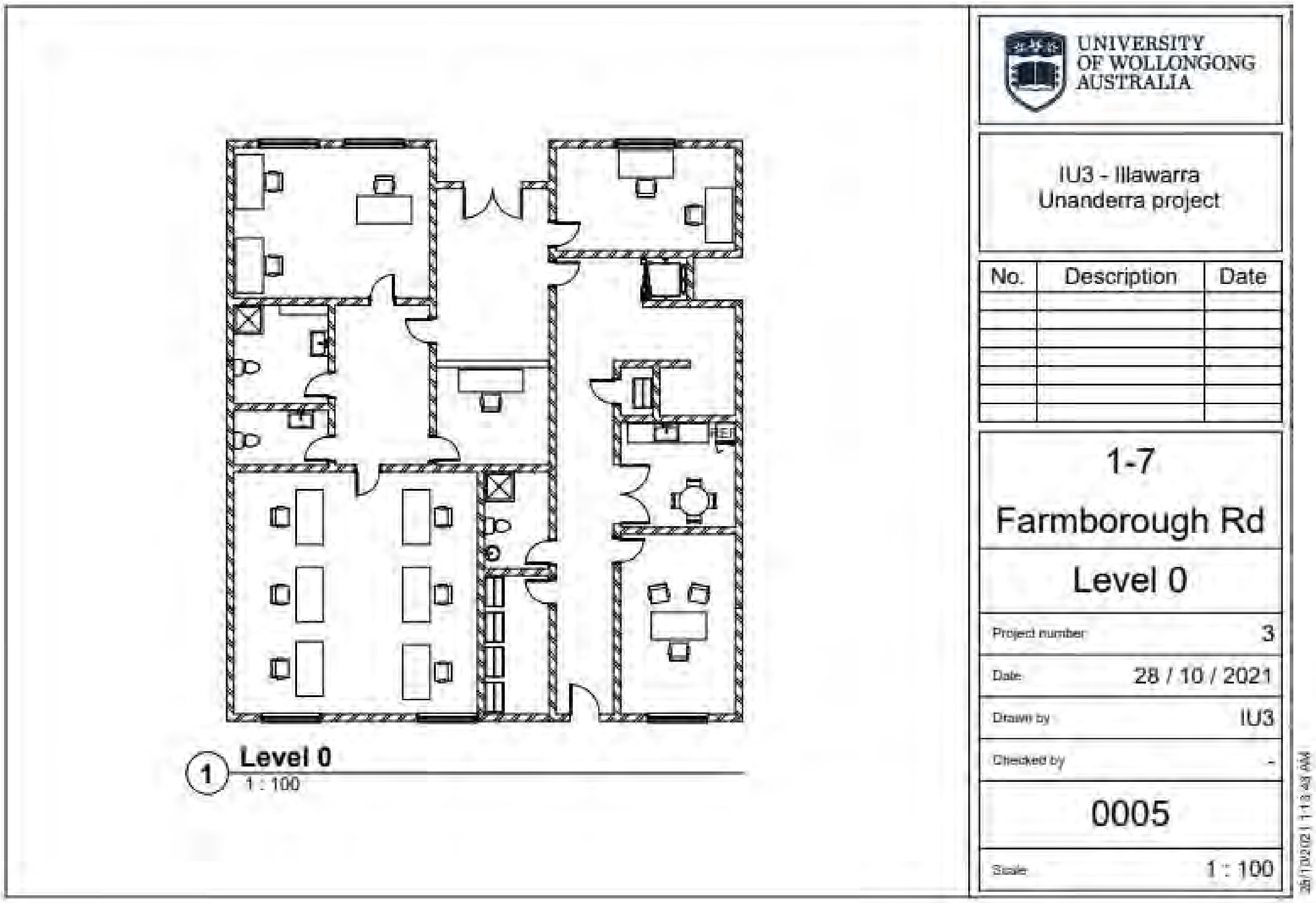


Appendix B.11 Typical Winters Days Thermal Performance

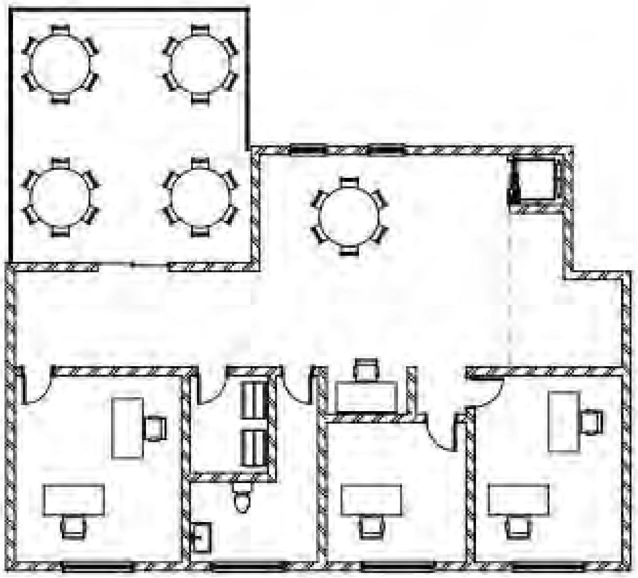


Appendix C Final Design

Appendix C.1 Ground Floor Plan



Appendix C.2 First Floor Plan



1 **Level 1**
1 : 100

UNIVERSITY OF WOLLONGONG AUSTRALIA

IU3 - Illawarra
Unanderra project

No.	Description	Date

1-7
Farmborough Rd

Level 1

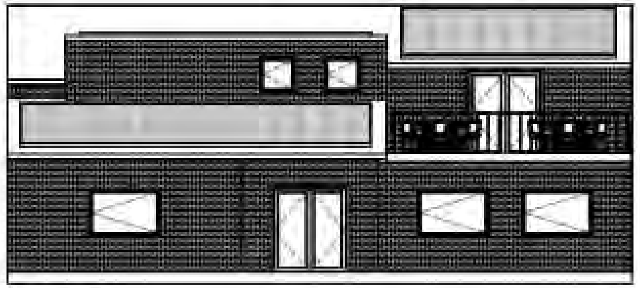
Project number	3
Date	28 / 10 / 2021
Drawn by	IU3
Checked by	-

0006

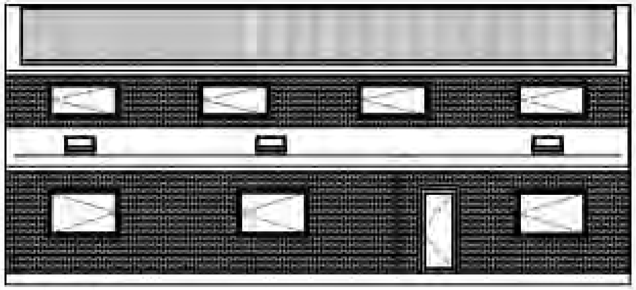
Scale	1 : 100

29/10/2021 2:28:02 AM

Appendix C.3 North and South Elevations



1 North
1 : 100



2 South
1 : 100

UNIVERSITY
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AUSTRALIA

IU3 - Illawarra
Unanderra project

No.	Description	Date

1-7
Farmborough Rd

Elevations

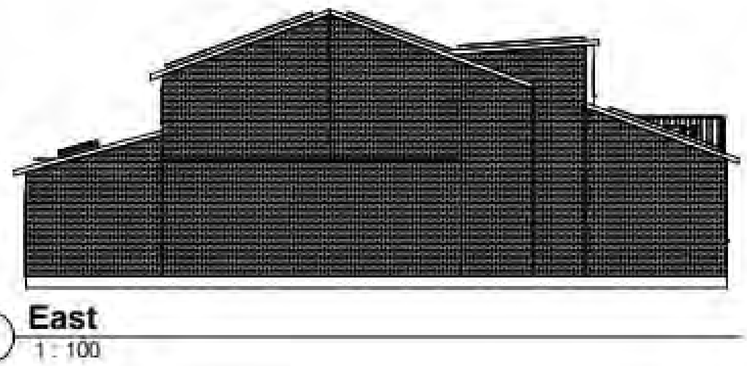
Project number	3
Date	28 / 10 / 2021
Drawn by	IU3
Checked by	-

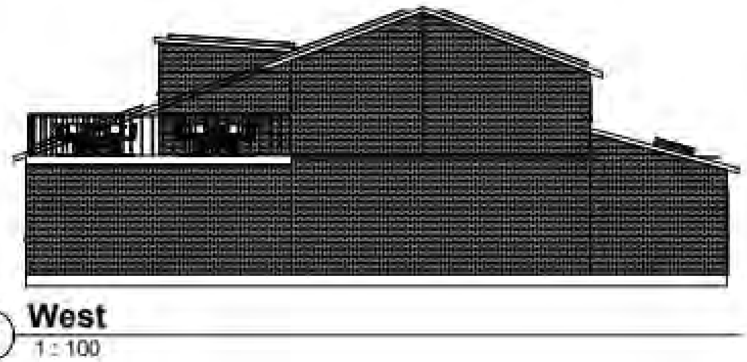
0003

Scale	1 : 100

28/10/2021 1:13:42 AM

Appendix C.4 East and West Elevations





UNIVERSITY
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AUSTRALIA

IU3 - Illawarra
Unanderra project

No.	Description	Date

1-7
Farmborough Rd

Elevations

Project number	3
Date	28 / 10 / 2021
Drawn by	IU3
Checked by	-

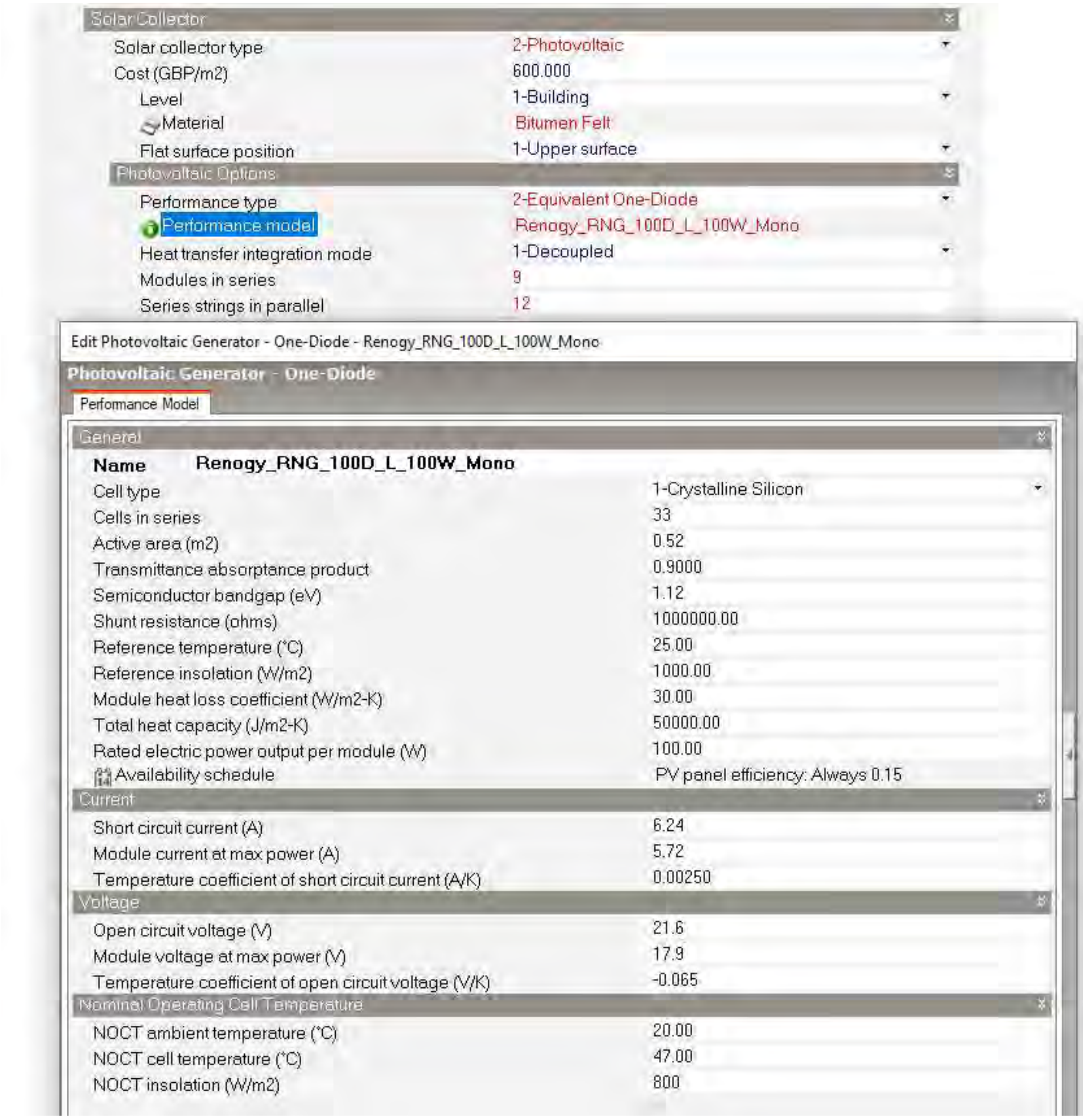
0004

Scale	1 : 100

28/10/2021 1:13:43 AM

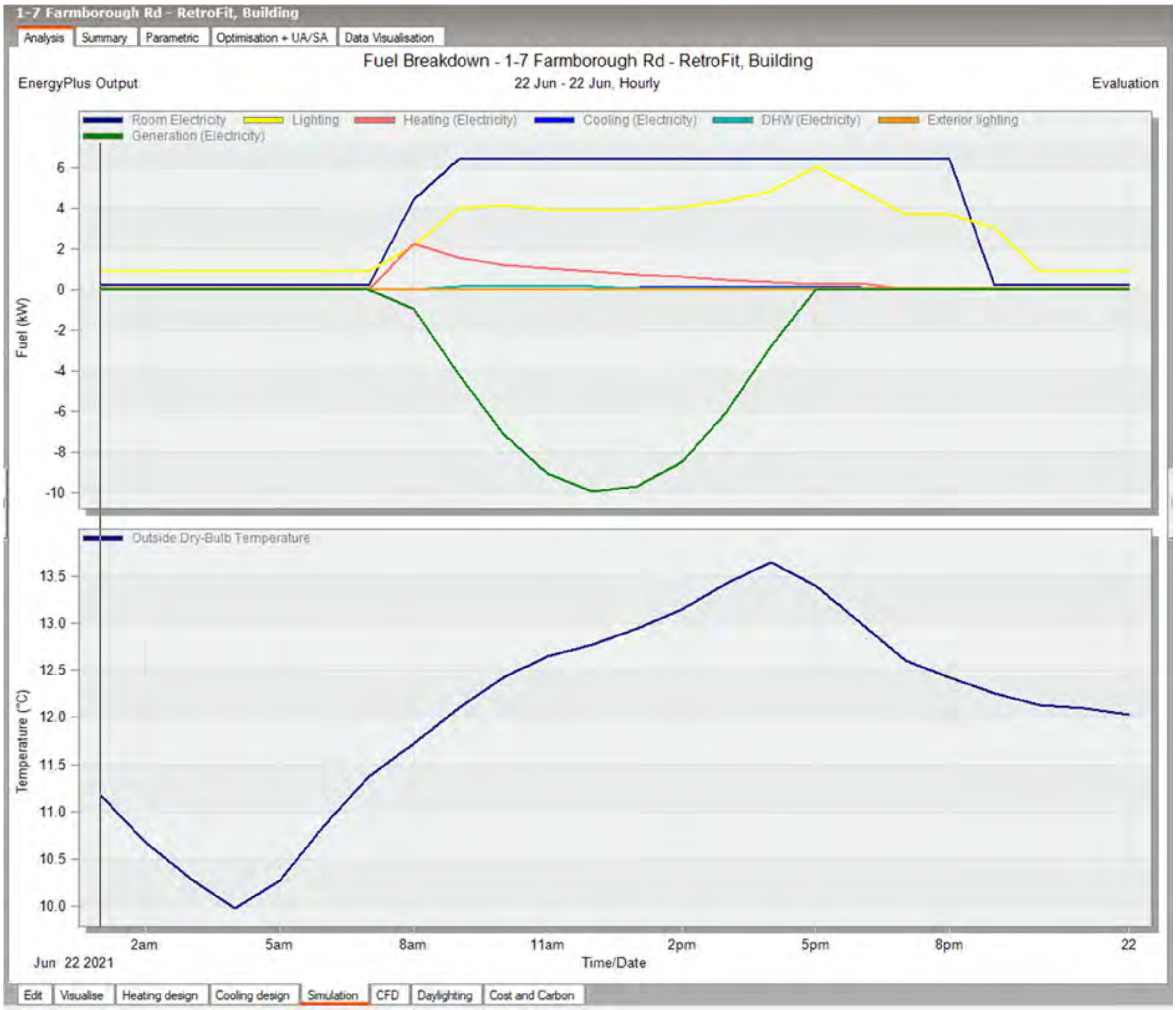
Appendix D NZE Design

Appendix D.1 Solar Panel Array 1 North



Appendix D.2 Typical Summers Day With PV

Appendix D.3 Typical Winters Day With PV



Appendix D.4 External Walls R Value

Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	0.263
R-Value (m2-K/W)	3.979
U-Value (W/m2-K)	**0.251**
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.3355
Km - Internal heat capacity (KJ/m2-K)	134.8000
Upper resistance limit (m2-K/W)	3.979
Lower resistance limit (m2-K/W)	3.979
U-Value surface to surface (W/m2-K)	0.263
R-Value (m2-K/W)	3.979
U-Value (W/m2-K)	**0.251**

Appendix D.5 Pitched Roof R Value

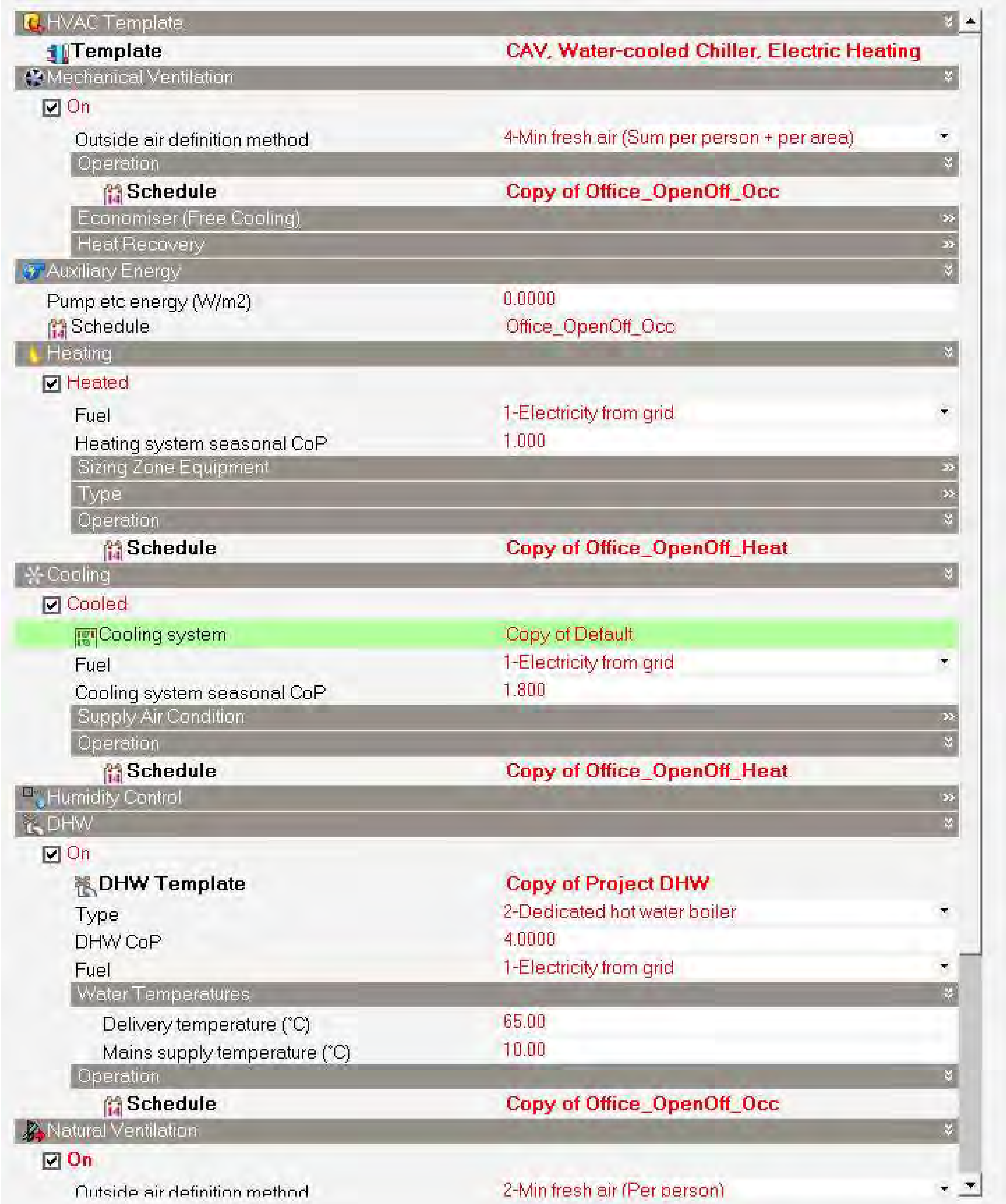
Inner surface	
Convective heat transfer coefficient (W/m2-K)	4.460
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.100
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	0.162
R-Value (m2-K/W)	6.321
U-Value (W/m2-K)	**0.158**
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.2752
Km - Internal heat capacity (KJ/m2-K)	6.4116
Upper resistance limit (m2-K/W)	6.321
Lower resistance limit (m2-K/W)	6.321
U-Value surface to surface (W/m2-K)	0.162
R-Value (m2-K/W)	6.321
U-Value (W/m2-K)	**0.158**

Appendix D.6 NZEB Windows

Appendix D.7 Lighting Upgrade

Lighting Template	
Template	LED with linear control
General Lighting	
☑ On	
Normalised power density (W/m2-100 lux)	2.5000
Schedule	Copy of Office_OpenOff_Light1
Luminaire type	1-Suspended
Return air fraction	0.000
Radiant fraction	0.420
Visible fraction	0.180
Convective fraction	0.400
Lighting Control	
☑ On	
Working plane height (m)	0.80
Control type	1-Linear
Min output fraction	0.100
Min input power fraction	0.100
Glare	
Lighting Area 1	
Lighting Area 2	
Task and Display Lighting	
Exterior Lighting	
☑ On	
Absolute power (W)	100.000
Schedule	On 24/7
Control option	2-Schedule + override off in daytime
Cost	
Cost per area (GBP/m2 GIFA)	100.00

Appendix D.8 HVAC Upgrade



Appendix D.9 NZE End Load Breakdown

	Electricity [kWh]	Natural Gas [kWh]	Gasoline [kWh]	Diesel [kWh]	Coal [kWh]	Fuel Oil No 1 [kWh]	Fuel Oil No 2 [kWh]	Propane [kWh]	Other Fuel 1 [kWh]	Other Fuel 2 [kWh]	District Cooling [kWh]	District Heating [kWh]	Water [m3]
Heating	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	421.34	0.00
Cooling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7984.08	0.00	0.00
Interior Lighting	10138.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	439.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	22224.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1503.44	23.54
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	32803.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7984.08	1924.77	23.54

Note: District heat appears to be the principal heating source based on energy usage.

Appendix D.10 PV REF Snippet

Date/Time	Room Electricity	Lighting	Heating (Electricity)	Cooling (Electricity)	DHW (Electricity)	Exterior lighting	Generation (Electricity)	Total energy requirements (hourly)	Renew. Gen. (abs)	REF values	REF values	REF values
1/01/2021 1:00	0.240162	0.923309	0	0	0.024875	0.1	0	1.288346	0	0	0	
1/01/2021 2:00	0.240162	0.923309	0	0	0.024875	0.1	0	1.288346	0	0	0	
1/01/2021 3:00	0.240162	0.923309	0	0	0.024875	0.1	0	1.288346	0	0	0	
1/01/2021 4:00	0.240162	0.923309	0	0	0.024875	0.1	0	1.288346	0	0	0	
1/01/2021 5:00	0.240162	0.90145	0	0	0.024875	0.05	0	1.216487	0	0	0	
24/06/2021	0.240162	0.923309	0	0	0	0.1	0	1.263471	0	0	0	
25/06/2021 1:00	0.240162	0.923309	0	0	0.024875	0.1	0	1.288346	0	0	0	
25/06/2021 2:00	0.240162	0.923309	0	0	0.024875	0.1	0	1.288346	0	0	0	
25/06/2021 3:00	0.240162	0.923309	0	0	0.024875	0.1	0	1.288346	0	0	0	
25/06/2021 4:00	0.240162	0.923309	0	0	0.024875	0.1	0	1.288346	0	0	0	
25/06/2021 5:00	0.240162	0.923309	0	0	0.024875	0.1	0	1.288346	0	0	0	
25/06/2021 6:00	0.240162	0.923309	0	0	0.024875	0.1	0	1.288346	0	0	0	
25/06/2021 7:00	0.240162	0.923309	0	0	0.024875	0.1	0	1.288346	0	0	0	
25/06/2021 17:00	6.442123	6.115359	0.319997	0.185831	0.08706	0.05	0	13.20037	0	0	0	
25/06/2021 18:00	6.442123	4.924308	0.345505	0.132425	0.024875	0.1	0	11.969236	0	0	0	
25/06/2021 19:00	6.442123	3.69323	0	0	0.062185	0.1	0	10.297538	0	0	0	
25/06/2021 20:00	6.442123	3.69323	0	0	0.012437	0.1	0	10.24779	0	0	0	
25/06/2021 21:00	0.240162	3.077694	0	0	0.012437	0.1	0	3.430293	0	0	0	
25/06/2021 22:00	0.240162	0.923309	0	0	0	0.1	0	1.263471	0	0	0	
25/06/2021 23:00	0.240162	0.923309	0	0	0	0.1	0	1.263471	0	0	0	
25/06/2021	0.240162	0.923309	0	0	0	0.1	0	1.263471	0	0	0	
26/06/2021 1:00	0.240162	0	0	0	0	0.1	0	0.340162	0	0	0	
26/06/2021 2:00	0.240162	0	0	0	0	0.1	0	0.340162	0	0	0	
26/06/2021 3:00	0.240162	0	0	0	0	0.1	0	0.340162	0	0	0	
26/06/2021 4:00	0.240162	0	0	0	0	0.1	0	0.340162	0	0	0	
26/06/2021 5:00	0.240162	0	0	0	0	0.1	0	0.340162	0	0	0	
26/06/2021 6:00	0.240162	0	0	0	0	0.1	0	0.340162	0	0	0	
26/06/2021 7:00	0.240162	0	0	0	0	0.1	0	0.340162	0	0	0	
6/08/2021 7:00	0.240162	0.898975	0	0	0.024875	0.05	0	1.214012	0	0	0	
24/06/2021 19:00	6.442123	3.69323	0	0	0.062185	0.1	-0.000001	10.297538	0.000001	9.7111E-08	9.71106E-08	
24/06/2021 20:00	6.442123	3.69323	0	0	0.012437	0.1	-0.000001	10.24779	0.000001	9.7582E-08	9.7582E-08	
24/06/2021 17:00	6.442123	6.115288	0.68255	0.050449	0.08706	0.05	-0.000002	13.42747	0.000002	1.4895E-07	1.48948E-07	
24/06/2021 18:00	6.442123	4.924308	0.685776	0.038199	0.024875	0.1	-0.000002	12.215281	0.000002	1.6373E-07	1.63729E-07	

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29	1259	2451	3852	0	7591	0.76541093

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0	977	2451	3852	0	7280	0.797999322

Appendix D.11 NZE REF Snippet

Date/Time	Room Electricity	Lighting	Heating (Electricity)	Cooling (Electricity)	DHW (Electricity)	Exterior lighting	Generation (Electricity)	Total energy requirements (hourly)	Renew. G	REF values	REF values	REF values
27/12/2021 12:00	0.238372	0	0	0	0	0	-25.79405	0.238372	25.79405	108.2092276		
19/12/2021 12:00	0.238372	0	0	0	0	0	-25.58681	0.238372	25.58681	107.3398302		
27/12/2021 13:00	0.238372	0	0	0	0	0	-25.36623	0.238372	25.36623	106.4144698		
19/12/2021 13:00	0.238372	0	0	0	0	0	-25.26583	0.238372	25.26583	105.9932794		
28/11/2021 12:00	0.238372	0	0	0	0	0	-25.07104	0.238372	25.07104	105.1761113		
12/12/2021 12:00	0.238372	0	0	0	0	0	-24.60121	0.238372	24.60121	103.2051164		
27/12/2021 11:00	0.238372	0	0	0	0	0	-24.53629	0.238372	24.53629	102.9327689		
28/11/2021 13:00	0.238372	0	0	0	0	0	-24.39879	0.238372	24.39879	102.3559395		
19/12/2021 11:00	0.238372	0	0	0	0	0	-24.37659	0.238372	24.37659	102.2628077		
17/01/2021 12:00	0.238372	0	0	0	0	0	-24.32295	0.238372	24.32295	102.0377813		
28/11/2021 11:00	0.238372	0	0	0	0	0	-24.23611	0.238372	24.23611	101.6734768		
17/01/2021 13:00	0.238372	0	0	0	0	0	-24.11349	0.238372	24.11349	101.1590707		
12/12/2021 13:00	0.238372	0	0	0	0	0	-24.02756	0.238372	24.02756	100.7985837		
21/11/2021 12:00	0.238372	0	0	0	0	0	-23.7272	0.238372	23.7272	99.53853641		
12/12/2021 11:00	0.238372	0	0	0	0	0	-23.55585	0.238372	23.55585	98.81970198		
9/01/2021 12:00	0.238372	0	0	0	0	0	-23.4792	0.238372	23.4792	98.49814576		
9/01/2021 13:00	0.238372	0	0	0	0	0	-23.42888	0.238372	23.42888	98.28704714		
27/12/2021 14:00	0.238372	0	0	0	0	0	-23.42158	0.238372	23.42158	98.25642273		
2/01/2021 13:00	0.238372	0	0	0	0	0	-23.3354	0.238372	23.3354	97.89488698		
3/01/2021 12:00	0.238372	0	0	0	0	0	-23.25526	0.238372	23.25526	97.55868978		
2/01/2021 12:00	0.238372	0	0	0	0	0	-23.19346	0.238372	23.19346	97.29943114		
21/11/2021 11:00	0.238372	0	0	0	0	0	-23.16749	0.238372	23.16749	97.19048378		

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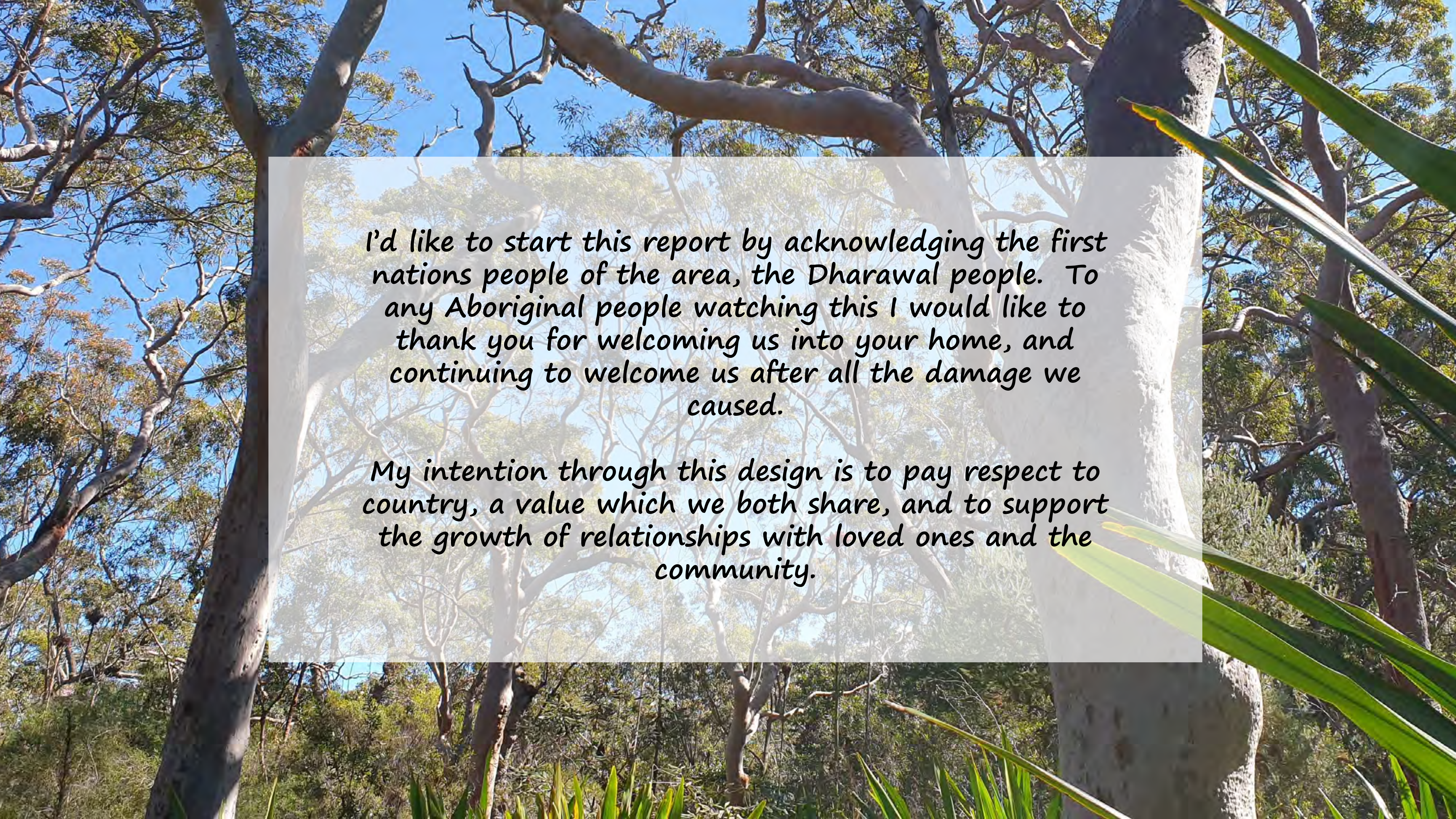
20	822	1206	5340	1372	8760	5.072935834

REF = 0	0<REF<0.3	0.3<REF<0.95	0.95<REF<1.05	1.05<REF	Check Sum	Avg. REF Value
20	822	1206	5340	0	7388	0.836545751

REF = 0	0<REF<0.3	0.3<REF<0.95	0.95<REF<1.05	1.05<REF	Check Sum	Avg. REF Value
0	404	1206	5340	0	6950	0.887001169

Design Proposal ENGG210



I'd like to start this report by acknowledging the first nations people of the area, the Dharawal people. To any Aboriginal people watching this I would like to thank you for welcoming us into your home, and continuing to welcome us after all the damage we caused.

My intention through this design is to pay respect to country, a value which we both share, and to support the growth of relationships with loved ones and the community.

EXECUTIVE SUMMARY

This project is a design proposal for the Ilawarra Local Aboriginal Lands Council (ILALC) and is designed to meet the brief requirements for ENGG210.

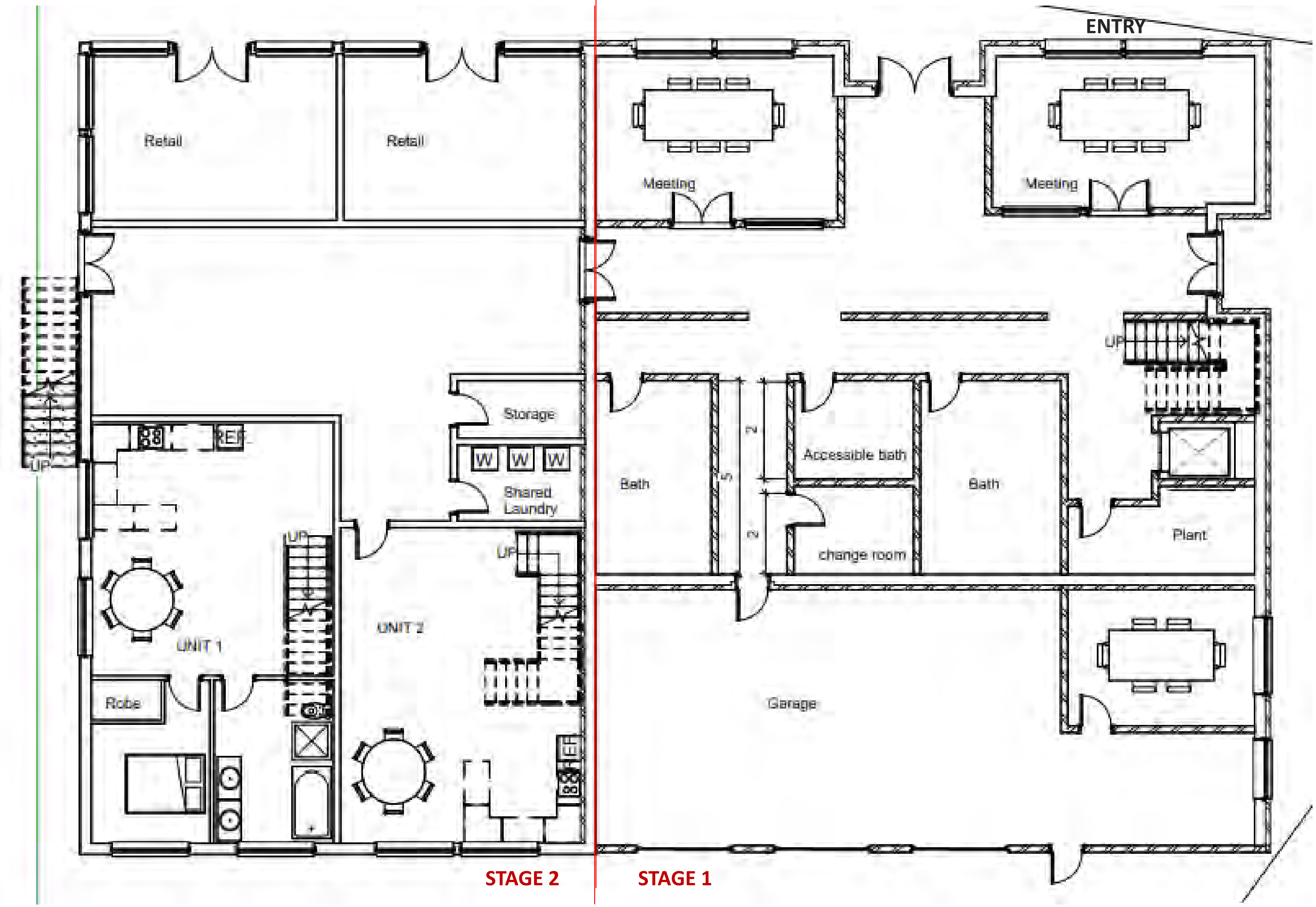
The ILALC purchased the block of land (1-7 Farmborough Road, Unanderra) with a building that was once the Unanderra police station. They specified the need for leasable spaces as a source of income, a large garage space to service their technicians, and an office space which they could one day move into themselves.

This development plan is designed to be constructed in two stages: Stage one is a retrofit of the existing building which features two northern meeting rooms, a large open office and a 3-4 car garage on the south, with shared restroom facilities. Stage two features a one bedroom unit and two bedroom unit with private patio area. The large northern terrace stretches across both stages and takes advantage of the mountain views.

The design had to be sustainably minded and in line with the values of the ILALC. According to the energy simulation results, the buildings PV system will produce 121% of the electricity requirements for the building, making it **net zero**. The building features sustainably sourced and reused materials, sourced locally where possible. The improvements made to the base model was; changing the lighting from 11W/m^2 to 5W/m^2 and adding north and east window shading. These changes improved the net energy consumption by over 14%.

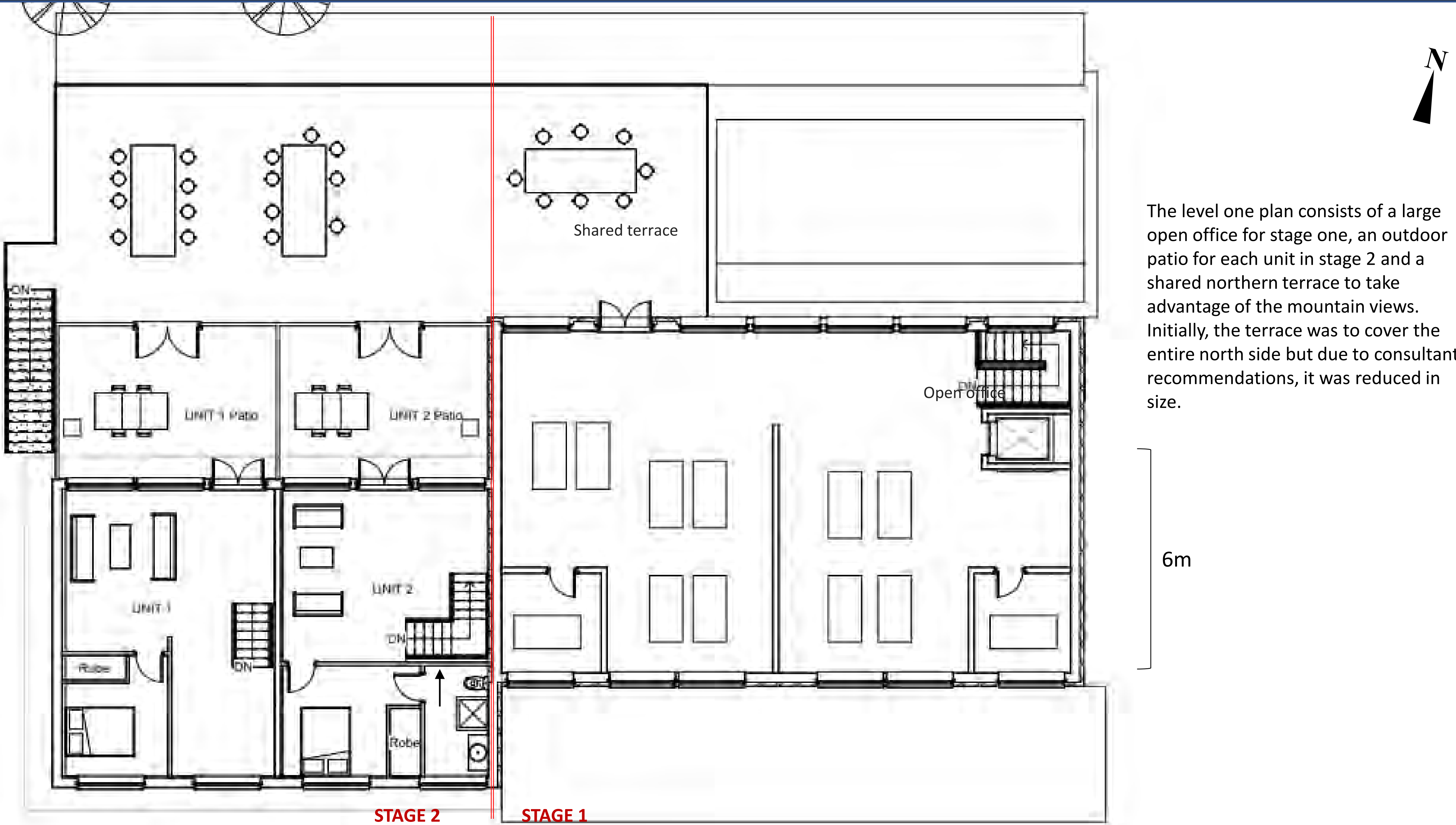
This design will service the ILALC's needs and provide a sustainable solution for the block.

FLOOR PLAN - GROUND



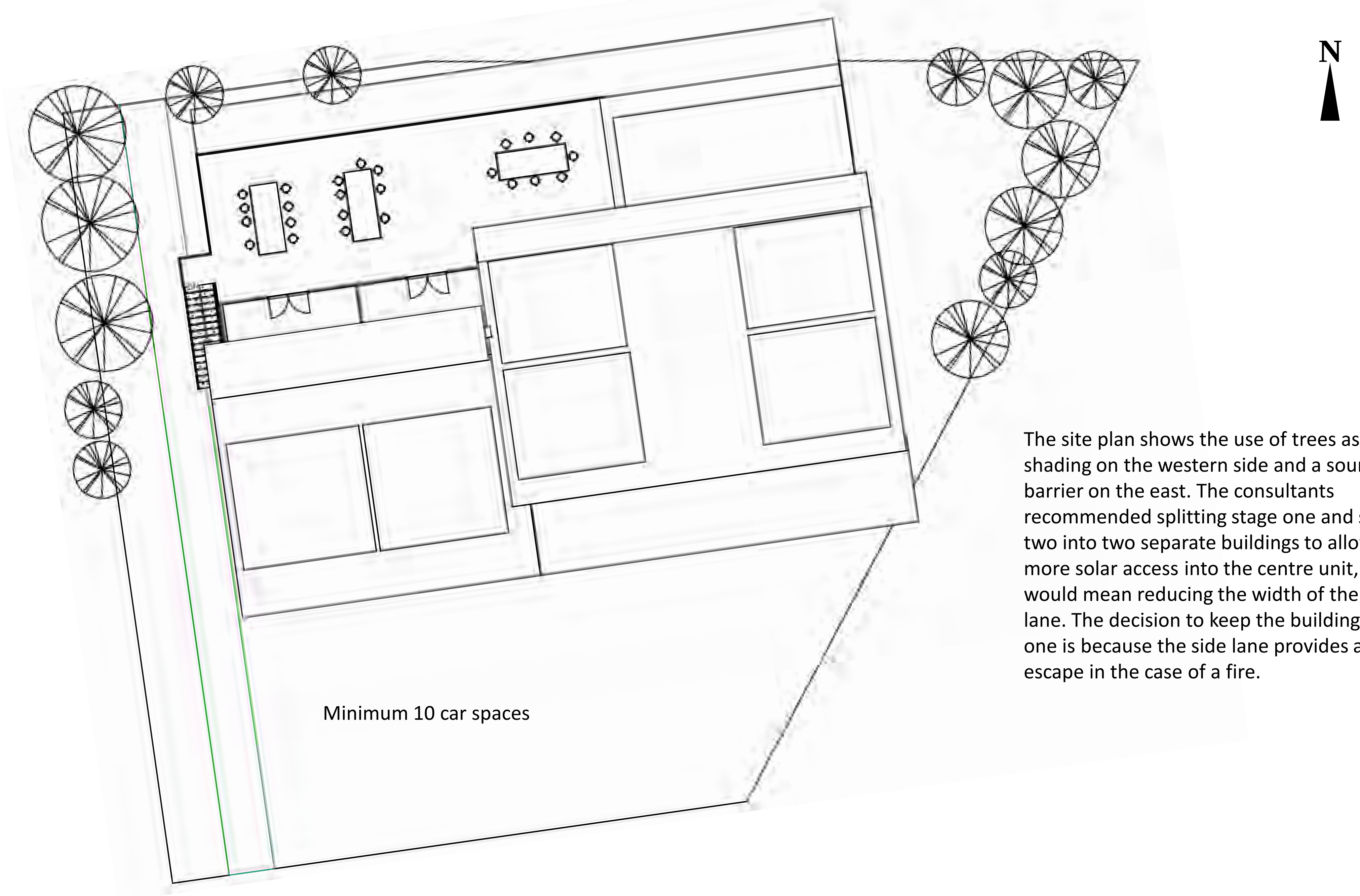
This ground floor plan consists of two northern meeting rooms, shared restroom facilities and a southern large 3 car garage in stage 1. Stage 2 features two northern retail spaces, a two bedroom unit and a one bedroom unit with shared laundry facilities.

FLOOR PLAN – LEVEL 1



The level one plan consists of a large open office for stage one, an outdoor patio for each unit in stage 2 and a shared northern terrace to take advantage of the mountain views. Initially, the terrace was to cover the entire north side but due to consultant recommendations, it was reduced in size.

SITE PLAN



The site plan shows the use of trees as shading on the western side and a sound barrier on the east. The consultants recommended splitting stage one and stage two into two separate buildings to allow more solar access into the centre unit, this would mean reducing the width of the side lane. The decision to keep the buildings as one is because the side lane provides an escape in the case of a fire.

SHADING

This shading diagram is representative of today at 10am. Its around that time of year when cooling demand increases in buildings and as can be seen here, there is no direct solar access through the glazing due to the awning.

Today
28/10/21 10am

The second diagram represents the winter solstice, a time of year when heating demand is at its peak. In this diagram you can see the awnings provide minimal obstruction of solar radiation from entering the glazing and warming the spaces.

Winter solstice
21/06/21 10am

CONSTRUCTION DETAIL

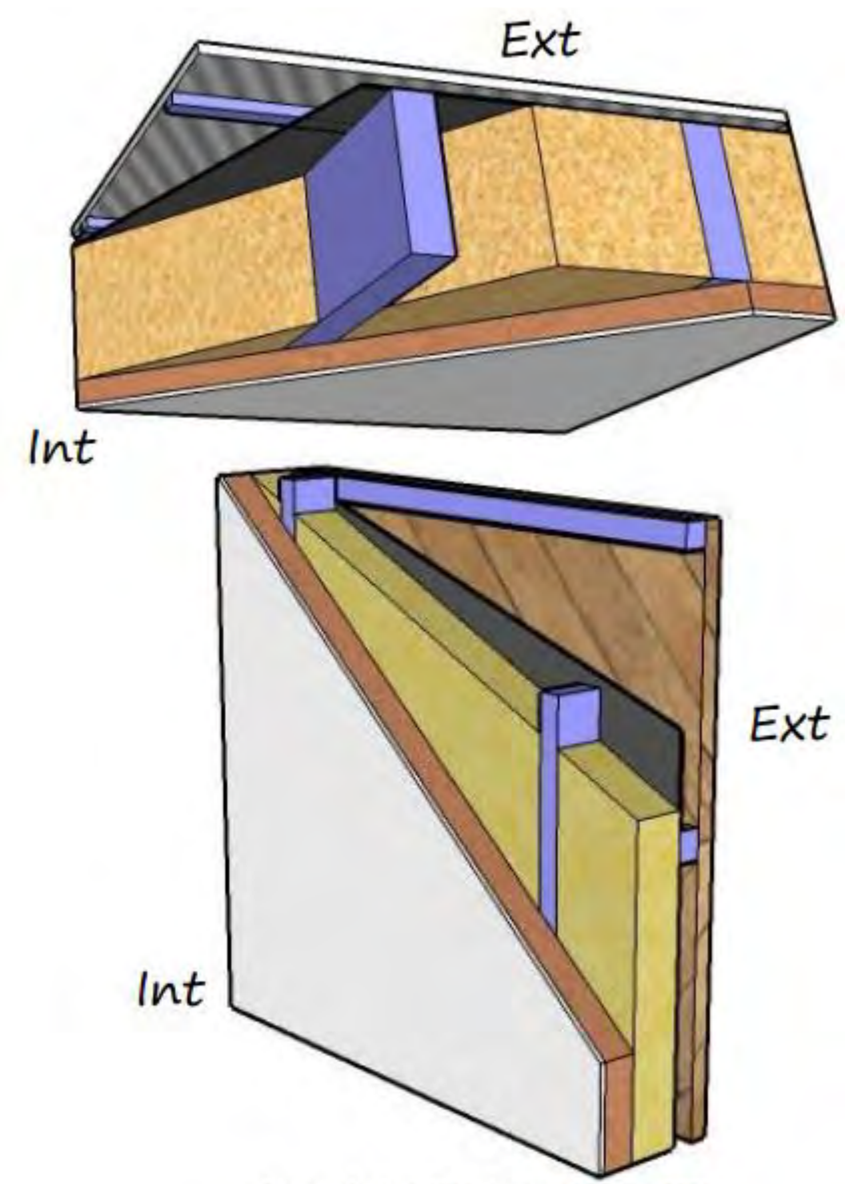


Diagram by Josie Whitehouse, Sketchup, 2021

New Roof fabric:

- Colorbond corrugated iron sheeting 16mm
- Air gap with steel battens 20mm
- Bradford thermoseal R0.3 1mm
- Parallel chord truss with Bradford Black Ceiling Insulation R5.0 240mm
- Kooltherm Insulated Plasterboard R1.16 35mm

Total R 6.46 Total thickness: 312mm

New Envelope Wall fabric:

- CYNDAN Fire Retardant Liquid coating
- Reused timber cladding: ~22mm
- Air gap and steel battens 40mm
- Bradford thermoseal R0.3 1mm
- Truecore steel studs with Bradford Wall Insulation R2.7 90mm
- Kooltherm Insulated Plasterboard R 2.91 70mm

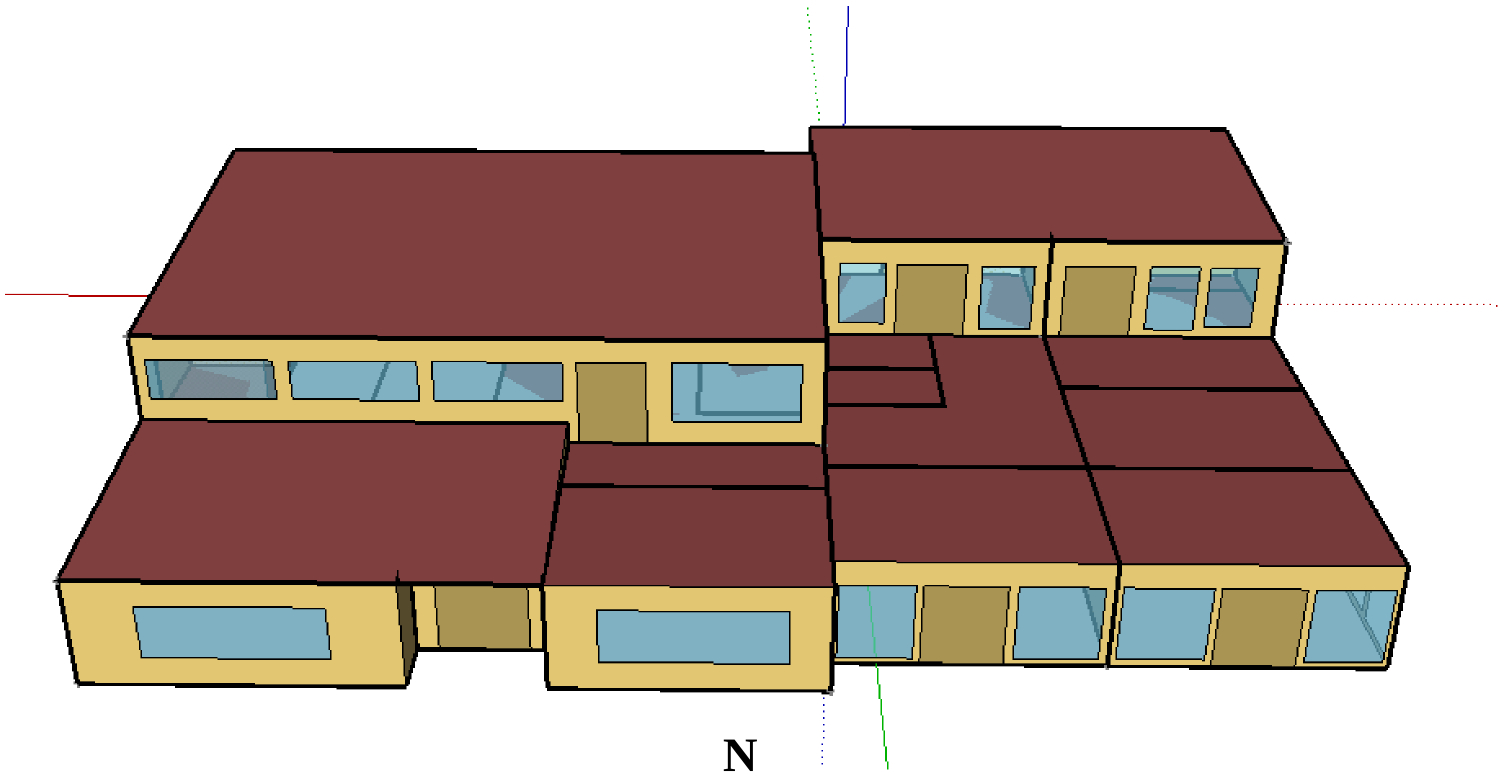
Total R 5.92 Total thickness: 223mm

Existing walls:

Lined with Kooltherm Insulated Plasterboard

The additional material required to insulate the building well will bring the construction cost up though as it will save energy cost, it is worth it. All the materials listed here can be sourced locally or are lightweight and do not come with large shipping cost.

BASE MODEL



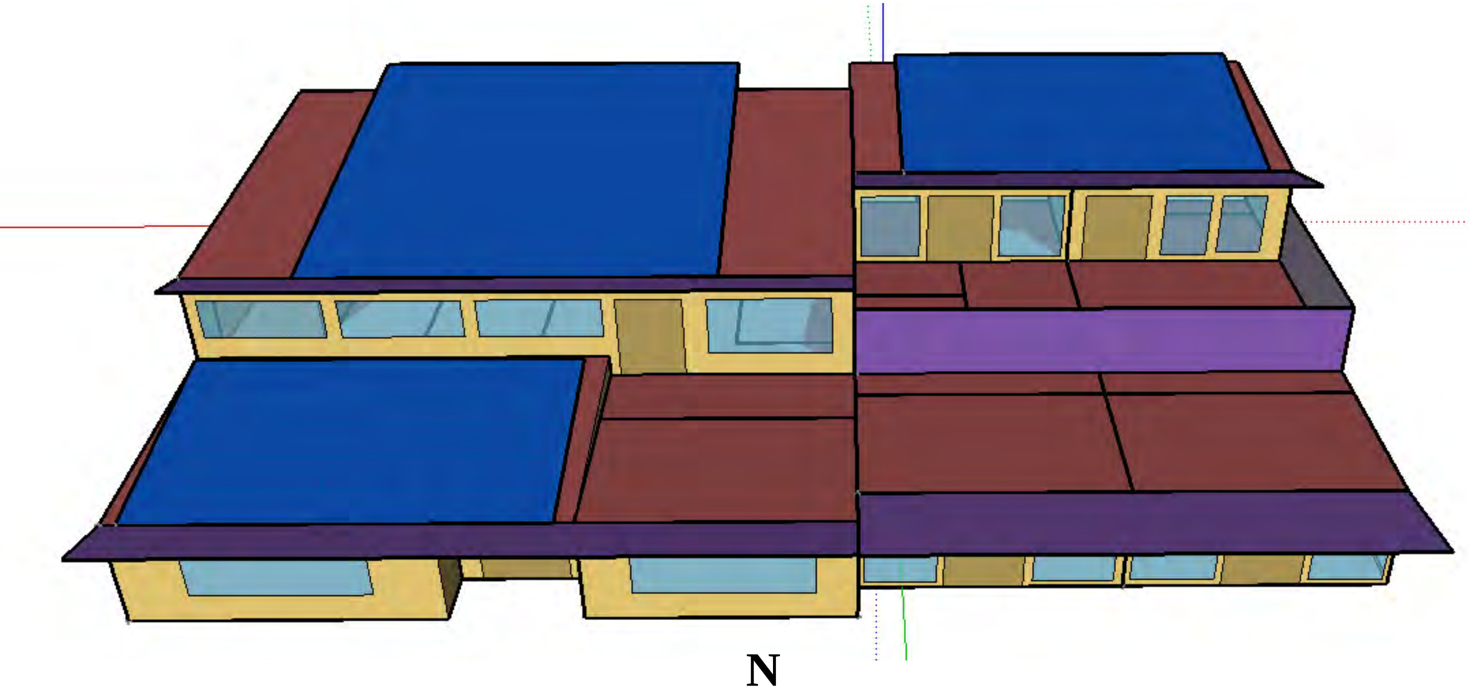
Assumptions:
The exterior walls and roof are set to climate zone 5.
The scheduling for the office spaces are set to 8am-6pm.

Annual heating load (kWh)	Per day average (kWh)
15100	41.4

Annual cooling load (kWh)	Per day average (kWh)
6460	17.7

Annual load total (kWh)	Per day average (kWh)
53300	146

MODIFICATIONS



Improvements made:
The improved model features north and east window shading, a 215m^2 PV system at 15% efficiency which is just under 60% of the total 360m^2 of north angled roof available. The lighting was changed to a maximum of 5W/m^2 which LED lights can provide, this was previously set to 10-12W/m^s.

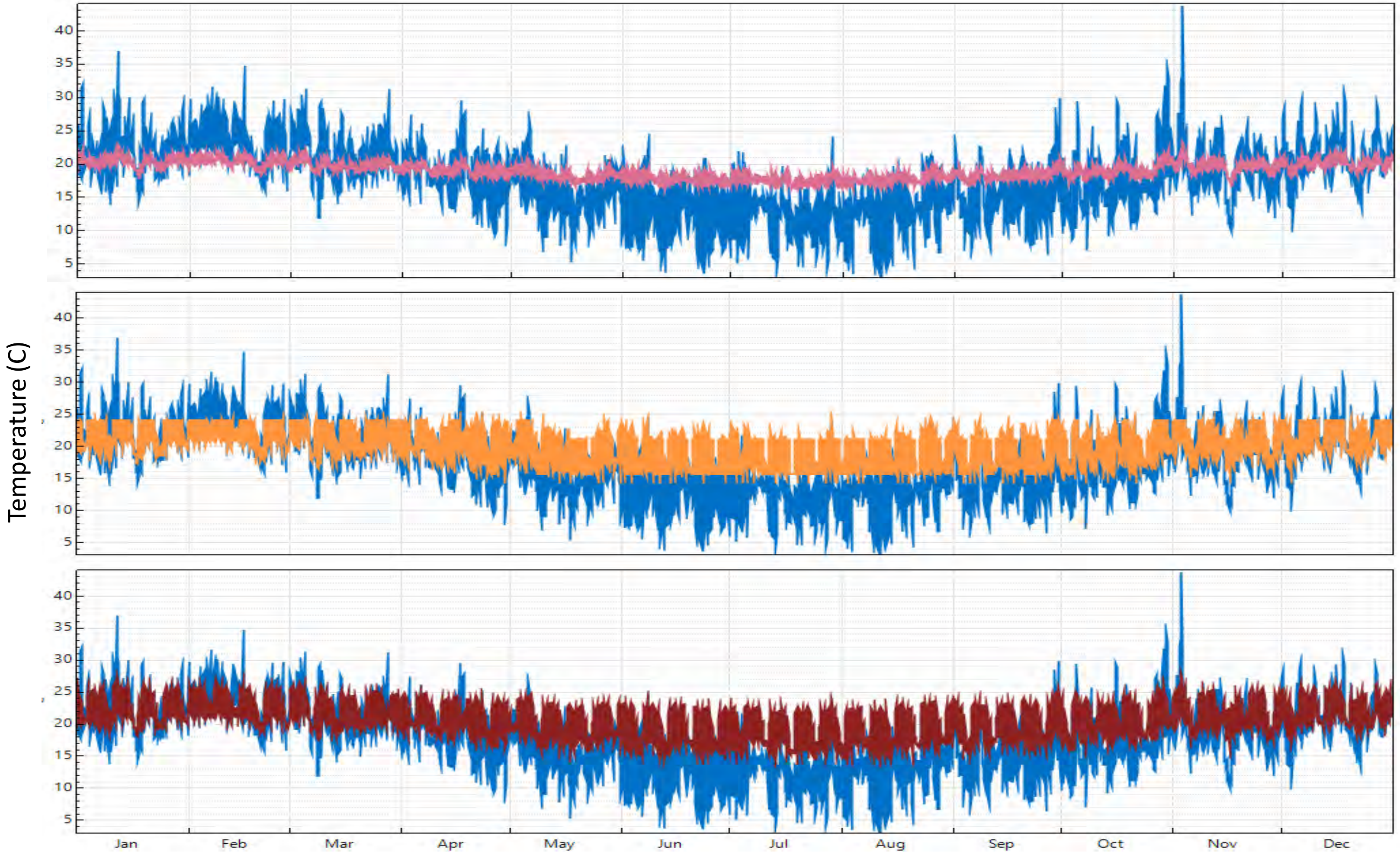
Annual heating load (kWh)	Per day average (kWh)	Improvement %
16500	45.2	-9.3

Annual cooling load (kWh)	Per day average (kWh)	Improvement %
5700	15.6	11.8

Annual load total (kWh)	Per day average (kWh)	Improvement %
45800	125	14.1

Total PV generation (kWh)	Net annual load (kWh)	Renewable energy fraction
55200	-8250	1.21

DATA OF SELECTED SPACES



Site outdoor drybulb temperature

Unit 1 air temperature (Conditioned)

Open office air temperature (Conditioned)

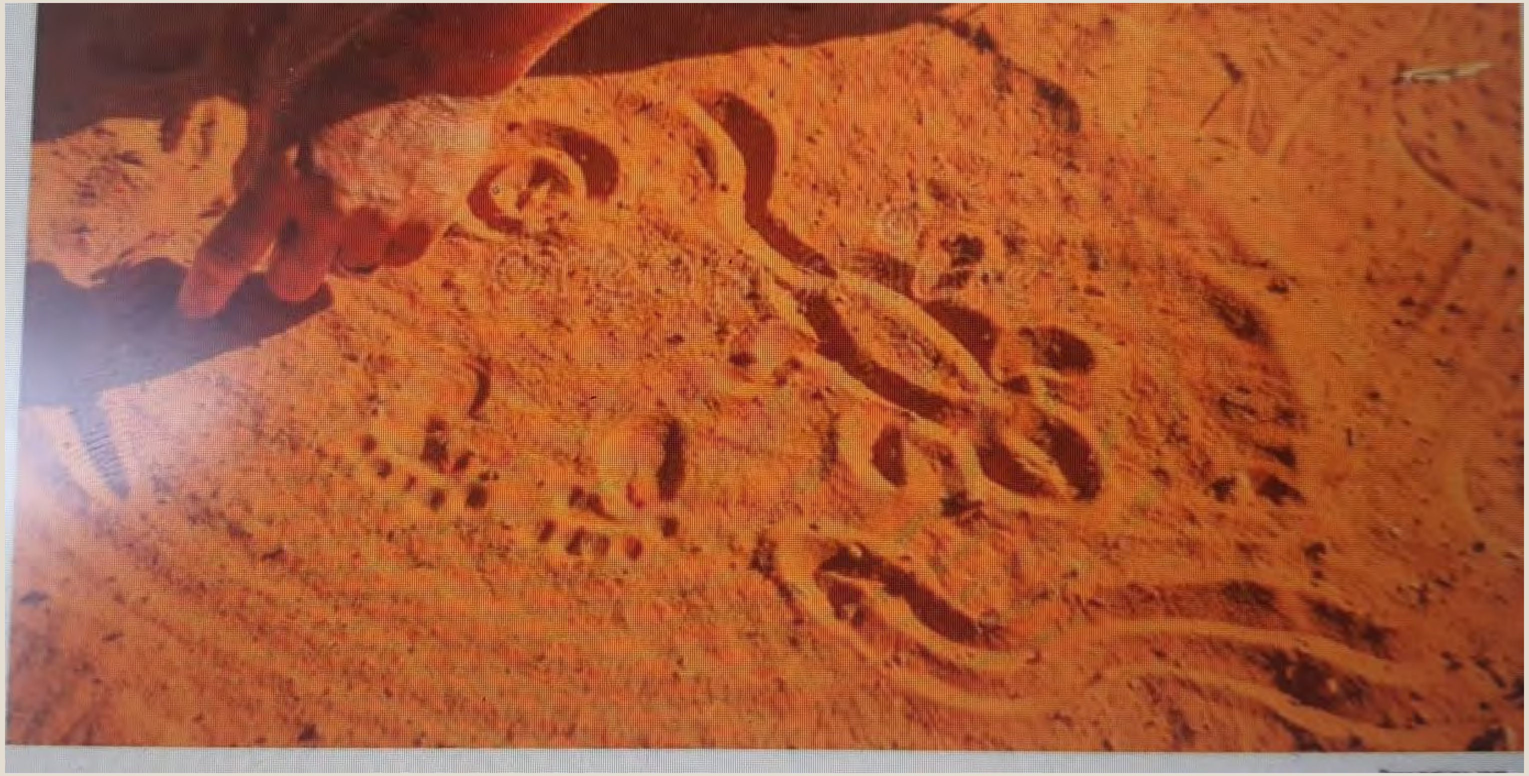
Technicians garage air temperature (Unconditioned)

These graphs are taken from the simulation results. The overlayed data represents a select few spaces around the building it shows that the spaces maintain a comfortable temperature year round. The technicians garage at the bottom was specified as unconditioned in the simulation and if that's accurate, then it is an excellent result.

References

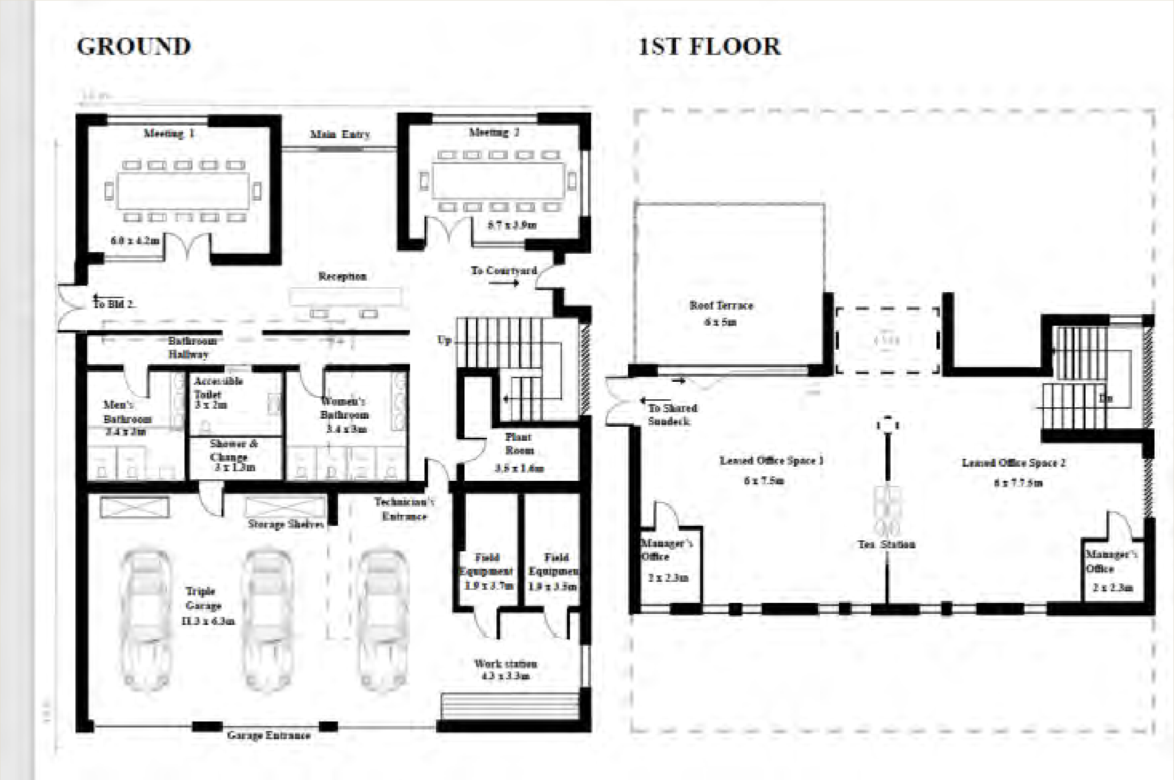
- Bradford black ceiling insulation: https://insulationaustralia.com.au/product/bradford-black-ceiling-insulation-r5-0-x-580-x-240mm/
- Bradford wall insulation: https://insulationaustralia.com.au/product/wall-insulation-r2-7-x-420-x-90mm-hp/
- Thermoseal wrap: https://www.bradfordinsulation.com.au/home-insulation/wall-wraps/thermoseal-wall-wrap
- Kooltherm insulated plasterboard: https://www.kingspan.com/au/en-au/products-brands/insulation/insulation-boards/kooltherm-range/kooltherm-k17-insulated-plasterboard
- Truecore steel studs: https://truecore.com.au/
- CYNDAN fire retardant: https://www.industrialsupplies.com.au/manufacturers/cyndan-2

ENGG210 ASSIGNMENT 3



Floor plan

Changes:
Add more tables and chairs in the spaces that is in the original floor plan.



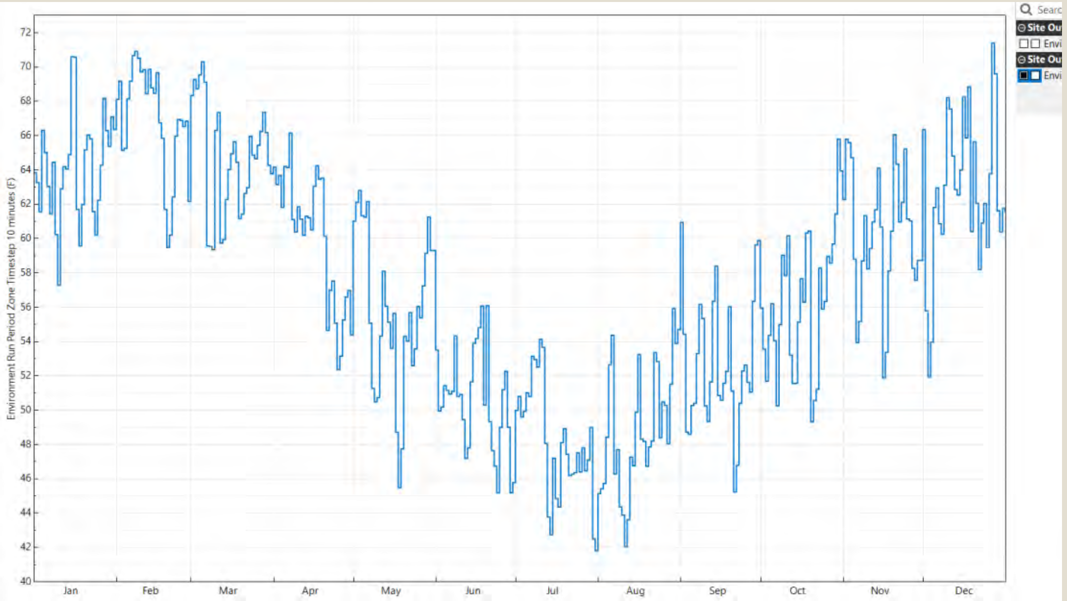
Design and site

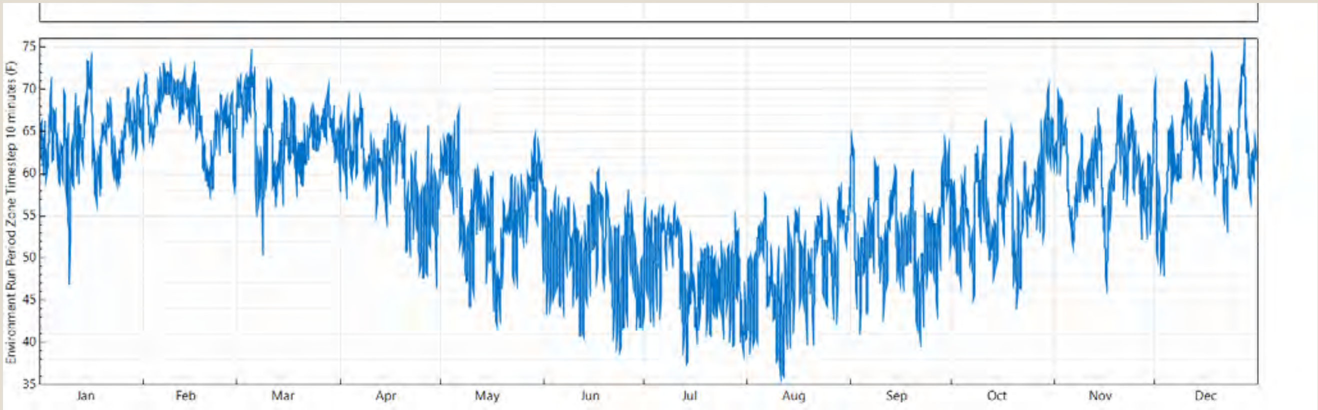
- Location: 1 Farmborough road, Unanderra
- What the design should have is: Retail shop, restaurants, meeting rooms, and roof terrace.
- It should have net zero strategy
- Air flow and ventilation
- Lighting and equipment

Baseline analysis

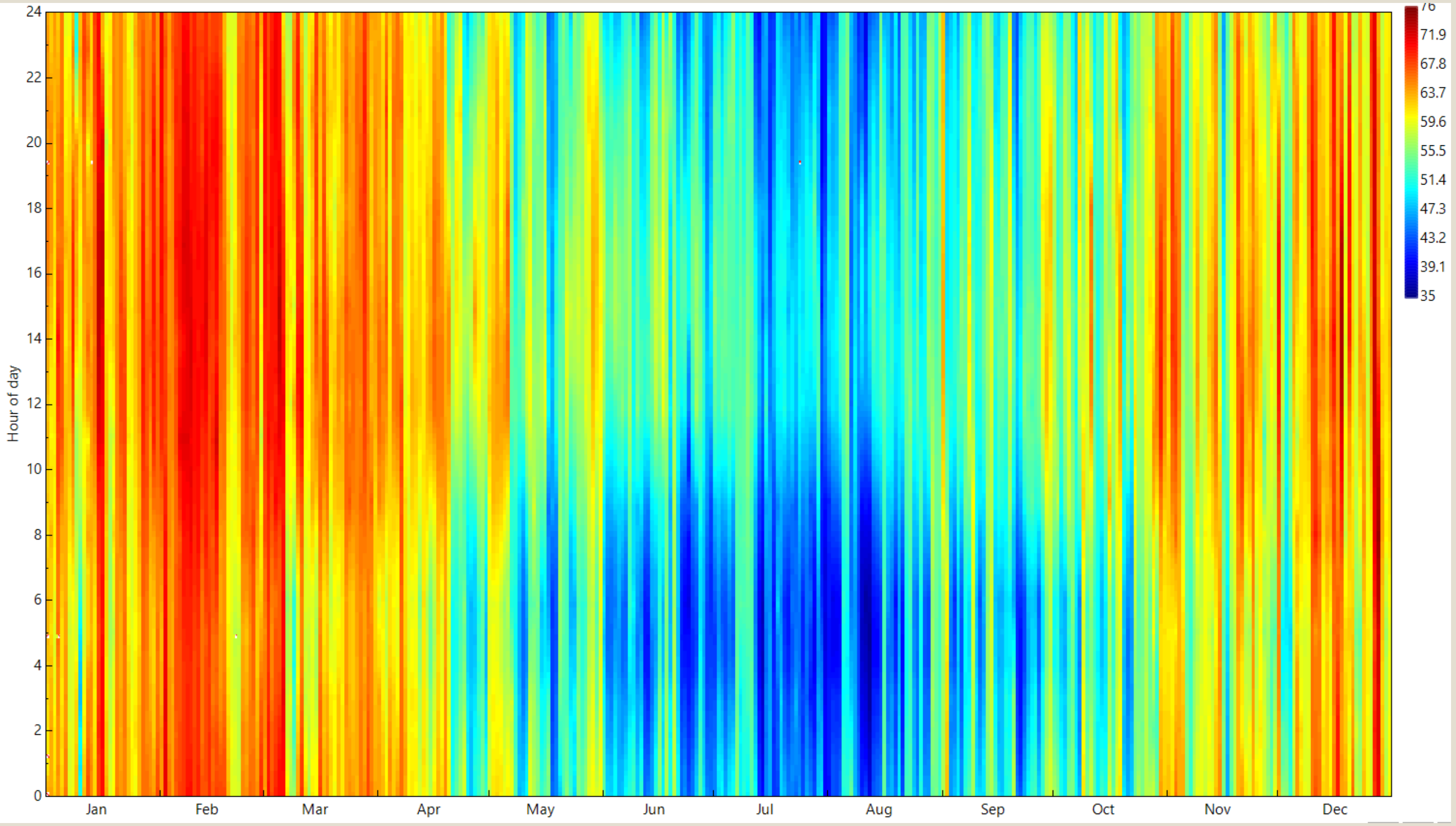
The program that is used in the benchmark model is the openstudio. And the reason why is because it can render the model easier, as well as its eligible to import outside

Environment run period zone (Heating)



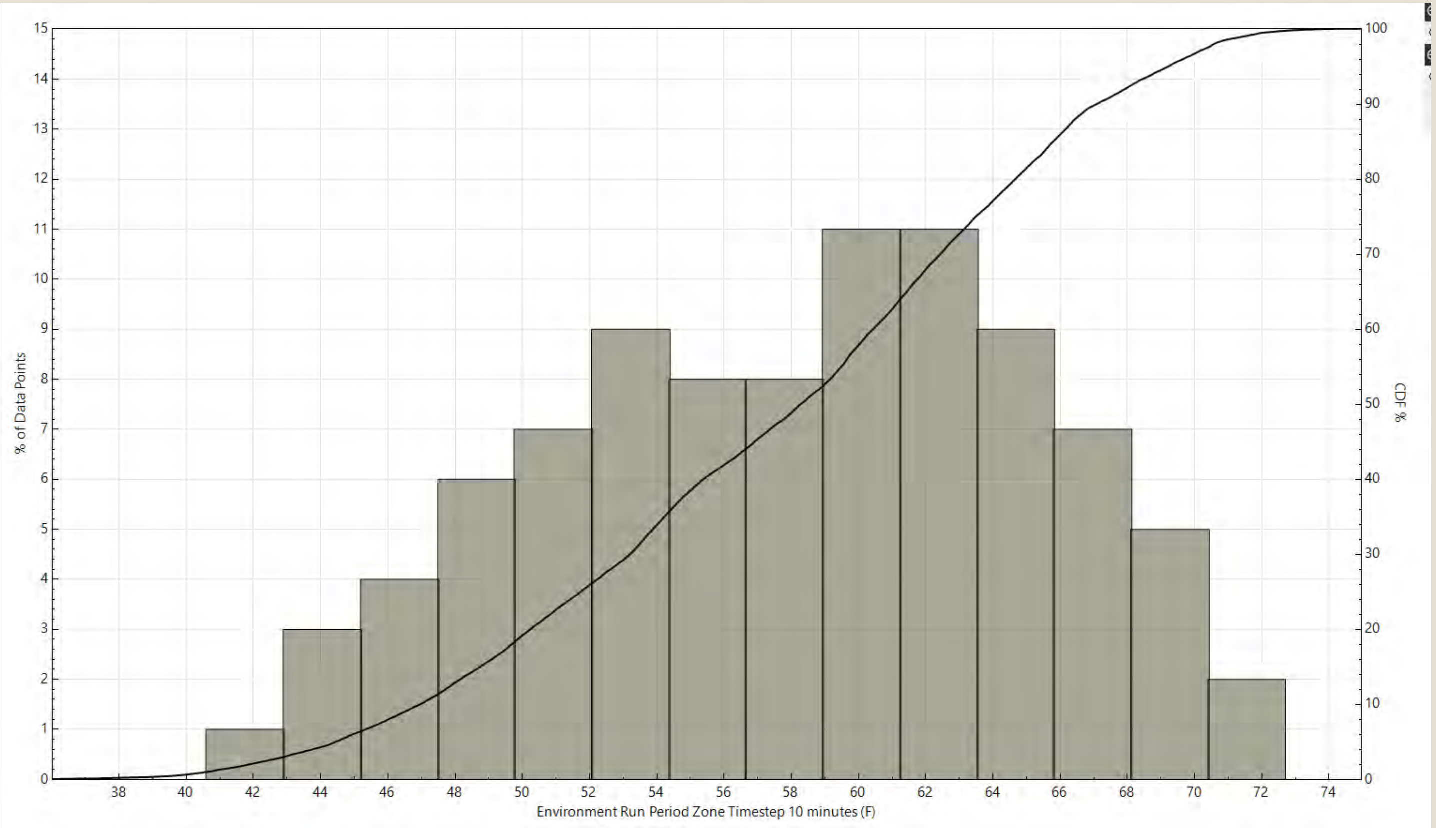


Heat map

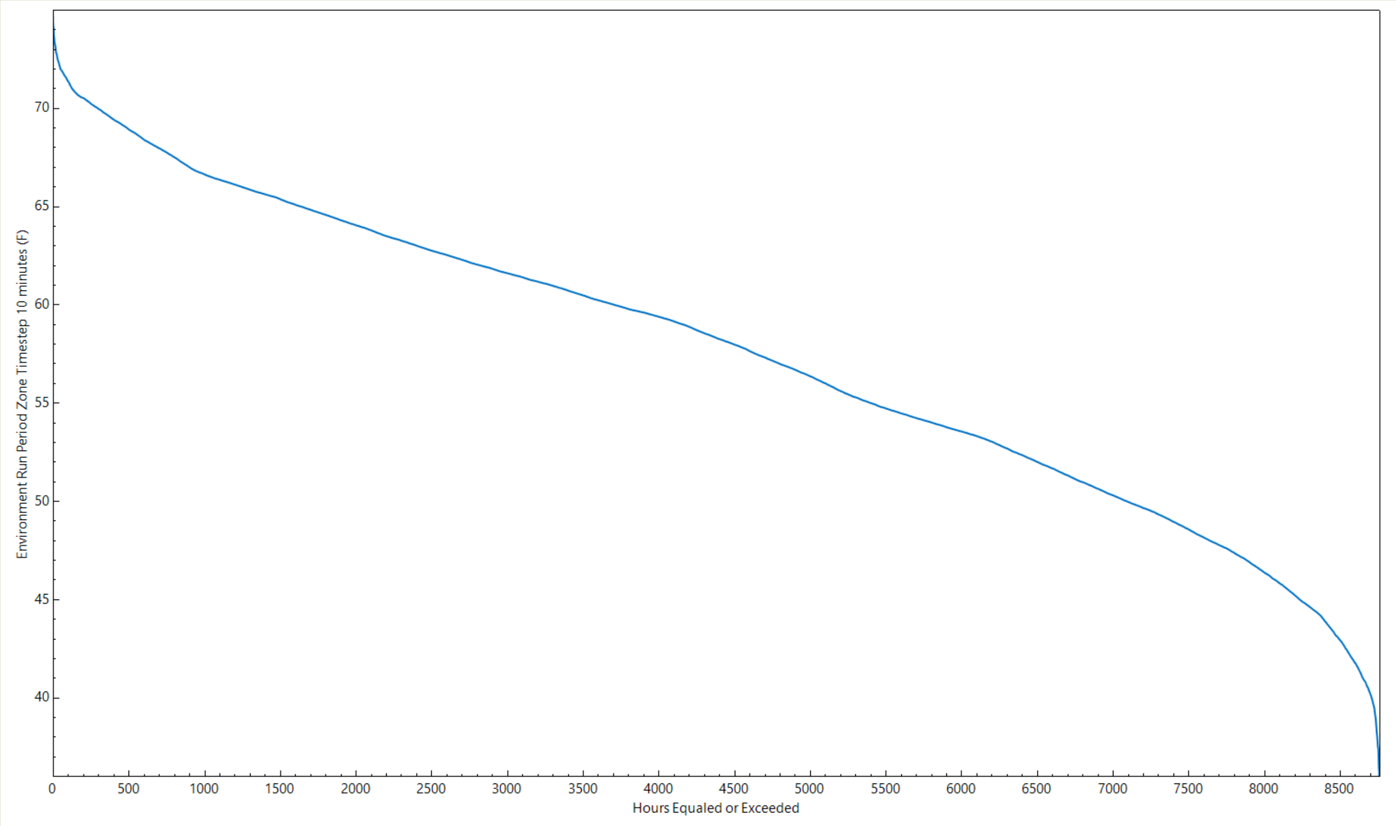


24
22
20
18
16
14
12
10
8
6
4
2
0
Hour of day
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
76
71.9
67.8
63.7
59.6
55.5
51.4
47.3
43.2
39.1
35

Histogram of the model



Duration curve



UNIVERSITY OF WOLLONGONG AUSTRALIA

AENG210: Building Physics and Building Services (S221)

Net Zero Energy Simulation Design Report

Supervisor:

Associate Professor Georgious Kokogiannakis

This report is presented as part of the requirement for the conferral of the degree:

Bachelor of Engineering

(Civil)

University of Wollongong

Faculty of Engineering and Information Sciences

October 2021

Word Count: 5466

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Following the acceptance of the schematic design submitted to council for the proposed development at 1-7 Farmborough Road, Unanderra, the design team were engaged by the client, Paul Knight, to proceed with the development of a design report detailing an investigation into the potential energy reduction approaches that might be adopted to achieve net-zero energy performance for the proposed retrofit. This was to be achieved using building simulation software to conduct various analysis on models of the proposed building.

The resultant outcomes of the conducted investigation were found to provide significant evidence to suggest the effectiveness of the various energy reduction strategies proposed. A justified baseline model along with three model iterations were produced and subjected to an annual simulation based on the Energy Plus engine.

Discussion around the validity and potential reasonings behind the findings has been included along with a conclusive recommendation as to the decision for the client to adopt the investigated sustainable strategies in the final design of the retrofit building.

1. DEVELOPMENT OF A BASELINE MODEL

The method utilised by the project team to validate and justify the likely performance improvements from the application of various NZE strategies was energy performance simulation. The first requirement of generating useful energy simulation data was the development of a robust baseline model from which energy performance results could be compared with.

Prior to proceeding with the development of this model it should be noted that it was of paramount importance to finalise the layout of the buildings. In accordance with advice from the design consultants, furniture was added to the AutoCAD dwg plans in an effort to highlight the need for any further layout alterations. Some final tweaks to the upper floor layout of the retrofit building were made; namely, a minor widening of the elevator access hall and the slight movement of the Northern walls of the office spaces towards the South to provide greater functionality to the shared flexibly work and amenity space. Refer to Figure 1 blow for an illustration of the finalised floor plan.

Figure 1: Adopted Retrofit Building Layout.

Another key action taken was altering the upper level of the proposed mixed-use development at Lot 102 to include four studio units of approximately 50 m^2 per unit, in contrast to the previously proposed dual unit, two-bedroom layout of approximately 100 m^2 per unit. Figure 2 below provides a comparison of the previously proposed layout and the finalised layout adopted for the simulation study.

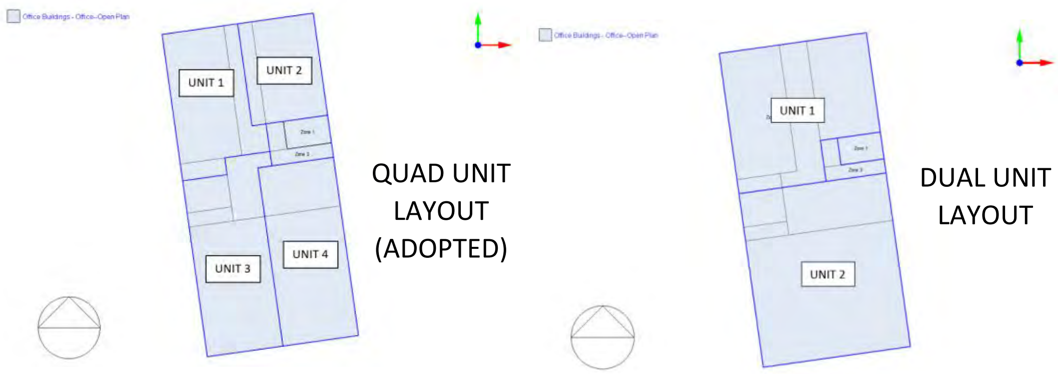


Figure 2: Mixed-Use Building Layout.

Following layout finalisation, the team then proceeded to the selection of an appropriate building simulation software. The two most applicable software packages determined were Open Studio and Design Builder, both of which are powered by Energy Plus – one of the leading building energy modelling engines that has been in development since 1997. The selection of Open Studio software was initially agreed upon as the preferred option among the team.

The initial effort made towards modelling the geometry of the retrofit building was performed using Sketchup, as it was believed that this would be directly compatible with Open Studio and some of the team members possessed existing knowledge of the SketchUp interface (refer to Figure 3 below).

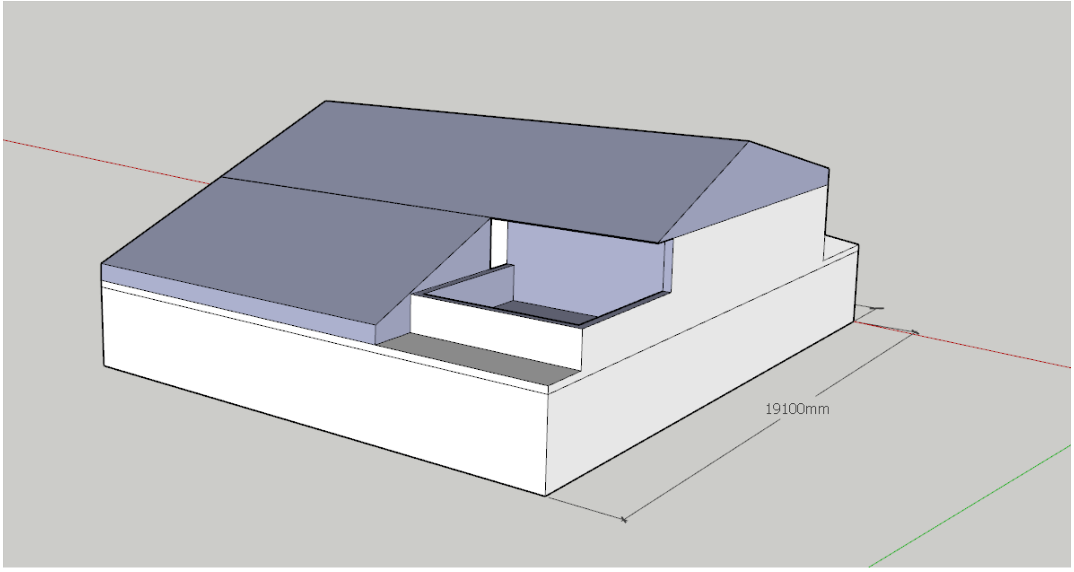


Figure 3: Initial model using SketchUp.

It was quickly discovered this method of constructing the geometry would be highly time intensive and an alternative more feasible method would be to construct the desired building geometry using a SketchUp plug-in developed specifically developed to allow direct compatibility with the Open Studio interface. This method was assisted through reference to materials provided by Professor Georgious Kokogiannakis. Figure 4 below shows an illustration of the model constructed using the Open Studio interface.

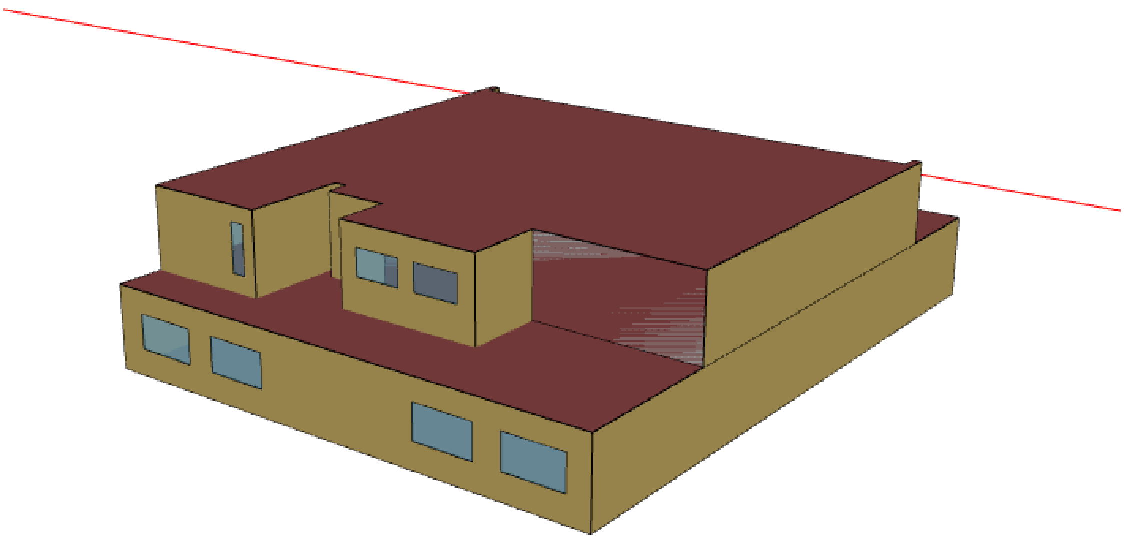


Figure 4: Geometry developed via the Open Studio SketchUp extension.

At this stage, the team witnessed the progress made by another team using the alternative software, Design Builder and decided it would be worthwhile to begin the development of a model using Design Builder in parallel with the Open Studio model. After a weekend of working with the Design Builder software, progress made on the Open Studio model was surpassed and the team collectively agreed to proceed in directly all efforts into the Design Builder model.

The building geometry developed using Design Builder can be seen in Figures 6 & 7. The layout of each floor was drawn in plan and orientated to suit the site conditions (approximately 8% anti-clockwise from North). Internal partitions could then be extruded to the desired height using an automated tool. A height of 2.7m was adopted for each floor of the building.

The roof pitch was calculated as 25 degrees falling to the South and 28 degrees falling North, through reference to Google Maps and simple trigonometry (refer to Figure 5).

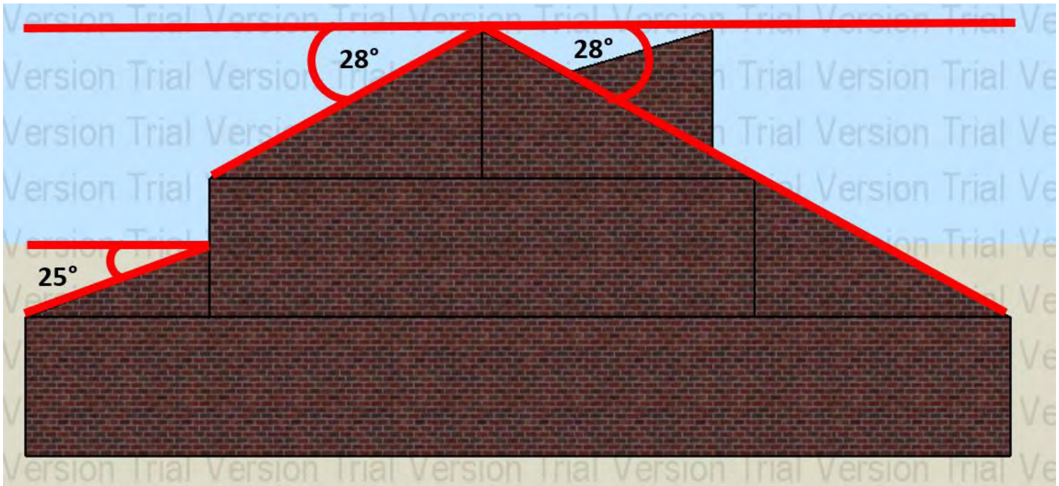


Figure 5: Determination of roof pitch.

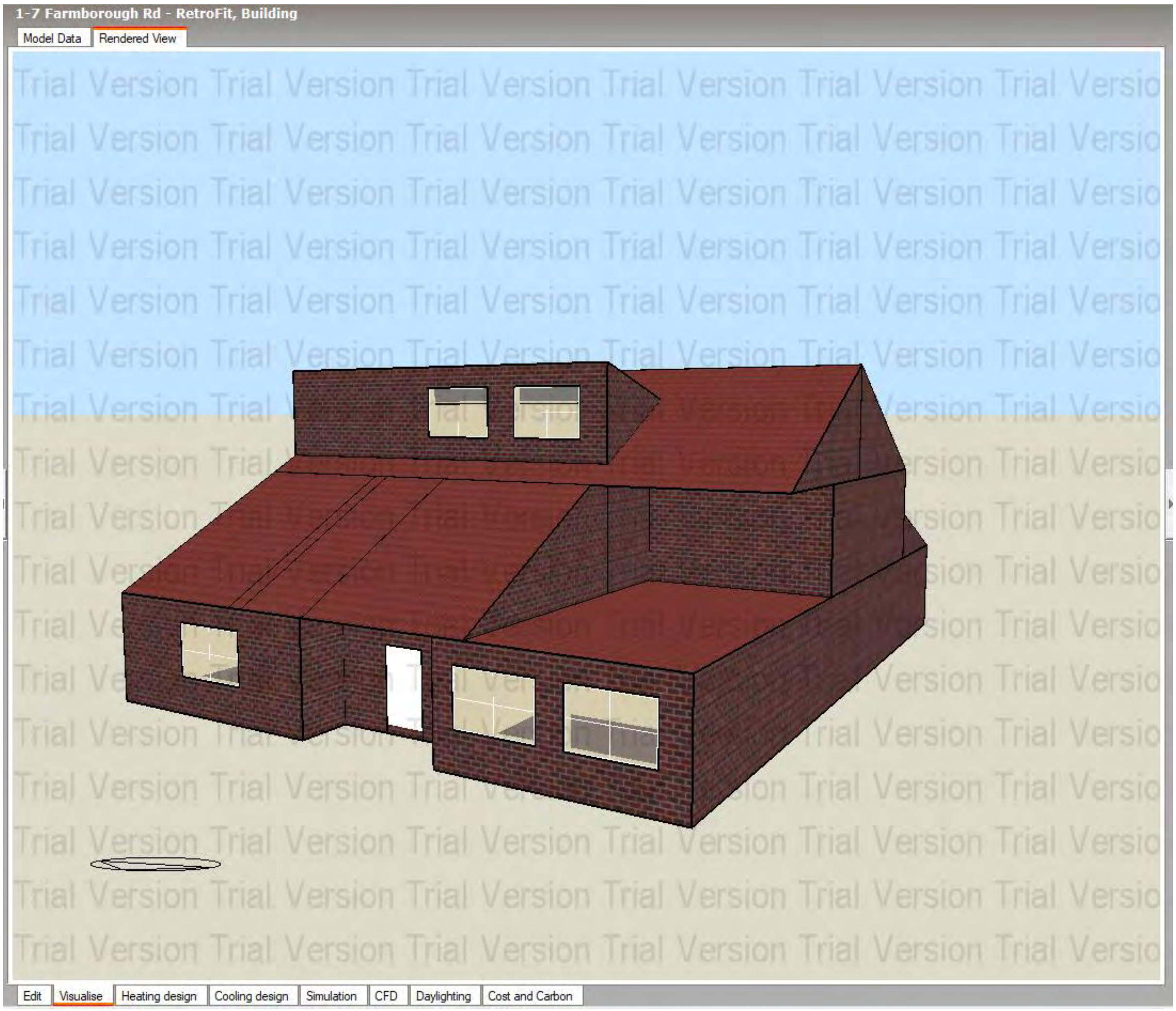


Figure 6: Geometry developed via Design Builder.

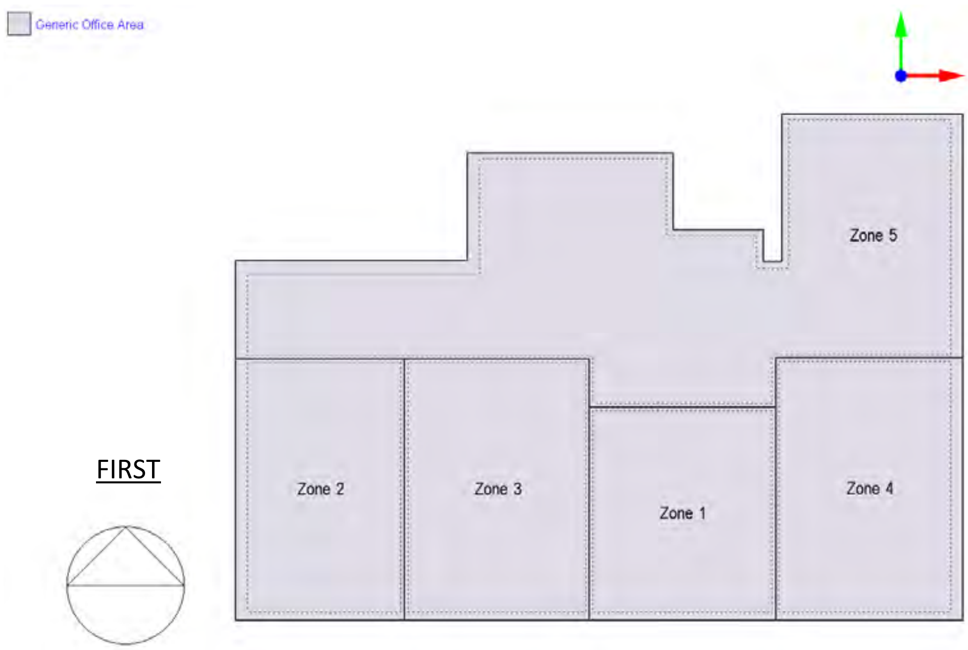


Figure 7: First floor layout developed via Design Builder.

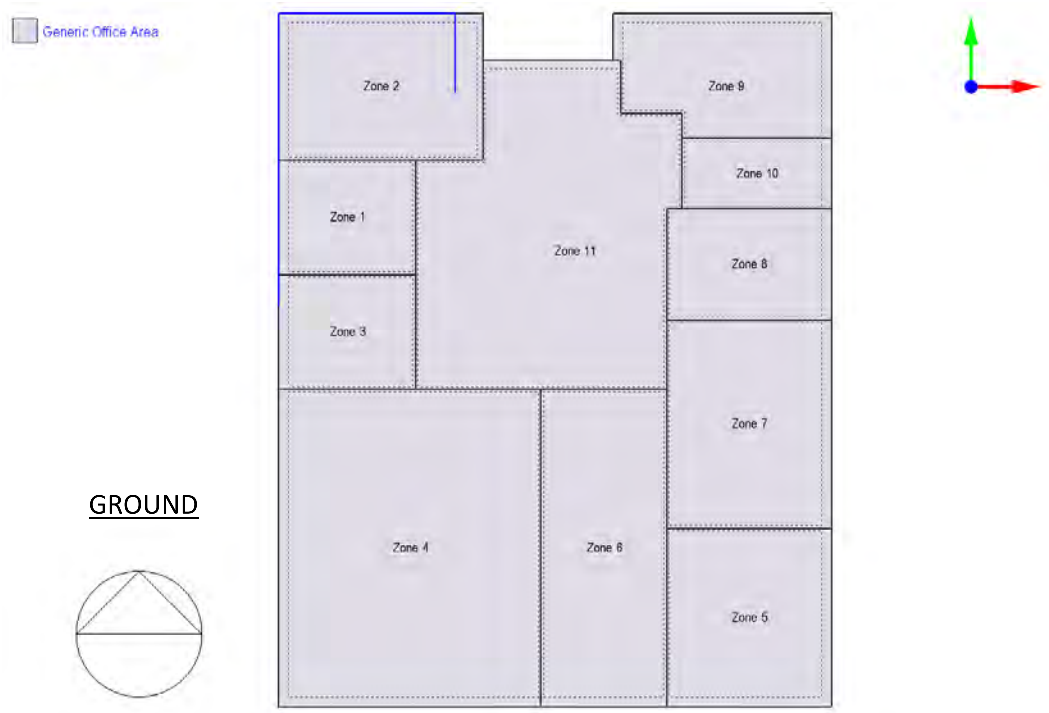


Figure 8: Ground floor layout developed via Design Builder.

In parallel with the above-described modelling, a desktop study into the parameters and assumptions necessary for the simulation of the baseline case was conducted. The adopted parameters and assumptions were compiled from a variety of sources, the primary of which being as follows:

- The National Construction Code (NCC) 2019: Volume 1
- Assessment Task 3 - Project Brief
- Climate.OneBuilding.Org 2021

A list of assumptions and parameters including the respective calculation methods used for the base case simulation has been provided as Appendix B to this report.

The most significant inputs parameters required were deemed as follows:

Weather data: An hourly weather data file from Kiama (Bombo) weather station was adopted, being the closest and most relevant location to that of the proposed site. This data was sourced from Climate.OneBuilding.Org 2021.

Power demand of the hot water system: Assumed as a constant demand of 2kW between the hours of 8am-8pm and 0kW at all other times (as specified by Assessment Task 3 - Project Brief). This value had to be translated into Design Builder in the form of power density value, which was calculated as 5.26 W/m^2

Water consumption rate: Calculated value of 0.243 L/ m^2-day based on Table 1, as specified by NREL 2011.

Normalised power density of lighting: Calculated as 4.068 W/m^2 based on power density tables provided by NCC 2019.

Normalised power density of office equipment: Value of 11.77 W/m^2 adopted based on general energy code provided by Energy Plus. Validity of this value was justified through comparison to information obtained from desktop research.

Occupancy density ratio: Calculated as 0.0660 people/m^2 based on assumption of 25 building occupants and 380 m^2 floor area of the building.

Infiltration rate: Value of 0.350 air changes per hour adopted based on *NCC 2019: Specification JVb – Section 2(d)*

Heating and cooling setpoint temperatures: A heating setback temp. of 20.0°C, cooling setback temp. of 26.0°C and ideal operating temp. of 23.0°C was adopted for the simulation. These values were based off specification guidelines provided by NSW SafeWork 2018.

Humidification and dehumidification setpoints: a maximum humidity of 70% and minimum humidity of 40% were adopted as setback values for the simulation, again guided by NSW SafeWork 2018.

Airflow and ventilation requirement: Calculated value of 4.3 L/s/person based on assumptions provided in Assessment Task 3 – Project Brief and calculations as presented in Appendix B.

Construction materials: The existing masonry structure was assumed to be of double brick construction with no insulation provided. Existing internal load bearing walls were assumed as single brick construction with plasterboard either side, again without insulation. To input these assumptions, the following material parameters were selected within the Design Builder program:

- External walls = Uninsulated Heavyweight Brick Wall
- Internal walls = 115 mm Single Leaf Brick (plastered on both sides)
- Ground slab = Uninsulated Heavyweight Slab On-ground
- Internal floor = 300 mm Concrete Suspended Slab
- Pitched gable roof = Uninsulated Heavyweight Tiled Roof

2. RESULTS OF BASELINE SIMULATION

The key results output from running a daily annual simulation on baseline model were as follows:

- A total annual energy demand of 59,209 kWh, consisting of 38,801 kWh of general electricity demand and 20,408 kWh heating / cooling demand.
- The cooling demand was found to be significantly greater than the heating demand as would be predicted for the site location.
- The peak energy demand for cooling occurred on January 21st with a value of 42.6 kWh for the day. Refer to Figure 11.
- The peak energy demand for heating occurred on June 21st with a value of 20.1 kWh for the day. Refer to Figure 12.
- Lighting and cooling were found to the two largest individual power consumers.

Figure 9 below presents the total annual breakdown of energy usage. Room electricity corresponds to the sum of energy consumed by all equipment and appliances. Figure 10 shows a more detailed individual fuel breakdown, shown monthly.

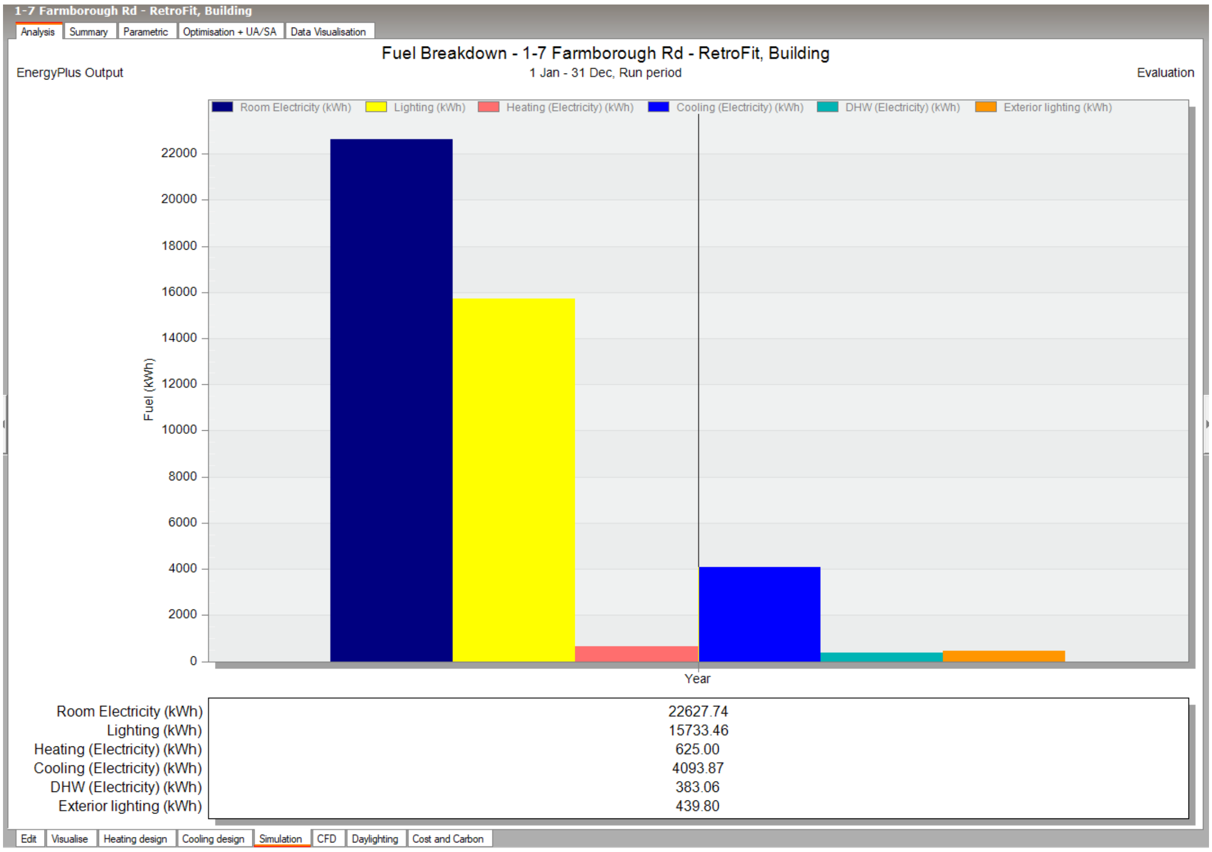
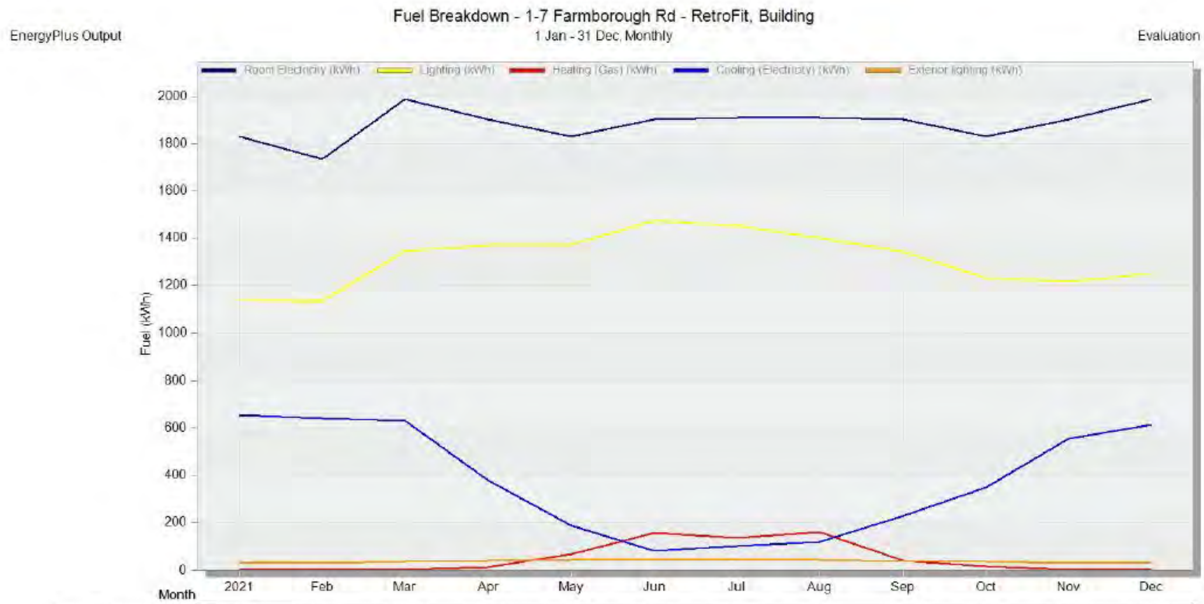
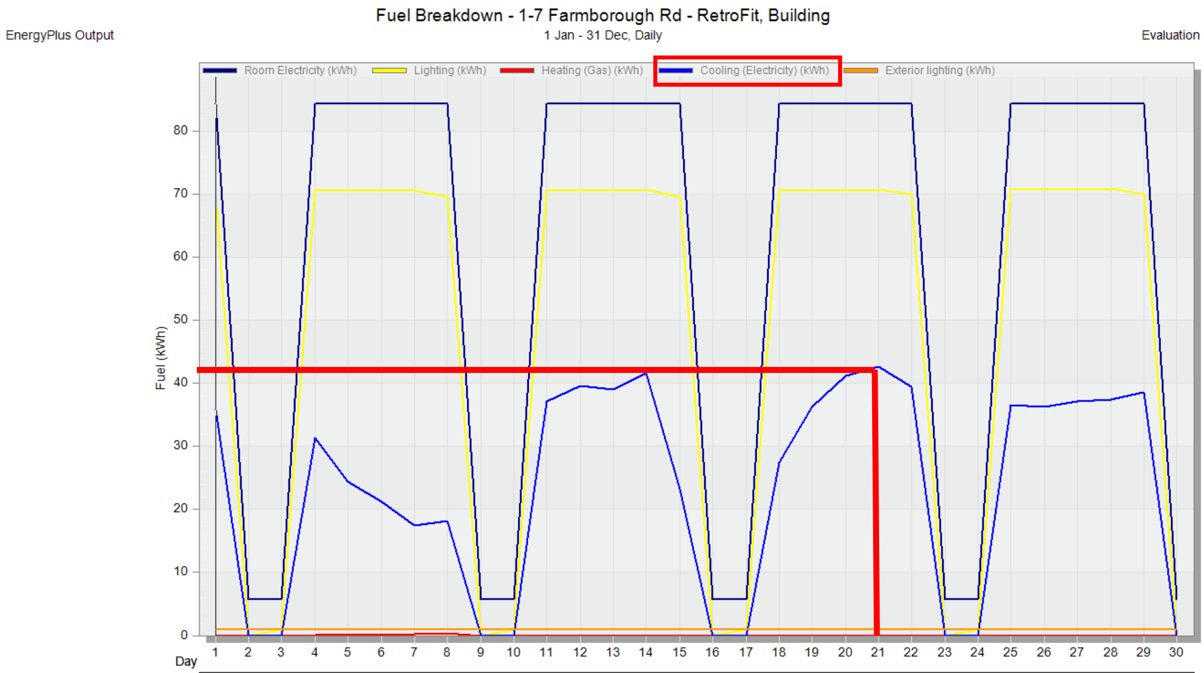


Figure 9: Total annual energy use breakdown



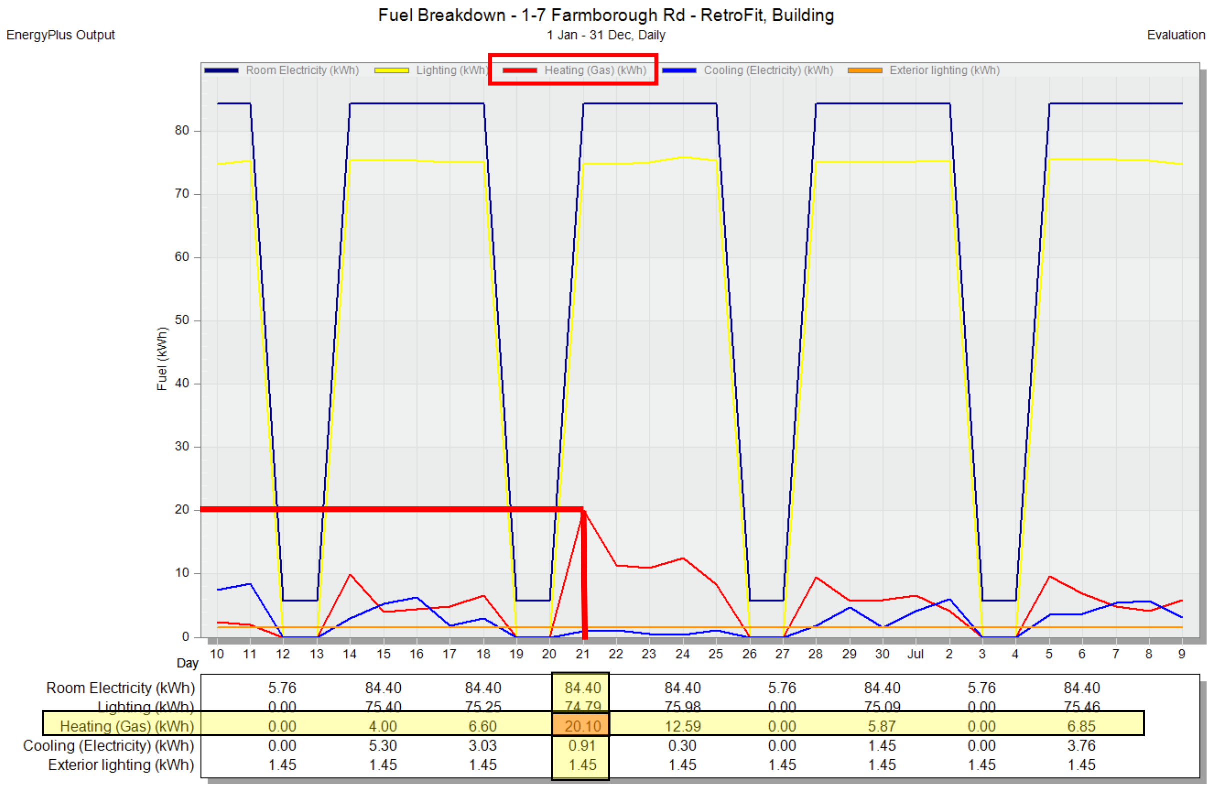
Month	2021	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Room Electricity (kWh)	1830.03	1734.10	1987.30	1902.90	1830.03	1902.90	1908.67	1908.67	1902.90	1830.03	1902.90	1987.30
Lighting (kWh)	1142.68	1131.32	1346.83	1371.01	1372.39	1471.62	1453.68	1400.63	1343.91	1234.04	1213.95	1248.63
Heating (Gas) (kWh)	1.11	0.41	0.79	10.43	65.89	155.25	136.42	158.55	38.98	15.59	1.05	1.26
Cooling (Electricity) (kWh)	656.49	641.99	631.77	379.19	188.63	80.64	100.31	119.53	229.41	347.68	555.03	613.20
Exterior lighting (kWh)	30.45	30.30	36.70	38.60	42.75	43.40	44.00	41.30	36.75	34.85	30.55	30.15

Figure 10: Individual fuel breakdown



Day	3	6	9	12	15	18	21	24	27
Room Electricity (kWh)	5.76	84.40	5.76	84.40	84.40	84.40	84.40	5.76	84.40
Lighting (kWh)	0.92	70.74	0.00	70.54	69.58	70.58	70.79	0.92	70.70
Heating (Gas) (kWh)	0.00	0.06	0.00	0.00	0.03	0.06	0.00	0.00	0.00
Cooling (Electricity) (kWh)	0.00	21.26	0.00	39.59	23.25	27.43	42.60	0.00	37.07
Exterior lighting (kWh)	0.95	0.95	0.95	1.00	1.00	1.00	1.00	1.00	1.00

Figure 11: Peak cooling load



Room Electricity (kWh)	5.76	84.40	84.40	84.40	84.40	5.76	84.40	5.76	84.40
Lighting (kWh)	0.00	75.40	75.25	74.79	75.98	0.00	75.09	0.00	75.46
Heating (Gas) (kWh)	0.00	4.00	6.60	20.10	12.59	0.00	5.87	0.00	6.85
Cooling (Electricity) (kWh)	0.00	5.30	3.03	0.91	0.30	0.00	1.45	0.00	3.76
Exterior lighting (kWh)	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45

Figure 12: Peak heating load

Hourly simulations of both a typical winter and typical summer day were also run on the model. The resultant graphs showing hourly usage can be seen in Figures 13 and 14 below.

Figure 13: Typical summer day energy demand breakdown (hourly)

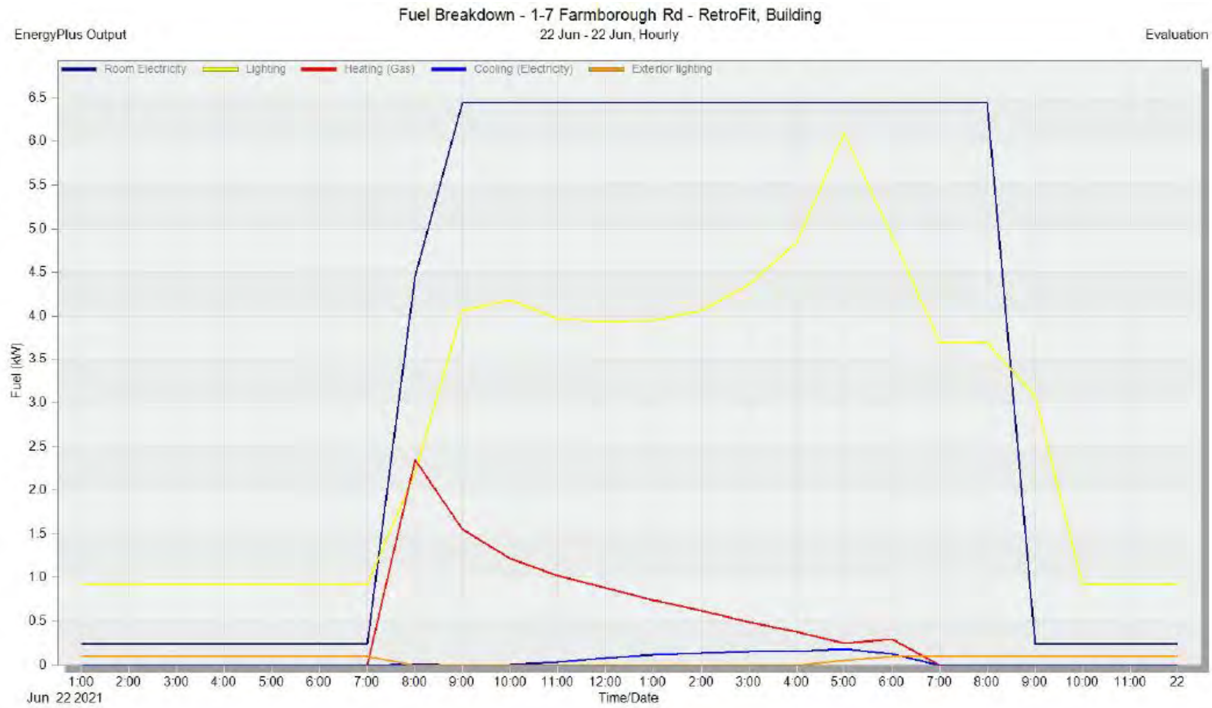


Figure 14: Typical winter day energy demand breakdown (hourly)

The total sum of energy demand required on both the typical summer day and typical winter day can be seen in Tables 2 & 3 below. Note that the demand on the summer day is significantly greater than that of the winter day (around 40% difference). This reflects the climate trends of the Wollongong region, whereby the winter temperature lows are relatively mild in comparison to the summer temperature highs.

Table 2: Total energy demand of typical summer day

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	463.03	1.22	1.22
Net Site Energy	463.03	1.22	1.22
Total Source Energy	1080.36	2.86	2.86
Net Source Energy	1080.36	2.86	2.86

Table 3: Total energy demand of typical winter day

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	195.31	0.52	0.52
Net Site Energy	195.31	0.52	0.52
Total Source Energy	627.56	1.66	1.66
Net Source Energy	627.56	1.66	1.66

3 DESIGN IMPROVEMENTS

3.1 PV Baseline Model

After establishment of the baseline model and collection of baseline simulation data, the addition of various energy improvement strategies could be simulated. Comparative analysis was then conducted to understand the energy performance improvements achieved by the respective strategies.

The first improvement to the baseline model, as specified by the project brief, was the addition of a standard photovoltaic solar system, limited to covering less than 60% of the building's total roof area. The details of the adopted PV system are presented in depth in Appendix B, however the basic features can be summarised as follows:

- A total of 274 solar panels installed, 130 (47%) of which facing South.
- Panel were modelled based on Renogy NRG-100D-L specifications (100W monocrystalline panels).
- The South facing panels were assumed to achieve the same efficiency as the North facing panels. It is proposed that this assumption is only feasible if polycrystalline panels are adopted for the South facing roof.
- 15% efficiency was adopted for simulation purposes as per brief requirements.
- The panels were angled at 34° from the horizontal, the optimal angle of solar incidence at the site location.

A visualisation after the adopted PV system can be seen in Figure 15.

Figure 15: Rendered visualisation of solar PV model

A simulation was run on the PV model to determine the total annual energy demands not met by the generation from the PV system over the course of a year. The results of this simulation were as follows:

- The total energy generated annually by the PV system was 46,064.5 kWh (refer to Table 4). From this a total of 43,349.2 kWh was deemed useable after the consideration of the 95% conversion efficiency (as shown in Table 5).
- The net energy demand not met by PV generation was found to be 15,859.5 kWh, as seen in Table 6.

Table 4: Annual PV energy generation

	Rated Capacity [kW]	Annual Energy Generated [kWh]
Photovoltaic	32.30	46064.46
Wind	0.00	0.00

Table 5: Electrical loads satisfied

	Electricity [kWh]	Percent Electricity [%]
Fuel-Fired Power Generation	0.000	0.00
High Temperature Geothermal*	0.000	0.00
Photovoltaic Power	46064.419	118.72
Wind Power	0.000	0.00
Power Conversion	-2281.54	-5.9
Net Decrease in On-Site Storage	-433.65	-1.1
Total On-Site Electric Sources	43349.234	111.72
Electricity Coming From Utility	6799.883	17.53
Surplus Electricity Going To Utility	11348.118	29.25
Net Electricity From Utility	-4548.24	-11.7
Total On-Site and Utility Electric Sources	38800.998	100.00
Total Electricity End Uses	38800.998	100.00

Table 6: Site and source energy demands

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	59208.74	156.52	156.52
Net Site Energy	15859.51	41.93	41.93
Total Source Energy	154739.68	409.06	409.06
Net Source Energy	17452.66	46.14	46.14

In terms of the times at which energy generation was not sufficient to meet the required demand, the generation was plotted on the same graph as the demand (as shown in Figure 16). The data suggest that the PV energy generated could not meet the demand across the period of March to August, a total of 6 months. A likely explanation for this decrease in generation is the decreased amount of solar intensity present during and either side of the winter season.

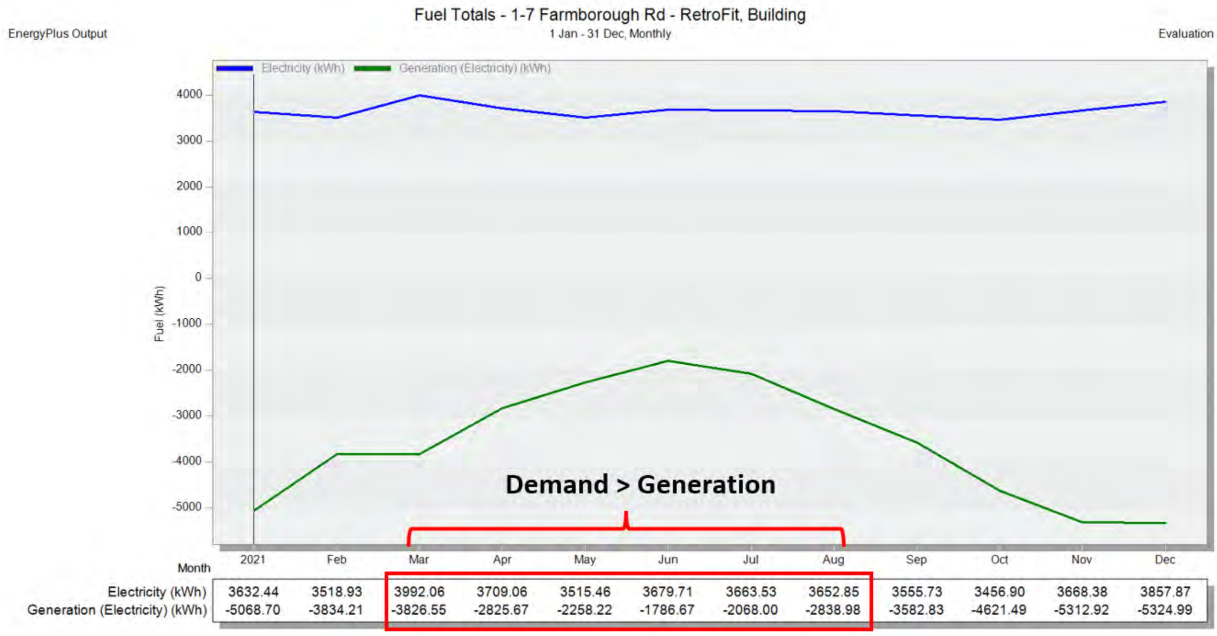


Figure 16: Comparison of annual energy generation and demand (monthly)

Graphs of the daily energy use profile on a typical summer and winter day were generated, similar to those generated from the baseline simulation, but with the addition of a line showing PV energy generation. These graphs are presented below as Figures 17 & 18 below.

Figure 17: Energy demand and generation profile on typical summer day

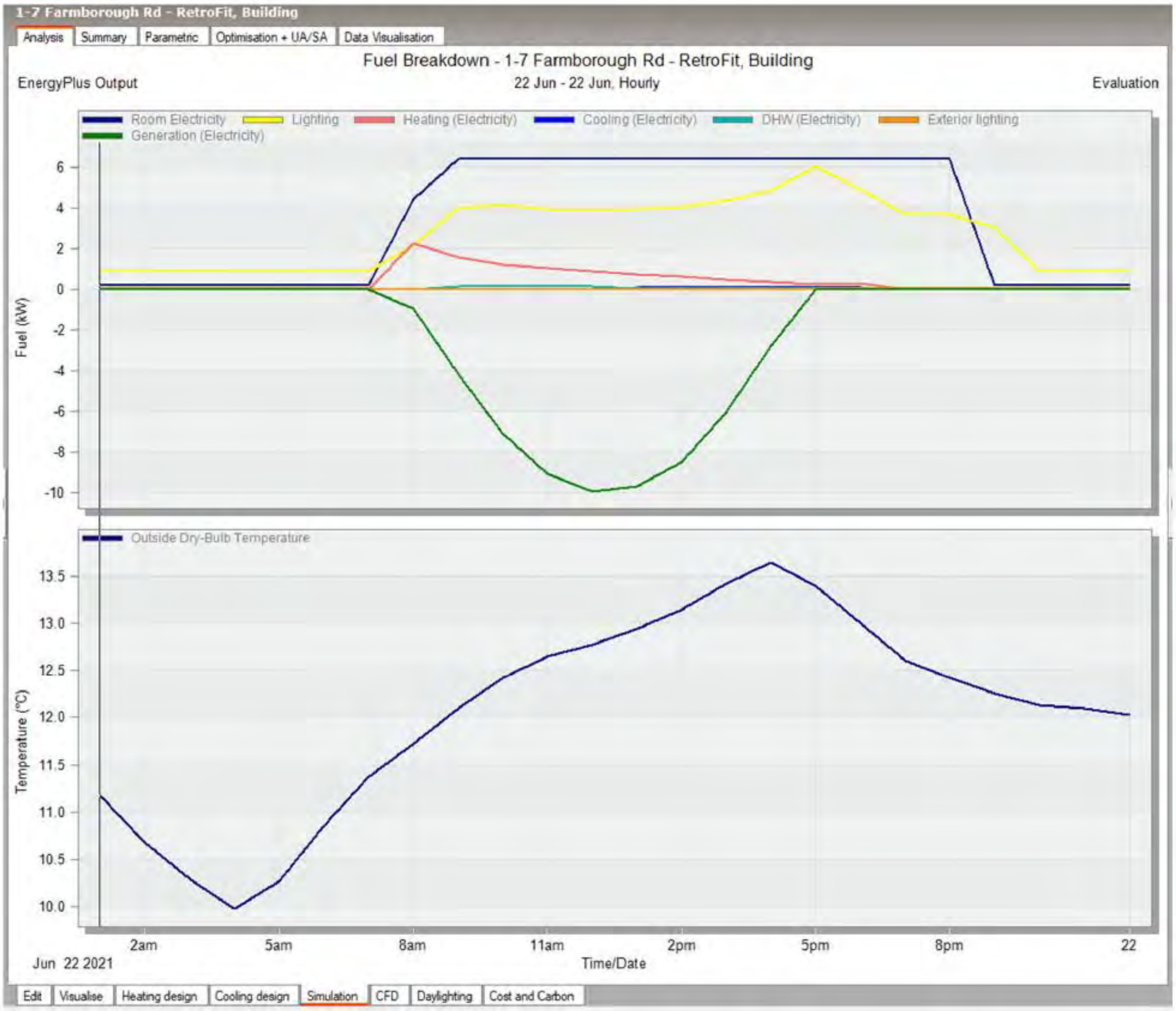


Figure 18: Energy demand and generation profile on typical winter day

3.2 Development of a Renewable Energy Fraction Analysis

Another way of quantitatively represent the energy performance of the building is the calculation of renewable energy fraction (REF) data at hourly intervals. The significance of a REF analysis is that provides supplementary information as to how close a building is to achieving net zero energy performance.

To find the REF at each hourly interval across the year, an hourly simulation first had to run on the PV baseline model. The renewable energy generated each hour could then be divided by the total energy demand for each hour to provide a total of 8760 individual REF values. The REF data was then averaged to determine the average REF across the year.

The initial calculation of average REF provided a value of 6.28 (refer to Table 7). This suggested that the PV system generated, on average, six times the amount of energy being demanded by the building, which we can be almost certain was not the case. The culprit behind this unreasonably high result is hypothesised to have been a significant set of outlying data that skewed the average.

Table 7: Average REF distribution (initial iteration)

REF = 0	0<REF<0.3	0.3<REF<0.95	0.95<REF<1.05	1.05<REF	Check Sum	Avg. REF Value
4530	424	1197	235	2374	8760	6.283011702

Firstly, it is known that during all hours of the year when the sun is not out, there will be no energy generated by the PV solar system. Hence, these values will act to move the average towards zero, effectively decreasing the energy performance of the building. It is however important to keep these values within the dataset as energy demands may still be present during dark hours throughout the year. There were also a set of extremely large REF values created from extremely low hourly demand values being paired with a significant renewable generation values.

Unfortunately, the author was unable to find a peer reviewed method of removing outliers from a REF dataset and thus had to resort to the use of logic and personal judgement.

The REF values of zero were assumed as redundant the intended use of the data. The REF analysis was defined as being intended for analysing how far the energy generation fell short of meeting demand on average during the significant hours of demand from the building i.e. during business hours – 8am to 8pm.

The author also decided that the inclusion of renewable generation values above 14.14 could be neglected since these values exceeded the maximum hourly demand across the entire year.

By removing the above-mentioned dataset (all zero values and values above 14.14) a revised average REF of 1.26 was determined, which started to seem more realistic (refer to Table 8).

Table 8: Average REF distribution (second iteration)

REF = 0	0<REF<0.3	0.3<REF<0.95	0.95<REF<1.05	1.05<REF	Check Sum	Avg. REF Value
0	424	1197	235	499	2355	1.256312085

Since this value was still greater than 1, adjustment was made to remove all REF values above 1.05, thus focussing the analysis only to hours in which the renewable energy generated did not significantly exceed the hourly demand. This can be justified as there is theoretically no use for this energy other than being fed back into the grid. The addition of a mean of storing energy on-site such as a battery would obviously change this, however.

A third average REF value of 0.58 was obtained following the removal of REF values above 1.05. This seemed like the most realistic value to try and improve and therefore was adopted as a target to improve upon.

Table 9: Average REF distribution (third iteration)

REF = 0	0<REF<0.3	0.3<REF<0.95	0.95<REF<1.05	1.05<REF	Check Sum	Avg. REF Value
0	424	1197	235	0	1856	0.579667551

It is worth noting that this dataset is only 1856 in size which happens to work out to approximately 36 hours per week when divided equally across a year. While this might seem small in size, it is reasonable to suggest that it is large enough to feasibly reflect the required hours of energy performance for this building.

3.3 Strategies Adopted to Achieve Net Zero

As highlighted in Section 3.1, the adopted PV solar system was not able to generate the necessary energy to meet the required energy demands for half of the year – specifically the six-month period between March and August (autumn and winter).

Interestingly, this period did not coincide with the period over which the HVAC demands were the greatest (during the spring and summer months). Referring to the energy demand and generation profiles over the course of the year (shown in Figure 16 above) it is evident that the reduction of generation incurred across the colder months of the year is not relatively reflected by the decrease in energy demand.

The reasons for this are not definitively evident, however based on personal judgement it is suggested that it is due to the heat gains during the summer months being able to significantly decrease the required heating demands. The thermal mass properties intrinsically provided by the building's double brick and concrete construction adds to the feasibility of this theory.

To reduce the discrepancy between the available annual renewable energy generation and the required annual energy demands, several energy consumption reduction strategies were applied the building model in order of their anticipated effectiveness.

3.3.1 Improved Lighting & Office Equipment

Since lighting and office equipment were established as the two greatest contributors to energy consumption, these were the first areas where reduction efforts were focussed. The rendered visualisation of this model is identical that of the solar PV model as shown in Figure 15 above.

As presented in the input parameter Figures provided in Appendix B.3, the following key modifications were made to the lighting and equipment power density input values:

- Office equipment power density ratio reduced from 11.77 W/m2 to 5.00 W/m2 in accordance with best practice guidelines.
- Normalised lighting power density ratio reduced from 4.068 W/m2-100 lux to 2.500 W/m2-100 lux in accordance with LED best practice template provided by Energy Plus software.
- Addition of linear lighting control, parameters as specified by LED best practice template.

These alterations resulted in a significant reduction in total annual energy demand, from 59,209 kWh to 39,104.55 kWh. As presented in Figure 19 below, the total energy consumed annually was simulated to be less than the total energy generated.

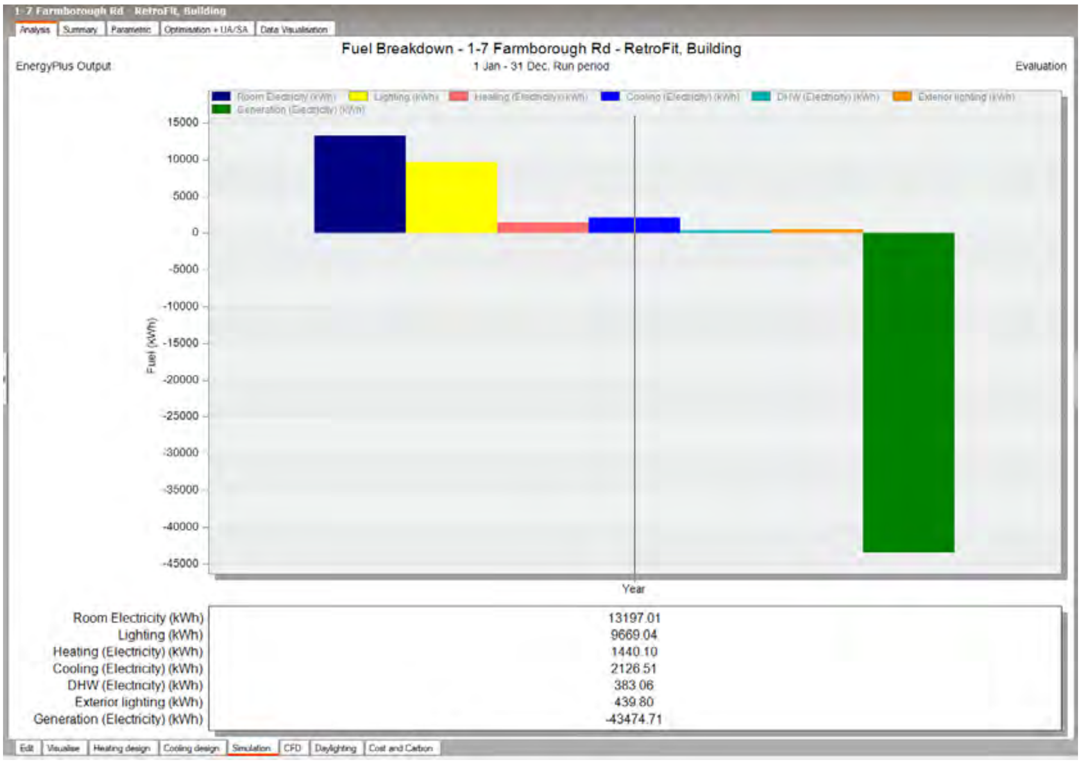


Figure 19: Total energy use breakdown including on-site generation (lighting model)

Further this primary finding, the sensible annual cooling loads were observed to decrease significantly from over 15,000 kWh to less than 7,000 kWh (refer to Figure 20). Accordingly, an increased sensible annual heating loads was observed, likely to balance the loss of heat gains previously provided by the less efficient lighting and equipment.

Looking at the graph of energy consumption against energy generation (as shown in Figure 21 below), the period over which energy generation falls short of demand was reduced from six months to only two months. The consumption reductions observed from implementing these strategies is significant and it is strongly advised that they be adopted in the final design of the building. While at first sight the fact that the total generation exceeds the total demand might suggest achievement of NZE, further analysis shows that this is not the case. Upon calculation of the average REF from this simulation (removing the same set of outliers as done previously), a value of 0.92 was found – a vast improvement on the baseline of 0.58 (refer to Table 10). A far larger dataset within the specified value range is also notable.

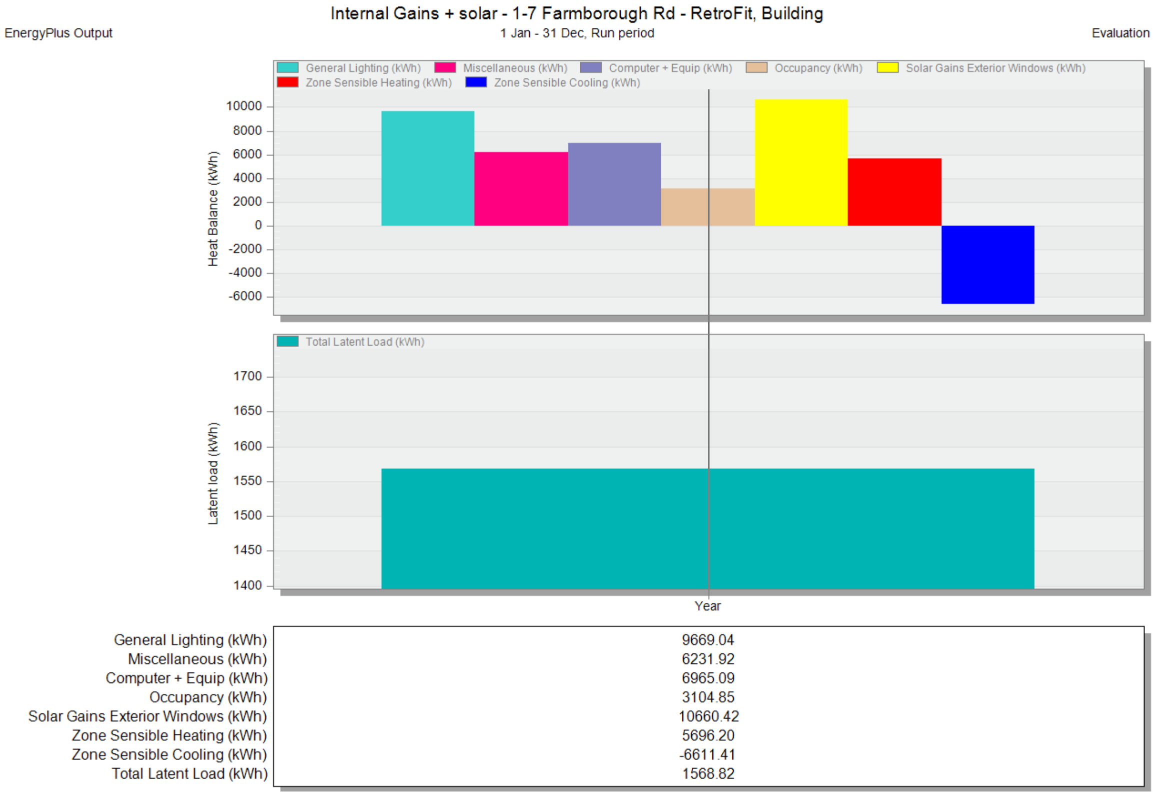


Figure 20: Internal heat balance (annual)

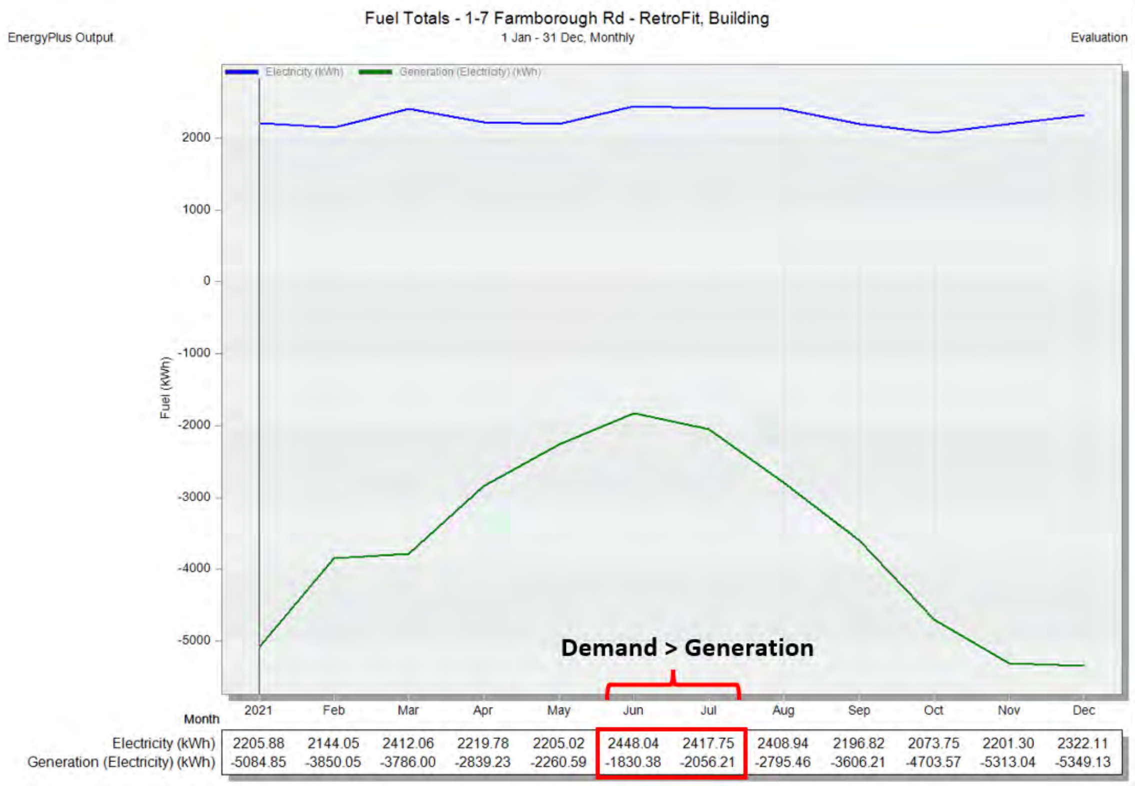


Figure 21: Comparison of annual energy generation and demand (monthly)

Table 10: Average REF distribution (Improved Lighting)

REF = 0	0<REF<0.3	0.3<REF<0.95	0.95<REF<1.05	1.05<REF	Check Sum	Avg. REF Value
0	151	1667	4883	0	6701	0.921554592

3.3.2 Passive Design Techniques

The next energy reduction strategy applied in order of priority was the implementation of passive techniques including adding insulation to the external walls, upgrading to double glazed windows, and improving the airtightness of the building envelope (in other words, decreasing the infiltration rate).

Another critical component to add during this iteration is a mechanical ventilation system. This was necessary to compliment the decreased heat transfer effect due to the reduced rate of infiltration. If mechanical ventilation was not to be added significant issues may have presented in the effectiveness of these strategies in terms of energy demand reductions. For a rendered visualisation of the rendered model refer to Figure 26 below.

As presented in the input parameter figures shown in Appendix B, the following key parameter values were adopted or altered:

- Construction materials upgraded to 'Best Practice – HeavyWeight' template provided by Energy Plus. The following key parameters were altered: external walls (refer to Figure 22), pitched roof – unoccupied (refer to Figure 23).

- Infiltration rate reduced from 0.450 ac/hour to 0.050 ac/hour.
- Windows upgraded to 6mm double glazed with 13mm air gap (standard).
- Aluminium window frames (with thermal breaks).
- Window shading added: MicroLouvre fixed external louvre system.
- HVAC system upgraded to 'Best Practice' template provided by Energy Plus and modified according parameters specified in brief. Fixed COP of 4.0 adopted for all components.
- Heating unit changed from gas to electricity.
- Mechanical ventilation with heat recovery added. Specification as per best practice template provided.

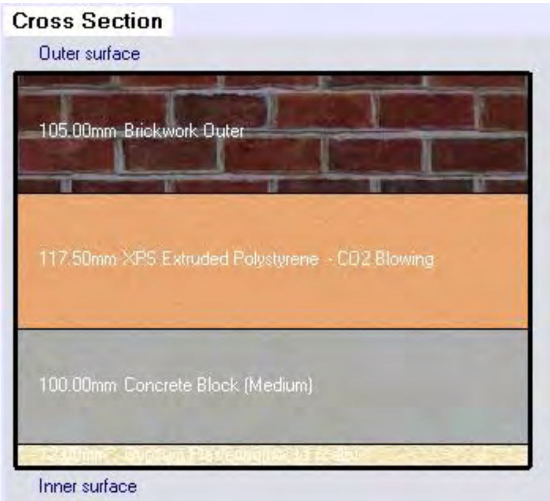


Fig. 22: External wall cross-section

Fig. 23: Pitched roof – unoccupied cross-section

The key results collected from this simulation were as follows:

- Total annual energy consumption further reduced from 39,105 kWh to 33,842 kWh (improvement of approximately 15%).
- Reduction of annual sensible heating and cooling demands to 165.49 kWh and 1486.28 kWh respectively (refer to Figure 24 below).
-

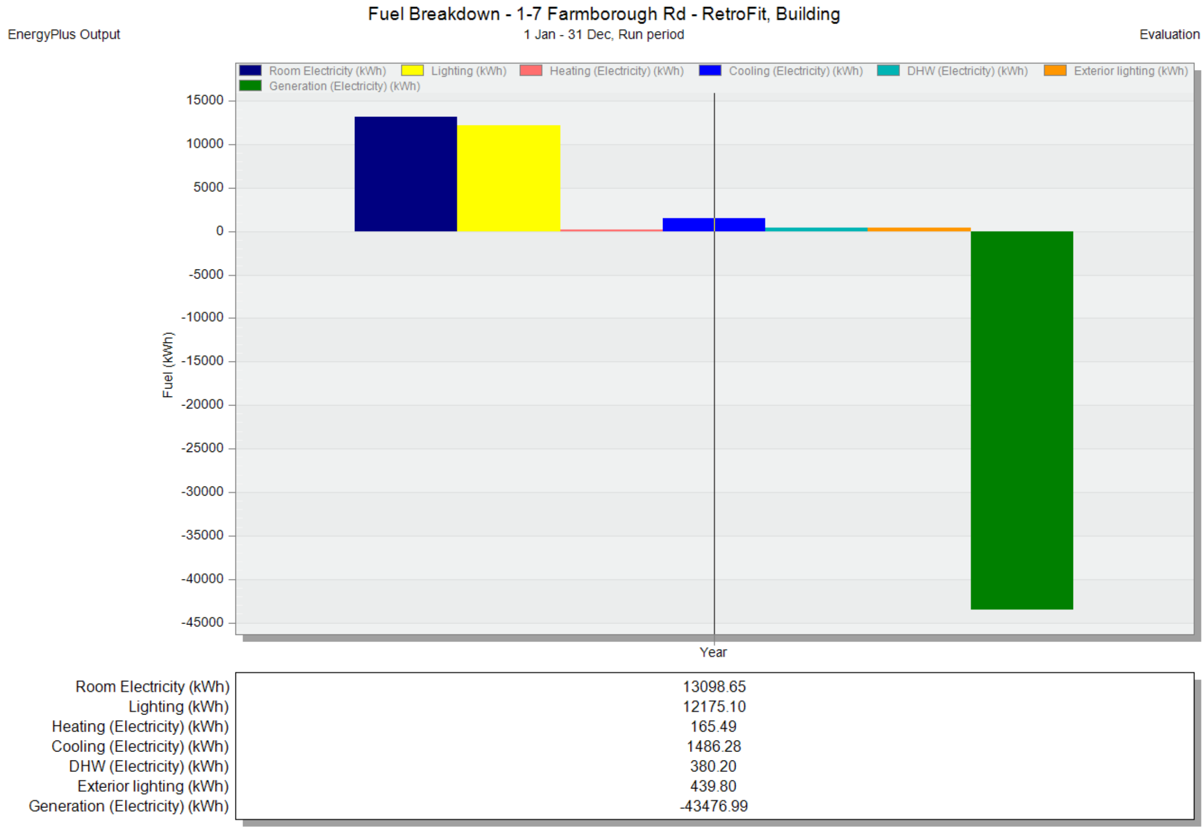


Figure 24: Total energy use breakdown including on-site generation (passive model)

At first, this model presents as having achieved NZE as suggested by the values in Table 11.

Table 11: Site & source total energy (Passive model)

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	33841.46	90.13	90.13
Net Site Energy	-9635.5	-25.7	-25.7
Total Source Energy	95598.02	254.61	254.61
Net Source Energy	-42093.6	-112.1	-112.1

Upon analysis of the annual energy demand vs generation graph (refer to Figure 25), it was found that generation during the two months of June and July still falls slightly short of the required demand. This is not to rule out that the building can still be classed as NZE, however promoted further investigation into the data.

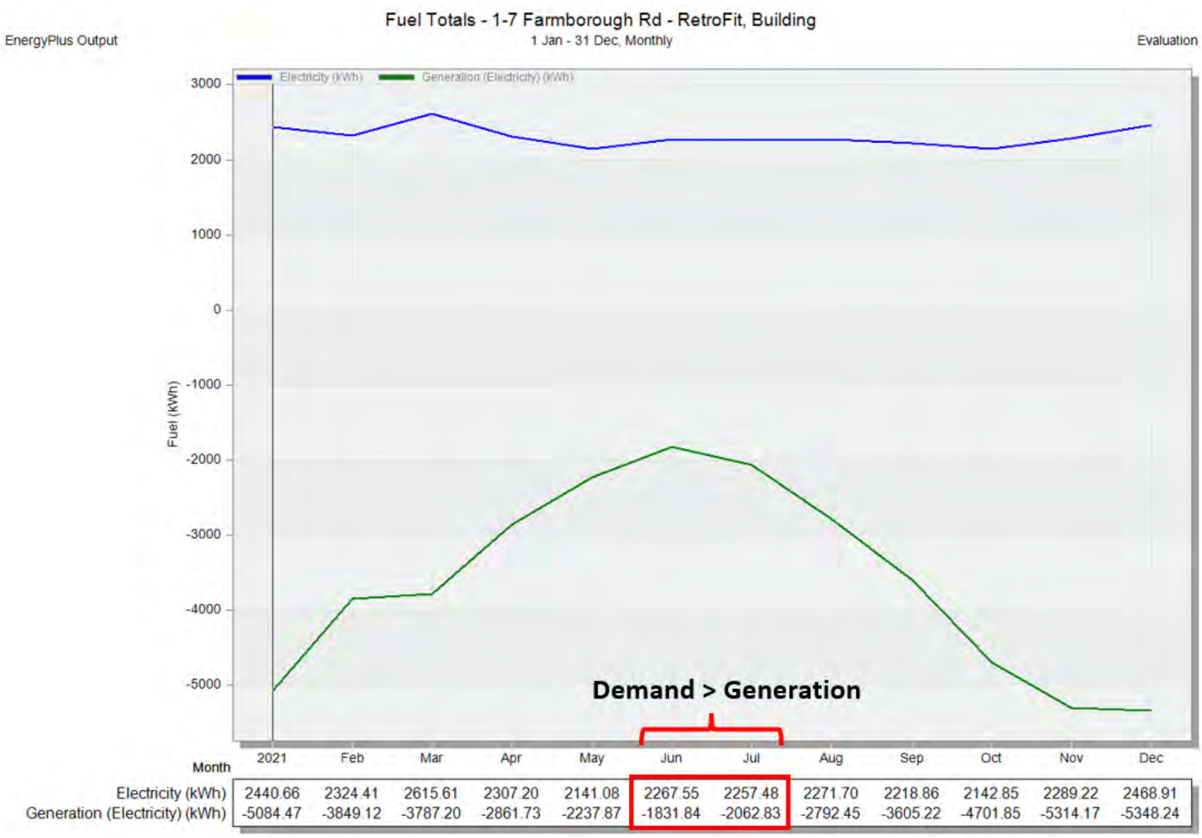


Figure 25: Comparison of annual energy generation and demand (monthly)

The average REF value determined for this simulation was 0.95, a 0.03 improvement over the previous simulation. Refer to Table 12 below for the distribution breakdown.

Table 12: Average REF distribution (Passive Strategies)

REF = 0	0<REF<0.3	0.3<REF<0.95	0.95<REF<1.05	1.05<REF	Check Sum	Avg. REF Value
0	115	714	5896	0	6725	0.948349325

Figure 26: Rendered visualisation of passive model

The achieved annual net energy balance of **-9,635 kWh** combined with the REF value of **0.95** for the above model has been deemed by the author to be an acceptable NZE design for the purposes of this investigation.

One potential improvement that could be made to the design is the implementation of an additional minor on-site renewable energy source to assist in generating extra energy during the winter months of June and July where generation is predicted to dip below the energy demands.

3.4 Shading & Sunpath

The angle at which direct sunlight enters the building at various times of the day can have immense impacts on various thermal performance parameters. As illustrated in Figures 27 & 28 below, the incidence of the sun can vary significantly through out the course of the year, having a higher angle of incidence in summer and low angle of incidence in winter. It is important to design with the influence of the sun at the forefront of key decisions such as positioning and orientation of windows, design of shading structures (e.g. louvres, trees, screens etc.) and angling of solar panels to achieve maximum generation.

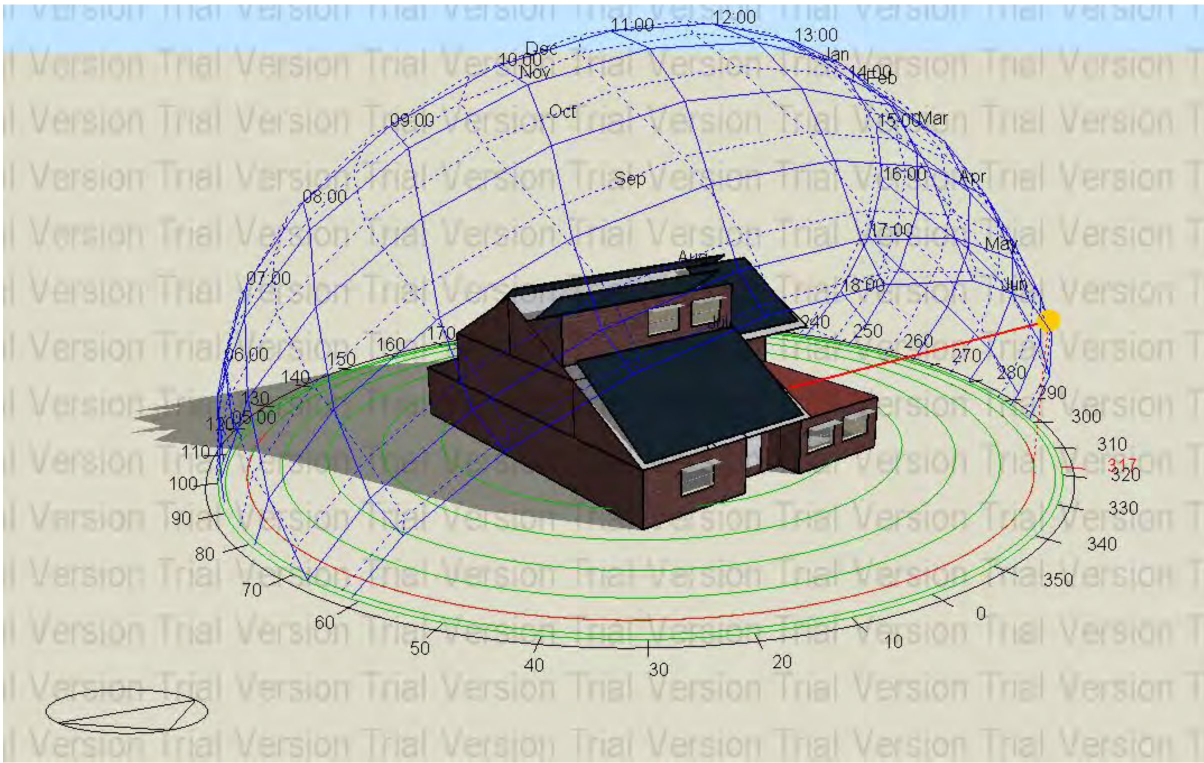


Figure 27: Shading diagram for 15th July 2021 at 15:00

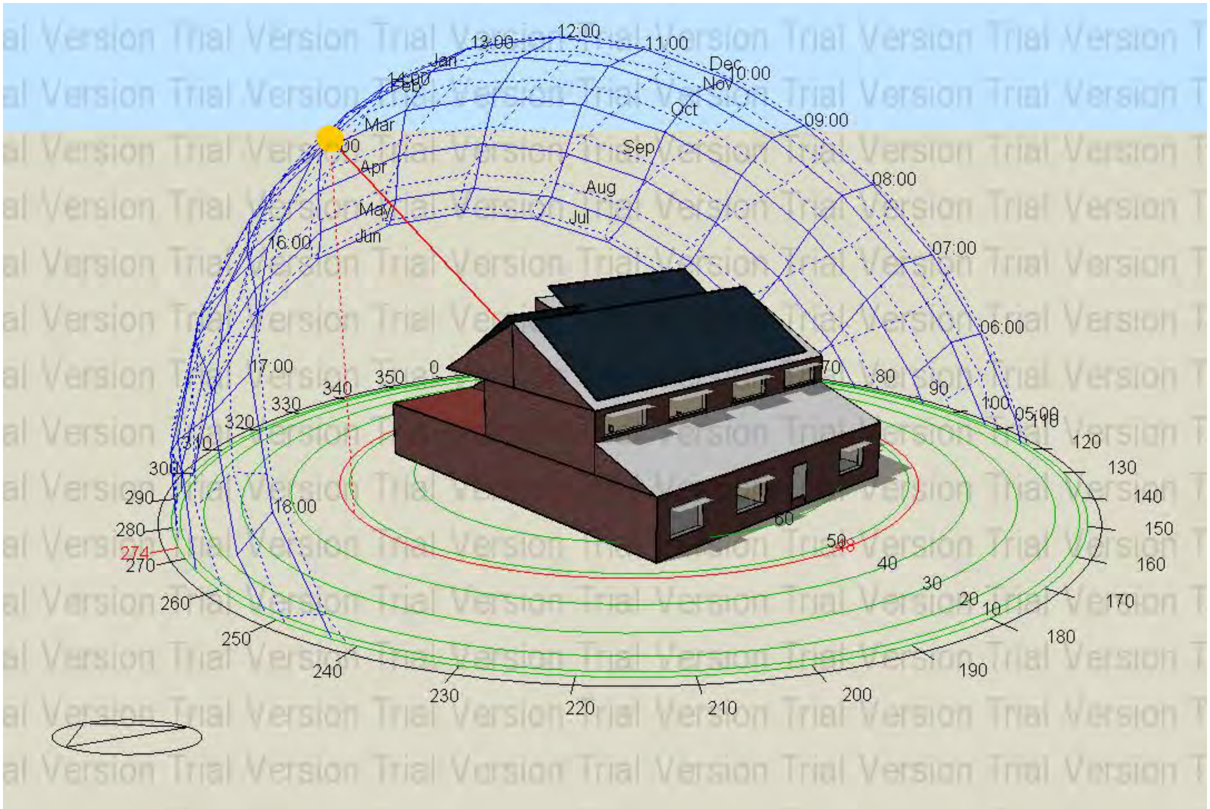


Figure 28: Shading diagram for 15th December 2021 at 12:00

3.5 Statement of Maintained Functionality

It is hereby certified that the initially specified functionality of the building's design shall not be impacted by the proposed strategies for achieving net-zero energy performance. The most significant risk to functionality degradation occurring has been deemed as the insulation of the external walls. The proposed solution to avoid loss of floor space is the filling of the air cavities between the double brick walls with an unbonded fibrous glass insulation, blown into the cavities with specialised equipment.

4. DISCUSSION AND CONCLUSIONS

The primary findings from the simulations conducted on the various building models included the identification of the baseline annual energy requirements for the building, the peak site energy demand, the annual net-energy discrepancy following the implementation of a standard photovoltaic solar system, the determination of an average renewable energy fraction and the predicted energy reducing effects of applying various sustainable strategies.

The baseline energy performance data was found to reflect an acceptable value for the size, location, and functions of the building. The annual cooling demand was found to be significantly larger than the annual heating demand for the baseline model. A possible explanation of this situation could be the thermal mass properties intrinsically provided by the building's double brick and concrete construction. This would be of benefit in the winter when the thermal mass could collect heat during the day and gradually release this heat. In contrast, during the summer this effect would work against the effort for achieving indoor thermal comfort, collecting, and distributing solar gains across the occupied hours of the day.

Considerable improvements were achieved to the balance of the heating and cooling loads, particularly following the adoption of passive design strategies in the third iteration of the simulation.

Initially, a net discrepancy of 15,859.5 kWh was determined for the baseline case with the addition of a standard PV solar system. The quantity of energy generated was also found to not meet required demand for 6 months of the year, which was also reflected in the poor average REF value of 0.58.

Net-zero energy balance for the building was achieved during the second iteration of the model, whereby improved lighting and office appliances were adopted. The total energy generated surpassed the total energy demands by 4,370 kWh, however generation still fell below generation during the two darkest months of the year. The REF value calculated for the model adopting improved lighting and appliances was found as 0.92, a marked improvement over the baseline case.

Finally, the third iteration of the model, whereby a series of passive strategies were implemented, output even further improved performance results. The total energy balance was further improved to reach a 9,635 kWh surplus of energy generation across the year. The same issue was seen in the generation during June and July slightly dipping below required demand, however the discrepancy was significantly reduced. The REF value of the third iteration was found to be 0.95, closely approaching the target value of 1.

In conclusion, the investigations of this report have demonstrated the significant impacts that certain sustainable construction strategies and technologies can provide to the energy performance of the proposed retrofit development at 1-7 Farmborough Road, Unanderra. It is hence strongly advised to proceed with the inclusion of the above-described design alterations moving forward with this project.

It is also proposed that the issue relating to the slight underperformance of the PV solar system during the months of June and July be rectified by one of two means:

- A minor improvement to the generation of the PV solar system which could be achieved either through the adopting panels of higher wattage of greater efficiency.
- The integration of an on-site battery such as a Tesla Powerwall or similar allowing the storage of renewable energy that may be accessed during periods of under-generation from the panels.

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APPENDIX A: REFLECTION ON STANDARDS

Reflecting on the implications of the design solutions presented in this report to key government certification schemes such as NABERS and GreenStar, it is of the author's opinion that the process through which such certification frameworks are setup is not yet highly applicable to the size and budget of the development that has been proposed.

Moving into the future, as the adoption of sustainable building strategies becomes more widely accepted in construction practice, it shall follow that the constraints currently present around the economics and adaptability of such schemes will decrease. As evidenced by large scale industry wide restructuring in the past, the acceptance of energy reducing construction practice, such as those presented in this report, will gradually filter their way through the hierarchy of scale from the largest, most high-profile projects, finally to the smallest scale sectors of industry such as private residential and commercial projects.

The two most important factor influencing the speed at which this process will progress are education and the shifting of market perspective. In terms of education, it is of paramount importance that the upcoming generation of construction professionals are well informed as to the significance of the work required to push the industry in the direction required for the necessary advancement of sustainable practice. Professionals working across all sectors of industry must unite their efforts collaboratively to mitigate the unavoidable frictions that come from such movements in practice.

The perspective of the market the other key player in the transition of practice, governing the distribution of major investments and paving the path to producing the next generation of trusted practice and methodology, particularly around engineering.

APPENDIX B: SIMULATION PARAMETERS & ASSUMPTIONS

Appendix B.1: Baseline Model Input Parameters

Activity Template	
Template	**Generic Office Area**
Sector	B1 Offices and Workshop businesses
Zone multiplier	1
☑ Include zone in thermal calculations	
☑ Include zone in Radiance daylighting calculations	
Floor Areas and Volumes	
Occupancy	
☑ Occupied?	
Occupancy density (people/m2)	**0.0660**
Schedule	**Copy of Office_OpenOff_Occ**
Metabolic	
Clothing	
Comfort Radiant Temperature Weighting	
Air Velocity	
Contaminant Generation and Removal	
Holidays	
DHW	
Consumption rate (l/m2-day)	**0.243**
Environmental Control	
Heating Setpoint Temperatures	
Heating (°C)	**23.0**
Heating set back (°C)	**20.0**
Cooling Setpoint Temperatures	
Cooling (°C)	**23.0**
Cooling set back (°C)	**26.0**
Humidity Control	
RH Humidification setpoint (%)	40.0
RH Dehumidification setpoint (%)	70.0
Ventilation Setpoint Temperatures	
Natural Ventilation	
Minimum Fresh Air	
Fresh air (l/s-person)	**4.300**
Mech vent per area (l/s-m2)	**0.300**
Lighting	
Target Illuminance (lux)	400
Default display lighting density (W/m2)	**4**
Computers	
Office Equipment	
☑ On	
Power density (W/m2)	11.77
Schedule	Office_OpenOff_Equip
Radiant fraction	0.200

Miscellaneous	
☑ **On**	
Power density (W/m2)	**5.26**
Schedule	**Copy of Office_OpenOff_Equip1**
Fuel	1-Electricity from grid
Fraction lost	0.000000
Latent fraction	0.000000
Radiant fraction	0.200000
Catering	
Process	

Figure B.1: Baseline Activity Input Parameters.

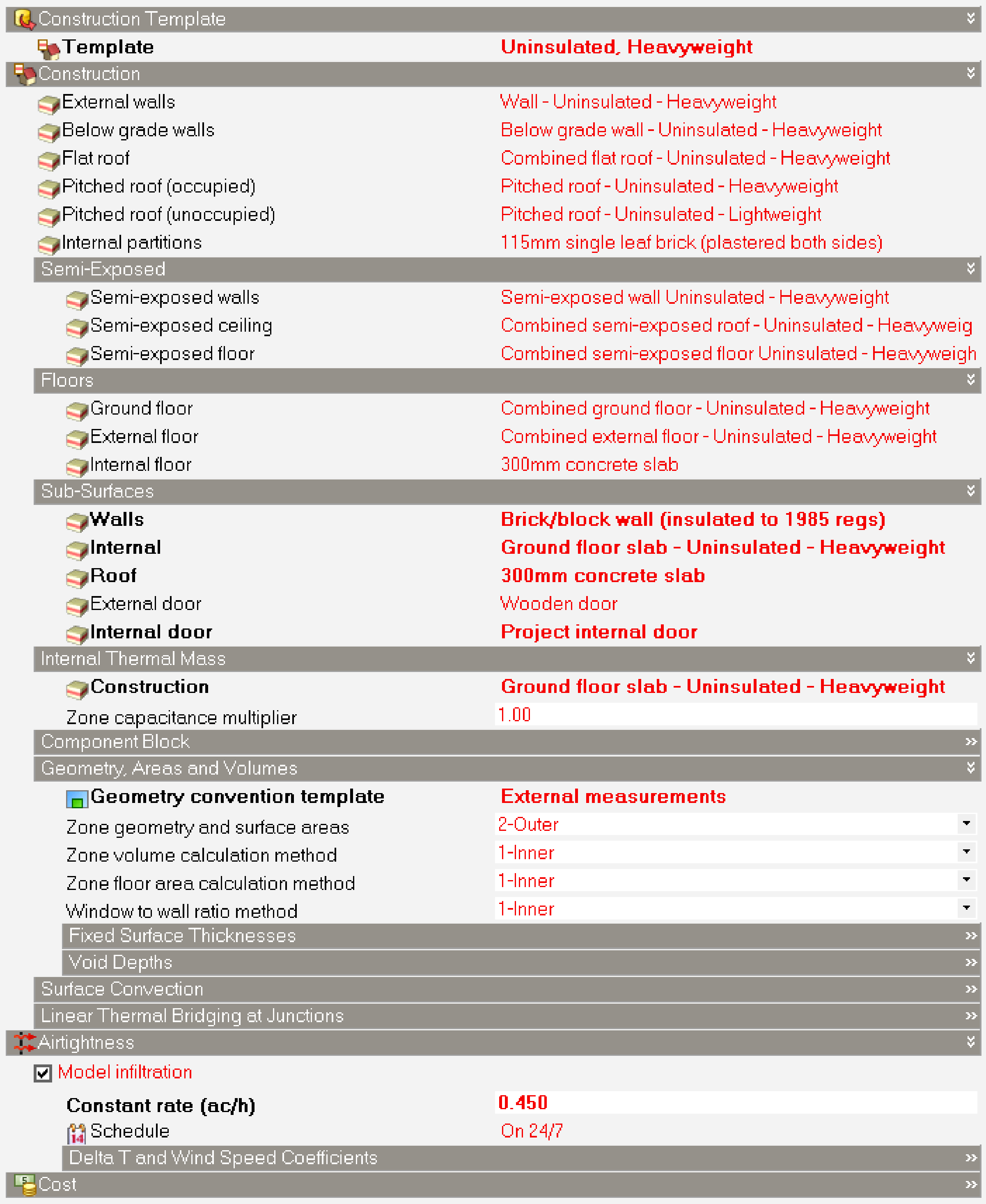


Figure B.2: Baseline Construction Input Parameters.

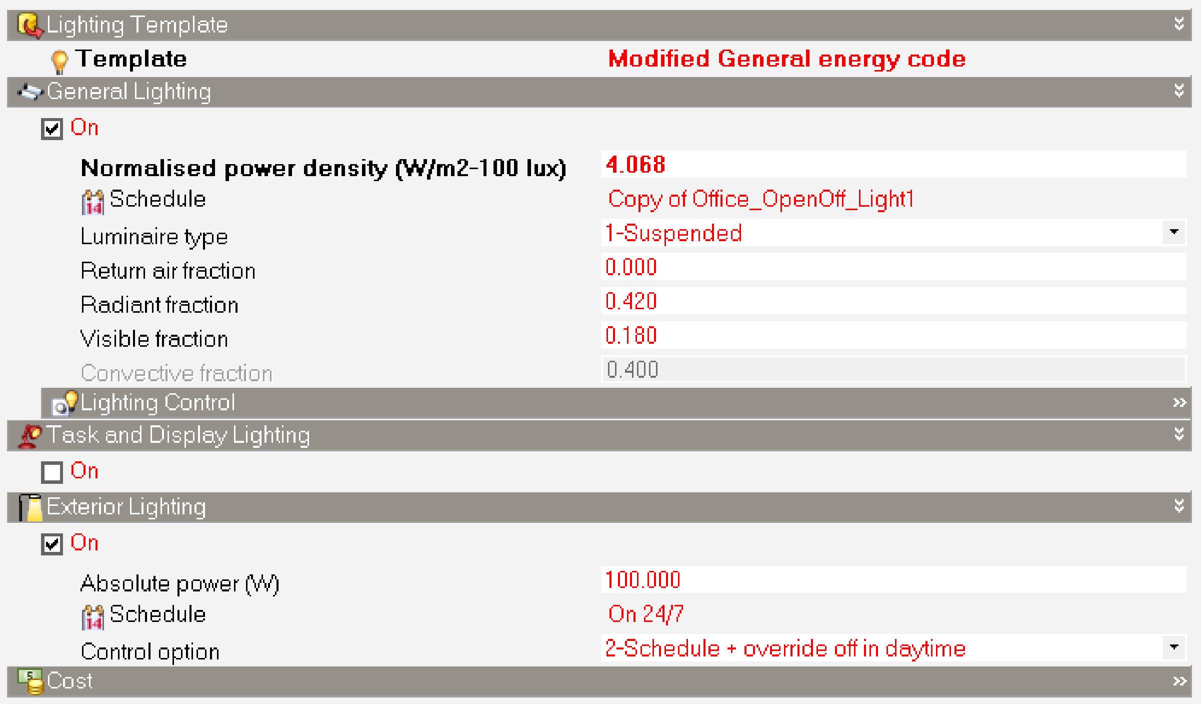


Figure B.3: Baseline Lighting Input Parameters.

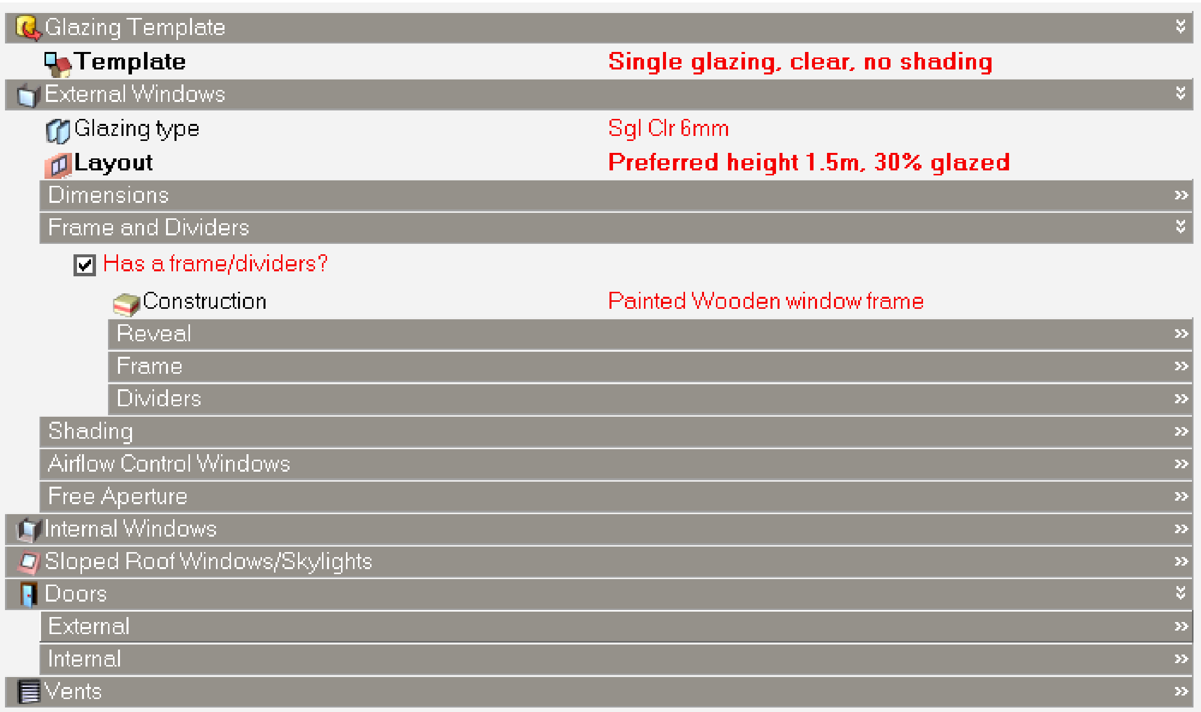


Figure B.4: Baseline Glazing Input Parameters.

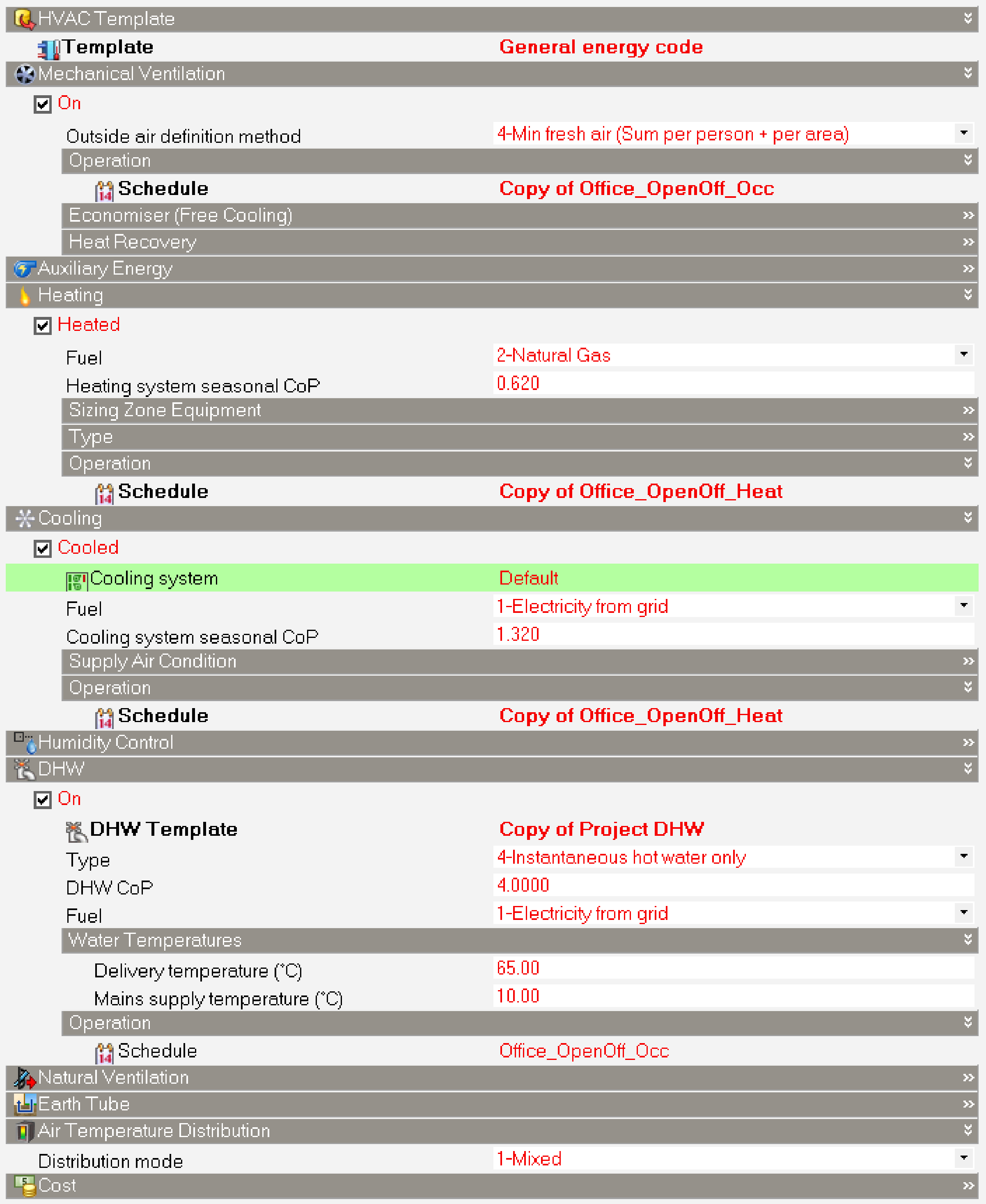


Figure B.5: Baseline HVAC Input Parameters.

Appendix B.2: PV Model Input Parameters

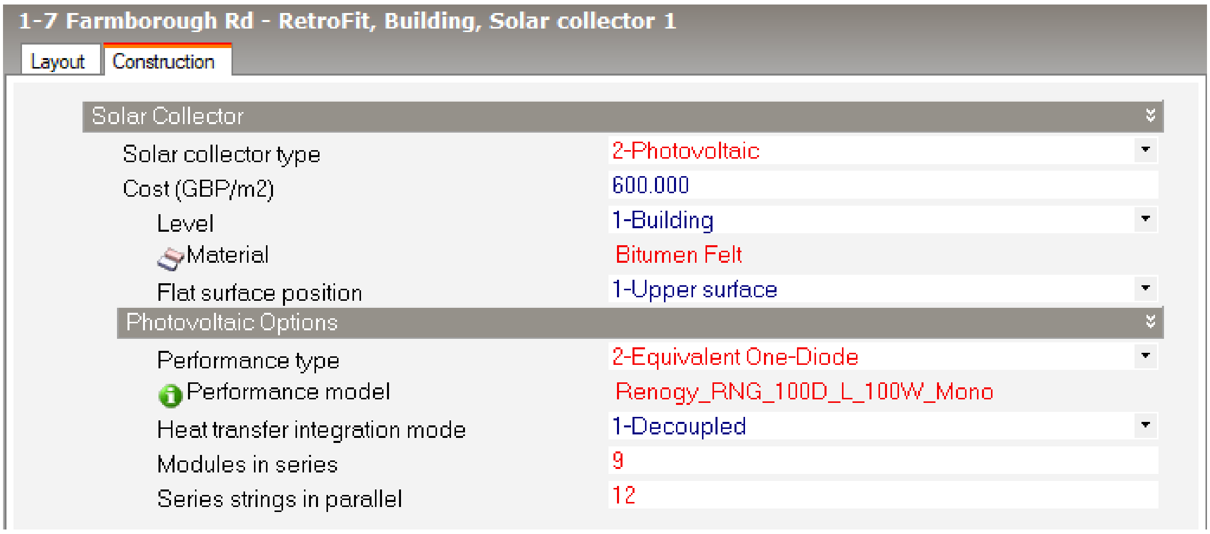


Figure B.6: Solar Array 1 Input Parameters.

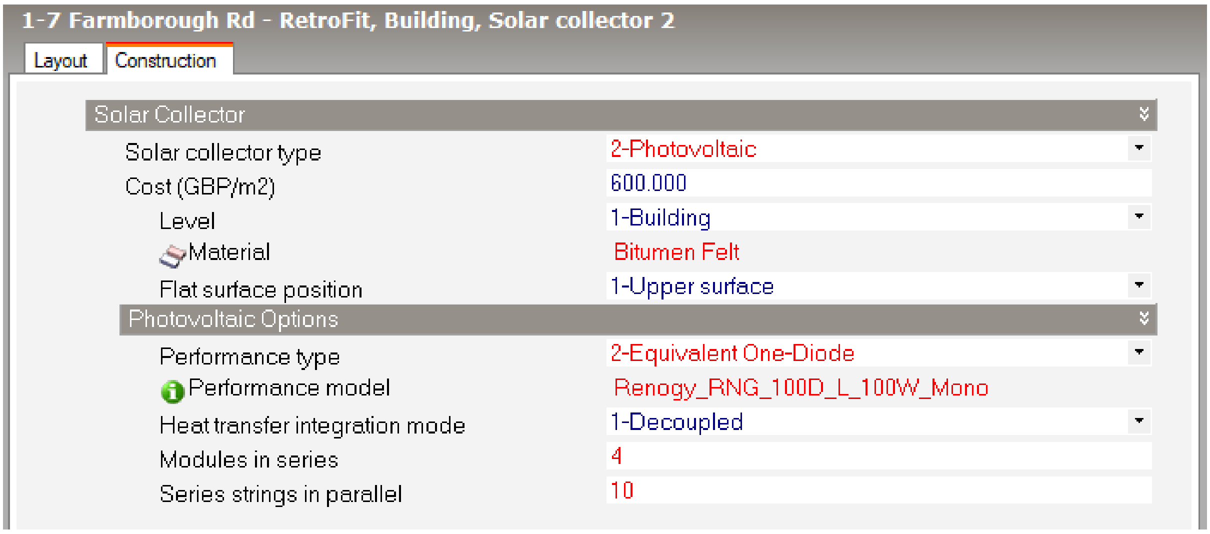


Figure B.7: Solar Array 2 Input Parameters.

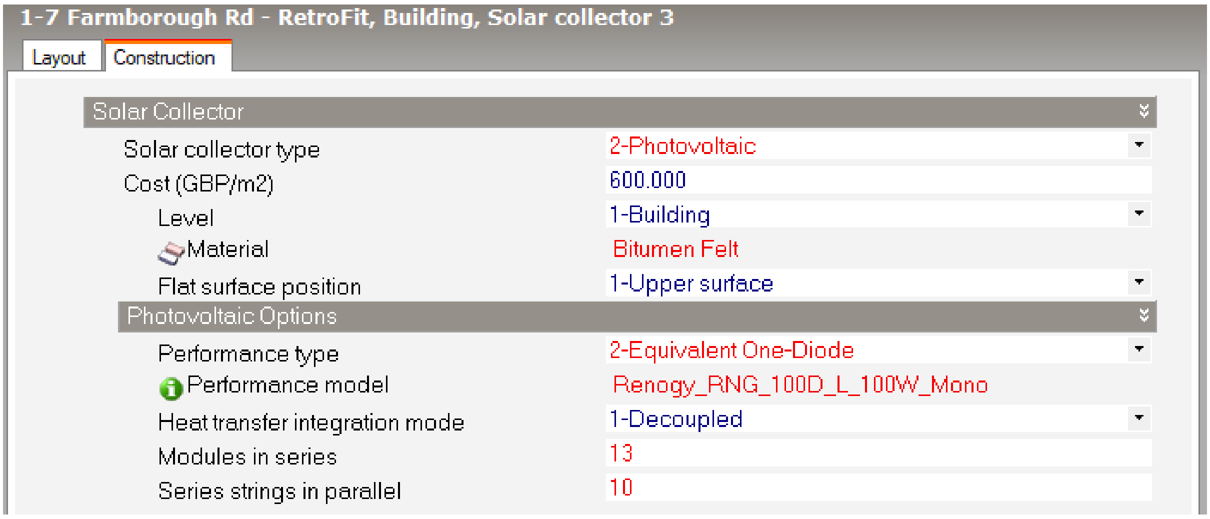


Figure B.7: Solar Array 3 Input Parameters.

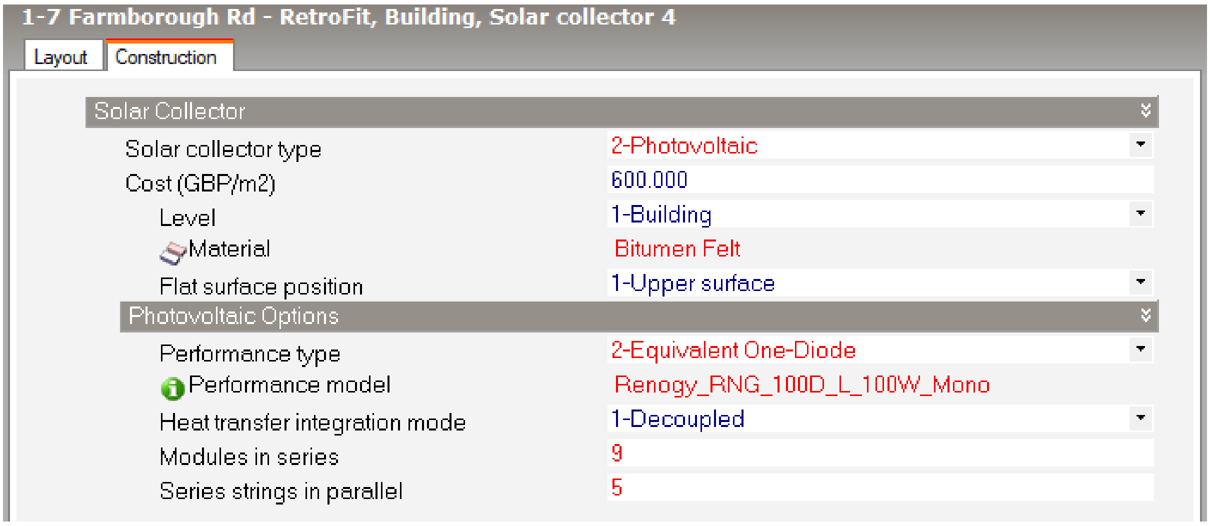
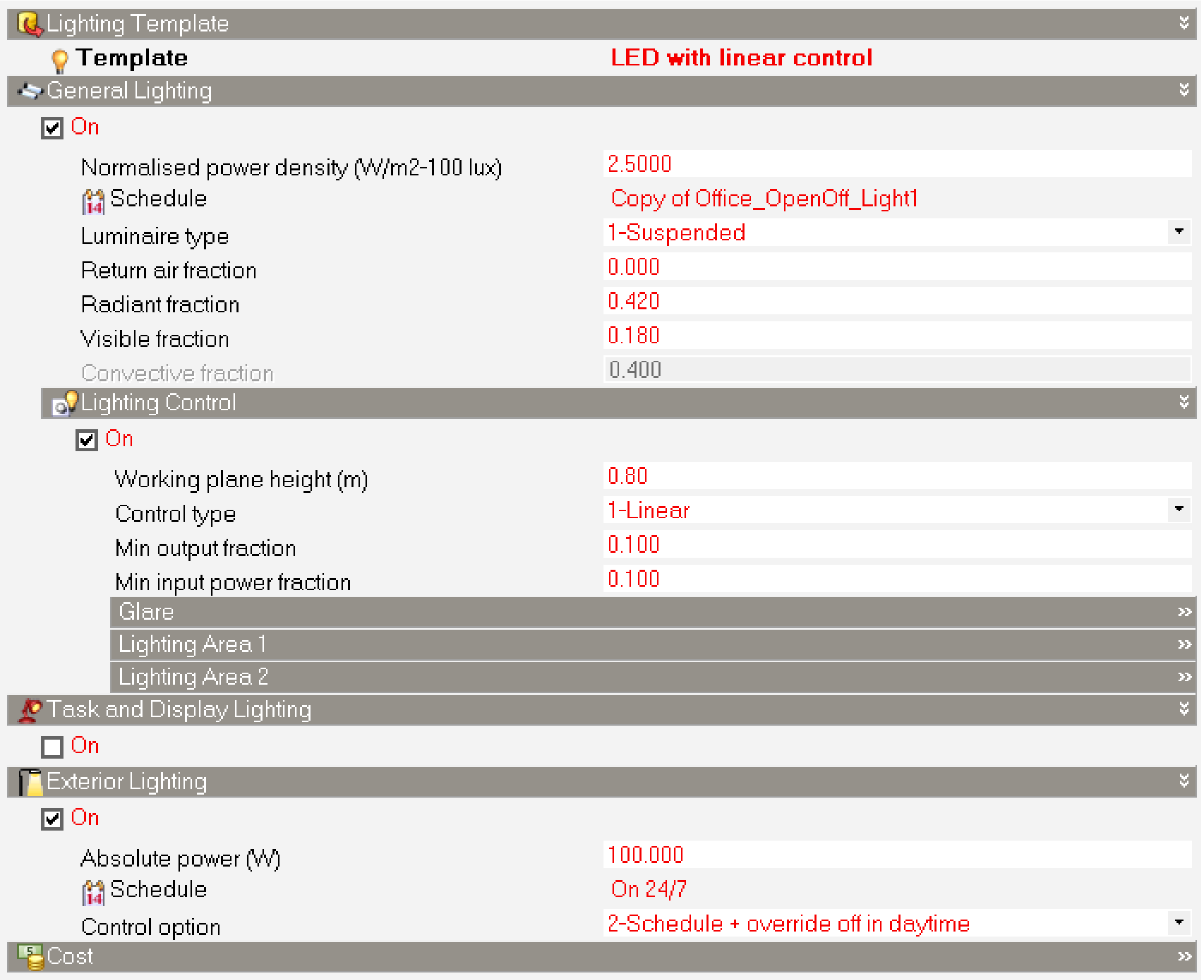


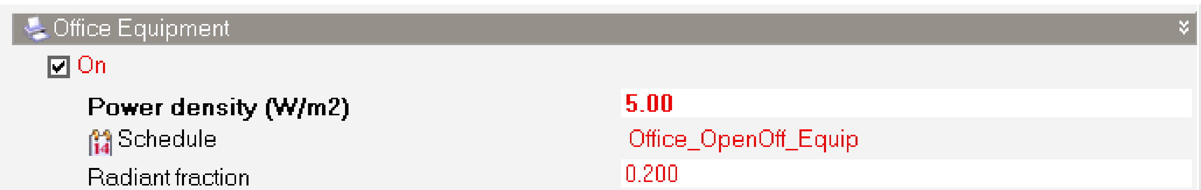
Figure B.8: Solar Array 4 Input Parameters.

Appendix B.3: Improved Lighting & Equipment Input Parameters



Lighting Template	
Template	LED with linear control
General Lighting	
☑ On	
Normalised power density (W/m2-100 lux)	2.5000
Schedule	Copy of Office_OpenOff_Light1
Luminaire type	1-Suspended
Return air fraction	0.000
Radiant fraction	0.420
Visible fraction	0.180
Convective fraction	0.400
Lighting Control	
☑ On	
Working plane height (m)	0.80
Control type	1-Linear
Min output fraction	0.100
Min input power fraction	0.100
Glare	
Lighting Area 1	
Lighting Area 2	
Task and Display Lighting	
☐ On	
Exterior Lighting	
☑ On	
Absolute power (W)	100.000
Schedule	On 24/7
Control option	2-Schedule + override off in daytime
Cost	

Figure B.9: Improved Lighting Input Parameters.



Office Equipment	
☑ On	
Power density (W/m2)	**5.00**
Schedule	Office_OpenOff_Equip
Radiant fraction	0.200

Figure B.10: Improved Office Equipment Input Parameters.

Appendix B.4: Passive Design Strategy Input Parameters

Figure B.11: Passive Construction Input Parameters.

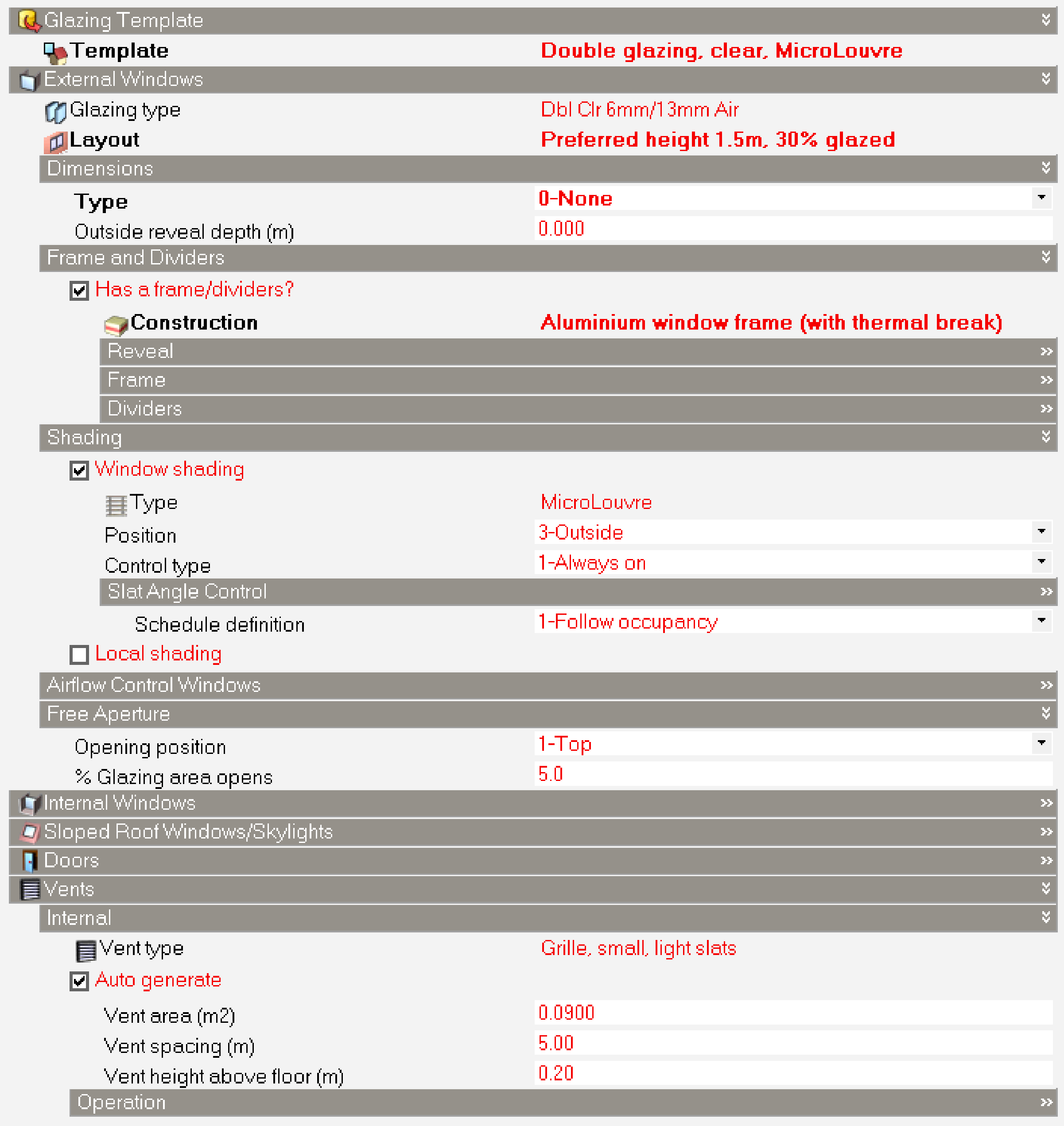


Figure B.12: Passive Glazing Input Parameters.

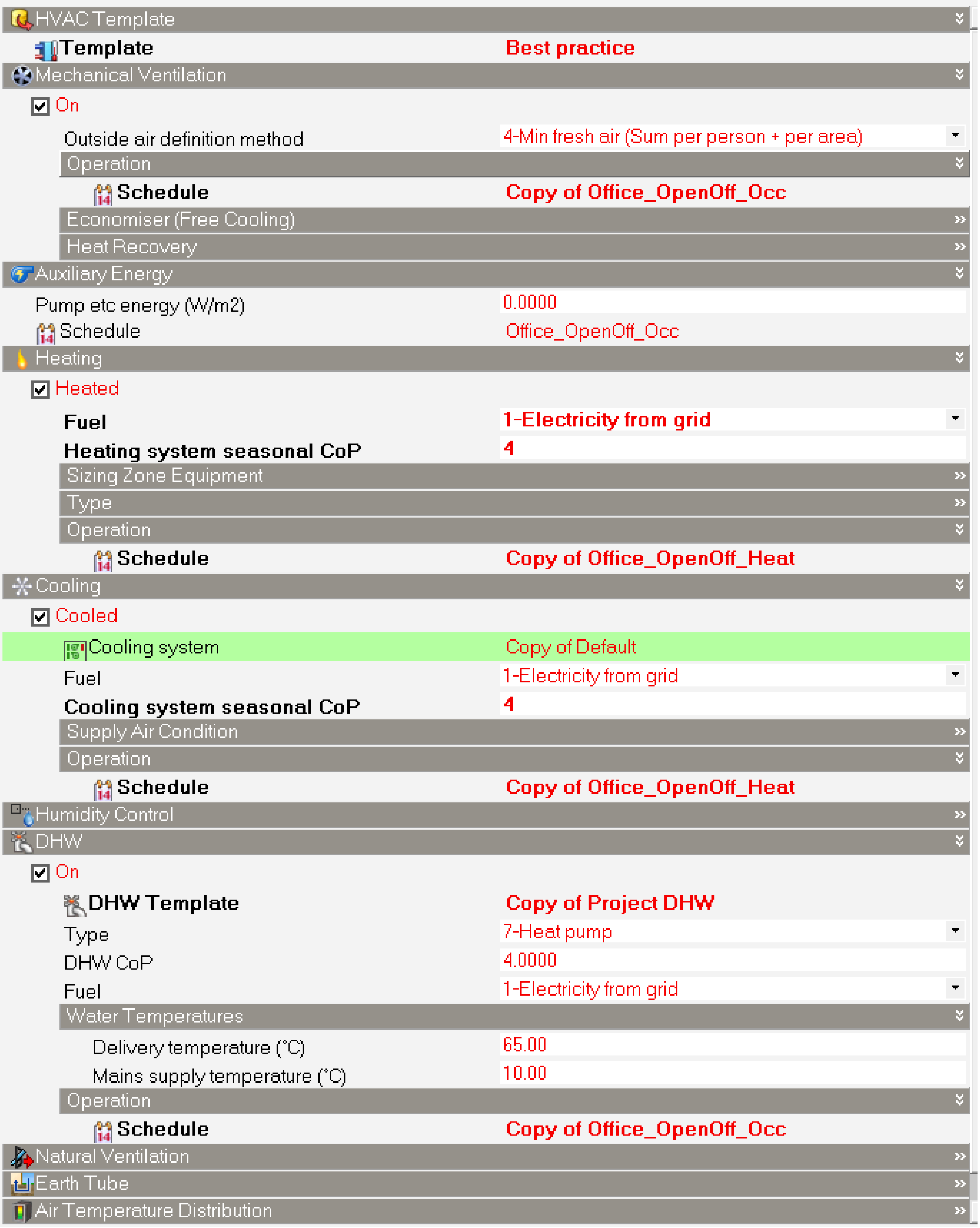


Figure B.13: Passive HVAC Input Parameters.

APPENDIX C: SIMULATION SCHEDULES

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

Time period (local standard time)	Occupancy (Monday to Friday)	Artificial lighting (Monday to Friday)	Appliances and equipment (Monday to Friday)	*Air-conditioning* (Monday to Friday)
12:00am to 1:00am	0%	15%	25%	Off
1:00am to 2:00am	0%	15%	25%	Off
2:00am to 3:00am	0%	15%	25%	Off
3:00am to 4:00am	0%	15%	25%	Off
4:00am to 5:00am	0%	15%	25%	Off
5:00am to 6:00am	0%	15%	25%	Off
6:00am to 7:00am	0%	15%	25%	Off
7:00am to 8:00am	10%	40%	65%	On
8:00am to 9:00am	20%	90%	80%	On
9:00am to 10:00am	70%	100%	100%	On
10:00am to 11:00am	70%	100%	100%	On
11:00am to 12:00pm	70%	100%	100%	On
12:00pm to 1:00pm	70%	100%	100%	On
1:00pm to 2:00pm	70%	100%	100%	On
2:00pm to 3:00pm	70%	100%	100%	On
3:00pm to 4:00pm	70%	100%	100%	On
4:00pm to 5:00pm	70%	100%	100%	On
5:00pm to 6:00pm	35%	80%	80%	On
6:00pm to 7:00pm	10%	60%	65%	Off
7:00pm to 8:00pm	5%	60%	55%	Off
8:00pm to 9:00pm	5%	50%	25%	Off
9:00pm to 10:00pm	0%	15%	25%	Off
10:00pm to 11:00pm	0%	15%	25%	Off
11:00pm to 12:00am	0%	15%	25%	Off

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2

Energy efficiency

Note to Table 2c: The occupancy profile is expressed as a percentage of the maximum number of people that can be accommodated in the building. The artificial lighting profile is expressed as a percentage of the maximum *illumination power density* permitted under Part J6. The appliances and equipment profile is expressed as a percentage of the maximum internal heat gain in Table 2I. The *air-conditioning* profile is expressed as the plant status.

Figure C.1: Occupancy, Lighting and Appliance Schedule (NCC 2019).

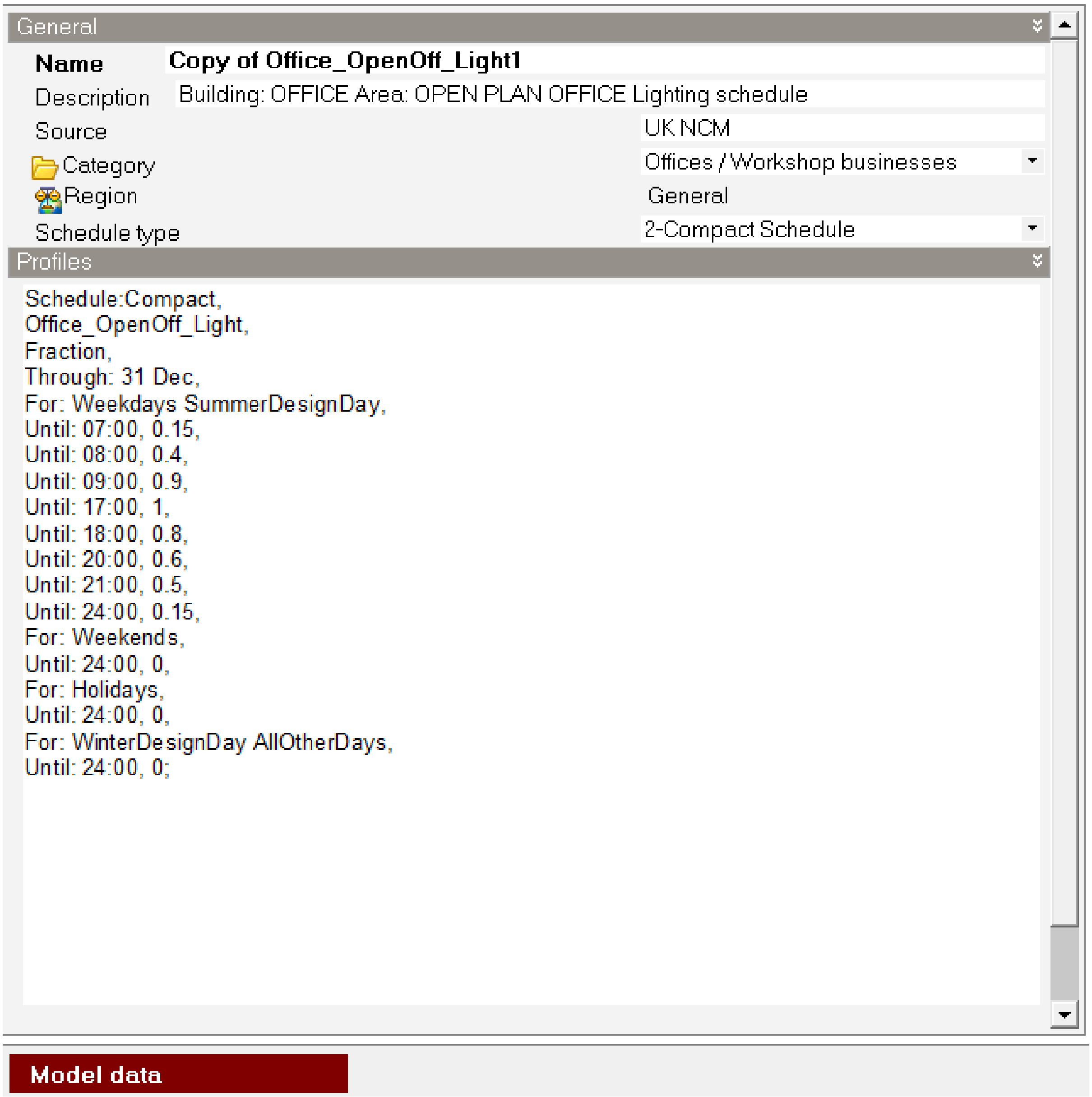


Figure C.2: Adopted Lighting Schedule

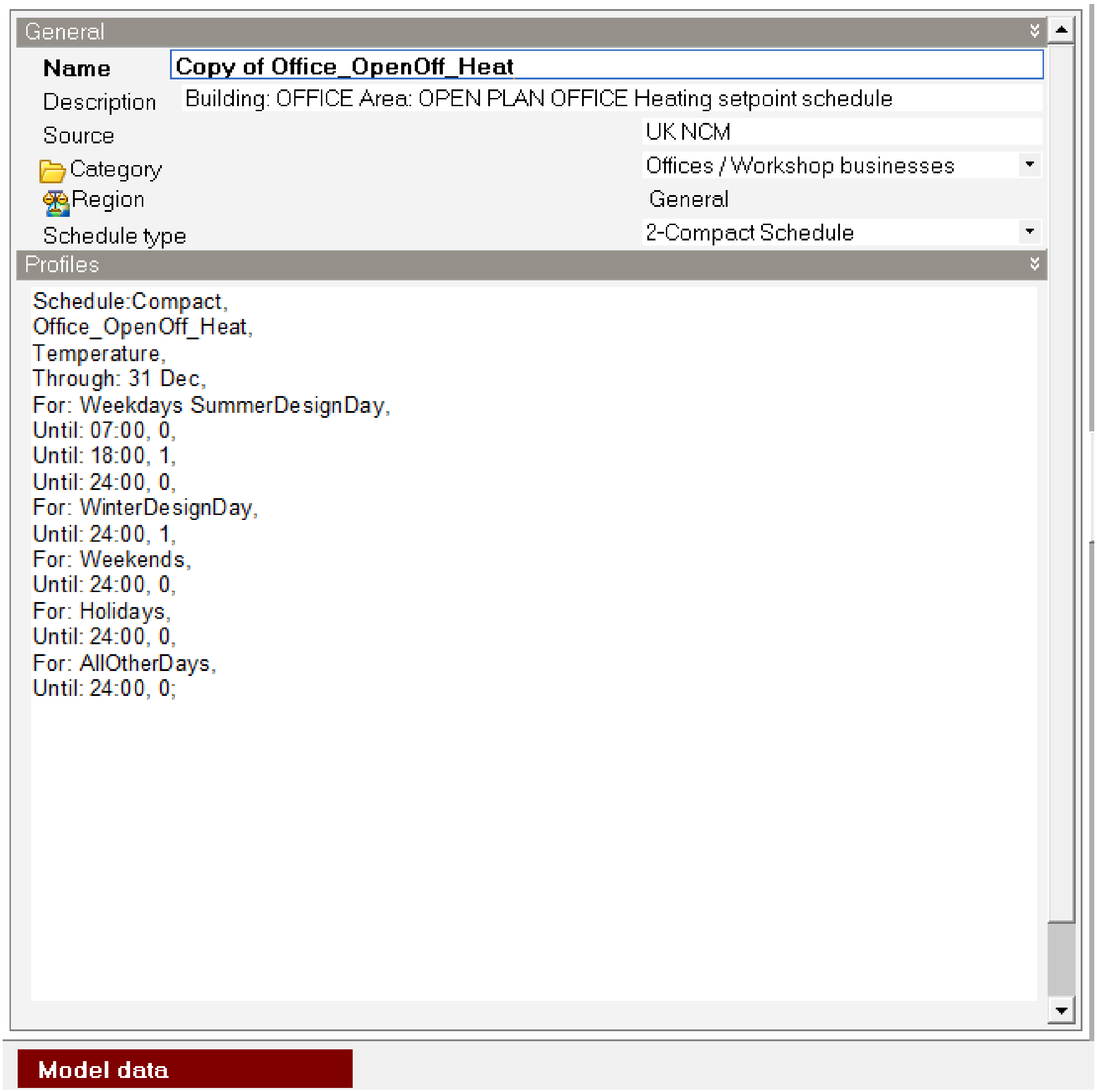


Figure C.3: Adopted Heating & Cooling Setpoint Schedule

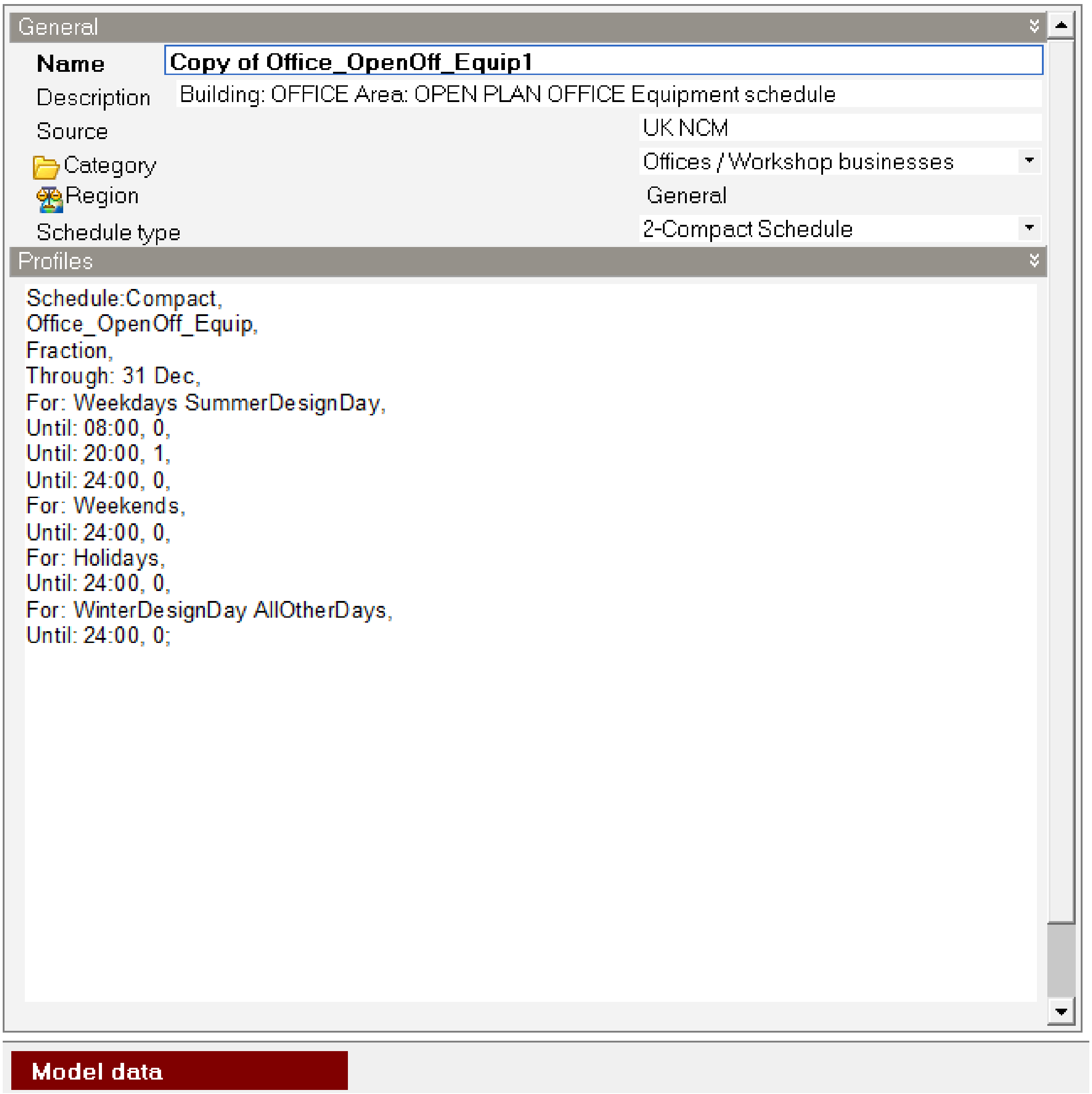


Figure C.4: Adopted Office Equipment Schedule

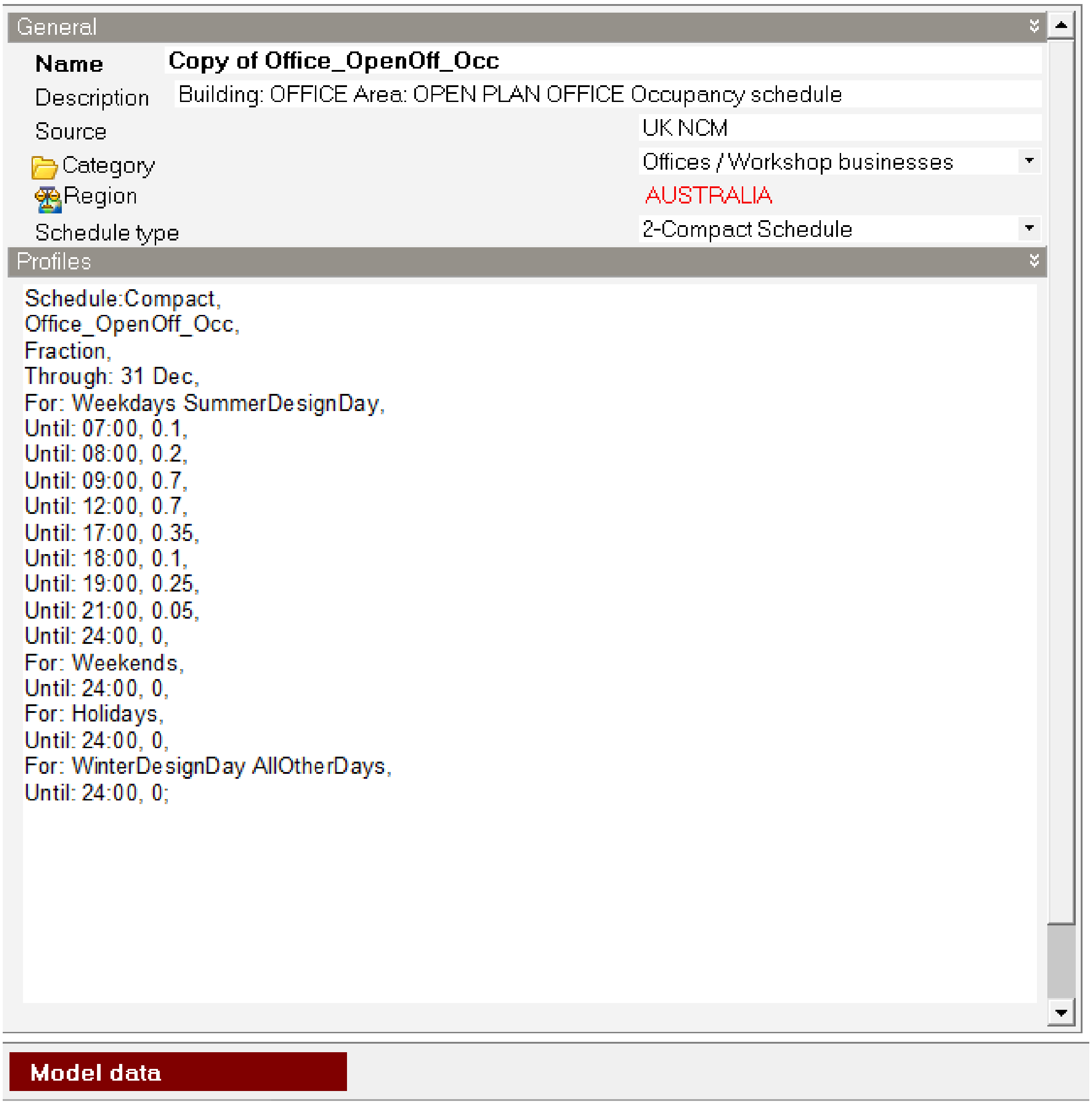


Figure C.4: Adopted Occupancy Schedule

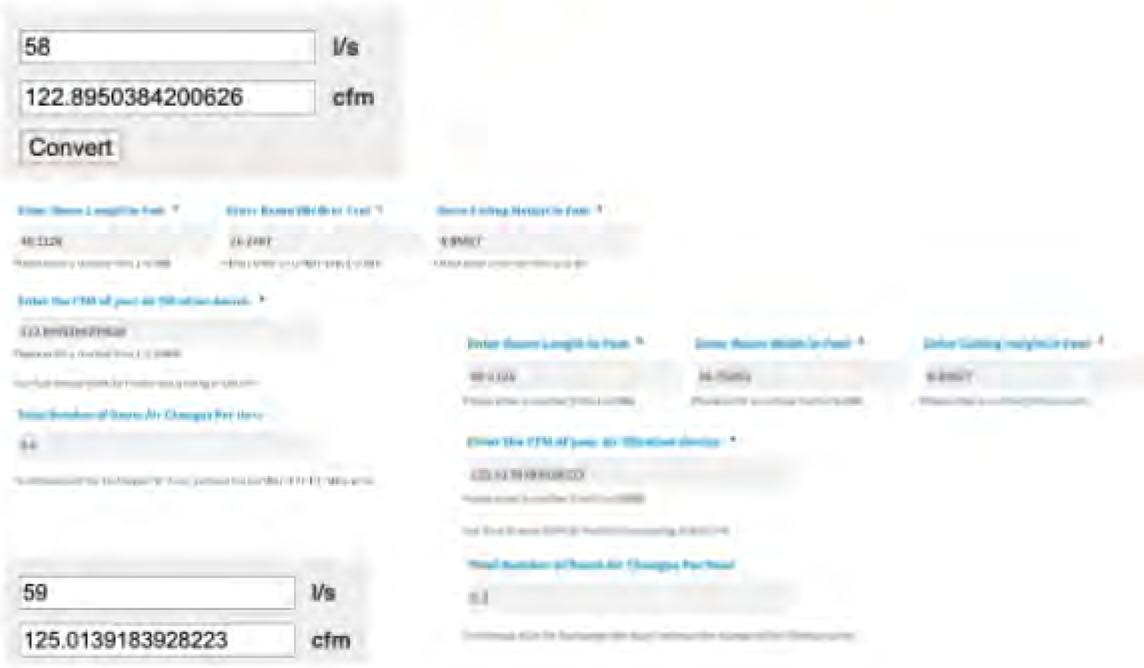
APPENDIX D: CALCULATION OF KEY PARAMETERS

Air flow and Ventilation

Calculations
120m^2 x 0.35 = 42 litres/s
Background ventilation (ILALC upstairs office area) = 42 litres/s
10 people x 10L/s per person = 100 L/s
Therefore 100 - 42 = 58 l/s for 10 people present

260m^2 x 0.35 = 91 litres/s
Background ventilation (downstairs office area) = 91 litres/s
15 people x 10L/s per person = 150 L/s
Therefore 150 - 91 = 59 l/s for 15 people present

= 108.25 L/s
Minimum Fresh Air = 108.25/25 people = 4.3 L/s per person
Mech Vent per area = 108.25/380 = 0.3



Solar Panels - Renogy RNG-100D-L 100W Monocrystalline Solar Panel

All panels angled at 34 degrees to maximise efficiency
Total area = 1.074 x 0.498

CALCULATIONS:
Effective area per panel
Eff. Area = 33 x 154.94 mm x 101.6 mm = 519,483 mm^2 = 0.52 m^2 (per panel)

Total area per panel
Tot. Area = Eff. Area + Area of Frame = 0.52 m^2 + 0.105 m^2 = 0.63 m^2 (per panel)

North Facing Roof Area (9 by 12 + 10 by 4) = 79.158m^2 = 148 Panels
Area = 6.58 x 10.36 mm + 6.02 x 4.84 + 1.77 x 10.36 = 115.64 m^2

South Facing Roof Area (10 by 13 = 69.53 m^2 + 5 by 9 = 24.07m^2)
Area = 6.02 x 15.20 mm + 3.80 x 15.20 = 149.26 m^2
*Solar area top = 10 x 0.498 + 13 x 1.074 - (0.105 * 130) =*
Spacing
Total Roof Area
Area = 115.64 m^2 + 149.26 m^2 + 33.22 m^2 = 298.12 m^2

Available Solar Roof Area (60%)
Area = 298.12 m^2 x 0.60 = 178.17 m^2

Total Solar Panels Required
Panels = 178.17 m^2 / 0.63 = 283 panels

Total Solar Panels Installed
Panels = 172.758m^2 = 274 panels

Assumed solar panel efficiency = 15%

Temperature coefficient of open circuit current (A/K)
= (6.24 x 0.04)/100 = 0.002496 A/K

Temperature coefficient of open circuit voltage (V/K)
= (21.6 x -0.30)/100 = -0.0648 A/K

OCCUPANTS

CALCULATIONS:
10 ILALC members for approximately 120m^2 (upstairs)
15 office members for approximately 260m^2 (downstairs)
TOTAL 25 Occupants for 380 m^2
Occupancy Density = 0.066 people / m^2

HOT WATER DEMANDS

CALCULATIONS:

Hot water
3.7L x 25 people = 92.5 L/day
92.5 / 380m^2 = 0.243 L/m^2/day
DHW = 0.243 L/m^2/day

LIGHTING & EQUIPMENT

LIGHTING:

Normalised Power Density: 4.068

CALCULATIONS:

Section areas
Office = 168.1 m^2
Stairs/lift = 35.4 m^2
Common Area = 126.1m^2
Toilet = 50.4m^2
Total = 380 m^2

Section Average Power W/m^2 (According to NCC)
Office = 4.5 W/m^2
Stairs/lift = 2 W/m^2
Common Area = 4.5 W/m^2
Toilet = 3 W/m^2

Power For Room Sizes
Office = 756.45 W
Stairs/lift = 70.8 W
Common area = 567.45 W
Toilet = 151.2 W
Total = 1545.9 W

Total W/m^2 divided by total area *= 1545.9 W / 380 m^2*
Final Normalised Power Density: *= 4.068 W/m^2*

EQUIPMENT:

1. **Office Equipment:**

Power Density: 11.77

2. **Catering Equipment:**

Hot water demand: *5.26* W/m^2

CALCULATIONS:

Given: 2kW per 12hr day
2000W / 380m^2 = 5.263 W/m^2

Specification JVb Modelling parameters

ACT Appendix

1. Scope

This Specification contains the *required* modelling parameters for JV2 and JV3.

2. Reference building

The *annual greenhouse gas emissions* must be calculated for the *reference building* in accordance with the following:

(a) The *reference building* must—

(i) comply with *Deemed-to-Satisfy Provisions* in Parts J1 to J7; and

(ii) have the minimum amount of mechanical ventilation *required* by Part F4.

(b) The *external walls* must have a solar absorptance of 0.6.

(c) The *air-conditioning* must—

(i) for 98% of the annual *hours of operation*, achieve temperatures between—

(A) 18°CDB to 25°CDB for *conditioned spaces* with transitory occupancy; and

(B) subject to (ii), 21°CDB to 24°CDB in all other *conditioned spaces*; and

(ii) if the proposed building has no mechanically provided cooling or has mixed mode cooling, have the same method of control and control set points for non-mechanical cooling as the proposed building.

(d) The infiltration rate in each zone must be—

(i) 0.7 air changes per hour throughout all zones when there is no mechanically supplied *outdoor air*; and

(ii) 0.35 air changes per hour at all other times.

(e) The artificial lighting must achieve the *required* maximum *Illumination power density* in Part J6 without applying the control device adjustment factors.

(f) *Minimum Energy Performance Standards* must be applied to *services* not covered by Parts J5 to J7.

Net Zero Energy Design

against

Business as Usual Case

ENGG210

Assessment Task 3

Contents

Table of Figures

Table of Tables

Executive Summary

This report presents the results and recommendations following a design process to improve a base case building to be a net zero energy building design. The site is located in Unanderra on the corner of Farmborough Road and the Princes Highway. The site has an existing building which will be renovated, and will hold the offices of the ILALC, as well as lettable professional suites. The new building will be constructed on the adjacent vacant block and will also hold lettable professional suites, as well as emergency housing studio apartments.

A base case model was established for each of the buildings, modelled within Design Builder. A solar system was added to each building to generate onsite renewable electricity. This solar system was limited to 60% of the roof area with an efficiency of 15%. The results from the energy simulation showed that the existing buildings total yearly demand was met by the onsite generation, however as the times of demand and generation weren't well matched the REF was below 1. The REF is the average value across the year of the generation divided by the demand calculated for every hour. The new building had a lower generation that did not match the total demand, for this reason it had a significantly lower REF.

The largest loads for both buildings were the room and hot water, which could not be changed through building design. The next largest loads were the lighting and cooling loads, the design was then modified to reduce these loads so the total demand can be met by the generation for more of the day, to achieve an REF of above 1. There were various modifications that were tested on each building. The primary ones were responsive lighting, external window shading, improved window glazing, additional windows, repositioning of the solar panels to a more optimal position, and the inclusion of a solar battery, and combinations of these.

Following the simulation of these modifications using design builder, the optimal design for the existing builder including improving the base case design with the following alterations, the addition of responsive lighting, and external window shading. The improved design achieved an REF of 1.1634. The optimal design of the new building improved the base case by adding responsive lighting and external window shading, as well as improving the windows to be double glazed, more windows were also added to the design. To increase the generation the solar panels were repositioned and to ensure the generation would better match the energy demand of the building a 20kWh solar battery was added. The improved design achieved an REF of 1.0280.

Overall, the modifications made to both buildings ensured that across the year the buildings solar generation exceeded the buildings demand. As well as this the REF value for each building was above 1, meaning the generation and demand was also well matched throughout the day.

Benchmark Model

Design

The site is located at 1 and 7 Farmborough Road, on the corner of Farmborough Road and the Princes Highway in Unanderra. There is an existing building on 1 Farmborough Road, which is the former Unanderra Police Station. This building will be renovated to hold the office space for the ILALC, as well as having lettable professional suites on the ground floor. The vacant block will be developed with a two-story mixed-use development. The ground floor will have lettable professional suites, with the top floor having emergency housing studio apartments.

Site Plan

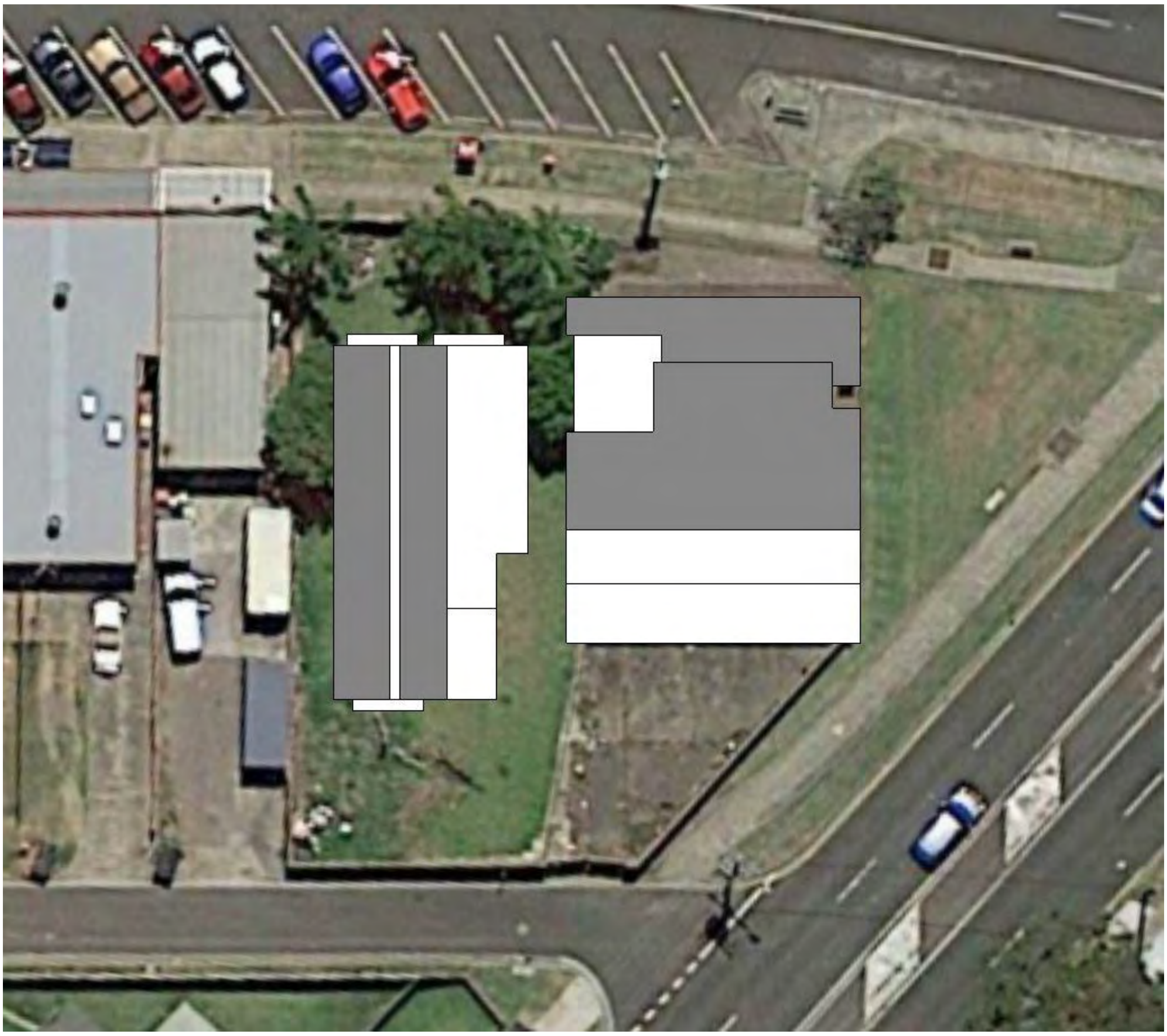


Figure 1 - Base Case, Site Plan

Existing Building

Floorplans

Figure 2 - Existing Building, Base Case, Floorplan Ground

Figure 3 - Existing Building, Base Case, Floorplan Top

Elevations

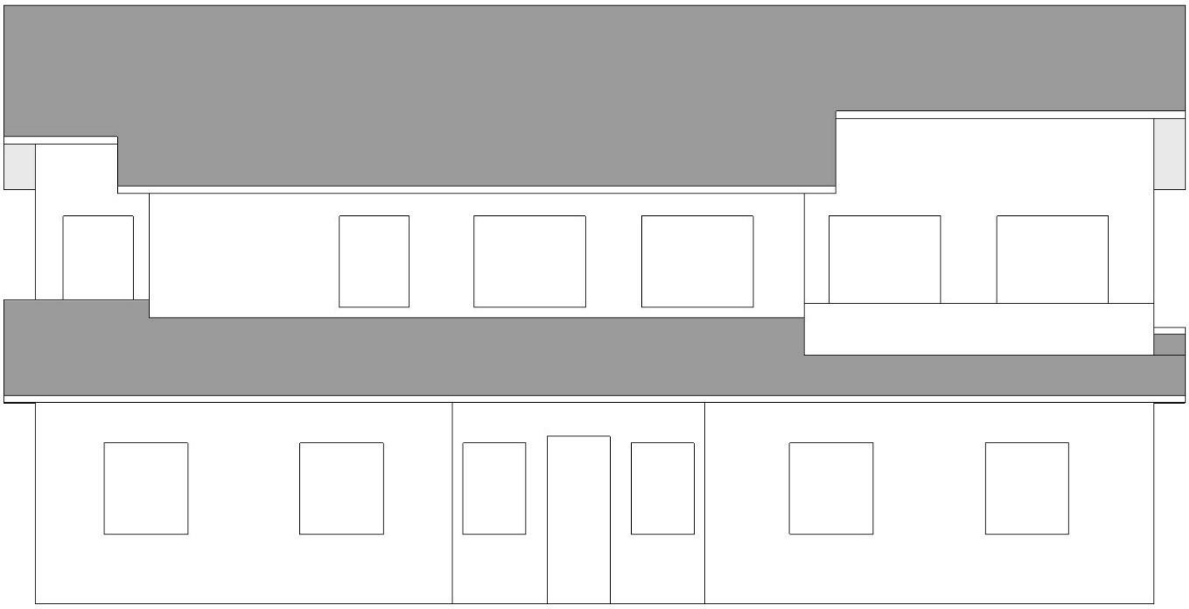


Figure 4 - Existing Building, Base Case, Northern Elevation

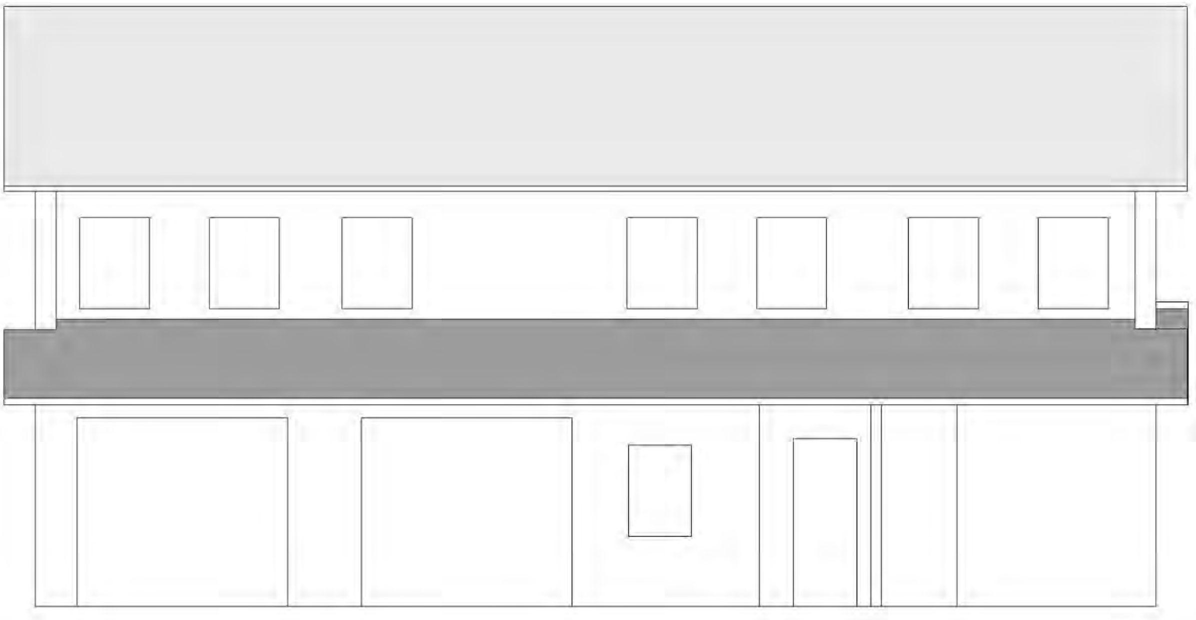


Figure 5 - Existing Building, Base Case, Southern Elevation

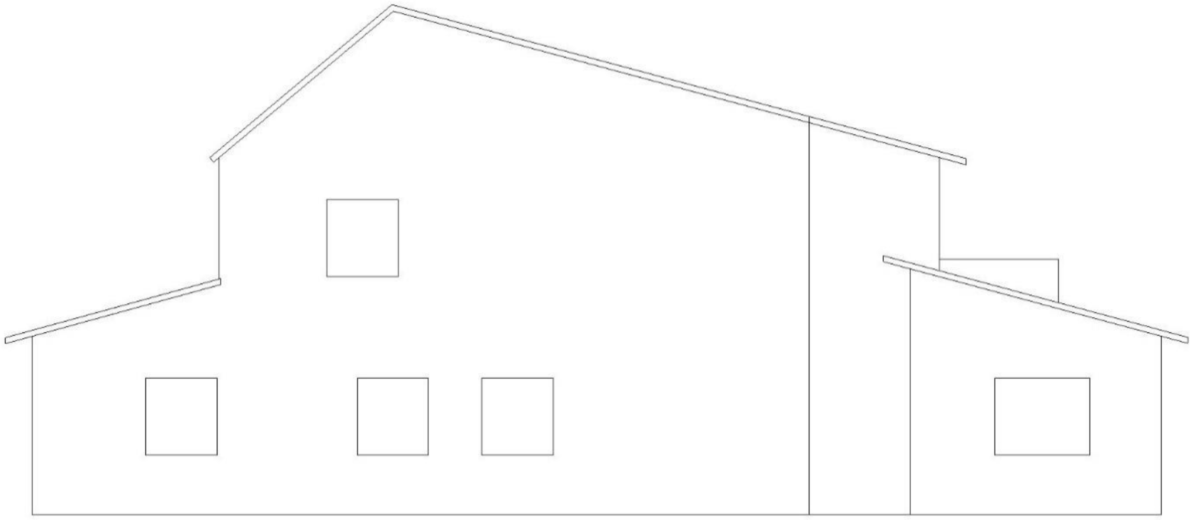


Figure 6 - Existing Building, Base Case, Eastern Elevation

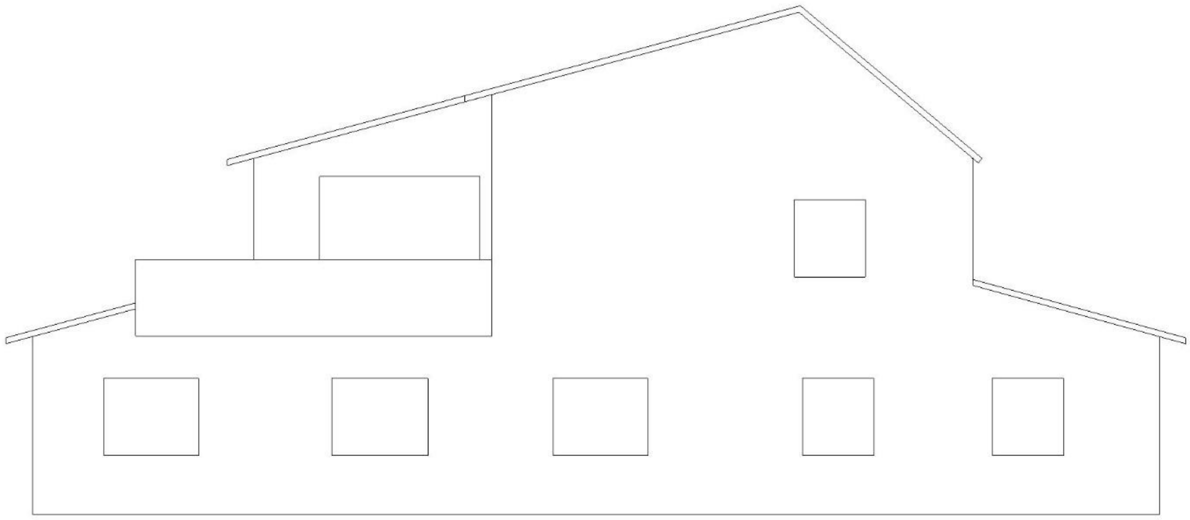


Figure 7 - Existing Building, Base Case, Western Elevation

New Building

Floorplans

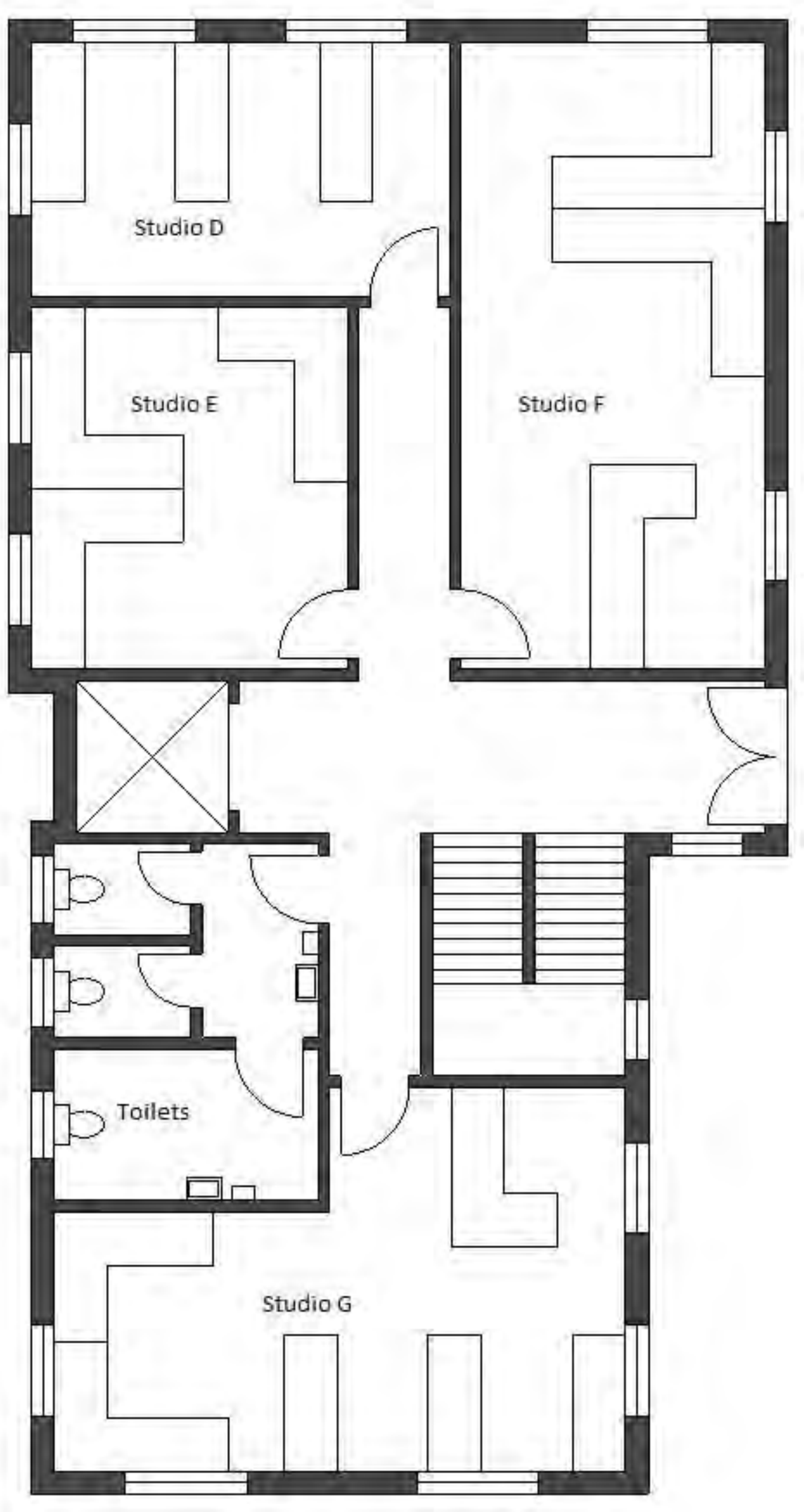


Figure 8 - New Building, Base Case, Floorplan Ground

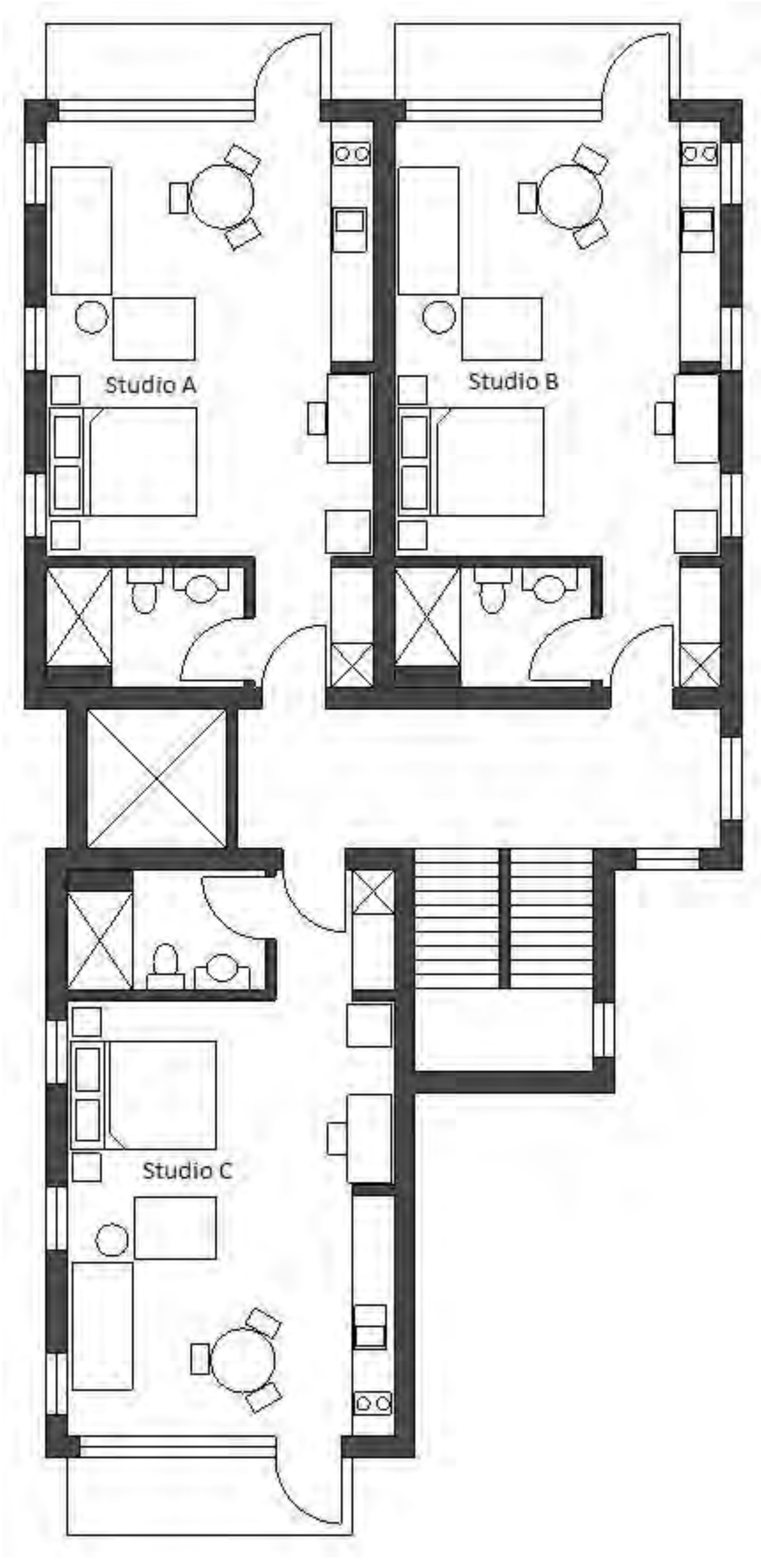


Figure 9 - New Building, Base Case, Floorplan Top

Elevations

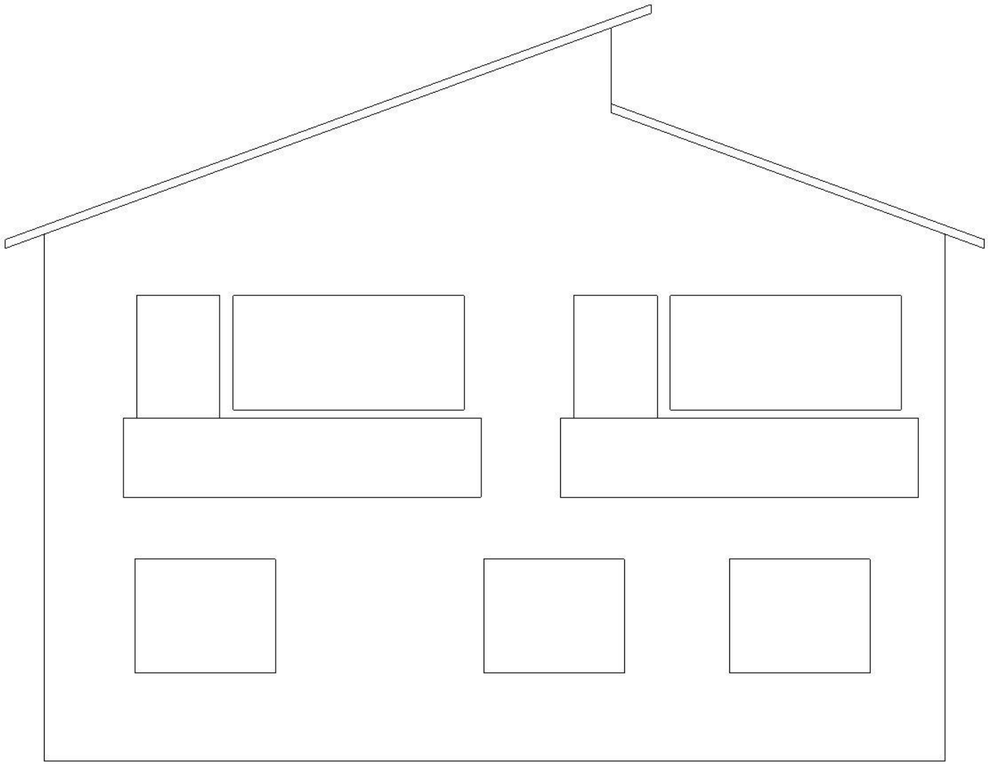


Figure 10 - New Building, Base Case, Northern Elevation

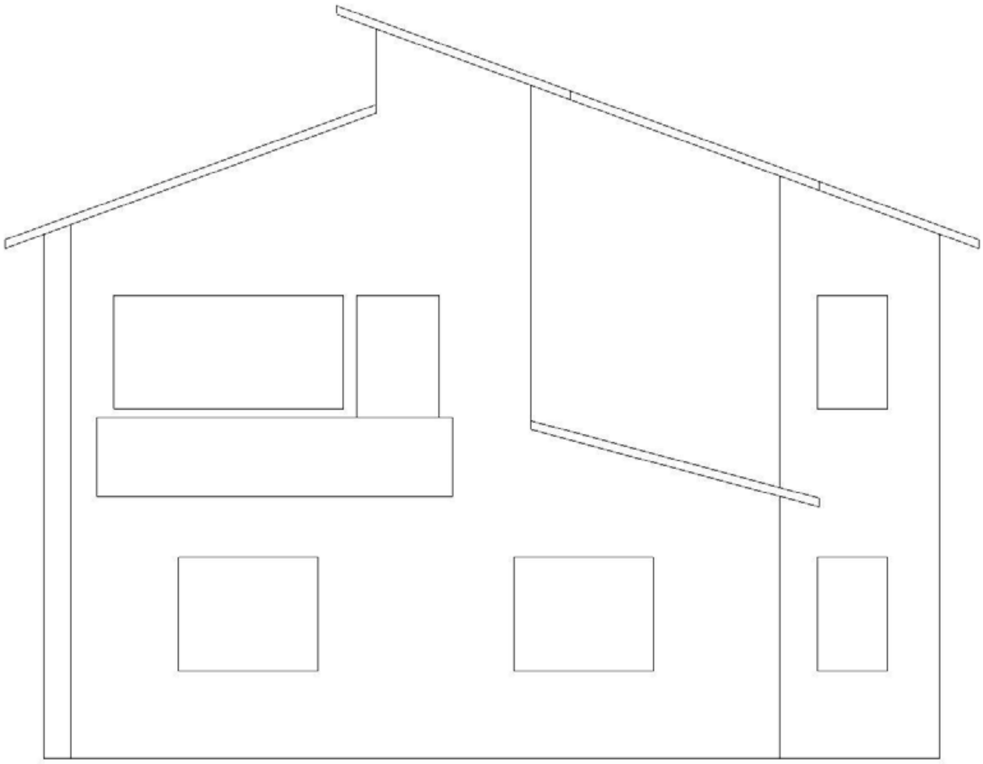


Figure 11 - New Building, Base Case, Southern Elevation

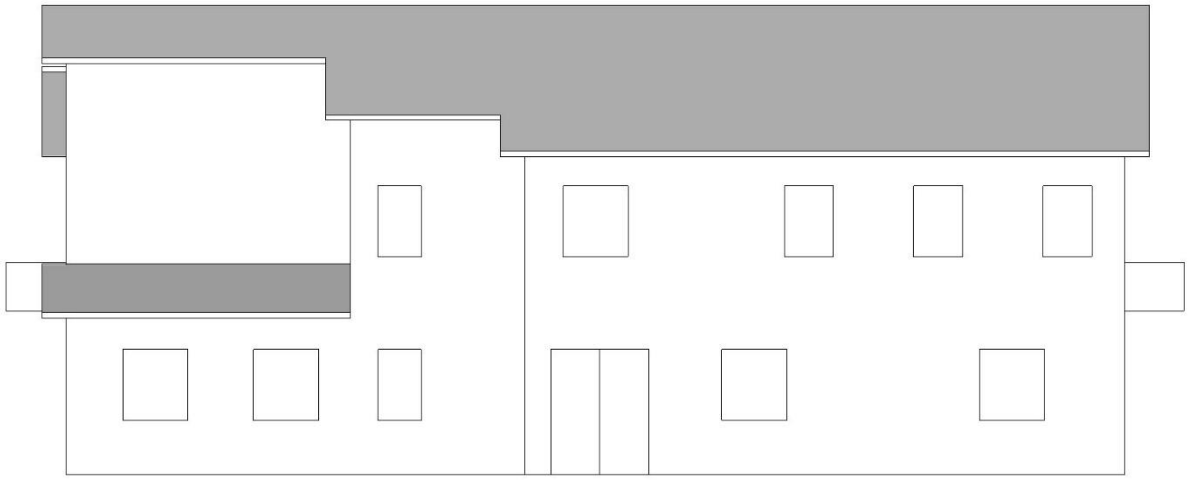


Figure 12 - New Building, Base Case, Eastern Elevation

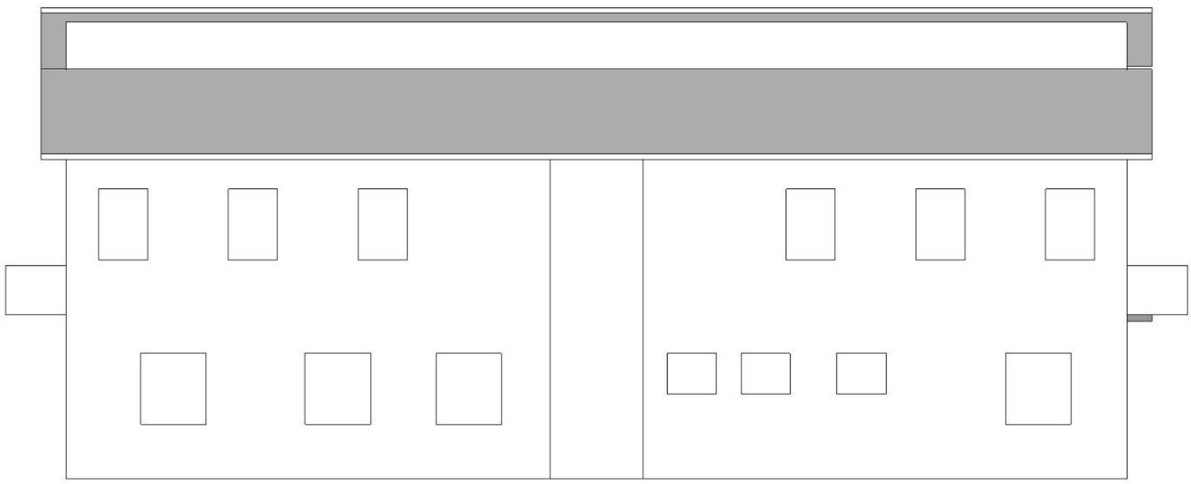


Figure 13 - New Building, Base case, Western Elevation

Base Case Energy Simulation

Simulation Assumptions

The simulations were completed within Design Builder. The extended simulation assumptions can be seen in Appendix B. The following will be a brief summary of the assumptions.

Schedules

Occupancy, HVAC, Lighting, and Equipment schedule profiles were obtained from the NCC. The profiles are shown in Appendix B.

Hot Water

The hot water demand for each building was simulated as a constant 2kW electrical demand per hour between 8am – 8pm.

Lighting

All lights in the base case were LED lights, with a power density of 2.5 W/m^2-100 lux.

HVAC

The HVAC system is a fan coil, air cooled chiller. The COP is set at 4.

Ventilation

The infiltration rate was 0.42 ac/h, calculated from the specified 0.35 liters/s per m^2 with the floors having a 3m ceiling height.

Materials

The material template was set to 'General Energy Code – Medium Weight'. The external wall of the existing buildings ground floor was set to a double brick cavity to match the existing buildings construction.

Existing Building

Table 1 - Existing Building, Base Case, Annual Energy Requirements

	Load (kWh)
Heating Load	675
Cooling Load	4629
Total Site load	36537

Table 2 - Existing Building, Base Case, Peak Energy Demands

	Load (kWh)	Time of Occurrence
Heating Load	3.9136	July 29th, 8 am
Cooling Load	4.9868	March 4th, 4 pm
Total Site Load	12.6885	March 4th, 4 pm

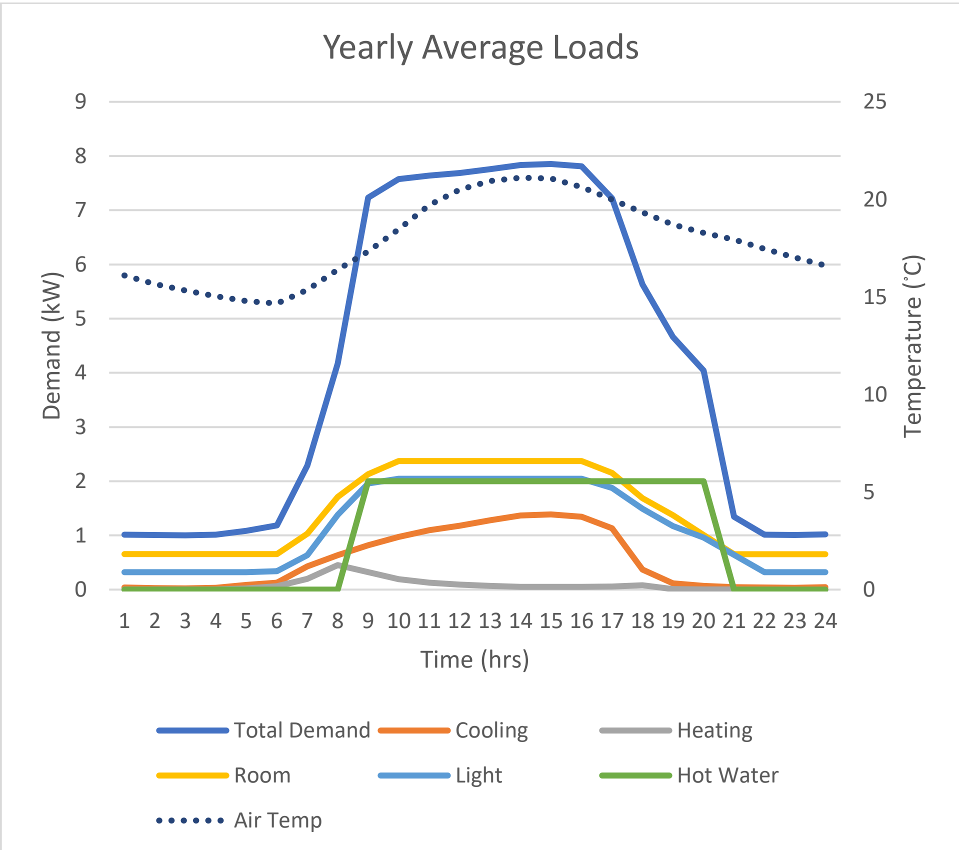


Figure 14 - Existing Building, Base Case, Yearly Loads

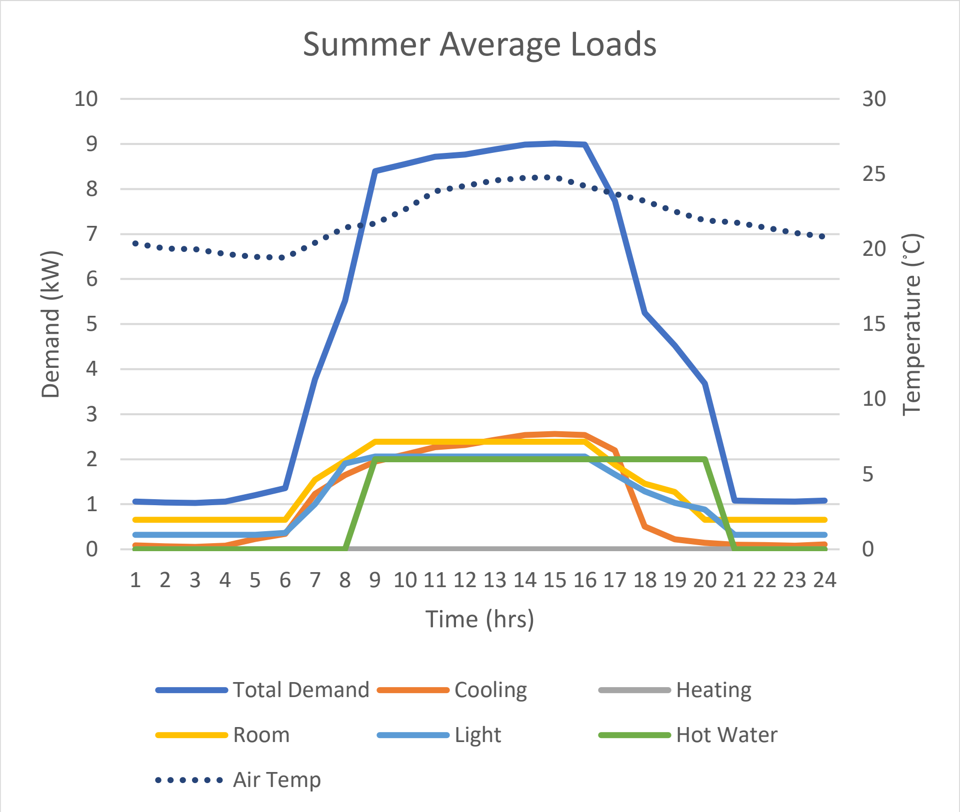


Figure 15 - Existing Building, Base Case, Summer Loads

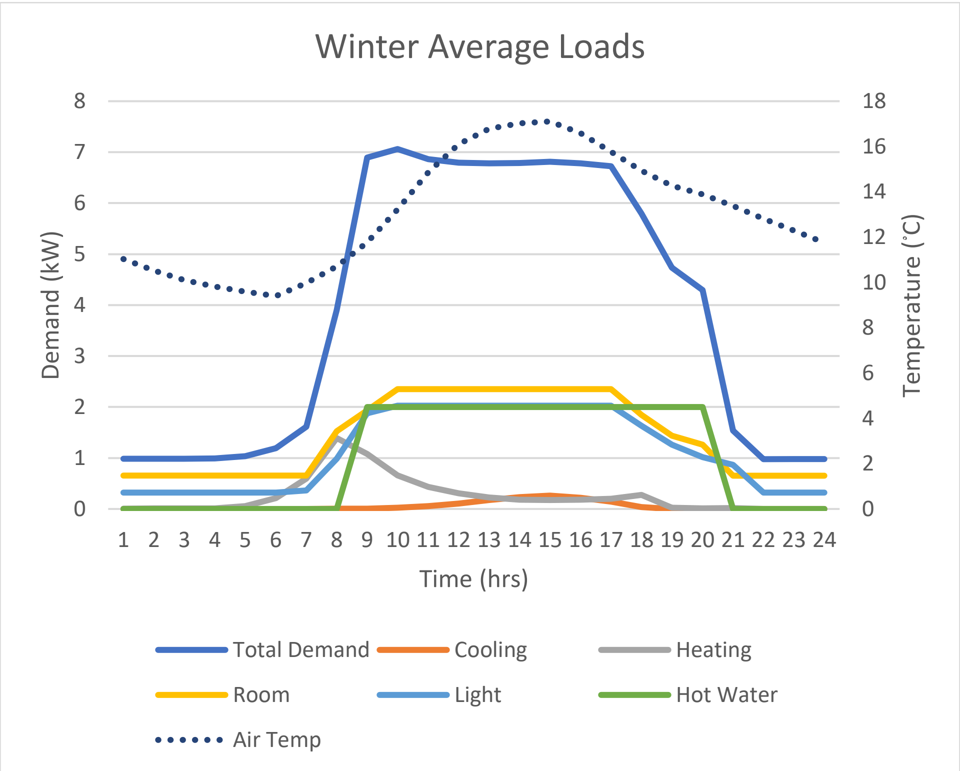


Figure 16 - Existing Building, Base Case, Winter Loads

New Building

Table 3 - New Building, Base Case, Annual Energy Requirements

	Load (kWh)
Heating Load	439
Cooling Load	5442
Total Site load	30925

Table 4 - New Building, Base Case, Peak Energy Demands

	Load (kWh)	Time of Occurrence
Heating Load	1.6417	July 29th, 8 am
Cooling Load	3.9574	March 4th, 4 pm
Total Site Load	9.6756	March 4th, 4 pm

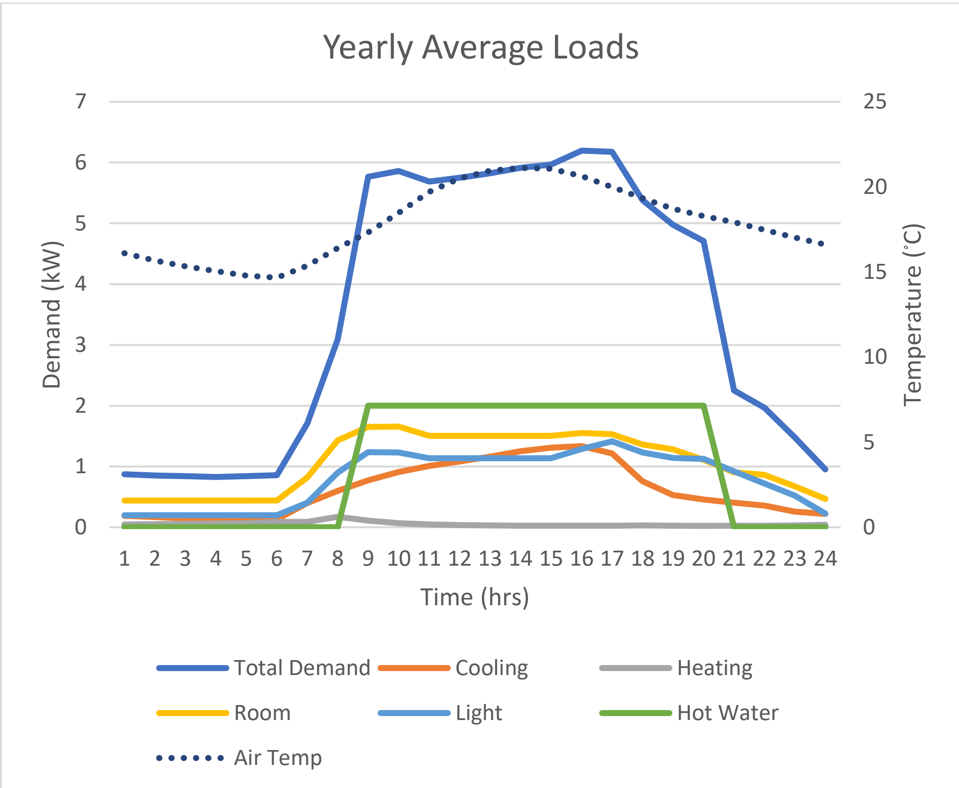


Figure 17 - New Building, Base Case, Yearly Loads

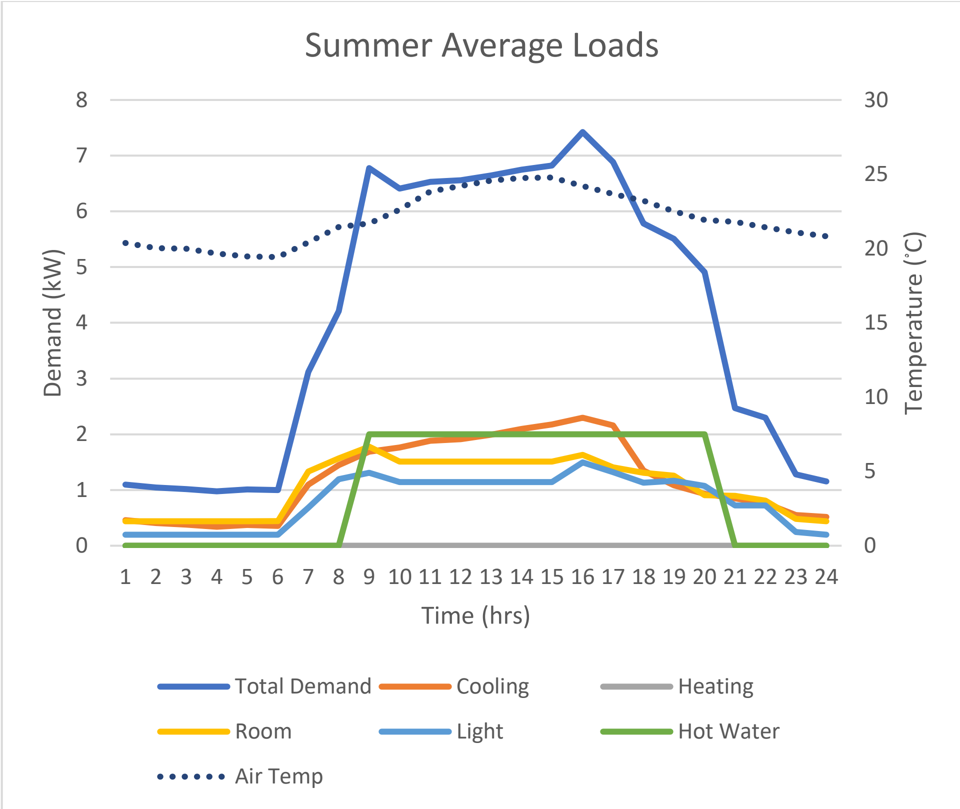


Figure 18 - New Building, Base Case, Summer Loads

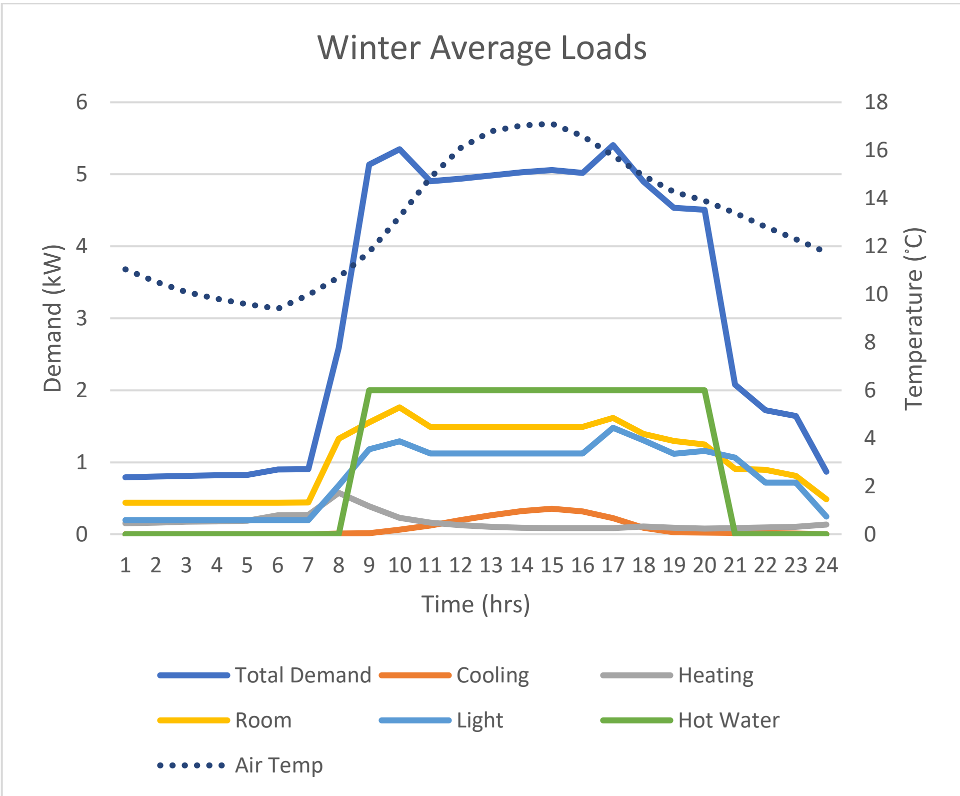


Figure 19 - New Building, Base Case, Winter Loads

Solar PV Energy Simulation

Existing Building

Table 5 - Existing Building, Base Case Solar PV, Yearly Net Energy Requirements

	Energy (kWh)
Total Demand	36,536.65
Total Generation	45,181.47
Net Energy Requirements	-8,644.82

Seen above in Table 5, the yearly generation for the existing building exceeds the demand. However as seen in the figures below, there is a large peak in the generation during the middle of the day which is roughly twice the energy demand. And later in the day, when the generation reduces into the night the energy demand remains, slowly reducing from sunset until it plateaus at around 10pm.

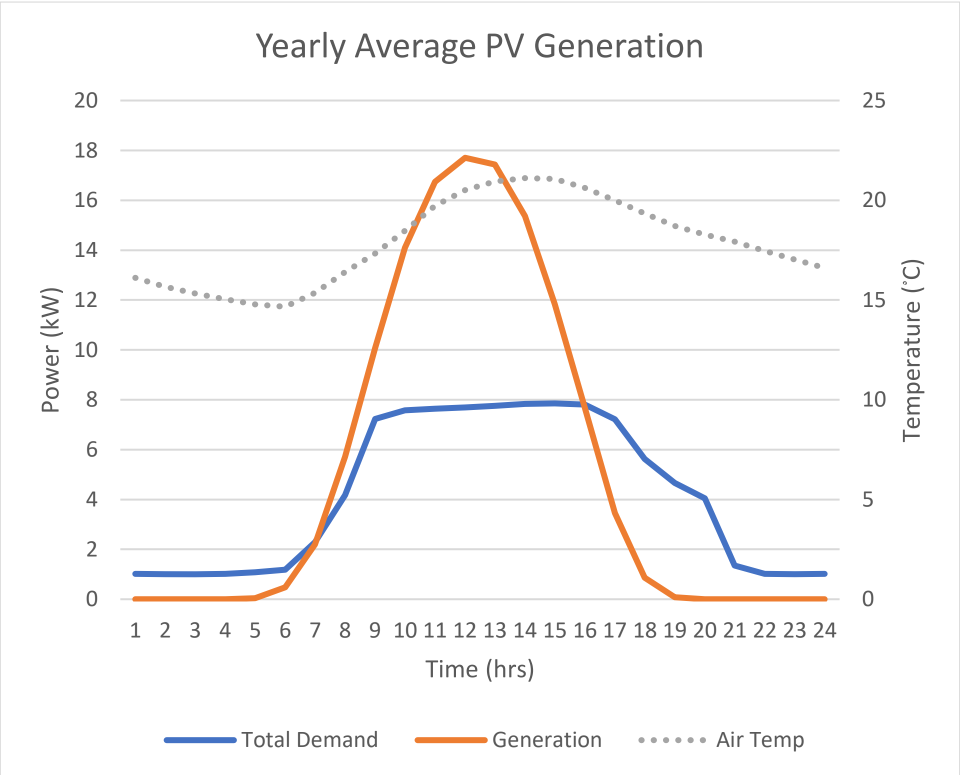


Figure 20 - Existing Building, Base Case, Yearly Average PV Generation

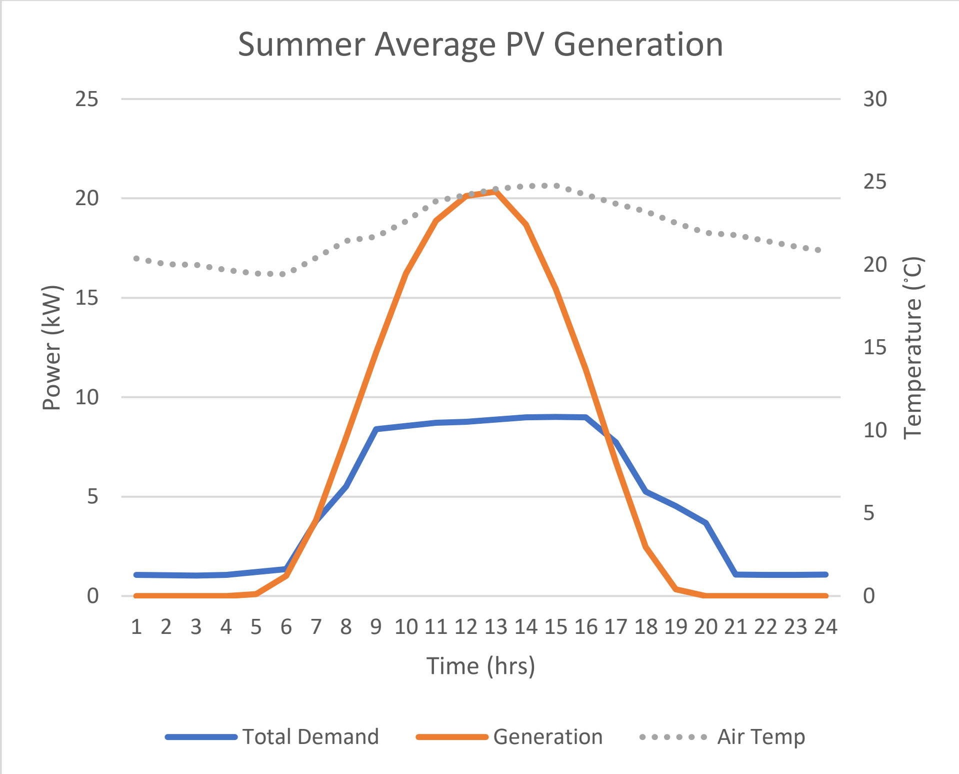


Figure 21 - Existing Building, Base Case, Summer Average PV Generation

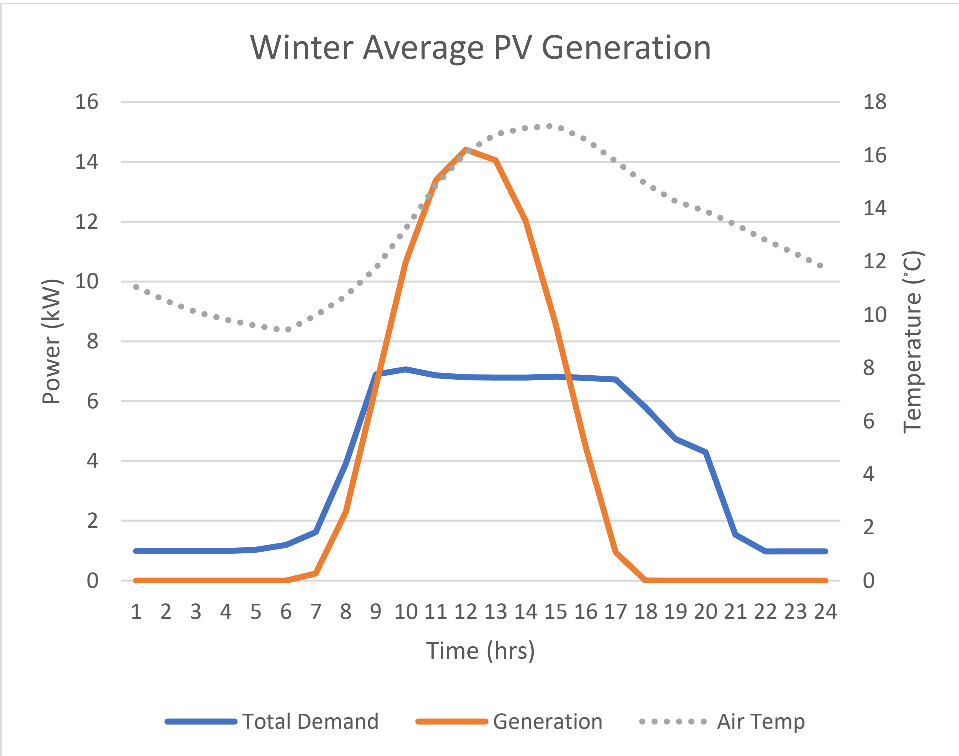


Figure 22- Existing Building, Base Case, Winter Average PV Generation

New Building

Table 6 - New Building, Base Case Solar PV, Yearly Net Energy Requirements

	Energy (kWh)
Total Demand	30,924.98
Total Generation	24,909.30
Net Energy Requirements	6,015.68

Seen above in Table 6, the yearly generation for the new building does not meet the demand. Seen in the figures below, like the existing building above, there is a peak in the generation during the middle of the day. Unlike the existing building though, when the generation reduces at sunset, the demand increases. This would be a result of the increase in occupancy in the residential spaces when people return home of a night. This demand slowly reduces till midnight. This larger demand later into the night would explain the significantly lower REF as will be discussed below.

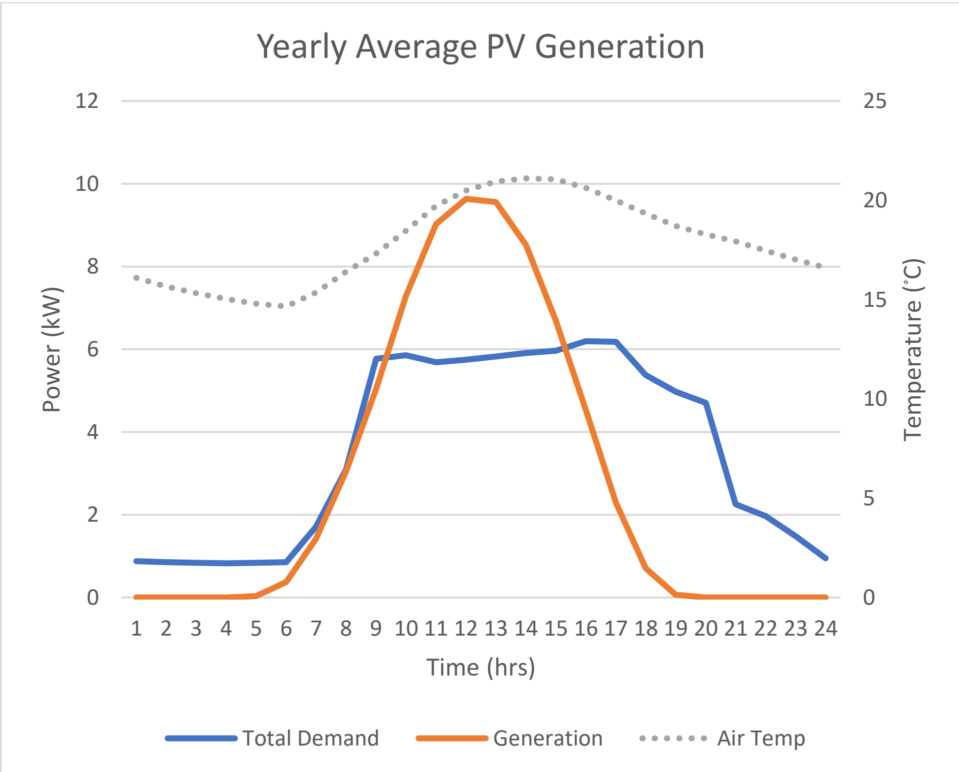


Figure 23 - New Building, Base Case, Yearly Average PV Generation

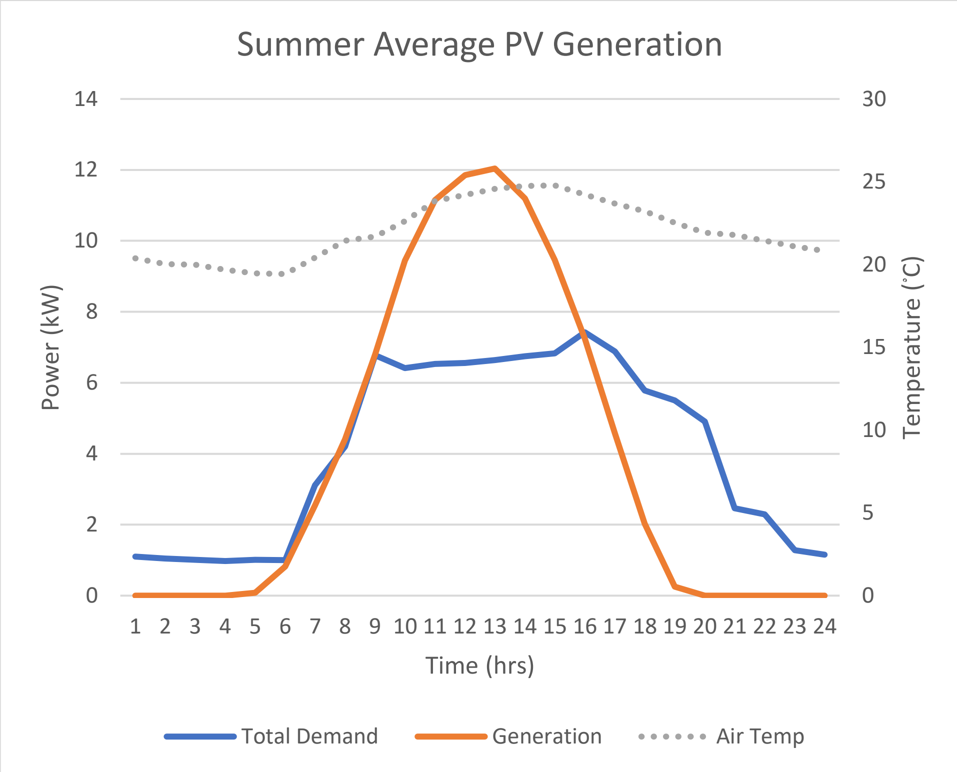


Figure 24 - New Building, Base Case, Summer Average PV Generation

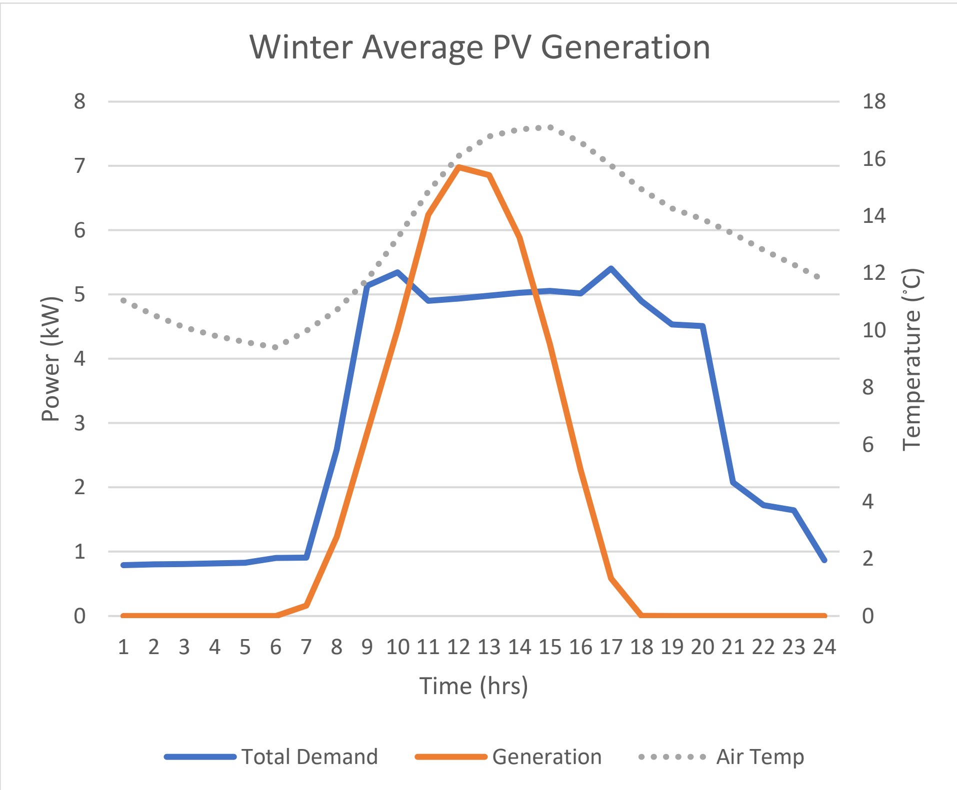


Figure 25 - New Building, Base Case, Winter Average PV Generation

Renewable Energy Fraction

The renewable energy fraction (REF) is calculated by dividing the total site demand by the renewable energy generation of the site. The REF was calculated for each hour of the energy simulation. When the REF exceeds one, the on-site generation exceeds the total building demand. When the REF is below one, the renewable energy generation will not meet the total energy requirements of the building.

Table 7 - Base Case, REF No. of Hours

	Existing Building		New Building	
REF Value	No. of Hrs.	% of Year	No. of Hrs.	% of Year
0	4197	47.9	4197	47.9
0 < REF < 0.30	626	7.2	702	8.0
0.30 < REF < 0.95	1121	12.8	1589	18.1
0.95 < REF < 1.05	132	1.5	199	2.3
1.05 < REF	2684	30.6	2073	23.7

It can be seen in Table 7 that for both buildings, 47.9% of the year has an REF value of zero. This corresponds to nighttime hours when the generation is zero. For both buildings a large portion of the year has an REF value greater than 1.05, this corresponds to the peak generation during the middle of the day when the generation far exceeds the demand for that hour. For both buildings, very few hours of the year have the ideal REF value of between 0.95 and 1.05, this means that for vast majority of the year there is either insufficient or too much generation.

Table 8 - Base Case, REF Yearly Average

	Existing Building	New Building
REF Yearly Average	0.9657	0.5803

The REF values for each building can be seen in Table 8. The existing building's REF is very close to 1 already, due to its well positioned northern facing roof line which has provided large energy generation. Therefore, the existing buildings design should not require much improvement to achieve an REF of above 1. Conversely, it is expected the new building will require significant modification due to its low REF of 0.5803 with the generation being much lower than the demand, as can be seen in Table 6.

Improved Model

Step Modifications

Following the base case solar PV energy simulations and the determination of the REF yearly average value for each building, the buildings designs would be modified to improve the REF yearly average value for each building to be at least 1.

To determine the best way to improve the buildings designs, the maximum building loads were determined from the base case buildings. For both buildings the maximum loads were found to be the room, lighting, cooling, and hot water loads. The hot water load was specified within the assignment requirements, so it could not be reduced through any building modifications. The room load is from the appliances and equipment within the building, it's reduction would be accomplished through using more energy efficient appliances and equipment, as well as altering the behaviour of the inhabitants by turning appliances off at night and when not in use. Because of these reasons the design modifications would be aimed at reducing the lighting and cooling loads, as these could be reduced through modifications to the buildings design. The extended results from all modifications can be seen in Appendix C.

Responsive lighting was added into the buildings first, this would turn artificial lighting off in spaces where there was sufficient natural lighting. This significantly reduced the lighting load as well as the cooling load due to the reduced heat gains from the artificial lighting. This significantly improved the REF values for both buildings compared to the base case, and the existing building had an REF of above 1, as was the goal of the modifications. Despite this the existing building will still be tested with the following modifications to try and improve the REF further.

The insulation was improved from the base case. This was achieved by upgrading the materials from 'General Energy Code – Medium Weight' to 'Best Practice – Medium Weight'. This had the unexpected effect of decreasing the REF value for both buildings. This is due to a slight increase in the total energy demand, from an increase in the cooling load. It is believed this is due to the increased insulation reducing the internal heat gains that can escape through the building's fabric, which increases the buildings cooling load.

The window glazing was next improved from 3mm single glazing to double glazing (LoE Clr 6mm/13mm Arg). The improved window glazing had resulted in a reduced cooling load for both buildings due to the increased window insulation. There was also a slight increase in the heating load in both buildings due to the decrease in the solar transmission from 0.837 for the single glazing to 0.474 for the double glazing. Overall, this reduced the total energy demand which slightly increased the REF for both buildings.

Of the above modifications, responsive lighting was the most effective at improving the energy performance of the buildings, followed by improving the windows to double glazing. Improving the building insulation will not be tested further as it was ineffective at improving the buildings energy performance, as seen above. The building was then tested with a combination of responsive lighting and double glazing. This improved the building performance the best so far, with the largest improvement in the REF value for each building.

To try and reduce the cooling load further, external shading was added along with the responsive lighting and double glazing. This slightly reduced the REF for the existing building compared to the responsive lighting and double-glazing case. Despite the total demand being lower, the generation had also decreased from slight shading of the solar panels. The new building however had an improved REF due to the decreased demand, and the roof profile meant the solar panels experienced no shading from the window shading.

Now to try and increase the natural light entering the building to reduce the lighting load, the window glazing was changed to single glazing with responsive lighting and external shading. This improved the REF of the existing building to its highest value of 1.1634, the new building however had a slightly reduced REF of 0.7060 compared to the best case of responsive lighting, double glazing, and external shading with an REF of 0.7153.

Table 9 - Initial Step Modifications, REF Yearly Average

	REF Yearly Average	
Modification	Existing Building	New Building
Base Case	0.9657	0.5803
Responsive Lighting	1.1605	0.6822
Improved Insulation	0.9639	0.5802
Double Glazed	0.9720	0.5941
Responsive Lighting, Double Glazed	1.1631	0.6988
Responsive Lighting, Double Glazed, External Shading	1.1596	**0.7153**
Responsive Lighting, Single Glazed, External Shading	**1.1634**	0.7060

Following the initial modifications shown in Table 9, the best case of modifications for the existing building of responsive lighting, single glazed windows, and external shading has an REF of 1.1634. This means the existing building has met the requirements of achieving an REF of greater than 1. The new building's best modification case of responsive lighting, double glazed windows, and external shading has an REF of 0.7153, which has not met the requirement of having an REF of greater than 1.

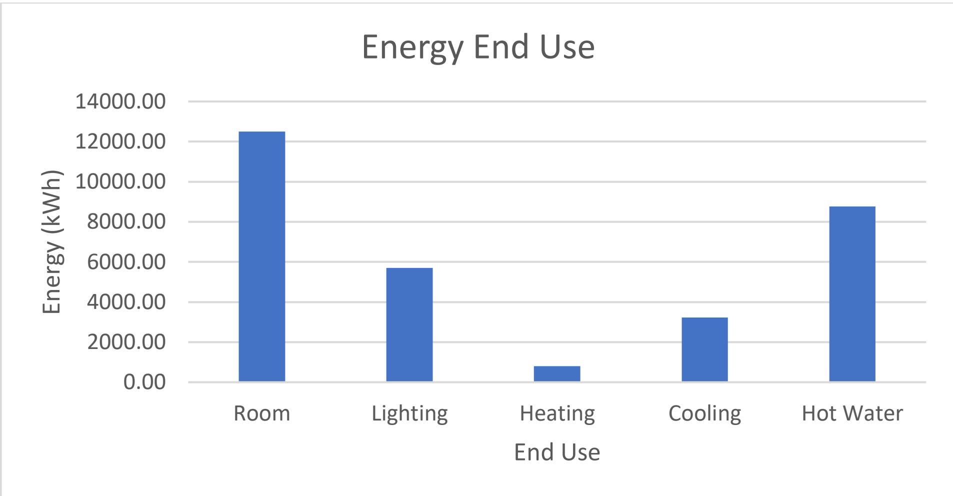


Figure 26 - New Building, Initial Best Case, Energy End Use

As can be seen above in Figure 26, the largest energy end use for the new building was lighting, not including the room and hot water loads, as discussed earlier the room and hot water loads will not be improved through building modifications. To reduce the lighting load the natural light entering the building will try and be increased. To achieve this the number of windows in the design will be increased, as shown below in Figure 27.

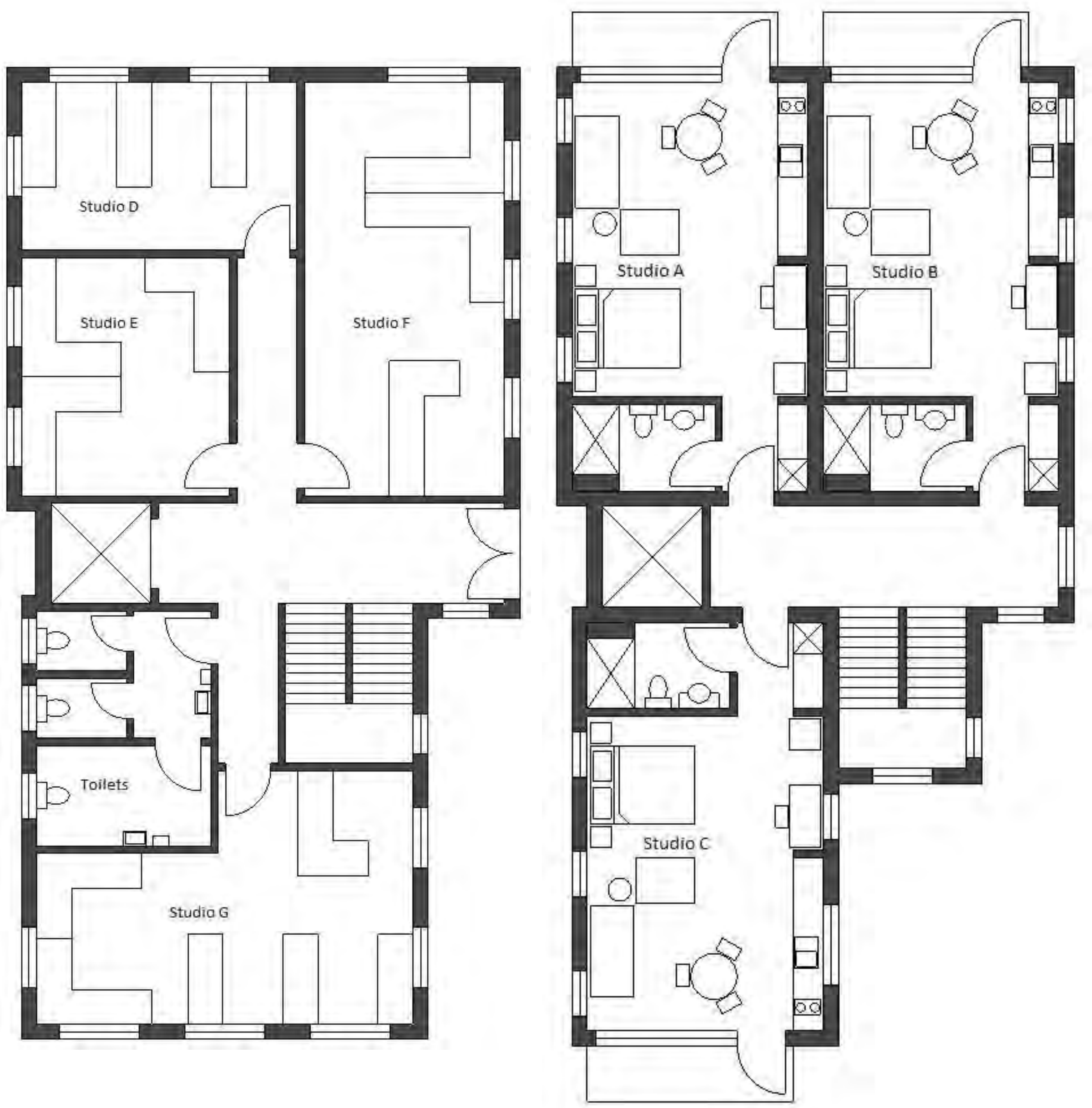


Figure 27 - New Building, Increased Window Floorplans

The increased windows were added into the best-case modification case for the new building. The increased windows had reduced the lighting and heating load and slightly increased the cooling load. Overall, the total demand had reduced which increased the REF to 0.7280. To increase the REF further, the demand can be decreased, or the generation can be increased. To increase the generation the position of the solar panel array was changed. The solar panels were originally positioned primarily on the western side of the roof, being shaded slightly by the eastern side of the roof. In the new configuration some of the panels from the western side of the roof were placed on the eastern side of the roof, meaning more of the solar panels would receive full sun for more of the day. The new layout of the solar panels is shown below in Figure 28.

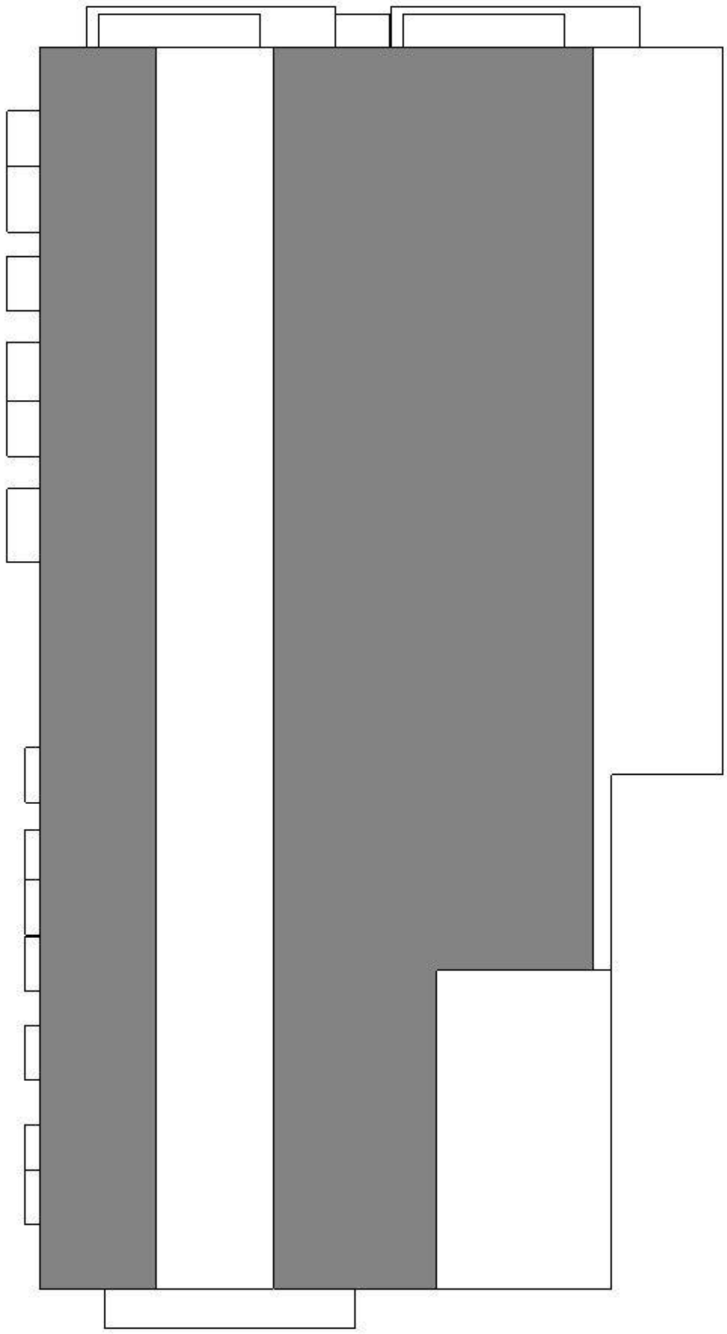


Figure 28 - New Building, Improved Solar Panel Layout

The improved solar panel layout increased the total generation of the building, this is the first time the total yearly generation exceeded the total demand. Therefore, when considering the year as a whole the building has achieved net zero energy. However, when considering the REF of the building, which depends on how well the generation matches the demand for every hour of the year, the improved solar panel layout only increased the REF to 0.8403.

To improve the REF further the generation curve will have to better match the demand curve, this can be achieved with the use of a solar battery. When the new building was fitted with a 20kWh solar battery along with the responsive lighting, double glazed windows, external shading, and the repositioned solar panels, the REF increased to 1.0280. The Results from all modifications are shown below in Table 10.

Table 10 - Complete Step Modifications, REF Yearly Average

	REF Yearly Average	
Modification	**Existing Building**	**New Building**
Base Case	0.9657	0.5803
Responsive Lighting	1.1605	0.6822
Material Upgrade, Single Glazed	0.9639	0.5802
Double Glazed	0.9720	0.5941
Responsive Lighting, Double Glazed	1.1631	0.6988
Responsive Lighting, Double Glazed, Shading (1.0m)	1.1596	0.7153
Responsive Lighting, Single Glazed, Shading (1.0m)	**1.1634**	0.7060
Responsive Lighting, Double Glazed, Shading (1.0m), more windows (building 2)	-	0.7280
Responsive Lighting, Double Glazed, Shading (1.0m), more windows (building 2), Re-fit Solar Panels	-	0.8403
Responsive Lighting, Double Glazed, Shading (1.0m), more windows (building 2), Re-fit Solar Panels, 20kWh battery	-	**1.0280**

Design

Site Plan

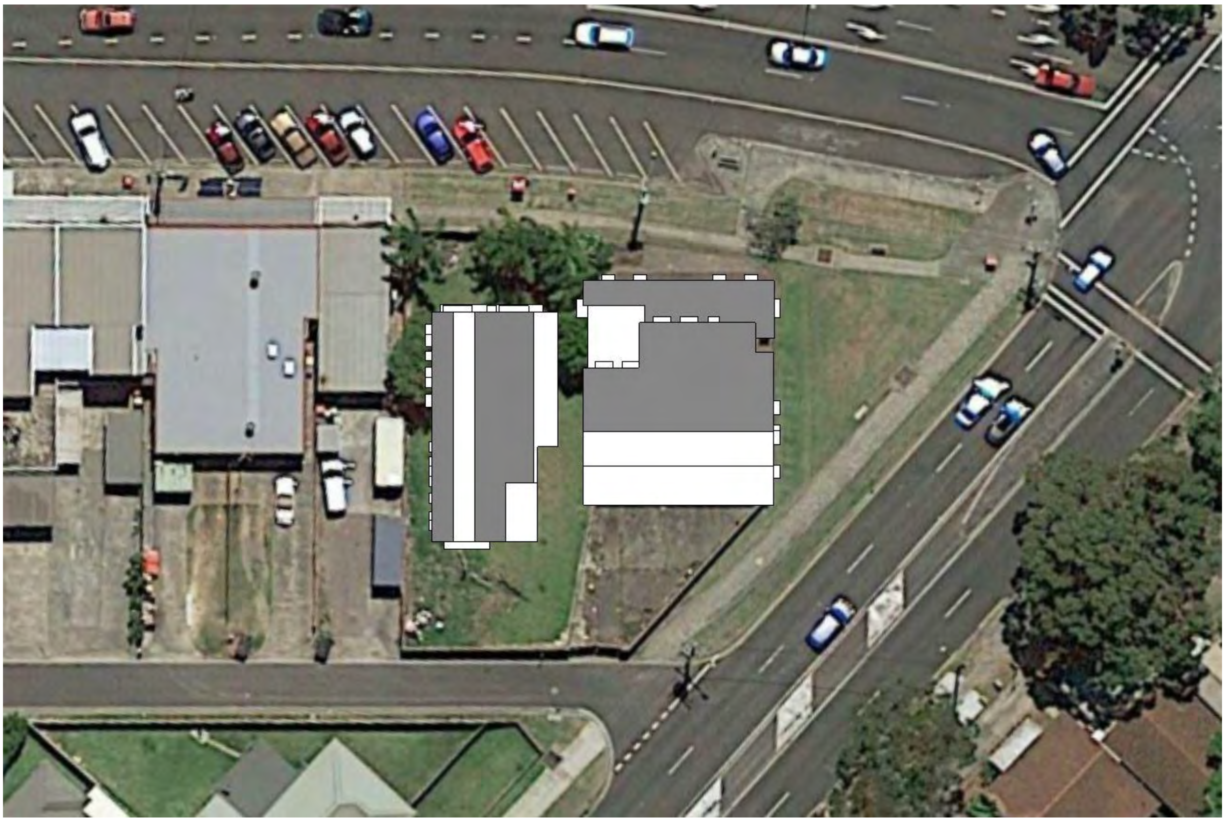


Figure 29 - Final Design, Site Plan

Existing Building

Floorplans

The floorplans of the existing building have remained unchanged from the base case. See Floorplans, page 3.

Elevations

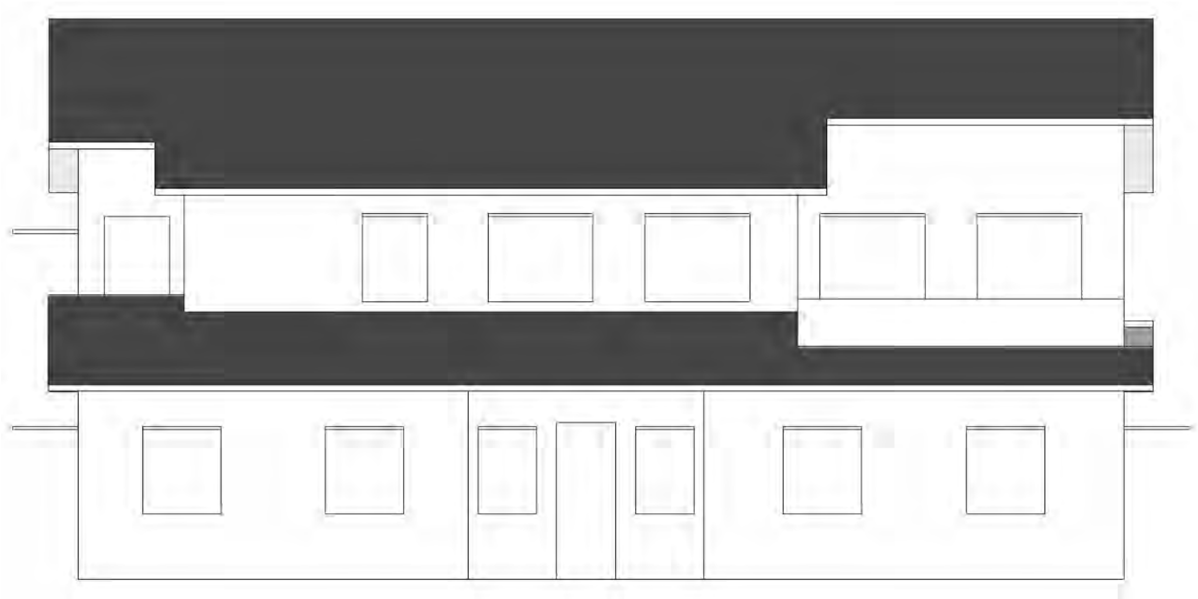


Figure 30 - Existing Building, Final Design, Northern Elevation

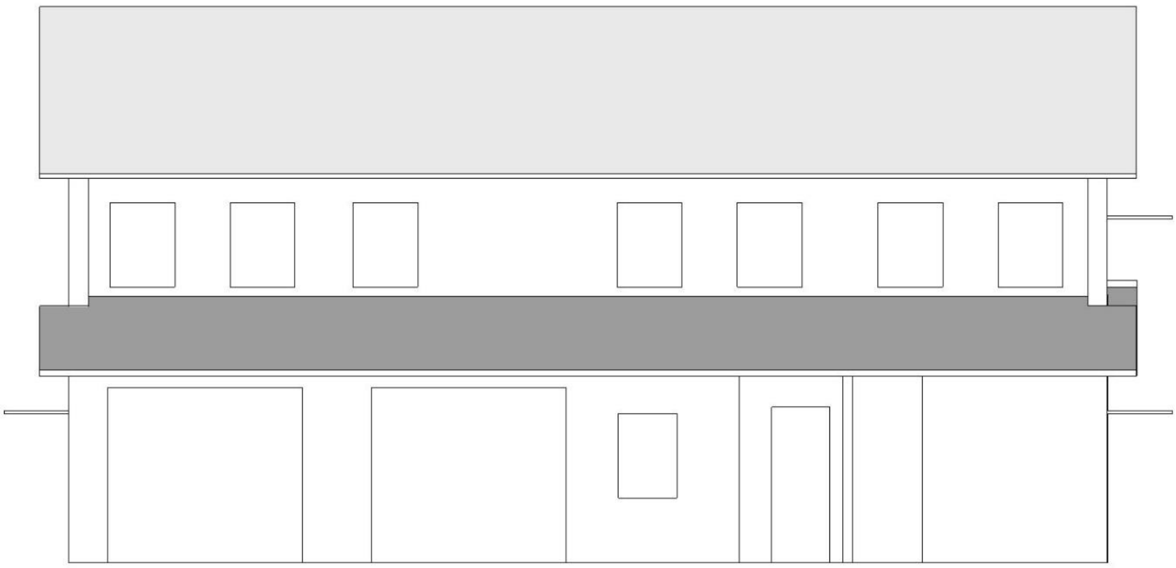


Figure 31 - Existing Building, Final Design, Southern Elevation

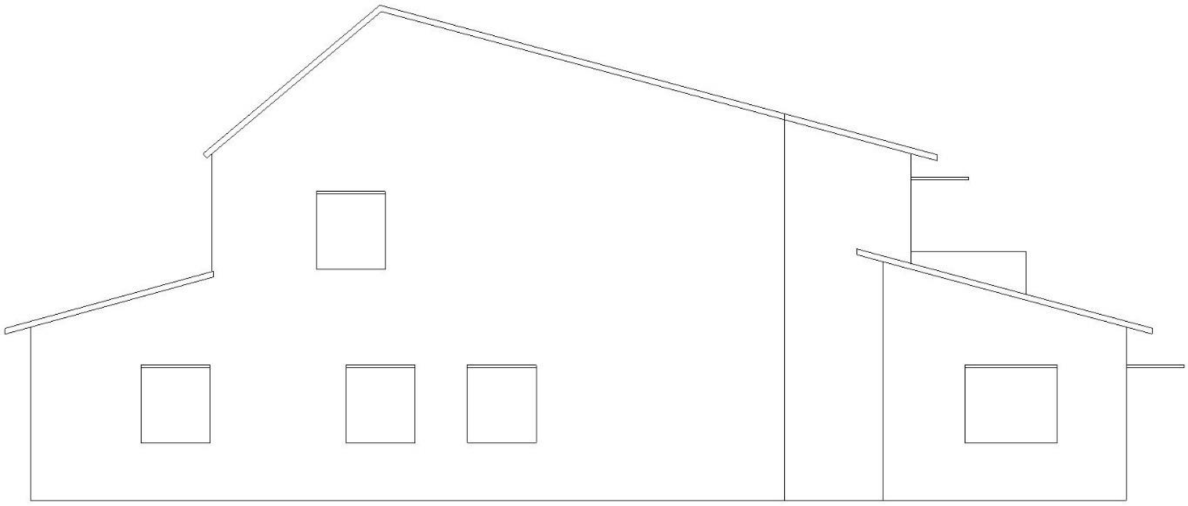


Figure 32 - Existing Building, Final Design, Eastern Elevation

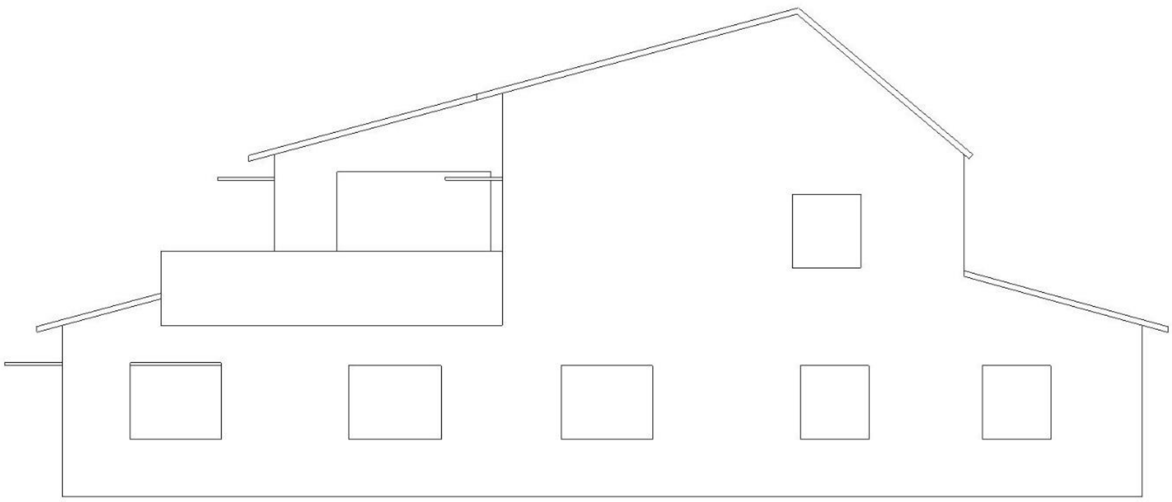


Figure 33 - Existing Building, Final Design, Western Elevation

New Building

Floorplans

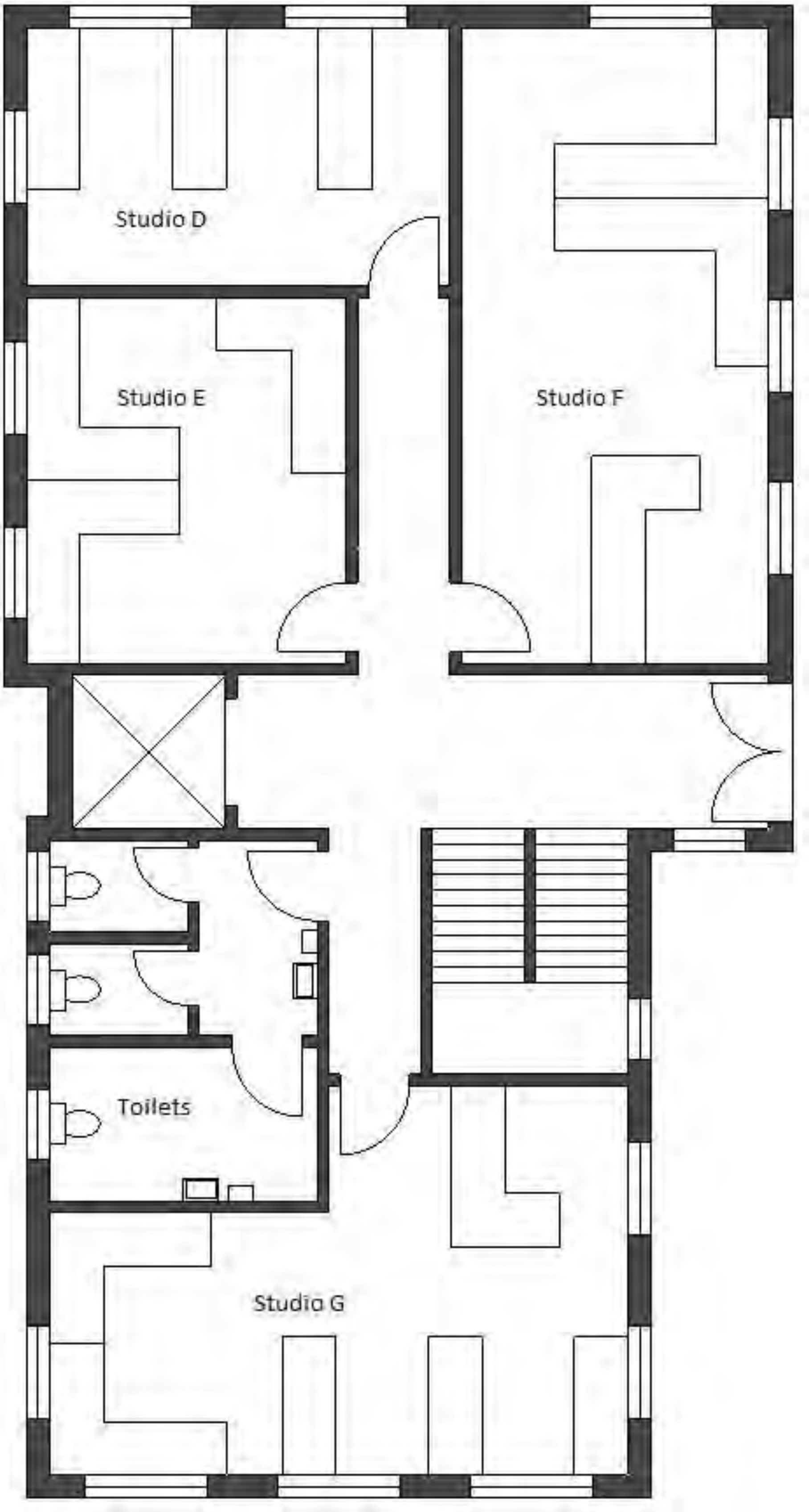


Figure 34 - New Building, Final Design, Ground Floor

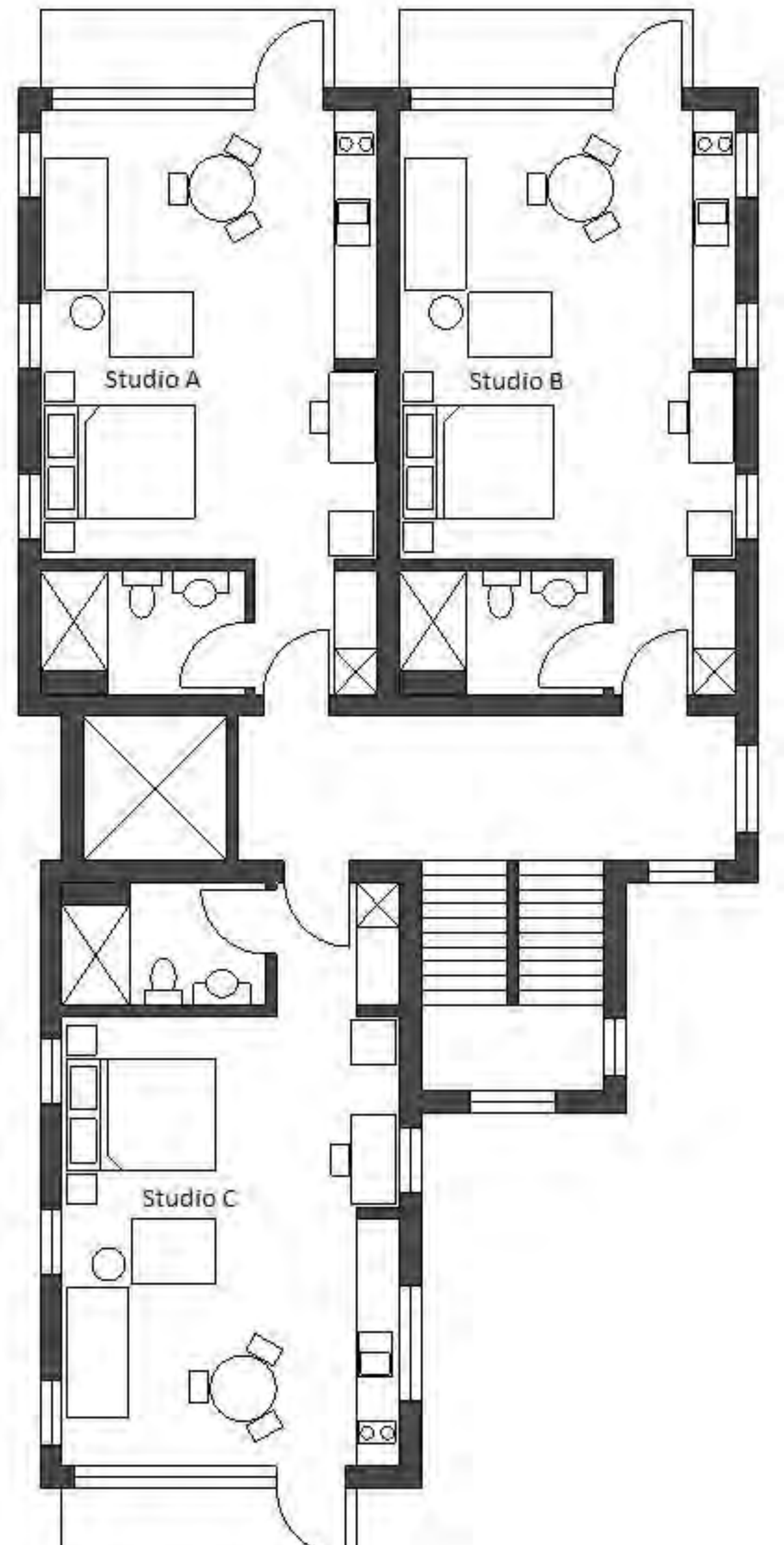


Figure 35 - New Building, Final Design, Top Floor

Elevations

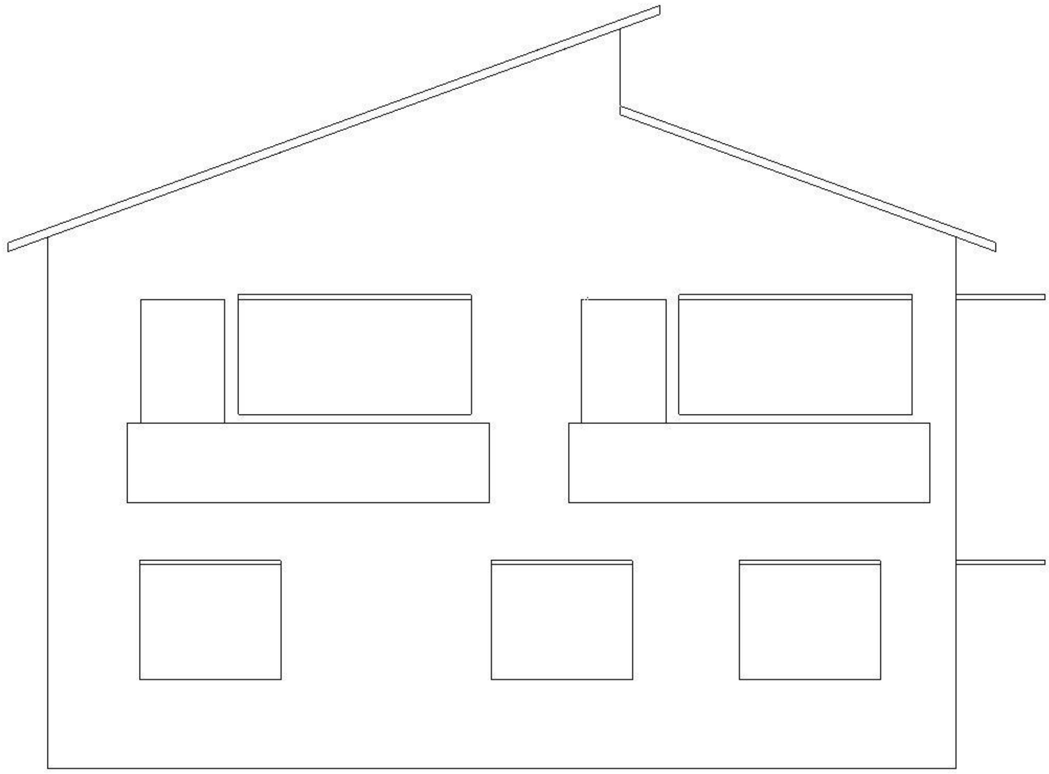


Figure 36 - New Building, Final Design, Northern Elevation

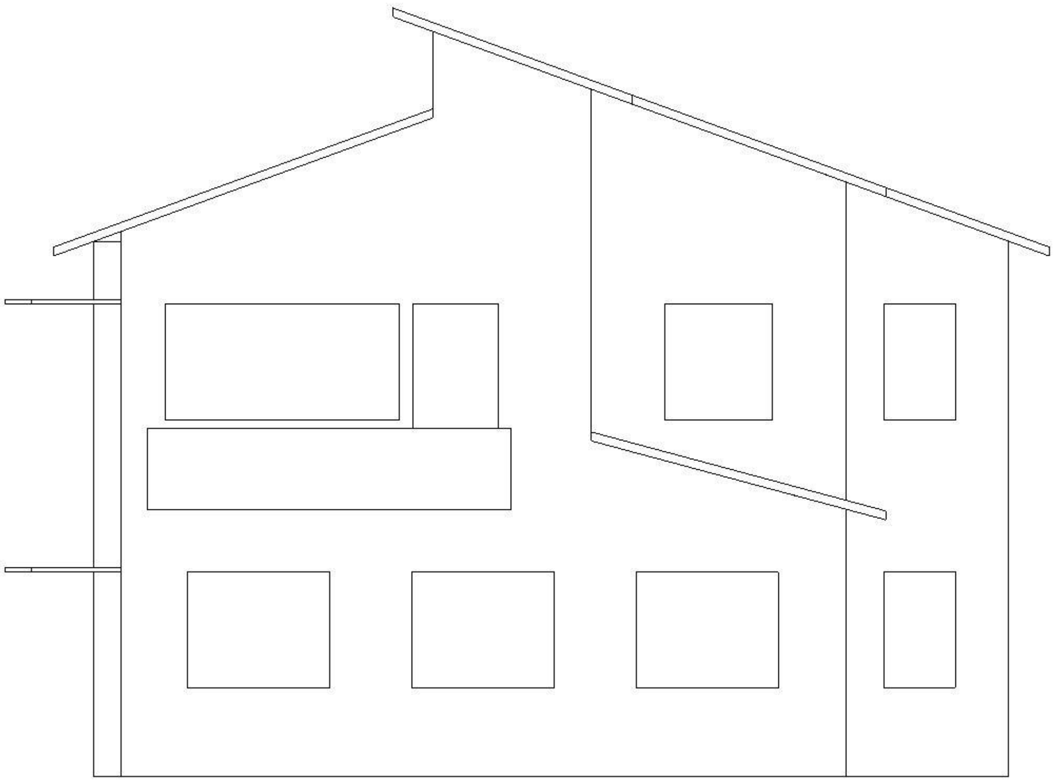


Figure 37 - New Building, Final Design, Southern Elevation

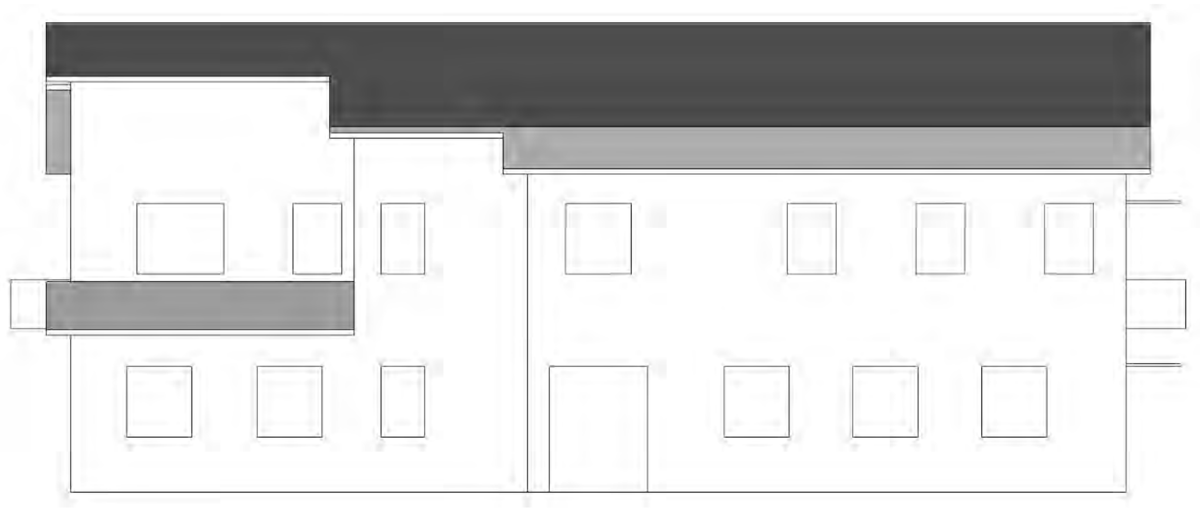


Figure 38 - New Building, Final Design, Eastern Elevation

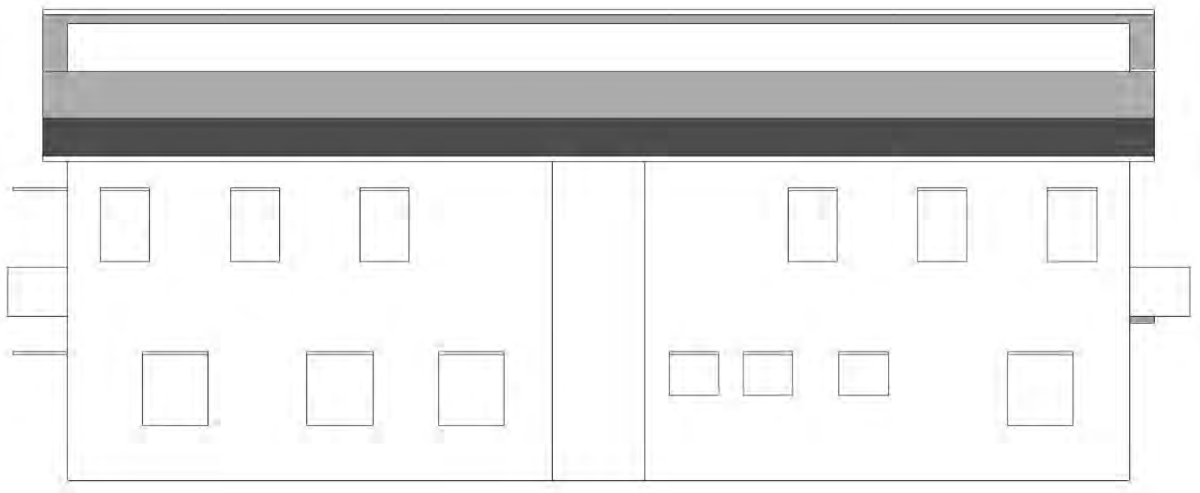


Figure 39 - New Building, Final Design, Western Elevation

Shading Diagrams

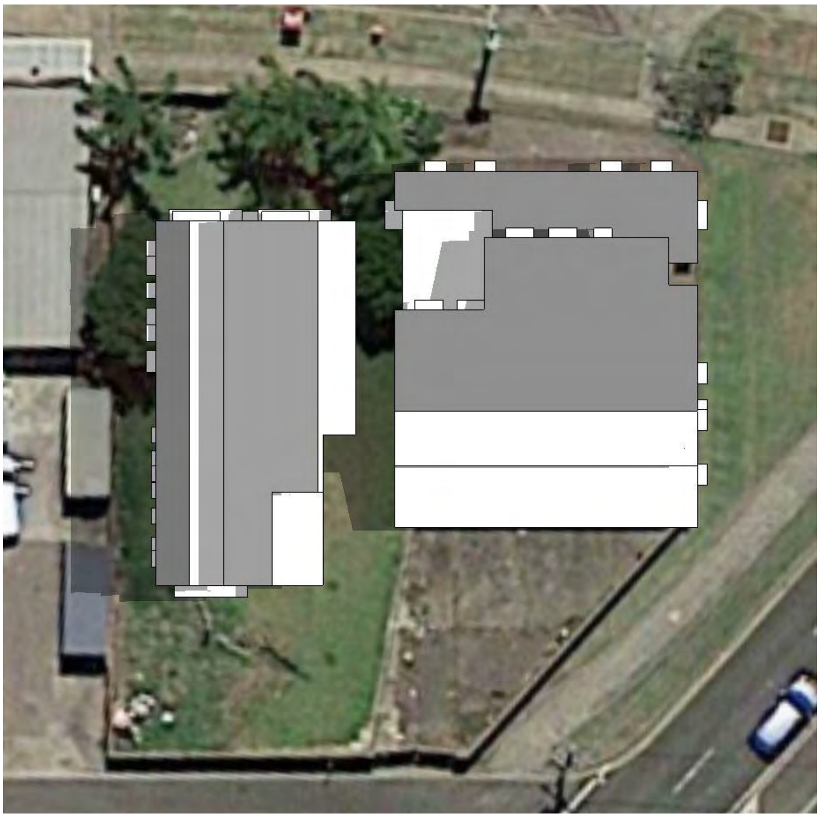


Figure 40 - Summer Shading 9am

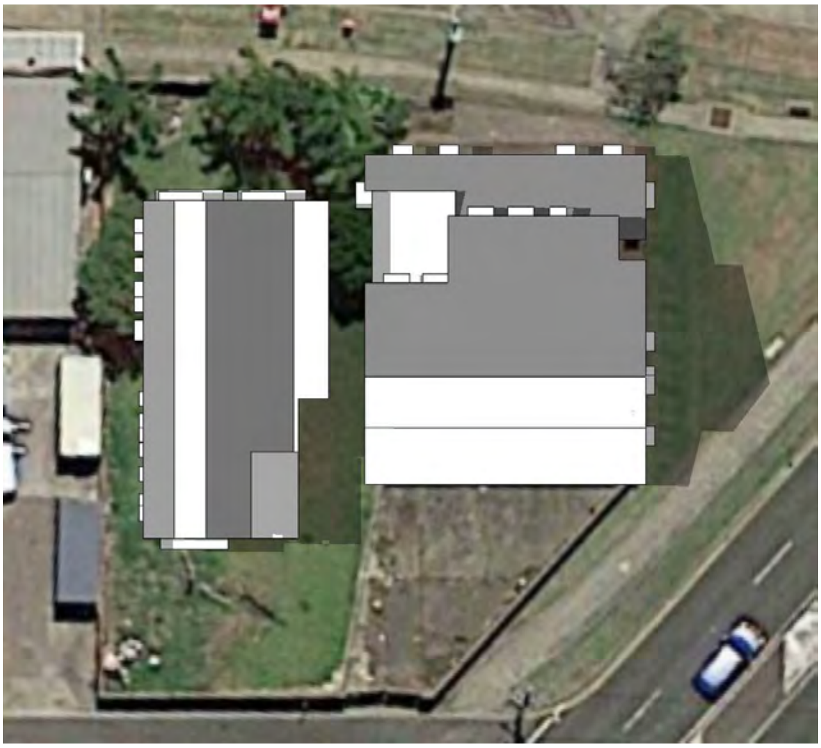


Figure 41 - Summer Shading 3pm

Figure 42 - Winter Shading 9am

Figure 43 - Winter Shading 3pm

The shading diagrams above show that the two buildings shade each other across the day. Because of this, each energy simulation was set to consider shading from the adjacent building. The solar panels of the new building are partially shaded by the existing building of an early morning. And likewise, the solar panels of the existing building are shaded by the new building of a late afternoon. However, for most of the day the windows facing the adjacent building were partially shaded. Reducing the solar gains and natural lighting entering the building; increasing the cooling, and lighting loads.

Discussion and Recommendations

The final design of each building has not hindered in any way their functionality. The improved design has not altered the layout of either building. The only key alteration to either building was the additional windows added to the new building, which has only improved the internal comfort of the building. The design specifications as outlined by the client have been upheld and continue to be achieved by the buildings throughout the modifications to their design.

It can be seen below in Figure 44, that the existing building's final design has a reduced energy demand compared to the base case. There was also a very slight reduction in the generation curve due to the slight shading of the panels from the window shading. Similarly, you can see in Figure 45 that the new building's final design had a reduced demand and an increased generation.

For both buildings the generation exceeds the demand significantly during daylight hours, the demand then exceeds the generation into the night. In the case of the new building, the final generation curve extends into the night, matching closer to the demand curve. This is a result of the solar battery using the stored energy during the night.

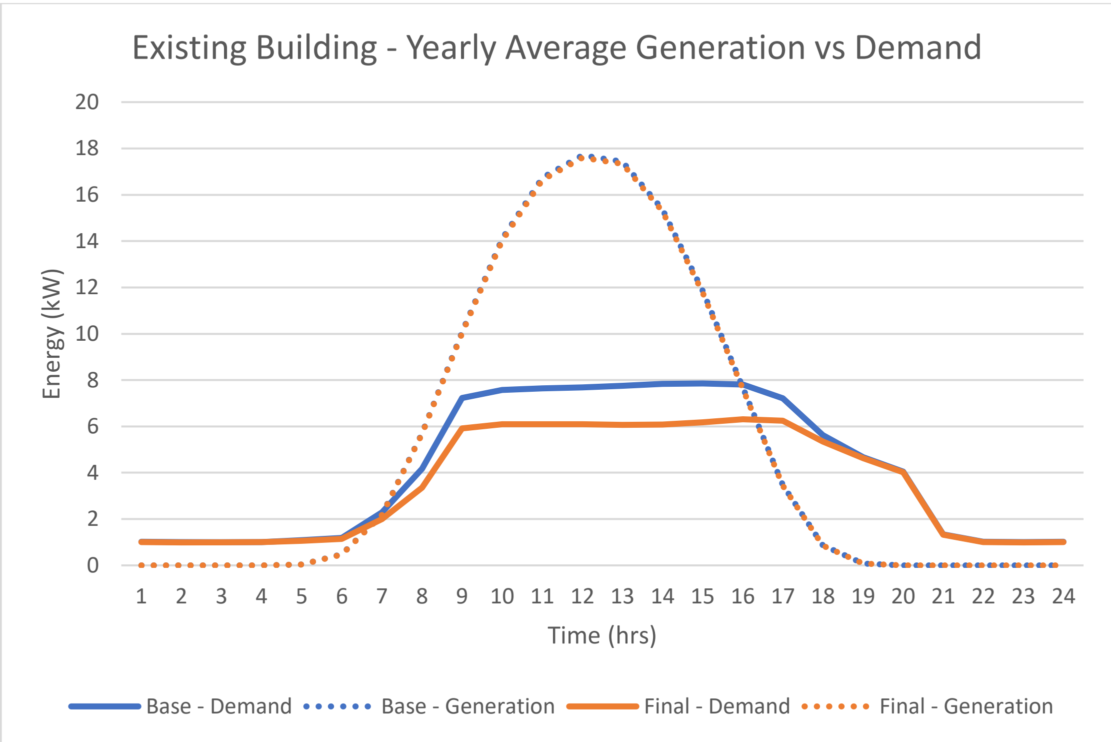


Figure 44 - Existing Building, Yearly Average Generation vs Demand

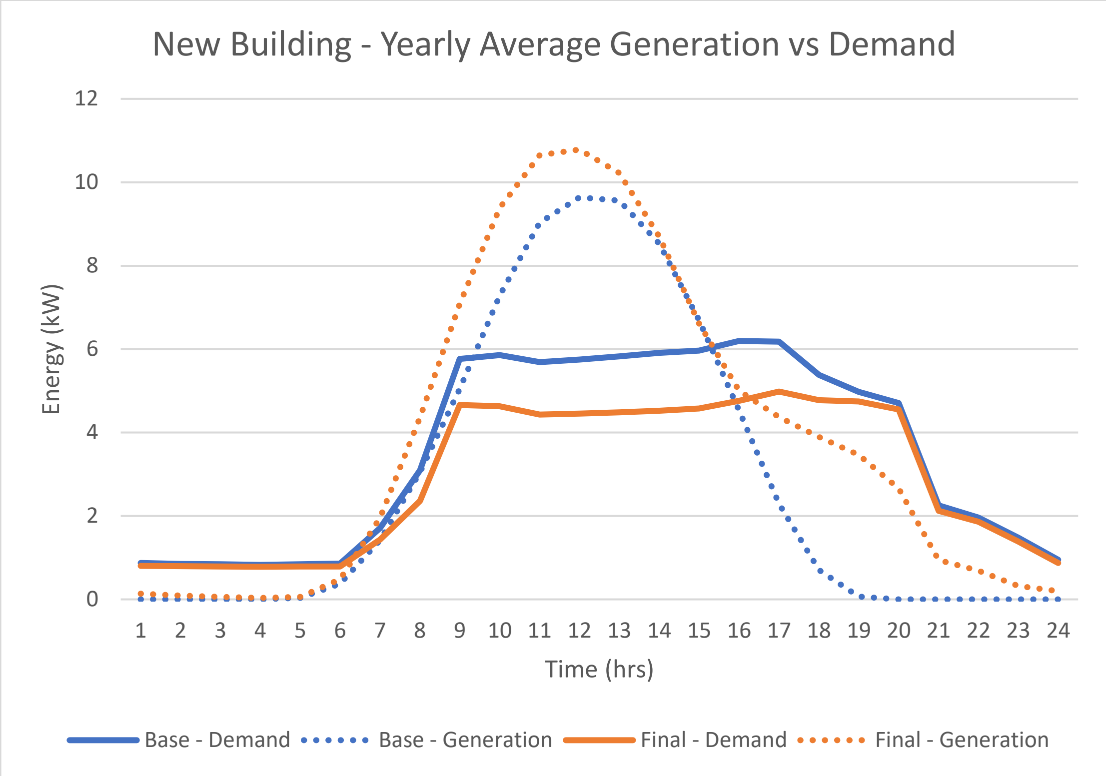


Figure 45 - New Building, Yearly Average Generation vs Demand

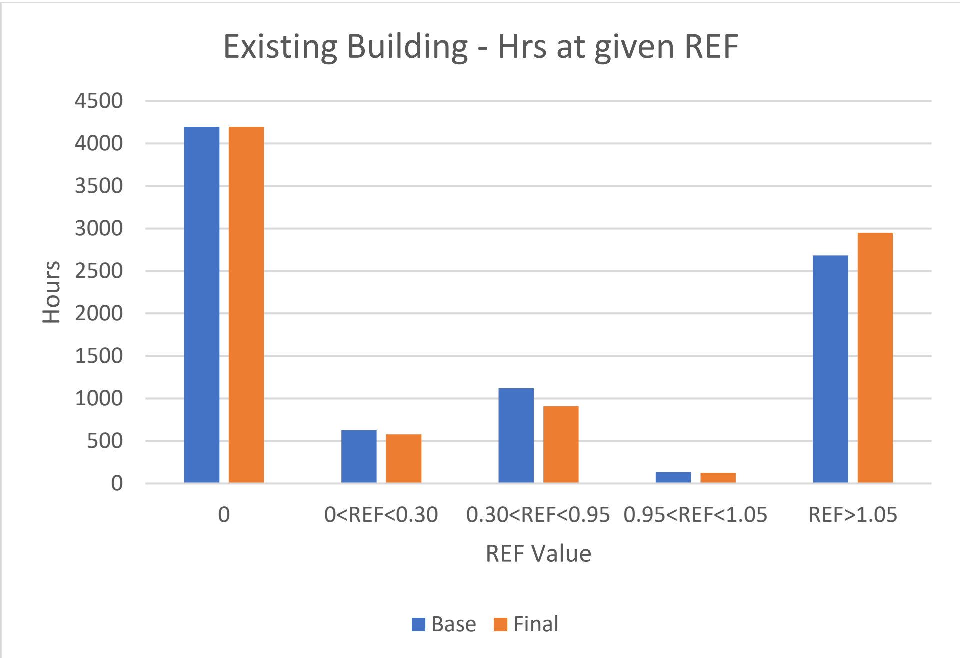


Figure 46 - Existing Building, REF Value Comparison

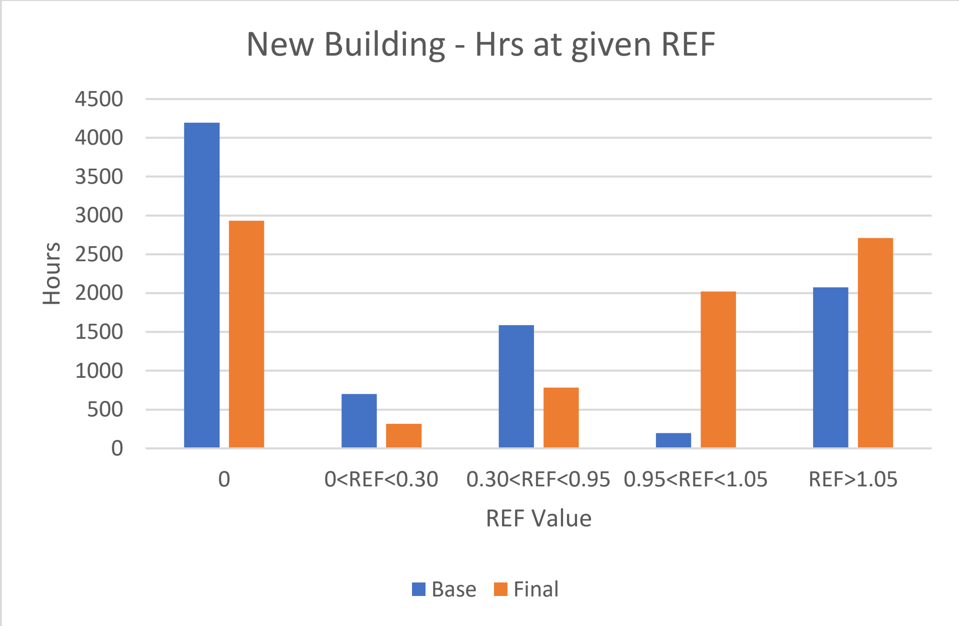


Figure 47 - New Building, REF Value Comparison

The existing buildings final design had an increased number of hours with an REF of greater than 1.05. This was a result of the reduced demand during the day but the relatively unchanged generation. This also resulted in a reduction in hours with an REF between 0 and 1.05. The new buildings final design had a significant change in the distribution of REF values. This was a result of the battery drastically changing the generation curve, stretching it further into the night, as well as the increased generation from the altered layout of the solar panels. There was a large increase in hours that the REF is in the ideal range of 0.95 to 1.05, this means more often the demand was better matched by the generation. Following the energy simulation analysis with the modifications made to the design, it is recommended that the buildings designs should be improved as follows.

Existing Building

The base case design of the existing building should be improved upon by including responsive lighting. The windows on the eastern and northern façade of the building should be fitted with 1.0m long horizontal external shading. The window glazing and materials should be kept as they were in the base case.

New Building

The base case design of the new building should be improved upon by including responsive lighting. The windows on the western and northern façade of the building should be fitted with 1.0m long horizontal external shading. The materials should be kept as they were in the base case. The window glazing should be upgraded to double (Clr 6mm/13mm Arg) glazing. The number of windows in the design should be increased, as well as the solar panels being repositioned, as shown in New Building, page 28. With these modifications the generation does exceed the demand, so across the entire year it achieves net zero energy, however it does not achieve an REF of above 1. However, to get the generation to better match the demand of the building a 20kWh solar battery can be placed in the building, this will improve the REF to 1.0280.

References

(2019) Transportenvironment.org. Available at: https://www.transportenvironment.org/wp-content/uploads/2021/07/2019_11_Analysis_CO2_footprint_lithium-ion_batteries.pdf (Accessed: 28 October 2021).

CO2 Emissions - Production (2021). Available at: https://www.sustainableconcrete.org.uk/Sustainable-Concrete/Performance-Indicators/CO2-Emissions-Production.aspx (Accessed: 28 October 2021).

Green Star Design & As Built V1.3, 2019, Green Building Council of Australia.
NCC, 2019, Building Code of Australia

Appendix A – Reflection Report

A key improvement to the new buildings design was the increased window area. The increased window area increased the natural lighting level within the building, this decreased the lighting load. It also increased the solar gains entering the building, this increased the cooling load while also decreasing the heating load. The net effect on the energy demand depended upon the climate of the site, being a cooling dominated climate. Yet within Green Star, there are points awarded for both increasing the natural lighting levels in the design, and for decreasing the buildings energy use, which are opposing goals. This shows one of the many complexities involved in designing a net zero energy building. Changing one aspect of the design will increase the energy demand in some respects while decreasing the demand in other ways but will also directly affect the internal comfort levels of the building.

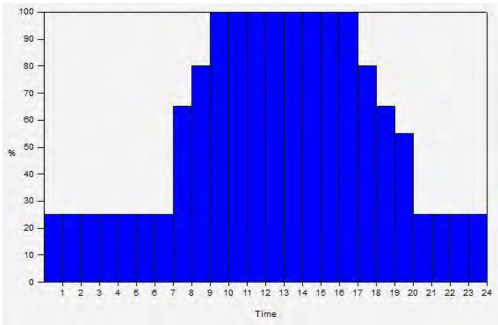
Another consideration, the use of the 20kWh solar battery within the new building was a key tool to achieve an REF of above 1. A battery of this size would have an embodied carbon of 1.46 tonnes of CO2-e (transportenvironment, 2019). This is roughly the equivalent embodied carbon from 20 tonnes of concrete (CO2 Emissions, 2021). Within Green Star there are points awarded for reducing the life cycle impact of the building's materials. There are also points awarded for energy efficient design which reduces the emission of greenhouse gases. The use of the battery has evidently improved the energy efficiency of the design, yet it would negatively affect the life cycle impact of the building. It is clear from this there are once again opposing goals within the buildings design and the Green Star certification scheme.

These two examples show the complexities involved in designing energy efficient, but also comfortable buildings; as well as the difficulties in creating the rating tools to assess their performance.

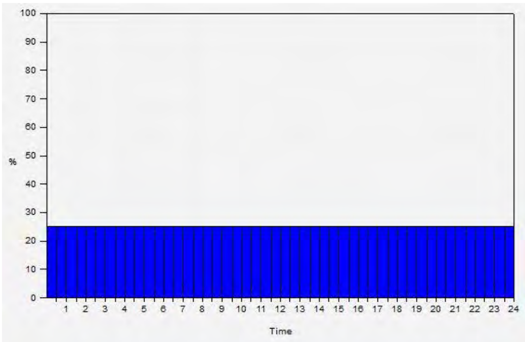
Appendix B – Simulation Assumptions

Schedule Profiles

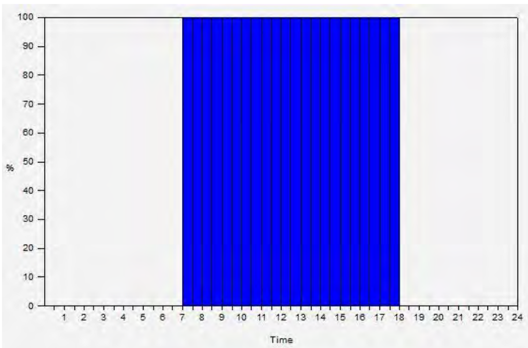
NCC – Equipment Weekday



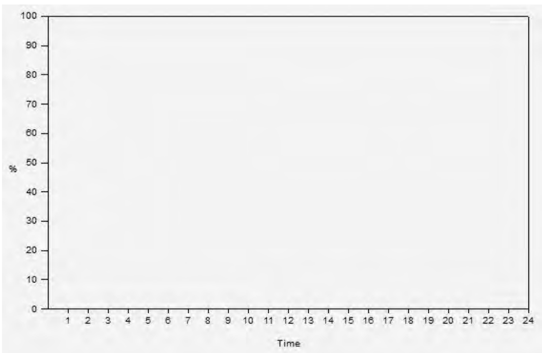
NCC – Equipment Weekend



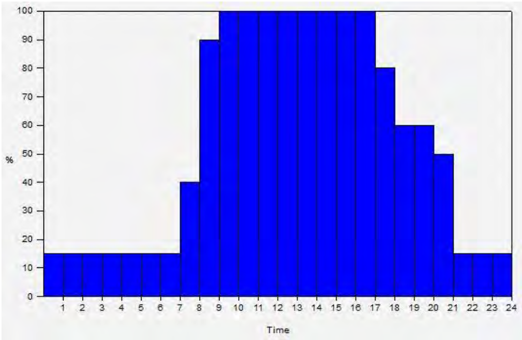
NCC – HVAC Weekday



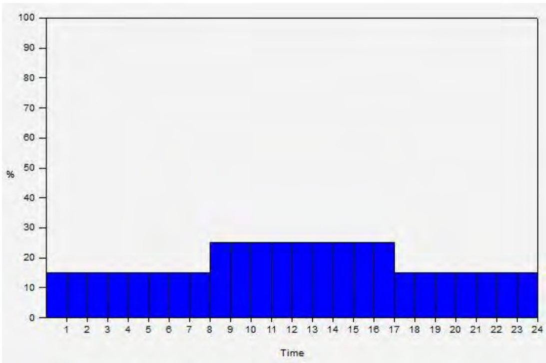
NCC – HVAC Weekend



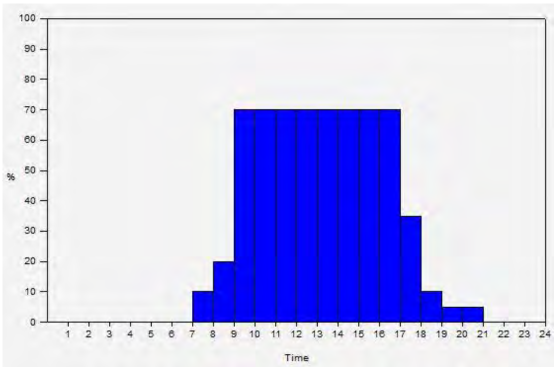
NCC – Lighting Weekday



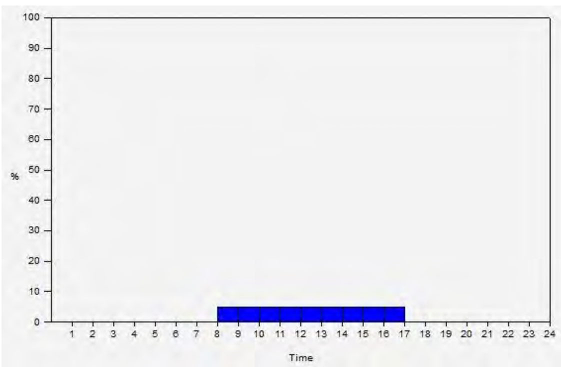
NCC – Lighting Weekend



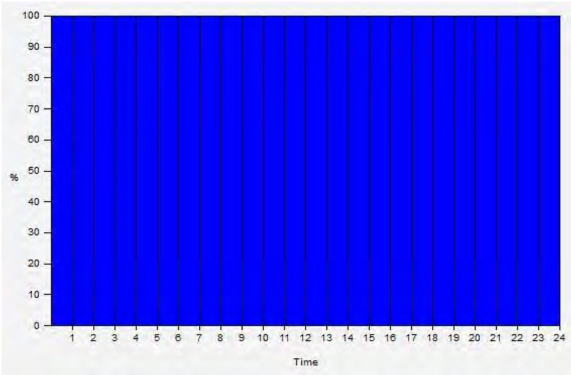
NCC – Occupancy Weekday



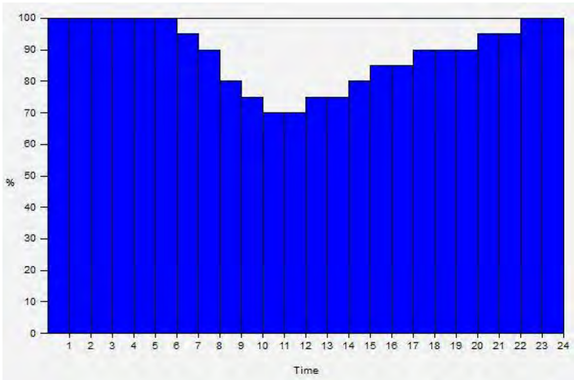
NCC – Occupancy Weekend



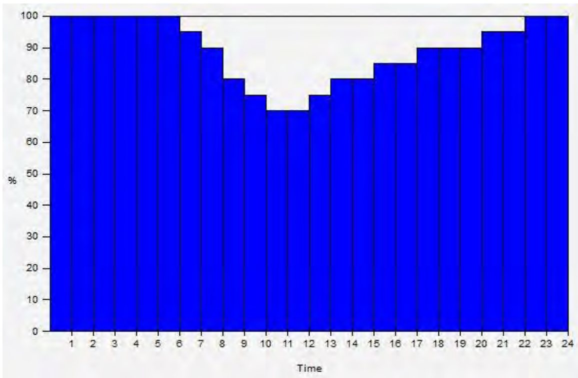
Studio – HVAC



Studio – Occupancy Weekday



Studio – Occupancy Weekend



Hot Water

2 kW demand per hour between 8am – 8pm.

Lighting

LED lighting was used, with the profile as shown above. Power density of 2.5 W/m^2 – 100 lux

HVAC

The HVAC system was a Fan Coil Unit, Air Cooled Chiller. With a COP of 4.

Ventilation / Infiltration

The infiltration rate for both buildings was set to 0.42 ac/h, calculated from the 0.35 litres/s per m^2 with the 3m ceiling height.

Shading

The simulations were run to consider shading from each adjacent building.

Materials

The material template was set to 'General Energy Code – Medium Weight'. The external wall of the existing buildings ground floor was set to a double brick cavity to match the existing buildings construction.

Appendix C – Modification Results

Responsive Lighting

	Existing Building		New Building	
REF Value	No. of Hrs.	% of Year	No. of Hrs.	% of Year
0	4197	47.9	4197	47.9
0 < REF < 0.30	570	6.5	615	7.0
0.30 < REF < 0.95	916	10.5	1332	15.2
0.95 < REF < 1.05	133	1.5	191	2.2
1.05 < REF	2944	33.6	2425	27.7

	Existing Building	New Building
REF Yearly Average	1.1605	0.6822

	Energy (kWh)	
	Existing Building	New Building
Total Demand	31,389.05	27,259.58
Total Generation	45,181.47	24,909.30
Net Energy Requirements	-13,792.42	2,350.28

	Existing Building		New Building	
End Use	Energy (kWh)	% of Total	Energy (kWh)	% of Total
Room	12,497.76	39.8	9,279.92	34.0
Lighting	5,358.62	17.1	3,889.24	14.3
Heating	809.50	2.6	500.12	1.8
Cooling	3,963.17	12.6	4,830.30	17.7

Improved Insulation

	Existing Building		New Building	
REF Value	No. of Hrs.	% of Year	No. of Hrs.	% of Year
0	4197	47.9	4197	47.9
0 < REF < 0.30	625	7.1	696	7.9
0.30 < REF < 0.95	1115	12.7	1580	18.0
0.95 < REF < 1.05	155	1.8	210	2.4
1.05 < REF	2668	30.5	2077	23.7

	Existing Building	New Building
REF Yearly Average	0.9639	0.5802

	Energy (kWh)	
	Existing Building	New Building
Total Demand	36,579.43	30,802.11
Total Generation	45,181.47	24,909.30
Net Energy Requirements	-8,602.04	5,892.81

	Existing Building		New Building	
End Use	Energy (kWh)	% of Total	Energy (kWh)	% of Total
Room	12,425.46	34.0	9,233.94	30.0
Lighting	9,918.41	27.1	6,978.01	22.7
Heating	367.88	1.0	197.89	0.6
Cooling	5,107.68	14.0	5,632.28	18.3

Double Glazing

	Existing Building		New Building	
REF Value	No. of Hrs.	% of Year	No. of Hrs.	% of Year
0	4197	47.9	4197	47.9
0 < REF < 0.30	622	7.1	690	7.9
0.30 < REF < 0.95	1113	12.7	1547	17.7
0.95 < REF < 1.05	129	1.5	205	2.3
1.05 < REF	2699	30.8	2121	24.2

	Existing Building	New Building
REF Yearly Average	0.9720	0.5941

	Energy (kWh)	
	Existing Building	New Building
Total Demand	36,130.57	30,106.84
Total Generation	45,181.47	24,909.30
Net Energy Requirements	9,050.90	5,197.54

	Existing Building		New Building	
End Use	Energy (kWh)	% of Total	Energy (kWh)	% of Total
Room	12,497.76	34.6	9,279.92	30.8
Lighting	9,975.46	27.6	7,004.07	23.3
Heating	561.43	1.6	218.84	0.7
Cooling	4,335.93	12.0	4,844.01	16.1

Responsive Lighting, Double Glazing

	Existing Building		New Building	
REF Value	No. of Hrs.	% of Year	No. of Hrs.	% of Year
0	4197	47.9	4197	47.9
0 < REF < 0.30	571	6.5	604	6.9
0.30 < REF < 0.95	905	10.3	1309	14.9
0.95 < REF < 1.05	130	1.5	175	2.0
1.05 < REF	2957	33.8	2475	28.3

	Existing Building	New Building
REF Yearly Average	1.1631	0.6988

	Energy (kWh)	
	Existing Building	New Building
Total Demand	31,155.15	26,515.50
Total Generation	45,181.47	24,909.30
Net Energy Requirements	-14,026.32	1,606.20

	Existing Building		New Building	
End Use	Energy (kWh)	% of Total	Energy (kWh)	% of Total
Room	12,497.76	40.1	9,279.92	35.0
Lighting	5,542.09	17.8	3,978.56	15.0
Heating	686.80	2.2	273.25	1.0
Cooling	3,668.49	28.1	4,223.78	15.9

Responsive Lighting, Double Glazing, External Shading

	Existing Building		New Building	
REF Value	No. of Hrs.	% of Year	No. of Hrs.	% of Year
0	4197	47.9	4197	47.9
0 < REF < 0.30	578	6.6	598	6.8
0.30 < REF < 0.95	908	10.4	1287	14.7
0.95 < REF < 1.05	129	1.5	167	1.9
1.05 < REF	2948	33.7	2511	28.7

	Existing Building	New Building
REF Yearly Average	1.1596	0.7153

	Energy (kWh)	
	Existing Building	New Building
Total Demand	30,983.41	25,968.35
Total Generation	44,916.85	24,909.30
Net Energy Requirements	-13,933.44	1,059.05

	Existing Building		New Building	
End Use	Energy (kWh)	% of Total	Energy (kWh)	% of Total
Room	12,497.76	40.3	9,279.92	35.7
Lighting	5,706.06	18.4	4,079.77	15.7
Heating	797.41	2.6	361.20	1.4
Cooling	3,222.18	28.3	3,487.46	13.4

Responsive Lighting, Single Glazing, External Shading

	Existing Building		New Building	
REF Value	No. of Hrs.	% of Year	No. of Hrs.	% of Year
0	4197	47.9	4197	47.9
0 < REF < 0.30	577	6.6	611	7.0
0.30 < REF < 0.95	911	10.4	1294	14.8
0.95 < REF < 1.05	125	1.4	171	2.0
1.05 < REF	2950	33.7	2487	28.4

	Existing Building	New Building
REF Yearly Average	1.1634	0.7060

	Energy (kWh)	
	Existing Building	New Building
Total Demand	31,012.59	26,372.19
Total Generation	44,916.85	24,909.30
Net Energy Requirements	-13,904.26	1,462.89

	Existing Building		New Building	
End Use	Energy (kWh)	% of Total	Energy (kWh)	% of Total
Room	12,497.76	40.3	9,279.92	35.2
Lighting	5,482.16	17.7	3,959.30	15.0
Heating	946.67	3.1	565.69	2.1
Cooling	3,326.01	10.7	3,807.28	14.4

Responsive Lighting, Double Glazing, External Shading, Extra Windows

	Existing Building		New Building	
REF Value	No. of Hrs.	% of Year	No. of Hrs.	% of Year
0	-	-	4197	47.9
0 < REF < 0.30	-	-	593	6.8
0.30 < REF < 0.95	-	-	1260	14.4
0.95 < REF < 1.05	-	-	162	1.8
1.05 < REF	-	-	2548	29.1

	Existing Building	New Building
REF Yearly Average	-	0.7280

	Energy (kWh)	
	Existing Building	New Building
Total Demand	-	25,689.28
Total Generation	-	24,909.30
Net Energy Requirements	-	779.98

	Existing Building		New Building	
End Use	Energy (kWh)	% of Total	Energy (kWh)	% of Total
Room	-	-	9,279.92	36.1
Lighting	-	-	3,706.82	14.4
Heating	-	-	358.64	1.4
Cooling	-	-	3,583.90	14.0

Responsive Lighting, Double Glazing, External Shading, Extra Windows, Repositioned Solar Panels

	Existing Building		New Building	
REF Value	No. of Hrs.	% of Year	No. of Hrs.	% of Year
0	-	-	4197	47.9
0 < REF < 0.30	-	-	579	6.6
0.30 < REF < 0.95	-	-	1122	12.8
0.95 < REF < 1.05	-	-	152	1.7
1.05 < REF	-	-	2710	30.9

	Existing Building	New Building
REF Yearly Average	-	0.8403

	Energy (kWh)	
	Existing Building	New Building
Total Demand	-	25,675.49
Total Generation	-	27,980.49
Net Energy Requirements	-	-2,305.00

	Existing Building		New Building	
End Use	Energy (kWh)	% of Total	Energy (kWh)	% of Total
Room	-	-	9,279.92	36.1
Lighting	-	-	3,706.82	14.4
Heating	-	-	360.24	1.4
Cooling	-	-	3,568.52	13.9

Responsive Lighting, Double Glazing, External Shading, Extra Windows, Repositioned Solar Panels, 20kWh Battery

	Existing Building		New Building	
REF Value	No. of Hrs.	% of Year	No. of Hrs.	% of Year
0	-	-	2931	33.5
0 < REF < 0.30	-	-	317	3.6
0.30 < REF < 0.95	-	-	783	8.9
0.95 < REF < 1.05	-	-	2019	23.0
1.05 < REF	-	-	2710	30.9

	Existing Building	New Building
REF Yearly Average	-	1.0280

	Energy (kWh)	
	Existing Building	New Building
Total Demand	-	25,675.49
Total Generation	-	27,980.49
Net Energy Requirements	-	-2,305.00

	Existing Building		New Building	
End Use	Energy (kWh)	% of Total	Energy (kWh)	% of Total
Room	-	-	9,279.92	36.1
Lighting	-	-	3,706.82	14.4
Heating	-	-	360.24	1.4
Cooling	-	-	3,568.52	13.9

ENGG210

DESIGN PROPOSAL AND BUILDING ENERGY MODELLING

For THE ILLAWARRA LOCAL ABORIGINAL LAND COUNCIL
1-7 FARMBOROUGH RD. UNANDERRA

EXECUTIVE SUMMARY

This report presents the final design iterations for proposal to the Illawarra Local Aboriginal Land Council showing how both the aesthetics and the function of the spaces meet the design criteria. The existing building on the site is to be remodelled into multiple office spaces with the ability for some of the rooms to be leased. Additionally, there will be a workshop and garage at the rear of the building to accommodate the ILALC's offsite operations. There is also to be a secondary building developed to the west of the site with two retail spaces on the ground floor adding to the flourishing row of store frontage on Farmborough Road. Three single bedroom apartments will be located on the first floor of the building, each with an internal floor area of 65 m^2 in addition to a private terrace facing north to take advantage of the mountain views.

Building energy modelling was also completed for the total development. The OpenStudio plugin for SketchUp Make was used to iterate upon the design to achieve a high performance building without sacrifice any of the design ideals and requirements stated by the client. Through the multi stage optimisation of the building it was found that it was possible to reduce the overall site energy demand while simultaneously increasing the PV generation to a point that the building achieved a net positive energy status. Passive solar design was maximised by the introduction of skylights to the residential spaces, appropriately sized windows and awnings, and the addition of shading controls that would automatically shade the north facing windows when the zone was experiencing a high cooling load. Additional PV panels were introduced in the form of a shade cover that also acts as an outdoor meeting area on the north eastern corner of the site. This proved to be effective, although depending upon the client's design needs additional PV could be incorporated in other areas instead such as BIPV on the walls or by renting roof space from the adjacent buildings. It was also found that for a large amount of time the development was generating more power than it needed consequently either feeding it back into the grid or wasting it. Investment in an energy storage system would be a further way to improve the buildings efficiency by ensuring the additional generation wasn't going to waste, instead being used when there was not enough PV generated for the site such as during the night.

Overall, it was shown through this report that it is possible to deliver a high performing building that meets all of the ILALC's design requirements.

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1 INTRODUCTION

This report will present the final design proposal of the Unanderra development for the Illawarra Local Aboriginal Land Council. Demonstrating the layout and functionality of the spaces to meet the ILALC's design requirements while also undertaking building energy modelling to achieve a high performance building, targeting net zero energy.

2 DESIGN CHANGES

The design has undergone changes since the previous task with minor adjustments to the layout of the office building and a redesign of the residential spaces. Full floor plans for the development are available in Appendix B.

Figure 2.1 Northern Facade Rendering

2.1 Existing Building

The existing building is to be used as the office space for the Illawarra Local Aboriginal Land Council with additional space to be rented out. The ground floor consists of two meeting rooms at the front with a central reception and includes a three car garage at the rear with a workspace and shower. The first floor has two large office spaces and a terrace at the front to take advantage of the mountain views. There is also a double sided exterior elevator between the two buildings providing access to both.

Figure 2.1.1 Office Terrace

2.2 Secondary Building

The secondary building will contain two retail spaces on the ground floor with three parking spaces for the apartments at the back. Three single bedroom apartments are located on the first floor with entry via the exterior walkway. Each apartment is 65 m^2, the minimum for a terrace as outlined by the Low Rise Housing Diversity Design Guide (NSW Department of Planning, Industry, and Environment, 2020). On top of that, each apartment has its own private terrace on the northern façade of the building. Figures 2.2.1 through 4 provide renderings of the interior and exterior layouts of the spaces.

Figure 2.2.1 Southern Façade

Figure 2.2.2 Terraces

Figure 2.2.3 Kitchen/Living

Figure 2.2.4 Bed

3 SHADING STUDY

A study was completed at two points of the year to investigate how the development and the surrounding structures would affect each other in regard to shading throughout the day. Figures 3.1 and 3.2 show the winter shading occurring during the afternoon and morning respectively. It can be seen that there is minor shading of the retail spaces later in the day which could increase the heating load, however this occurs after the hours of operation of the space and therefore shouldn't negatively impact occupant experience. Figures 3.3 and 3.4 show the shading during the middle of summer to which extensive shading can be seen by the development to the adjacent building. As the building is commercial in nature and has no glazing on that façade, the shading shouldn't be a cause of concern.

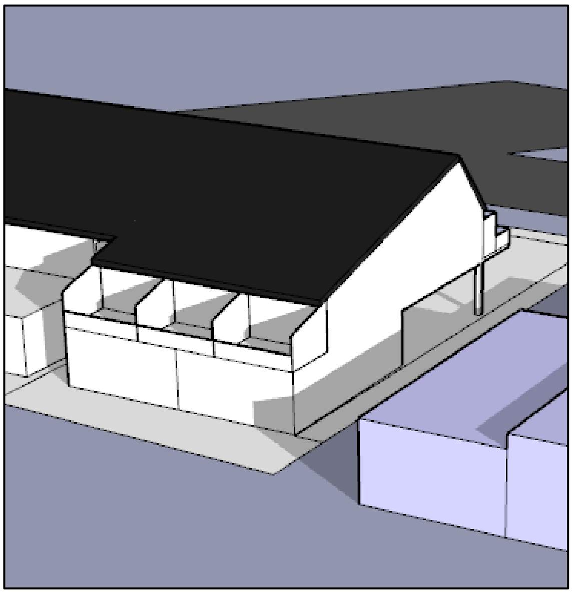

Figure 3.1 July 5pm

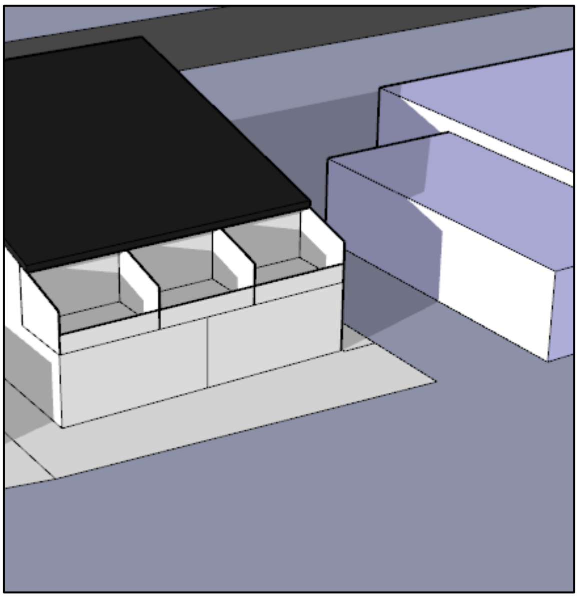

Figure 3.2 July 7am

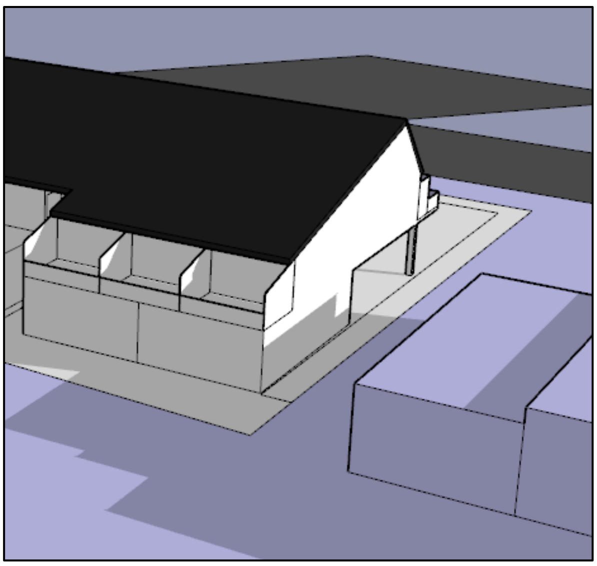

Figure 3.3 January 5pm

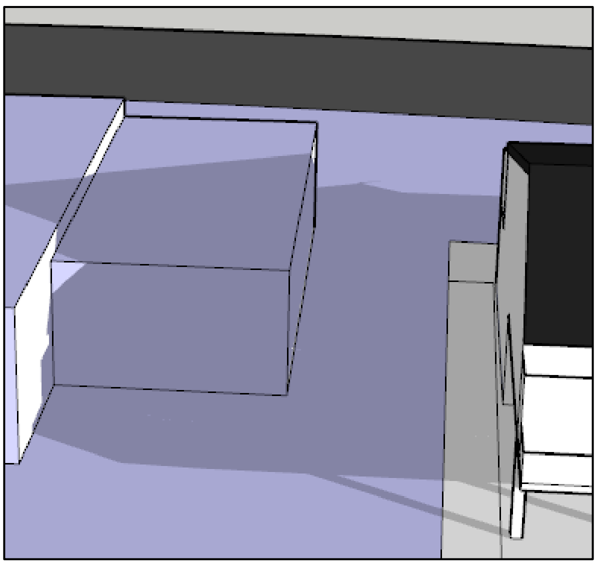

Figure 3.4 January 7am

4 ENERGY MODELLING

The building energy modelling was performed using the OpenStudio version 2.9.1 plugin for SketchUp Make 2017. The model, demonstrated in figures 4.1 and 4.2, was created from the drafted floor plans ensuring that each space was a dimensionally correct representation of the corresponding room. Care was taken to accurately model the buildings glazing and shading structures as there was to be a strong focus on passive design elements through the optimisation stages and these would play a critical role.

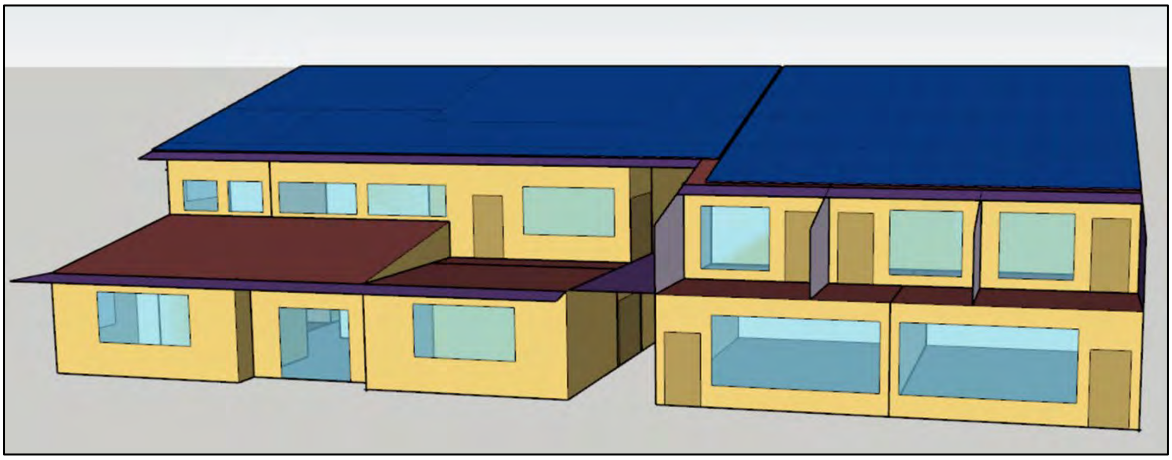

Figure 4.1 OpenStudio Base Model View 1

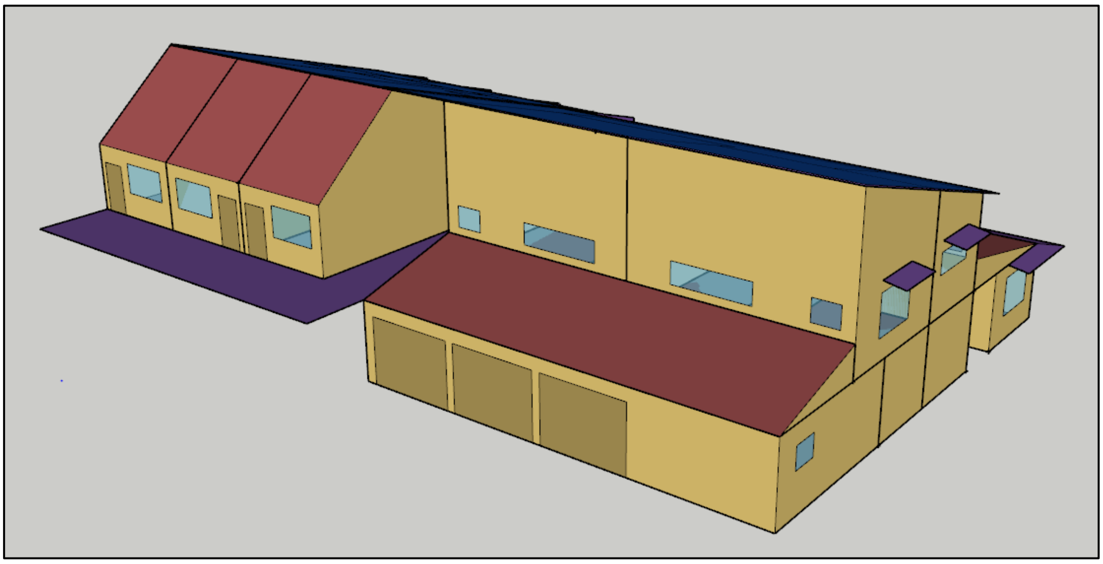

Figure 4.2 OpenStudio Base Model View 2

4.1 Model Assumptions

The main assumptions for the simulation were taken from the NCC 2019 Volume One, Section J (Australian Building Codes Board 2019). Firstly, the project was classified as a multiuse development consisting of a class 2 residential, class 5 office, and class 6 retail spaces identified in figure 4.1.1.

Figure 4.1.1 Class Designations

Scheduling for the occupancy, lighting, appliances, and air conditioning was found in section JVC of the NCC as well as the office equipment load of 11 W/m^2. The values used for lighting loads are displayed in table 4.1.1

Table 4.1.1 Lighting Loads

Space Type	Office	Corridors	Residential	Plant Room	Retail	Stairs	Restroom
Lighting Load (W/m^2)	4.5	5	5	4	14	2	3

The hot water supply was set up as a 2 kWh electrical load, scheduled to be active between the hours of 8am to 8pm, with 100% of the heat lost. This allows the load to be purely electrical and won't affect the heat gains of the building. R-Values for the building fabric were also taken from section J of the NCC and are shown in table 4.1.2. All windows were assumed to be double glazed with a U-Value of 2.5.

Table 4.1.2 Building Fabric R-Values

Element	Exterior Walls	Residential Exterior Walls	Roof
R-Value	1.4	2.4	3.7

The ventilation for the model was set to be the greatest of either 0.35 l/s per m^2 or 10 l/s per person currently occupying the space. Occupancy was established based on space type.

- Office: 15 persons per floor, as indicated by the client.
- Retail: Taken from *NCC 2019 Volume One, Section N* as 3 m^2 per person.
- Residential: One person per unit.

Heating and cooling set points were 21°C and 24°C respectively and the efficiency of the system was assumed to be a coefficient of performance of 4 which was calculated post simulation. The weather file chosen was the Mascot-Sydney Airport EPW file (EnergyPlus) which is within the same climate zone as the Unanderra area on the Climate Zone Map of NSW (Australian Building Codes Board, 2019) and was therefore deemed appropriate for use.

Lastly, solar PV panels with an efficiency of 0.15 were added to 60% of the models roof which was calculated to be 333 m^2 of panel area.

4.2 Baseline Model

The simulation was run for the base model with the results entered into table 4.2.1 totalling the energy demand for the heating, cooling, lighting, and equipment over the year as well as the total PV AC output from the inverter. The baseline site net energy demand was found to be 86.9 GJ per annum. The hourly values for PV output were divided by the hourly total energy demand to produce a range of Renewable Energy Fraction (REF) values which were averaged for a yearly value of 0.79.

Table 4.2.1 Base Simulation Results

Case	Heating (GJ)	Cooling (GJ)	Lighting (GJ)	Equipment (GJ)	**Total (GJ)**	PV AC Output (GJ)	Site Net (GJ)	**REF**
Base	185.3	92.3	64.8	56.1	**398.5**	311.6	86.9	**0.79**

The peak loads for the baseline model are shown in table 4.2.2 and indicate that the heating places a much higher peak demand on the energy requirements than the cooling. In addition, the peak heating is so high that it causes the peak of all loads to occur at the same time demonstrating the significance of the heating drain upon the building which is orders of magnitude more than the other loads.

Table 4.2.2 Peak Loads

Load	**Demand (W)**	**Time**
Heating	179606	12-AUG-6:10
Cooling	47857	03-NOV-14:00
All Loads	180731	12-AUG-6:10

The outputs from the simulation were used to create typical daily energy profiles in both Summer and Winter for analysis. During Summer, figure 4.2.1, it can be seen that the highest load comes from the cooling as well as small peak of heating in the morning. The PV output was higher than all the loads through most of the day, however during winter, figure 4.2.2, there is a high heating load concentrated during the morning causing the PV generation to not be able to handle the energy demand.

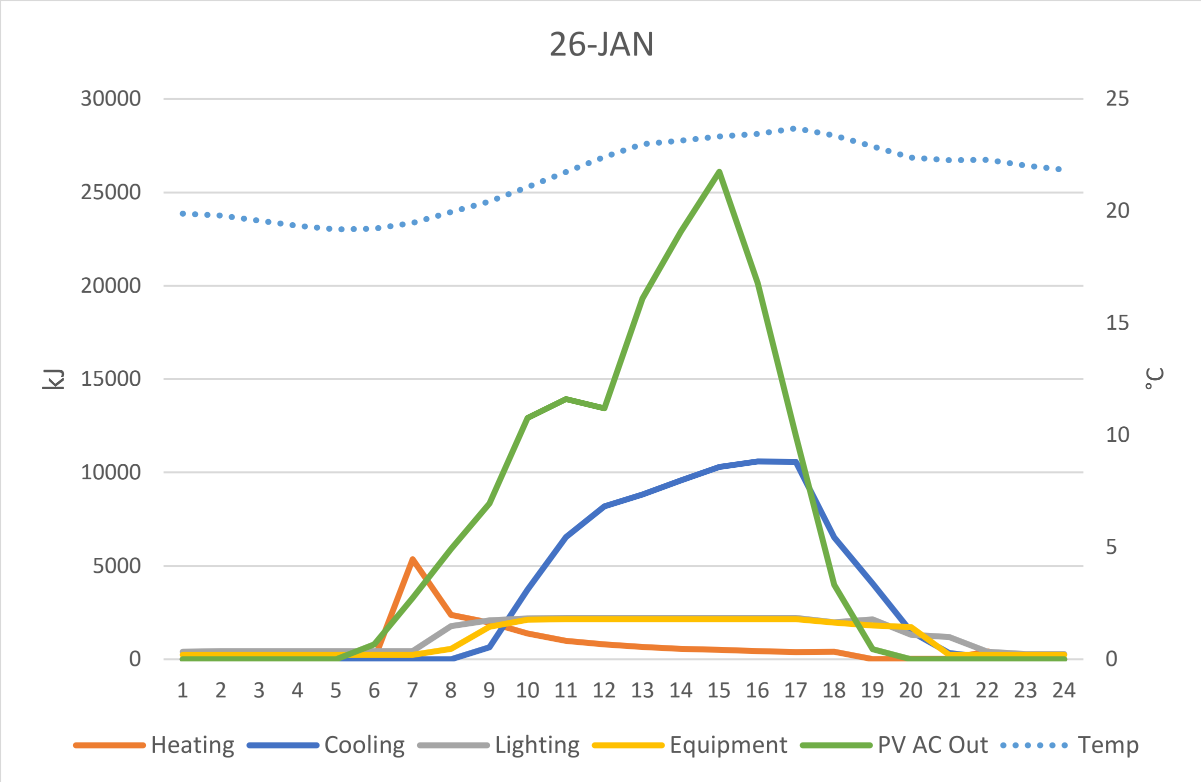

Figure 4.2.1 Typical Summer Daily Energy Profile

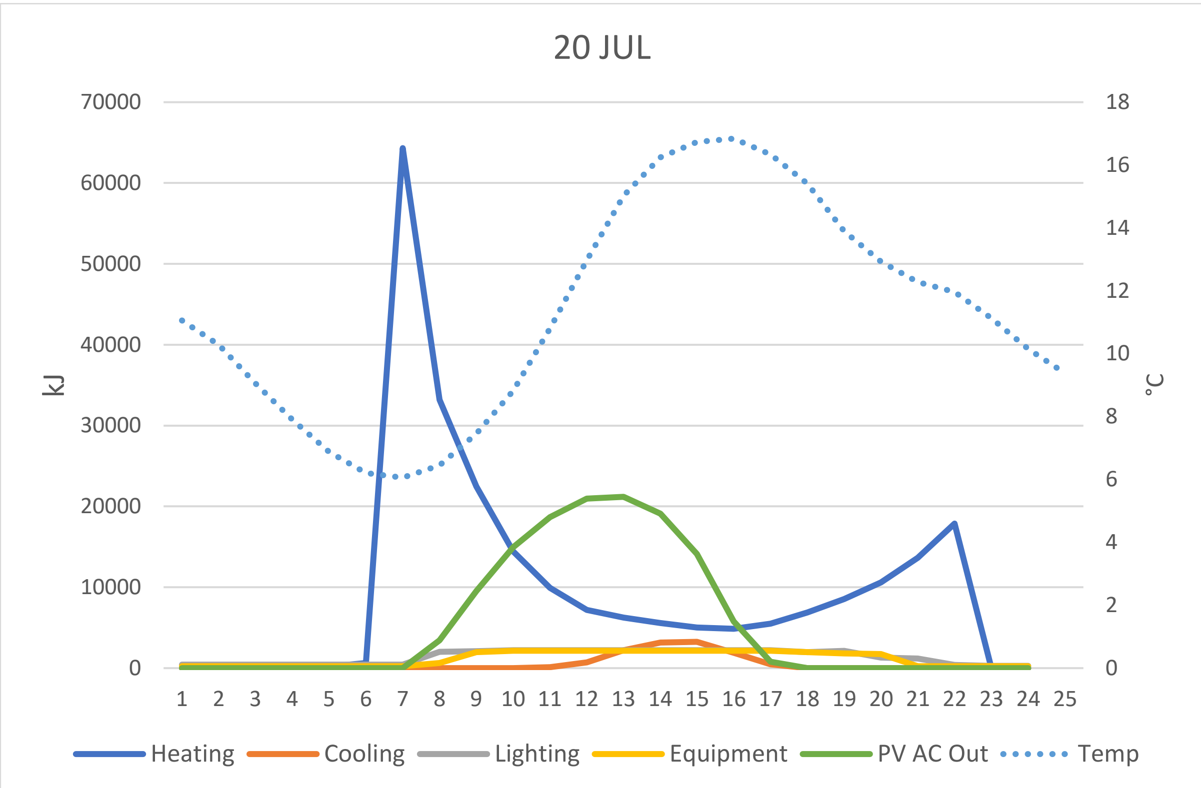

Figure 4.2.2 Typical Winter Daily Energy Profile

4.3 Insulation Optimisation

The first optimisation done to the building was to increase the minimum insulation requirements to a higher performance level. All elements of the building fabric were upgraded to an R-Value of 5 which will help to limit unwanted heat transfer. The results for this simulation were entered into table 4.3.1 from which it can be seen that the optimisation reduced the site net energy requirements by over 20 GJs. However, averaging the hourly REF values resulted in the same as the baseline of 0.79.

Table 4.3.1 Insulation Optimisation Results

Case	Heating (GJ)	Cooling (GJ)	Lighting (GJ)	Equipment (GJ)	**Total (GJ)**	PV AC Output (GJ)	Site Net (GJ)	**REF**
Base	185.3	92.3	64.8	56.1	**398.5**	311.6	86.9	**0.79**
Insulation	167.3	86.6	64.8	56.1	**374.8**	311.6	63.3	**0.79**

4.4 Skylights and Shading Control

Analysis of the daily zone temperatures from the previous simulation showed that the residential kitchen/living areas were becoming overly cold when the air conditioning was not scheduled to be active. This was determined to be due to the fact that they were located on the southern side of the building and consequently having low solar access. To address this a portion of the PV panels was moved to the lower roof, as shown in figure 4.4.1, to allow for the addition of skylights to increase solar gain into the space. In addition to this, automatic shading controls were added to the skylights and the north facing windows that shade the glazing with an exterior blind when the zone is experiencing a high cooling load.

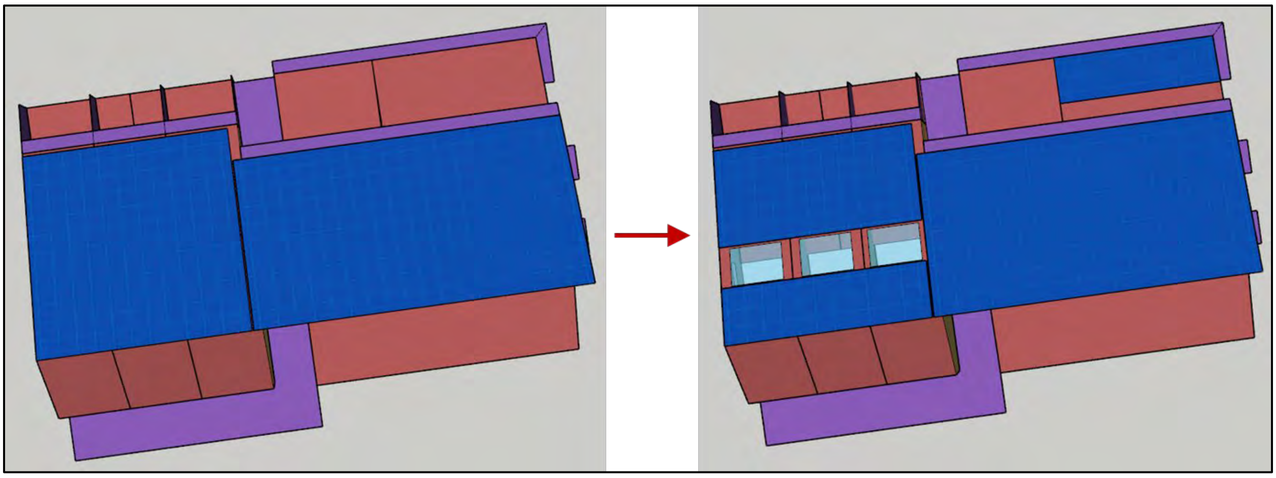

Figure 4.4.1 Skylight Addition

The results for this simulation are tabulated into table 4.4.1 and the additions reduced the total site net energy requirements to 32.2 GJ per annum with an hourly averaged REF value increased to 0.89.

Table 4.4.1 Skylight Simulation Results

Case	Heating (GJ)	Cooling (GJ)	Lighting (GJ)	Equipment (GJ)	**Total (GJ)**	PV AC Output (GJ)	Site Net (GJ)	**REF**
Base	185.3	92.3	64.8	56.1	**398.5**	311.6	86.9	**0.79**
Insulation	167.3	86.6	64.8	56.1	**374.8**	311.6	63.3	**0.79**
Skylights	**143.6**	**79.2**	**64.8**	**56.1**	**343.8**	**311.6**	**32.2**	**0.89**

4.5 Redesigned Windows and Awnings

The simulation outputs were analysed once again, and it became apparent that the north facing spaces were experiencing high thermal gain during the day then losing heat quickly overnight and becoming cold. This caused a heavy drain on the heating system which then had to reheat the spaces back up to 21°C in the morning before they became too hot during the day and the cooling system had to take over to keep them cool. The large amount of glazing at the front of the building was determined to be the cause as it was admitting high amounts of solar during the day and then allowing too much of the heat to escape during the night through the more thermally conductive glass when compared to the walls. The windows were redesigned to a more appropriate size for the building, as shown in figure 4.5.1, and shading was also added above the retail spaces.

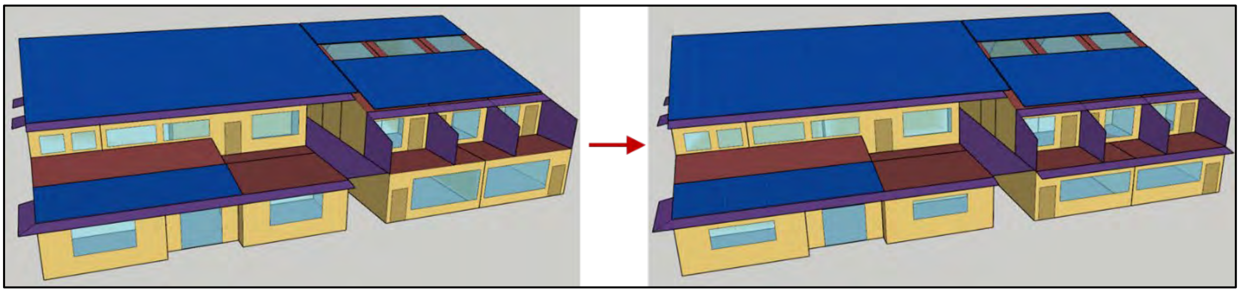

Figure 4.5.1 Window Redesign

The results from this simulation, displayed in table 4.5.1, saw another decrease in the total energy demand and a site net of only 13.3 GJ per annum. This mostly came from the reduction in cooling that had previously been required by the overheating spaces. The hourly averaged REF value was calculated to be 0.99, coming just shy of achieving net zero energy for the building.

Table 4.5.1 Window Redesign Simulation Results

Case	Heating (GJ)	Cooling (GJ)	Lighting (GJ)	Equipment (GJ)	**Total (GJ)**	PV AC Output (GJ)	Site Net (GJ)	**REF**
Base	185.3	92.3	64.8	56.1	**398.5**	311.6	86.9	**0.79**
Insulation	167.3	86.6	64.8	56.1	**374.8**	311.6	63.3	**0.79**
Skylights	143.6	79.2	64.8	56.1	**343.8**	311.6	32.2	**0.89**
Shade + Windows	**141.4**	**62.5**	**64.8**	**56.1**	**324.8**	**311.6**	**13.3**	**0.99**

4.6 PV Shade Cover

The last addition to the design was the construction of a PV shade cover, demonstrated in figure 4.6.1, on the north eastern corner of the site. The panel has area of 32 m^2, angled at the optimum of 34° for the latitude and can act as an outdoor meeting area.

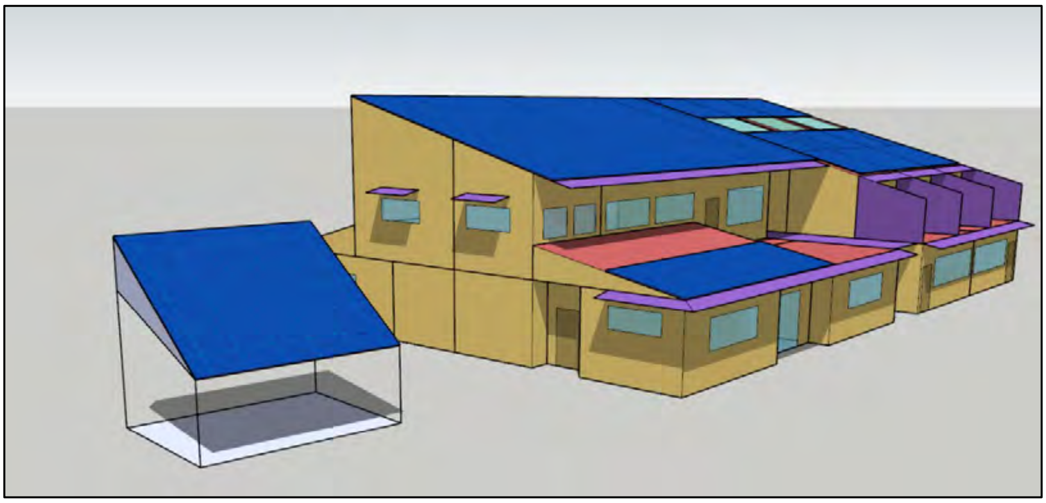

Figure 4.6.1 PV Shade Cover

The results of the final simulation were entered into table 4.6.1 and the same total energy demand as the previous simulation was recorded. However, the PV AC output was increased to 342 GJ which was able to reduce the site net to -17.1 GJ per annum. The hourly REF value was then calculated to be 1.08 meaning that the site has achieved net positive energy.

Table 4.6.1 PV Shade Cover Simulation Results

Case	Heating (GJ)	Cooling (GJ)	Lighting (GJ)	Equipment (GJ)	**Total (GJ)**	PV AC Output (GJ)	Site Net (GJ)	**REF**
Base	185.3	92.3	64.8	56.1	**398.5**	311.6	86.9	**0.79**
Insulation	167.3	86.6	64.8	56.1	**374.8**	311.6	63.3	**0.79**
Skylights	143.6	79.2	64.8	56.1	**343.8**	311.6	32.2	**0.89**
Shade + Windows	141.4	62.5	64.8	56.1	**324.8**	311.6	13.3	**0.99**
PV Shade	**141.5**	**62.5**	**64.8**	**56.1**	**324.9**	**342.0**	**-17.1**	**1.08**

4.7 Comparison of REF Ranges

Figure 4.7.1 displays the hours spent in the REF ranges for each of the simulations. Time spent at 0 was the same for each case as this represents the night when the PV system wasn't generating any power. The middle ranges all trended downwards, and hours spent above an REF of 1.05 increased meaning the site was generating than it needed, with the excess either being wasted or fed back into the grid.

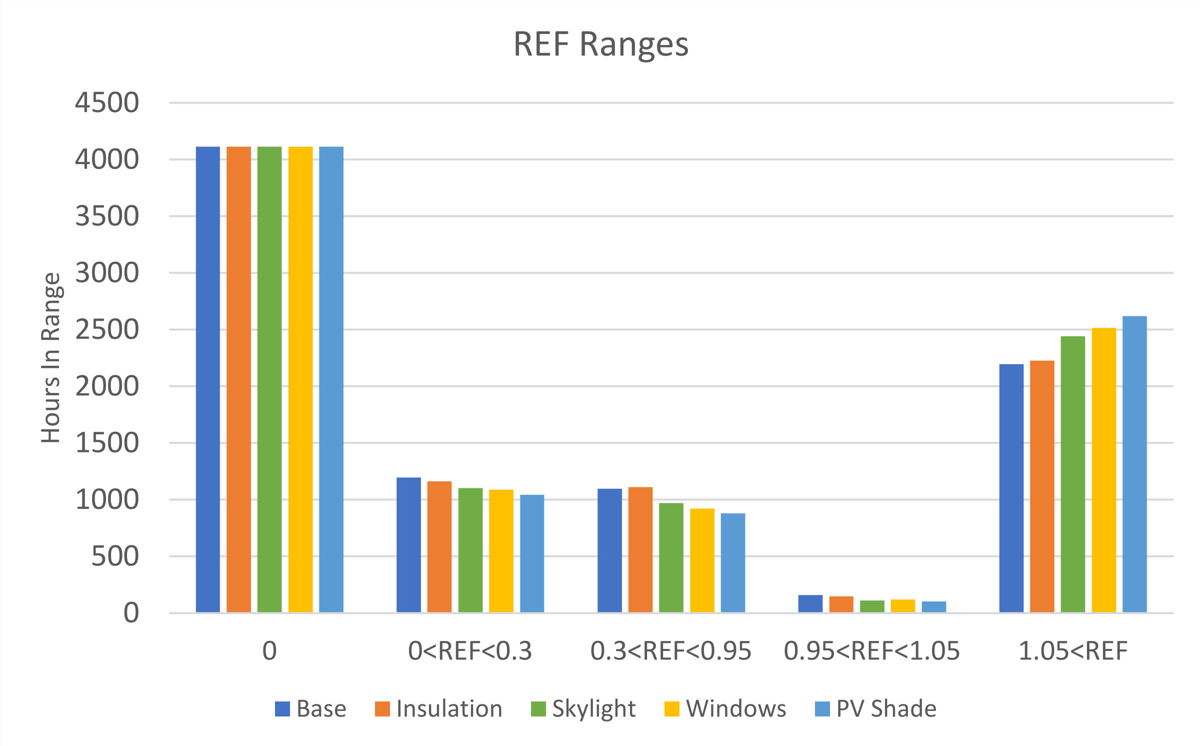

Figure 4.7.1 Comparison of REF Ranges

5 DISCUSSION AND RECOMMENDATIONS

The results achieved from the building energy modelling show that through continued optimisation of the development it is possible to achieve net zero or even net positive energy by both the reduction in total energy demand and simultaneously increasing PV generation. Each of the design elements simulated in the previous section played an integral part in increasing the performance of the building. The more efficient regulation of solar gain to the spaces by the use of skylights, automatic shading control, and appropriately designed windows and awnings allowed the building to reach an hourly averaged REF value of 0.99 demonstrating the importance of effective passive solar design. Even though upgrading the thermal properties of the insulation did not influence the REF value it is still an important part of the design as it allows the other optimisations performed on the building to be more effective. Part of the reason why the insulation did not have as great of an effect on this particular building could have been because the majority of the roof was already shaded by the solar panels. The way in which OpenStudio treats shade structures, from which the PV panels are based upon, meant there was little heat transfer through the roof fabric and therefore increased insulation had no great affect. Increasing the PV area by the implementation of a shading structure is what allowed the building to become net positive however additional PV could be incorporated in other ways such as BIPV in the walls or by renting roof space from the adjacent buildings.

As the building was at an REF value greater than 1.05 for a large amount of time, the building was generating more energy than it needed and consequently wasted or fed it back into the grid. A further way to optimise the performance of the building would be to invest in energy storage to ensure that the additional energy isn’t going to wasted and to allow the building to be powered by renewables overnight. This would have the effect of bring more of the lower REF values up to closer to the ideal 0.95 to 1.05 range.

Overall, it has been shown that by careful optimisation of the passive elements of the building as well as active measures such as automatic shading controls and increasing PV generation the Illawarra Local Aboriginal Land Council will be able to facilitate a development that can achieve net zero or even net positive energy without sacrificing their design ideals in both aesthetics and functionality of the spaces.

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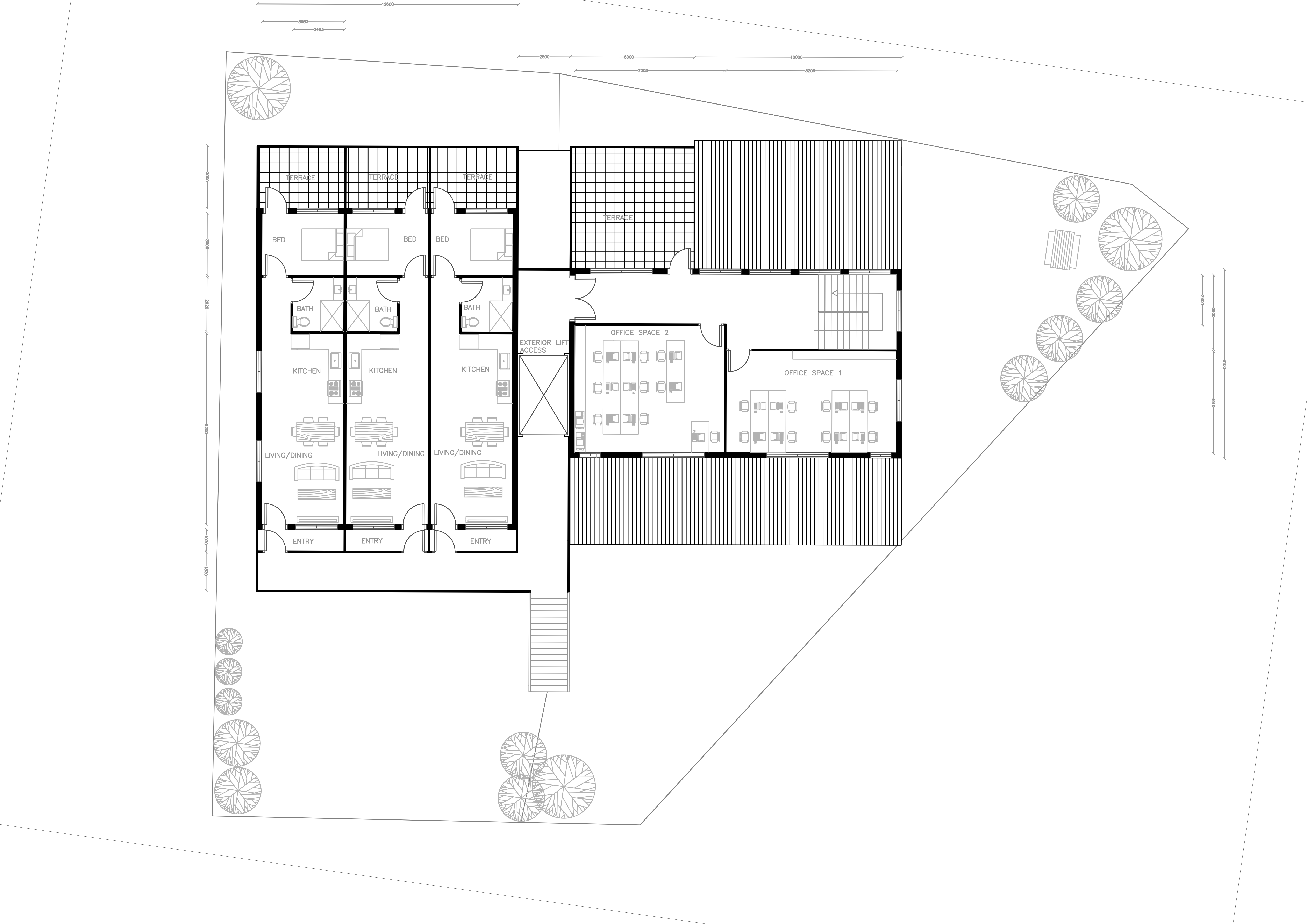
7 APPENDIX

Appendix A – Reflection

The design proposal highlights key areas of the certification schemes such as Green Star's criteria to create healthy homes by maximising occupant comfort with implementation of passive solar design and simultaneously ensuring safety and privacy of the spaces while also encouraging a positive and responsible connection to the surrounding environment. The evidence based and customer focused ideals of the WELL V2 standard are also implemented through the optimisation of the building. It is important for the certification schemes to recognise a wholesome approach to a development ensuring that the building is running as efficiently as possible through the use of passive measures where possible before implementing active technologies and offsetting with renewable energy. Once a building is optimised the creative use of renewable energy generation in non-traditional areas would provide a greater energy yield than just using the available roof space enabling larger developments and communities to create their own microgrids and move towards net zero energy.

Appendix B – Floor Plans

RETAIL SPACE 2
RETAIL SPACE 1
MEETING 2
MEETING 1
MEN'S BATH
ACCESSIBLE BATH
WOMEN'S BATH
SHOWER
PLANT ROOM
STORAGE
WORKSPACE
GARAGE
APTM. 3 GARAGE
APTM. 2 PARK
APTM. 1 GARAGE



12600
3953
2463
2500
6000
10000
7205
8205
TERRACE
TERRACE
TERRACE
TERRACE
BED
BED
BED
BATH
BATH
BATH
KITCHEN
KITCHEN
KITCHEN
LIVING/DINING
LIVING/DINING
LIVING/DINING
ENTRY
ENTRY
ENTRY
EXTERIOR LIFT ACCESS
OFFICE SPACE 2
OFFICE SPACE 1

APPENDIX B – TRANSCRIPTS OF CONSULTANT INTERVIEWS

Interview 1: Integrated Design Studio 12 – Illawarra LALC Former Unanderra Police Station Redevelopment – 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 2: Integrated Design Studio 12 – Illawarra LALC Former Unanderra Police Station Redevelopment – 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 3: Integrated Design Studio 12 – Illawarra LALC Former Unanderra Police Station Redevelopment – 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 4: Integrated Design Studio 12 – Illawarra LALC Former Unanderra Police Station Redevelopment – 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.

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, identification of interactive and engaging platforms, and 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 a dedicated section in this Appendix.

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, interaction and 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. 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.

When you're on Zoom… it's so hard to get people to talk and discuss and share ideas. – Consultant 2 (Structural Consultant)

Communication was also identified as a significant contributor to the success of the studio. However, communication was restricted by the use of video conferencing apps, meaning only one voice could dominate the conversation at any given time, which is the precise opposite to what is recommended by a consultant to create a conducive integrated design environment. Open and constructive communication allows for *other peoples views* to be considered, ensuring that design responses are sympathetic to the requirements of multiple specialisations.

…enabling [a diverse range of people] *to speak so that somebody doesn't dominate, one particular view doesn't dominate* – Consultant 4 (Architectural Consultant)

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 lacking, especially when compared to the brief provided by the IDS running in parallel (IDS09), while the other architectural consultant believed the opposite was true. Though there is no definitive way to say which is true, it was clear that overall, 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.* Additionally, the consultant expressed that what was delivered to the students in the brief was more what the client *thought people wanted to hear and wasn't strictly what he wanted to do.* Part of the challenge in understanding the brief is being able to extract from the client *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 an 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)

As discussed previously, 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.

Overall, the consultants did not have a unanimous consensus on their opinion of 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.

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 building (or buildings), 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. Due to the existing structure located on the site, the architectural consultants advised students to evaluate the necessities of space before imposing restrictions given the available volume of the building to evaluate if the existing structure is suitable for the needs of the client. The consults remarked that there appeared to be a push to use technology to visualise and present the building, which also 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 *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.

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 commented that it is very important for students to have a fundamental understanding of cultural and social necessities, *particularly when there is an indigenous overlay*. While initial information cultural information was relayed in the brief (i.e. highlighting the cultural significance of the escarpment/Mt. Keira view), further interactions with the client were limited, with little-to-no discussion of culture. An architectural consultant was critical of the lack of engagement from the client throughout this process (as ultimately it is their project), also commenting that this is very hard for the designers, indicating that this made the design process more difficult for the students.

That's really hard from a designers point of view, because your down at concept and then somebody throws another bit in… it becomes a bit of a compromise to the process – Consultant 1 (Architectural Consultant)

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.

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, climatic conditions, building operation, 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, though this was also more limited given the use of an existing structure. Students were able to consider how these aspects affected 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)

Integrated design definitions

The understanding of integrated design was similar from the perspective of all the consultants and studio tutors. An architectural consultant best summarised this definition, specifying that the design would be considered a successful integrated design when an optimal outcome is achieved *both in terms of architecture and engineering*. The architectural consultant outlined that these outcomes are more readily achieved through listening to and understanding the behaviours, desires, and aspirations of the client, using these key factors to drive the design. It was iterated that while listening and understanding is critical for design in general, it is imperative when undertaking integrated design.

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)

Constraints impacting integrated design engagement and colaboration

A number of consultants 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. 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 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)

I 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)

Value of integrated design experience at university

While many of the consultants 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.

…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 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)

APPENDIX D – 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	0%
Slightly familiar	43%
Somewhat familiar	0%
Moderate familiar	43%
Extremely familiar	14%

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	57%
Imagination and creativity	71%
In depth knowledge of technology for collaboration	57%
Time assigned to the dialogue between Architects and Engineers	57%
Software skills to simulate and analyse building performance	71%

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	14%
Somewhat supportive	0%
Moderate supportive	71%
Very supportive	14%

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?)

- The client brief was vague and the brief changed half way through. It would be better if the client could give more regular feedback.
- Client brief gave an idea around the desired function of the building but didn't really have any more specific environmental goals other than "net-zero"
- Having a real client to work with was a great experience, in the Illawarra LALC group it was very vague in the beginning and reaching Paul was difficult which made having a clear understanding hard
- It was not very organized and changed throughout the session. It was adequate but could definitely have been better

- Paul Knight's client brief was mostly verbal, with some follow-up notes. I initially hoped that the brief would be more substantial, with figures of intended occupants for example. The follow-up conversations resulted in the initial brief changing to accomodate additional specialised occupants, yet the information after a few consultations was adequate
  In terms of the user requirements, the initial brief was very minimal from Paul Knight. However, following the request for further information and follow-up conversations, sufficient information was provided. Also, the plans of the pre-existing building were very helpful.

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.

- How to make it structurally sound and aesthetically pleasing while while keeping it environmentally minded
- How the design proposal would affect the everyday life and whether it would have a positive impact upon them and not just a statistical improvement in environmental optimisation
- Balancing function and practicality with aesthetics such as incorporating a view of Mt Kembla
- 1. What assumptions will be made? 2. When proceeding with a retrofit design, what conflicts will arise between optimal passive design and structural viability? 3. Are the embodied energy savings inherent to retrofit design superior than the ideal savings from a knock-down, rebuild design?

6) Where did the inspiration for your solutions come from?

- Brainstorming as a team
- Mostly the client brief and local aboriginal values. 'The shed' in Bulli was a small inspiration.
- Various precedents, acquired knowledge, consultant assistance, intuition, iterations and team collaboration.

7) What guidance by the consultants was most useful for you (and why)? Describe in your own words.

- Input surrounding the functionality and sizing of spaces, making them actually useable
- Taking textbook ideas and putting them in real practice context
- Guidance on the layout of the interior was most useful in making sure all the spaces were functional.
- All guidance was equally useful as this design was a combination of all design areas.

8) What would you change in order to maximise their input (if anything?)

- Produce plans earlier in the semester allowing more time for input and change
- Having in-person class
- It wasn't always clear what was expected of us each week. This meant that we didn't always come to class prepared for their input.
- There isn't much at all that I would change outside of encouraging more individual specialist feedback on design submissions. As well as, ensuring some structural criteria is set to enable the structural consultant’s skillset.

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	0%
Moderate supportive	20%

Very supportive	60%
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	20%
Slightly compromised	40%
Somewhat compromised	0%
Moderate compromised	20%
Very compromised	20%

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.

- With enough planning, consultation, and creativity, compromise can be avoided
- Not really, otherwise every building would be perfect, there is always give and take within industry
- I prefer a more 'practical' aesthetic that engineering design offers.
- In regards to my current understanding of passive design, orientation, shading, glazing volumes, etc are almost necessities, which in turn, inevitably set the design on familiar path. Tensions between retrofit design and structural viability also slightly impeded the design, however, these concerns were not enforced.

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.

- Choosing what to compromise and what elements were most important
- I don't believe the creativity of the design was guided enough by the consultants.
- Sourcing innovative technologies and manifesting innovation were my greatest struggles.

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	80%
Time constraints on projects	60%
Education in isolation	40%
Contractual/fee barriers	80%
Inability to define joint goals	40%

14) How would you describe integrated design.

- Looking at all aspects from the beginning
- Open communication where all ideas are considered and all requirements respected.
- Maximising collaboration, minimising conflicts and creating the most holistic final 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	60%
Extremely useful	40%

Note: When evaluating student responses, the response rate may not sum to exactly 100% (+/- 1%) due to rounding.

Environmental and sustainable design

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

All students that participated in the survey have previously experienced (or are familiar with) environmental or sustainable design practices, though the degree of prior engagement varied across the cohort. 43% of student respondents were only slightly familiar with these practices, whereas the alternate 57% were moderately or extremely familiar with these principles. 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 work experience etc.). It is also unknown to what extent these students have previously engaged in *Environmental Design*, with this being a self-assessed response of the students.

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 8. Interestingly, the greatest contributing factors (from student responses) were *imagination/creativity*, and *software skill*, though these two responses only received support from 71% of the total responses. 57% of students found that the remaining three factors (*time*, *technology*, and *existing expertise*). What is of most interest from these responses is that no single factor received a 100% response rate from students, nor was any factor found to be 'most important', rather that all these factors were sound to be somewhat important to environmental and sustainable design practices. Opposingly, it is interesting to note that 29% - 43% of students found these factors unimportant when conducting environmental and sustainable design. Unfortunately, further insights were not obtained about student beliefs around factors they considered to be important, as this may highlight other key factors which had not been considered within the survey.

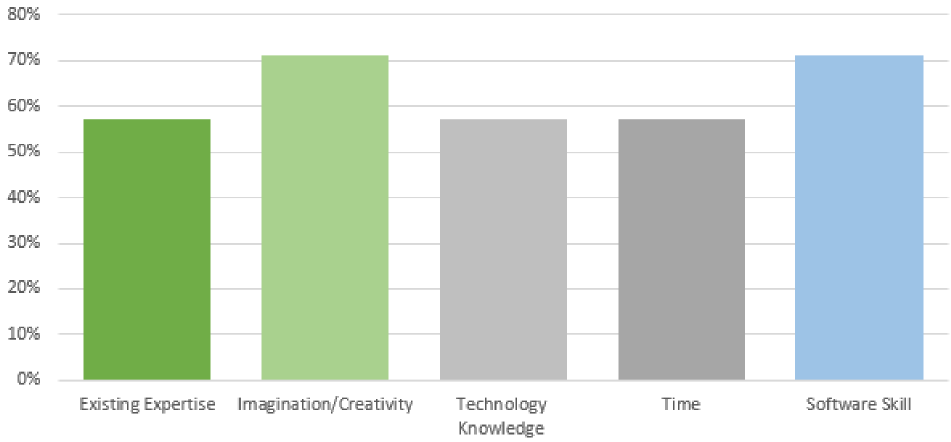


Figure 8: Simplified breakdown of student responses (Student Survey - Question 2)

Further insights from participating students were desired to better understand where they drew their design inspiration from. Most responses iterated that team brainstorming activities were a primary means of developing and iterating designs, though inspiration was sought from discussions with the consultants and the client, researching similar building typologies within the region, and from the client brief. While other sources of inspiration are likely to have been used, these were not outlined within the student responses.

Following on where inspiration was drawn from, the question was asked to ascertain where students had the greatest struggle in advancing their sustainable designs. The responses were insightful, as students appeared to recognize their own personal limitations and inexperience. One student highlighted that the sourcing of innovative technologies and *manifesting innovation* were their *greatest struggles*, which is understandable given the typical experience of the students (i.e. second year student). This resulted in students incorporating *low hanging fruit* solutions (i.e. improved insulation, double/triple glazing, efficient HVAC, PV systems etc.) as they are the most commonly know solutions and easily implemented. Additionally, a student identified that they had difficulty in what aspects of the design to compromise so that other features could be prioritised. Another student also found that the *creativity of the design* was lacking, sighting that they needed additional guidance from the consultants. Many of the aspects identified by the students recognise their own limitations due to their inexperience, highlighting that further consideration is required when developing the studios if a younger student cohort is anticipated. This also identifies the necessity of time when undertaking an integrated design, as innovative technologies and strategies need to be considered and thought through, in addition to taking the time to identify which aspects are most critical to the design.

Factors impacting integrated design

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

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 e*ducation in isolation* were the least likely to be barriers impacting integrated design, likely believing that these aspects were able to be overcome. 40% of student respondents selected these factors as being seen as a barrier. Students likely saw these factors as being surmountable, given that they were capable of defining joint goals themselves, while also being in an isolated environment from their team, but also considering that their own education (for their given specialisation) was conducted in isolation to other specialisations, and this did not impede their ability to collaborate and complete their design. 60% of respondents found that *time constraints of projects* were a considerable factor (given their own experiences), though again some found this to be an obstacle which may be overcome. The majority of students (80%) indicated that they believed the biggest barriers/constraints that exist between engineers and architects were *knowledge gaps* and *contractual/fee barriers.* Given that these are factors *outside* the design process, it is understandable that *contractual/fee barriers* can impact any collaborative process. It is also understandable that *knowledge gaps* would be a significant barrier between these specialisations *outside of the design process* as many parallels and crossovers between these specialisations occur during design. Outside a design framework, the two knowledge bases diverge. A breakdown of these results is shown in Figure 9**Error! Reference source not found.**.

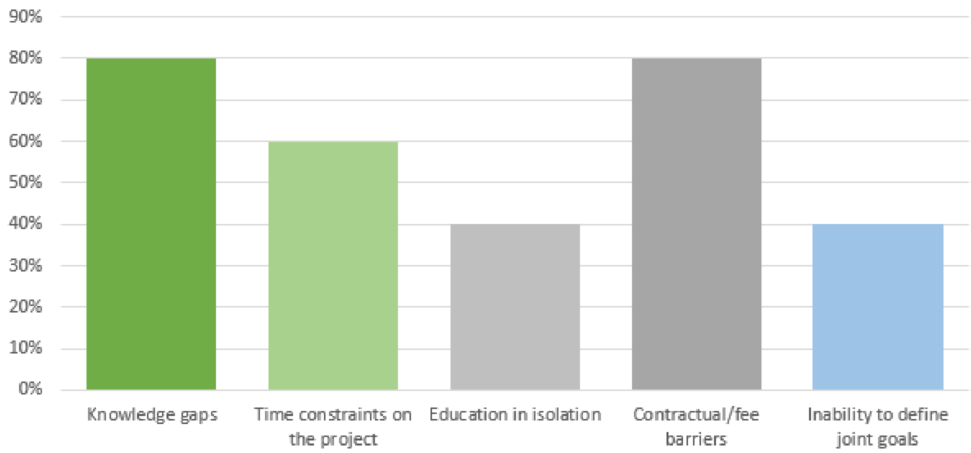


Figure 9: Simplified breakdown of student responses (Student Survey - Question 13)

Descriptions of integrated design found students having a sound understanding of this being collaborative a process requiring input from a diverse range of experts, where *all ideas are considered and all requirements respected*. It was also identified that all aspects need to be considered *from the beginning* (meaning from project inception) rather than attempting to incorporate integrated design aspects part way through a design. The suggestion of *minimising conflicts* was also suggested, though this is idealised and may be difficult to achieve given that many specialisations will consider their requirements as necessary and integral to the success of the design. When asked if there was benefit in learning about integrated design process' within a university environment, the response was overwhelmingly positive, with 40% of respondents claiming the experience was *extremely useful*, with the other 60% claimed it was *very useful*. While the learnings of the students may have varied, overall, the experience appears to have been positively received by all the students involved within the IDS.

The client brief

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

In response to the client brief, students were (mostly) of the opinion that the client brief greatly supported their ability to achieve a balanced engineering/architectural design. 85% of total respondents found that the brief was at least moderately supportive (71% *moderately supportive*, 14% *very supportive*). The remaining respondents (14%) only found that the brief was *slightly supportive*, meaning that these respondents likely found that it did not contain a sufficient level of detail necessary to undertake an effective integrated design, and achieve the desired outcomes.

Respondents were asked to elaborate on their survey response in more detail, providing what they believe the impact of the brief was overall, and if the information was adequate. It was highlighted by several students that the initial client brief was provided verbally, with no physical (or digital) document being provided which summarised the aspirations of the client. In evaluating the responses, approximately 83% of students appear to have been unsatisfied with the information provided in the client brief following this initial discussion, with the brief being described as *vague* and *minimal*. However, this stance changed over time, given further interactions with the client to refine the brief. Following further consultation, it appears that 83% of the responses deemed the brief as being adequate (which aligns with the previous survey response), though students still did not appear to be completely satisfied by the quality of the brief.

Many respondents highlighted that *the brief changed half way through* the design studio. While this is not uncommon, with clients requesting changes and providing clarification during further consultations, given the limited timeframe for the design studio, any changes became difficult to integrate at a later time. Some, who found the information within the brief to be adequate, still found that the brief could have been improved. It was also found that contacting the client was difficult, meaning that obtaining feedback and clarification on design details was challenging, with assumptions needing to be made in lieu of this necessary information. Overall, though a sufficient brief was eventually obtained, a more detailed initial brief was required. In addition, better responsiveness from the client could also have improved the final design outcomes.

Personal assessment of consultant involvement

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

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):

- Space functionality and sizing
- Translating conceptual ideas into practice
- Spatial awareness

It is worth noting that these aspects were found to be the most beneficial to those who completed the survey, and do not holistically represent all the aspects in which the consultant's offered guidance, with one student elaborating that *all guidance was equally* useful. For this IDS specifically, it is evident that students placed a greater value on understanding space and functionality, given the bounds of the existing building. 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. Unsurprisingly, some feedback desired in-person studios, which would have been ideal, but given the situation at the time made this arrangement impossible. Some feedback asked for greater clarity on what was expected each week to allow for greater preparation. While this would give greater clarity and focus for everyone involved (i.e. consultants, studio tutors and students), this would also be closer aligned to a typical university tutorial, and also negatively impact those who are unprepared. The lack of specificity on the desired outcomes each week allow student teams to create their own path and investigate what they wish for their design, more closely aligning with typical design procedure in industry. However, it may be beneficial to develop a timeline with each group, where they may specify their own milestones to ensure they complete their design without falling behind. This also aligns with some student feedback, desiring to complete plans earlier to maximise the remaining time for feedback and alterations. Finally, one student requested that a greater specificity be provided around structural criteria to enable the structural consultants skillset to a greater extent. While this would maximise the specialised input from the consultant, a structural design was not necessarily the desired outcome for the project. It may be worth outlining within the design studio early on that though the consultants work in a specified profession (and they certainly can offer advice and guidance based on that specialisation), they should not only be considered as an architect or as a structural engineer, but as an expert within the building sector.

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. All responses were found to be (generally) positive, with 100% of participants finding the consultants to be at least *moderately supportive*. 60% found the consultant input to be *very supportive,* with 20% finding them to be *extremely supportive*. Though student responses are subjective, when evaluated holistically (i.e. when examining the responses to survey questions 7, 8 and 9), it appears that interactions with the consultants were viewed positively, with their involvement being an overall beneficial experience for student participants.

Balancing engineering and architectural priorities

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

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. One such response was of particular note, outlining that the design should positively impact the typical daily operations of both the building and the occupant. This response highlighted the symbiotic relationship between building and occupant, outlining that a buildings design should improve the quality of life of the occupant while also considering the buildings performance, rather than evaluating the building as a discreet element. Additionally, students recognised that it is important to determine the design assumptions before further developing the design. Understanding the projects limitations and boundaries can ultimately save an unnecessary loss of time when these are identified early.

When polled about their projects, a vast variety of responses were provided about the degree of compromise within the teams' designs. 20% of respondents believed that there was no compromise required in either aesthetic or functional aspects, 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, though this is only speculative. The remaining 80% of respondents believed that compromise was necessary when completing their design (40% *slightly compromised*, 20% *moderately compromised*, 20% *very compromised*), however, it is unclear which aspect was compromised (building aesthetics or functionality). Additionally, due to survey anonymity, it is impossible to determine if any of the respondents were in teams together.

Additional feedback indicates that student perspectives are divided about compromise. Some believe that given sufficient *planning, consultation and creativity*, compromise is unnecessary, and an ideal outcome can be achieved where all parties are satisfied. However, others believe this to be practically impossible, reasoning that if compromise could be avoided, then *every building would be perfect*, and that no such 'perfect' building exists. To support this, one respondent specified that they *prefer a more 'practical' aesthetic that engineering offers*. Similarly, it can be assumed that others would not necessarily agree with their 'practical' aesthetic, indicating that compromise is a necessity when undertaking any design.

APPENDIX F – 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.

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 G – CONSULTANT VETTING REPORT

IDS12 – Unanderra Police Station Redevelopment

Illawarra Local Aboriginal Land Council (ILALC)

Vetting Report 2nd May 2022

Image: Student 9 Assignment Submission, IDS12

Document Verification

Report Authors:

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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.

In this studio, the students investigated sustainable design options for the redevelopment of the Unanderra Police Station building for the Illawarra Local Aboriginal Land Council. This study investigated ways to improve the performance and sustainability of two proposed designs for the ILALC, with the intention to reach a net zero energy goal. The two designs were for an existing building (old police station) and a new mixed-use building - both to be located in Unanderra, NSW Australia

This summary report documents the vetting process undertaken by the supporting consultants following the completion of the studio. 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.

Existing

Image: Group 1 Assignment Submission, IDS12

Proposed

Image: Student 9 Assignment Submission, IDS12

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 IDS12 design studio were given the task of designing a sustainable, net-zero, redevelopment for a Local Aboriginal Land Council facility at the existing Police Station building at Unanderra. A range of feasible opportunities for minimising the project carbon footprint and energy usage were to be considered including active and passive solutions. This had the overall target of achieving a Renewable Energy Fraction (REF) of 1.0 to demonstrate net zero.

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.

Australian Government
Australian Renewable Energy Agency
ARENA

AIRAH

UNIVERSITY OF WOLLONGONG AUSTRALIA

Edmiston Jones

NORTHROP

MIENGINEERS

Net-Zero Carbon

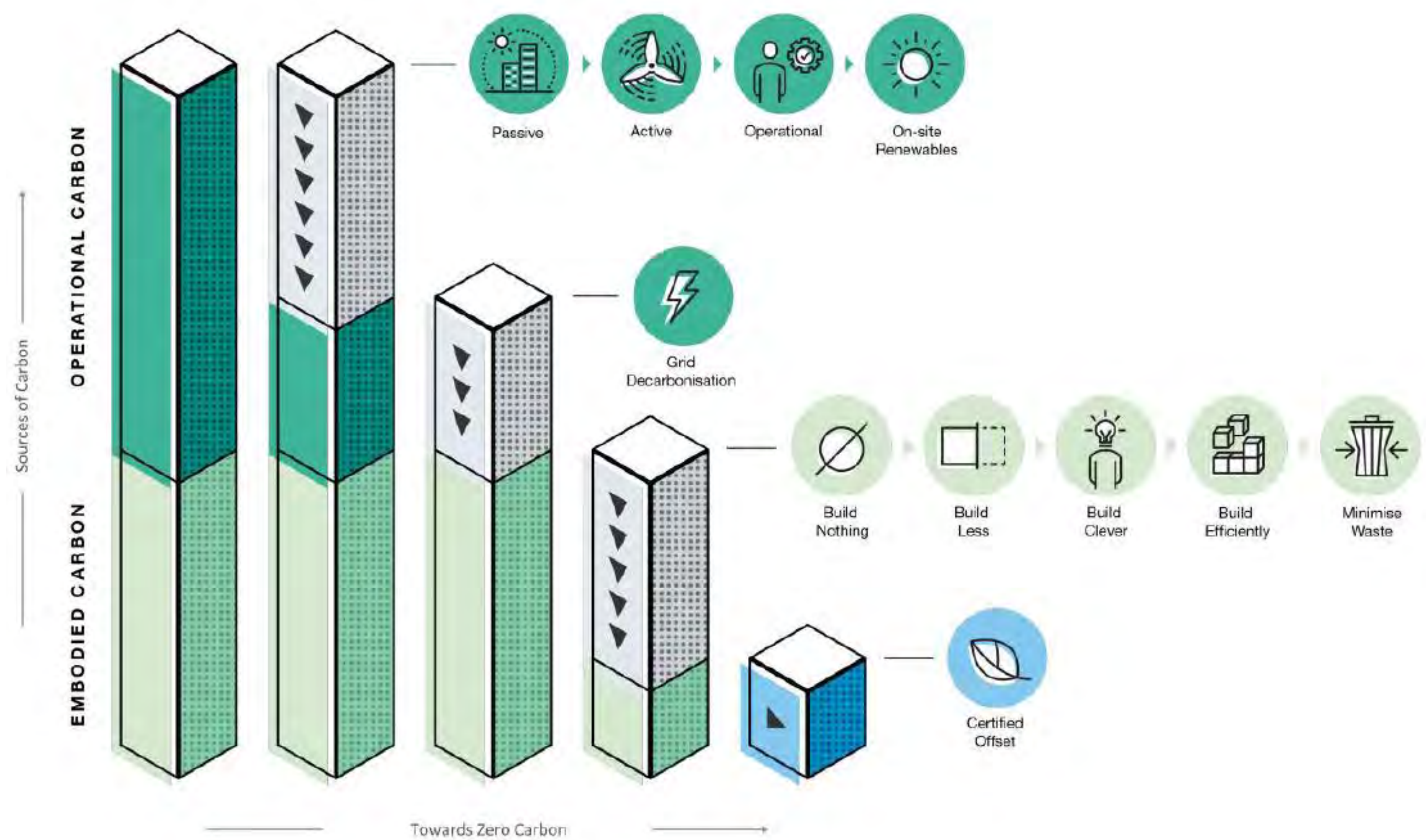
This term is commonly used across industry but its definition varies due to a lack of consensus on where the boundary for assessment is defined for a given building.

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)

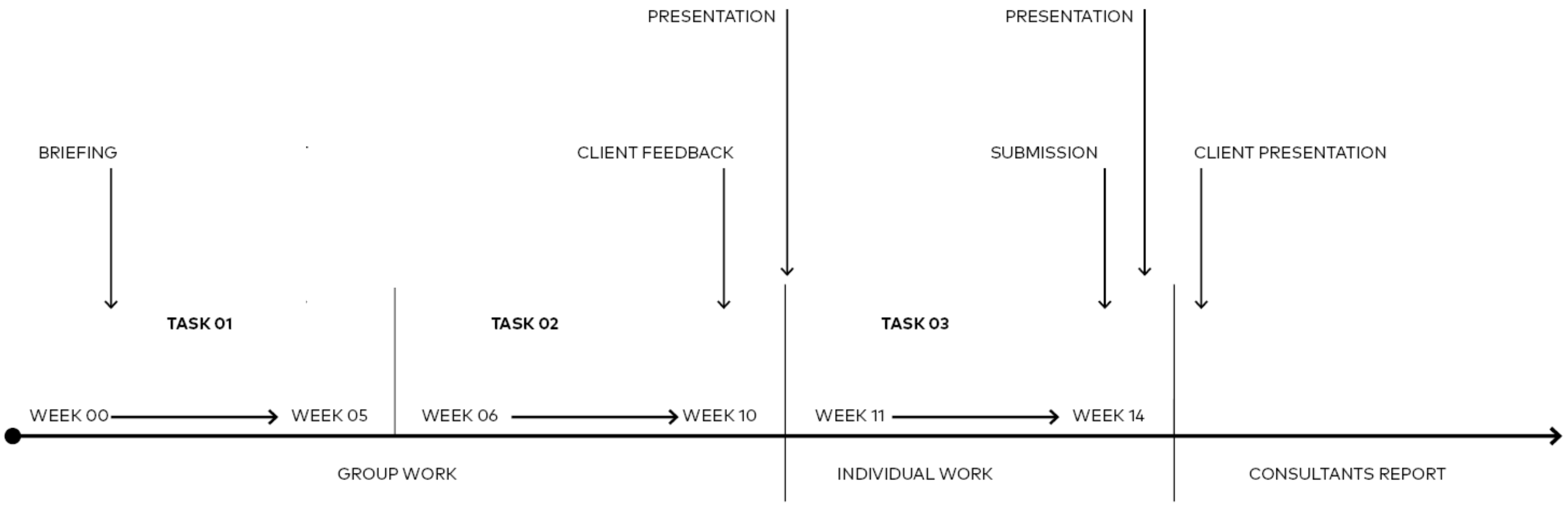
Studio Structure

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 Mr. Paul Knight from the Illawarra Local Aboriginal Land Council to direct the avenue of inquiry. A previous design option had been developed by Merribi Group and was presented as an example of options for usage of these spaces.

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 two key initiatives to research in more detail and explore with computer modelling and analysis of building performance.



Studio Interactions

IDS12 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 IDS12

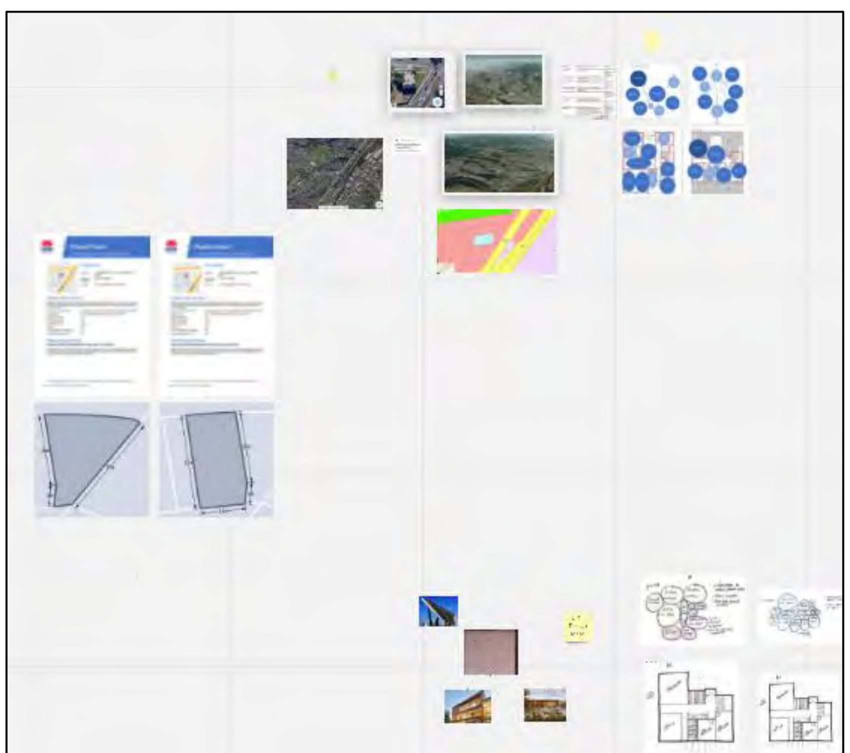


Image: Miro online collaboration environment from IDS12

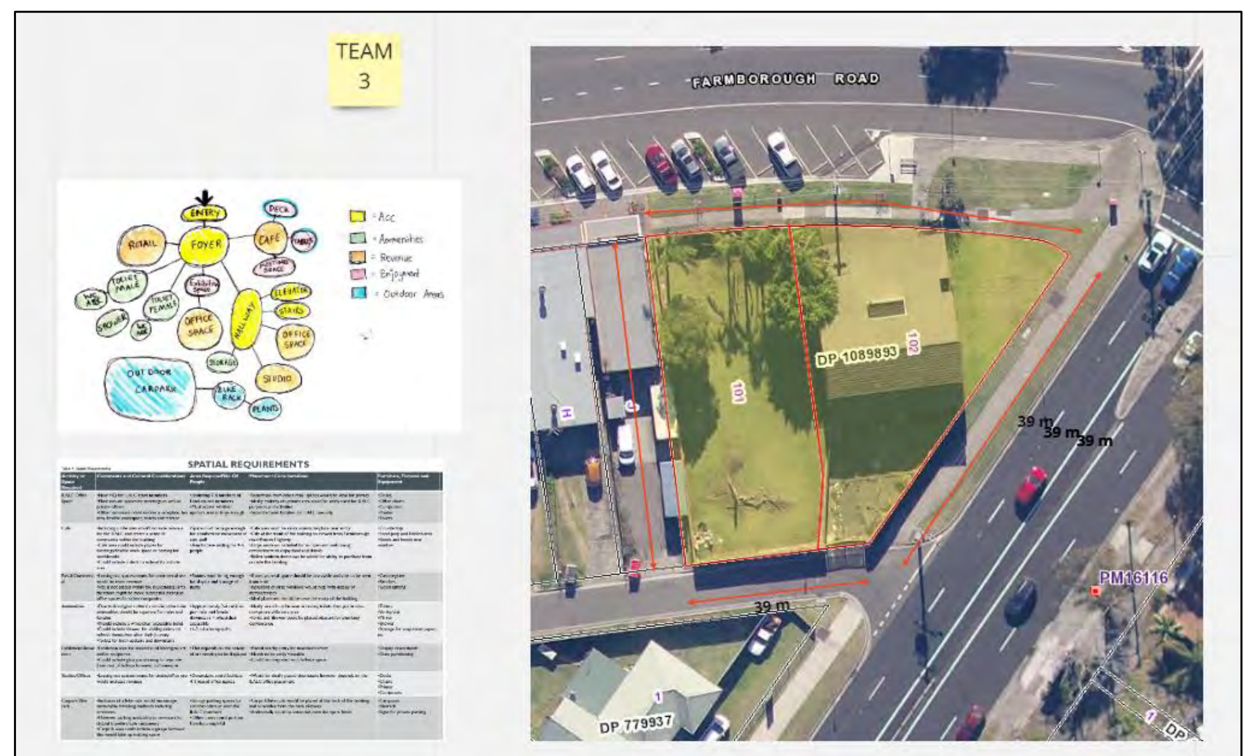


Image: Miro online collaboration environment from IDS12

Introduction

Location and Site

The site is located in Unanderra, NSW on the corner of Farmborough Road and the Princes Highway. The building is currently owned by Wollongong City Council who have presented this location as an option to ILALC for redevelopment.

The site occupies a central position in the suburb with good access to the main business areas in Unanderra good links to both bus and train public transport

The former police station building is a two-story, brick structure with a pitched tiled roof. The building structure is in reasonable condition and appropriate for reuse, however, a refurbishment of the internal space is required for the new usage. The building was recently damaged in a fire on 8 Feb, 2022 and thus requires a full upgrade.

The site also includes a vacant block to the West which was also considered as available to the redevelopment.

Image: Group 1 Assignment Submission, IDS12

Image: Dr Steve Burrows Foundation

Introduction

The Climate

A review of the local climactic conditions was undertaken. This appreciation for weather and climate effects is a key component in developing holistic sustainable design solutions appropriate for a given location.

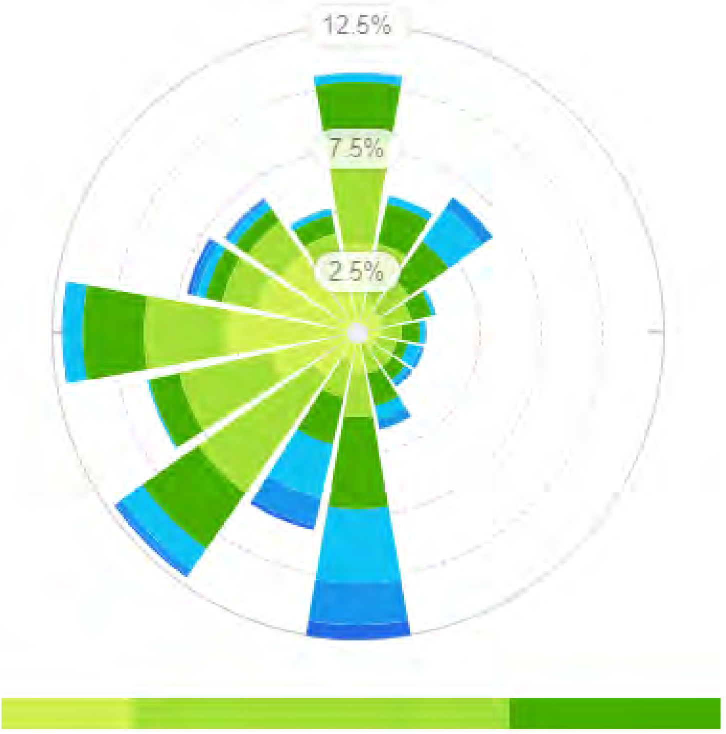
Unanderra categorised as a ‘Zone 5’ climate to the building code which is described as oceanic and typically warm with a significant amount of rainfall.

Average high temperature of 25.7°, with January being the warmest month and an average low temperature of 19°C with July being the coldest month. The average humidity is 75% (February being the most humid month) with a UV-index reading of 4. January and December however have an average of 6 UV indexes, being the months with the highest index. November has the most sunshine within a year with an average of 9.8hours while June has the least sunshine with an average of 5.9hours.

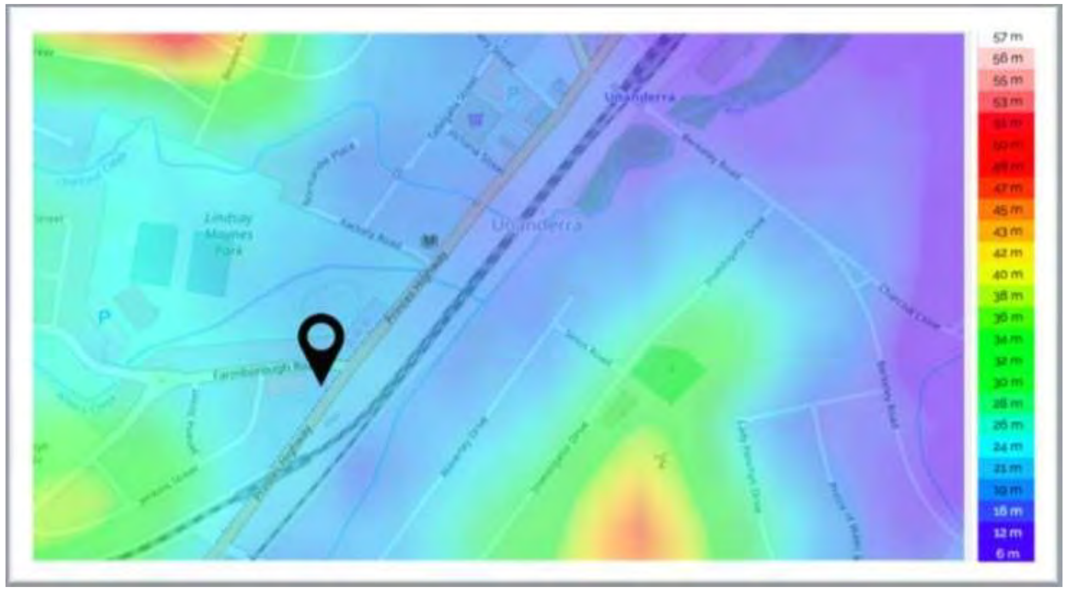
Throughout the year, there are approximately 170 rainfall days with a total of 678mm of precipitation over this period. The windiest month is August with an average wind speed of 16.2km/h. This is in comparison to April which is considered the calmest month with the lowest average wind speed being 13.9km/h.

The most predominant wind direction is from the South-West.

Solar Paths
Source: Group 3 Assignment, IDS12



Wind Mapping
Source: Group 3 Assignment, IDS12



Topology Mapping
Source: Group 3 Assignment, IDS12

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 propose options for sustainable measures for the redevelopment of the police station 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 1 Assignment, IDS12

Images: Group 2 Assignment, IDS12

Image: Student 5 Assignment, IDS12

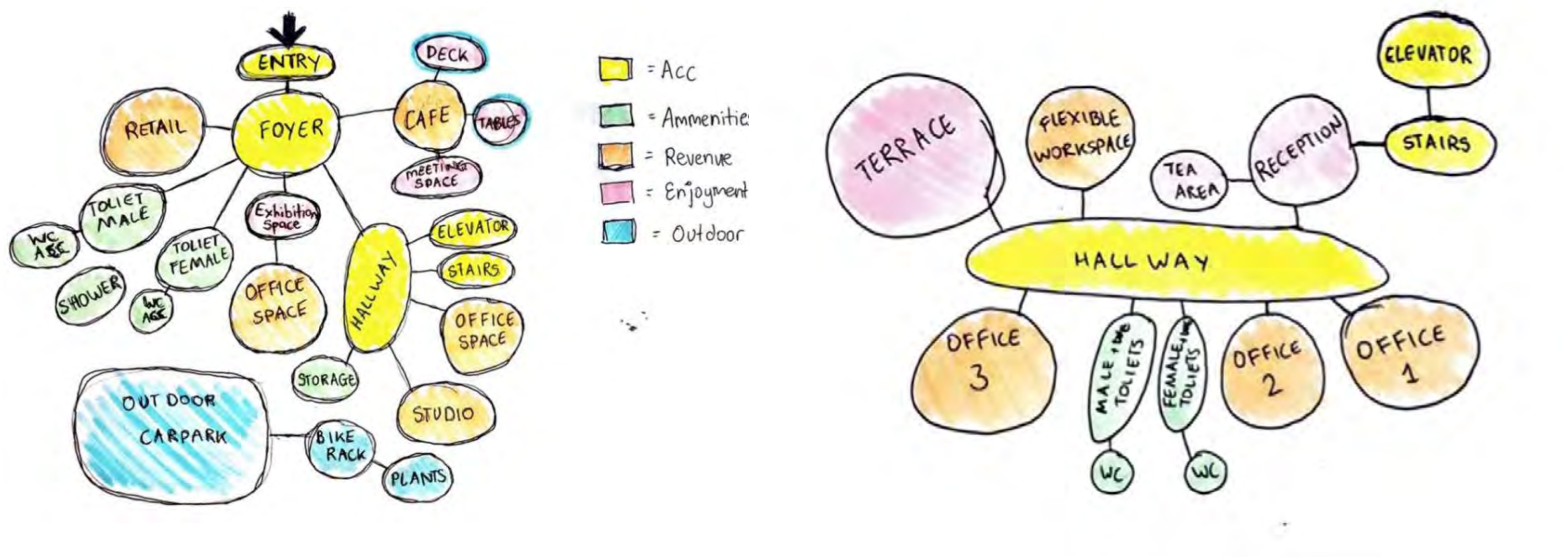
Task 1 Site Analysis and Return Brief

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.

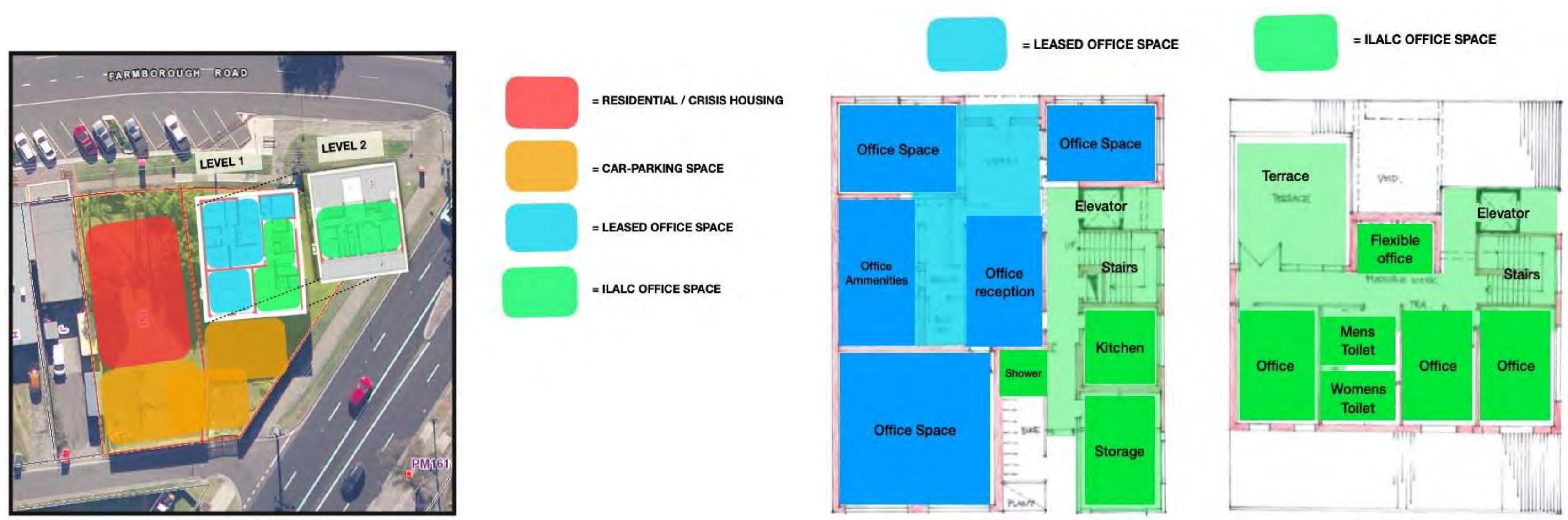
Bubble diagrams were developed to explore the connections between internal spaces and the possible options for usage.

In the initial brief, examples of the areas of consideration were:

- Natural features
- Indigenous heritage
- Heritage
- Transportation & connectivity
- Character of built environment
- Services – existing and new
- Climate/microclimate, solar access, predominant wind direction
- Constraints & opportunities



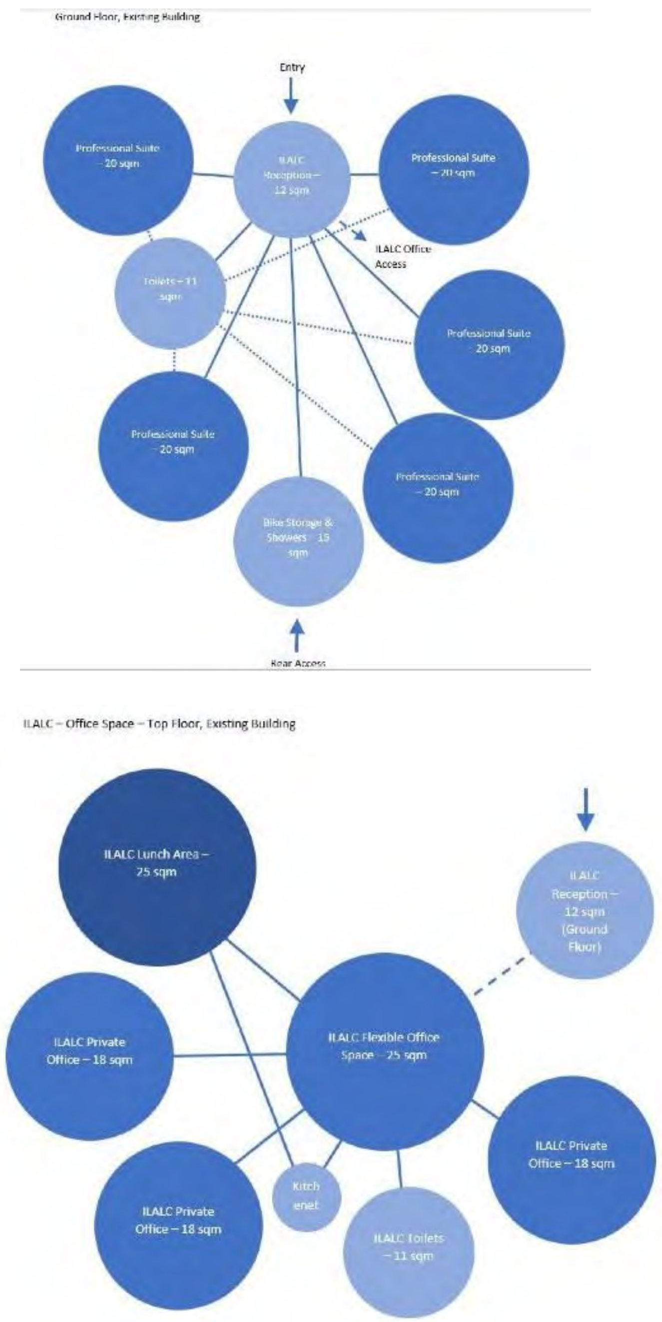
Images: Group Assignment, IDS12



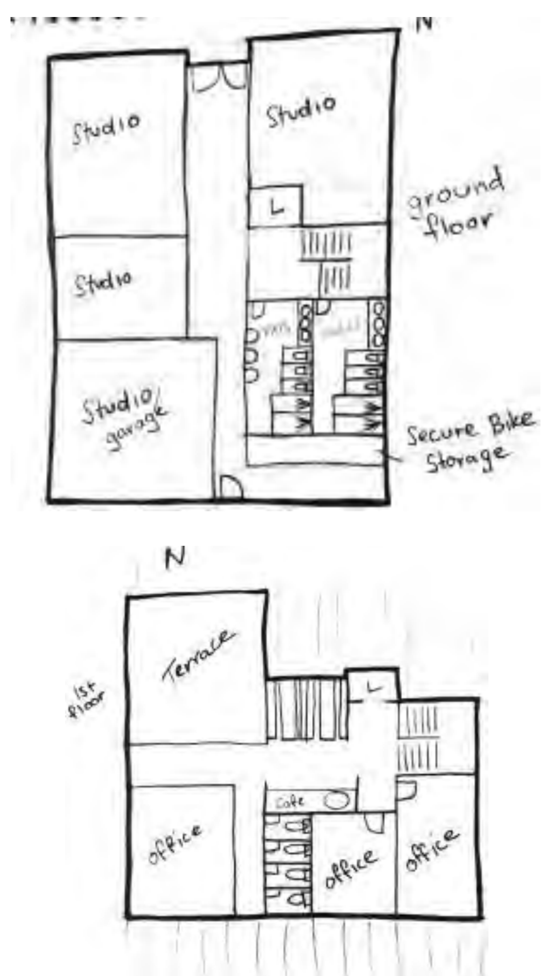
Images: Group 3 Assignment, IDS12

Studio

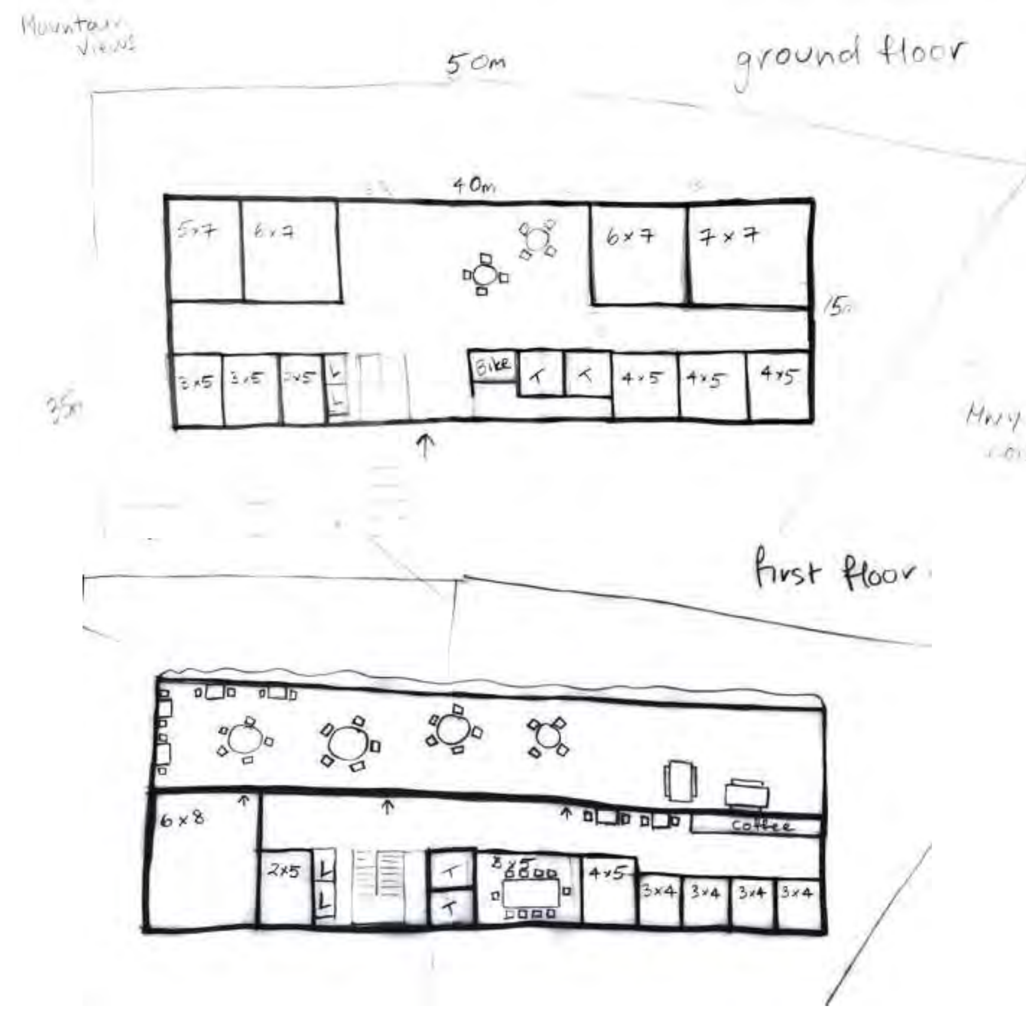
Task 1 Site Analysis and Return Brief



Images: Group 2 Assignment, IDS12



Images: Group 1 Assignment, IDS12



Studio

Task 2 Research

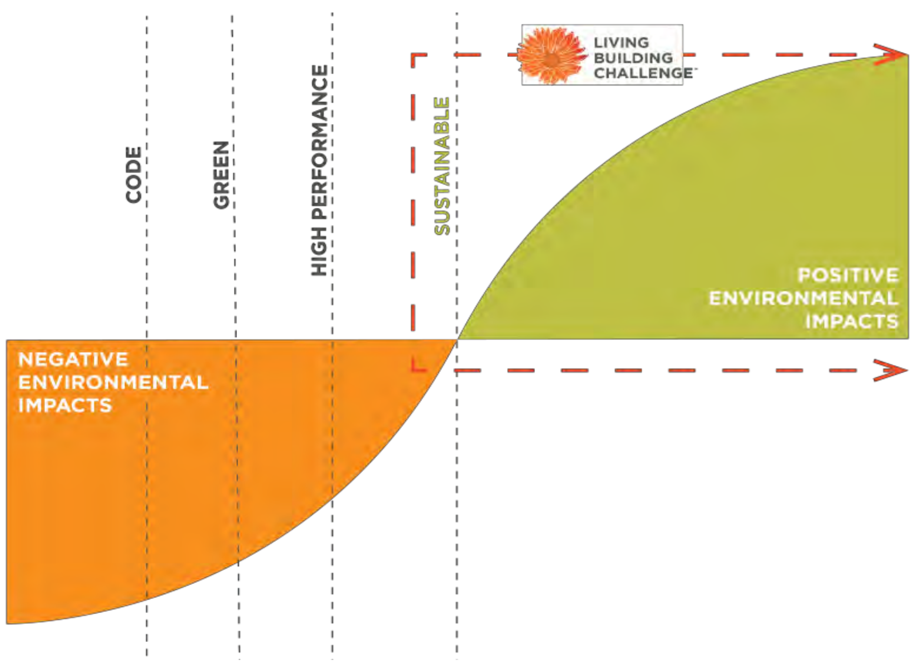
With the brief defined, and the facility details confirmed, the students reviewed technology and processes that might address any perceived any energy efficiency issues. These ideas were required to be specific to the site and the problem at hand. The solution had to work for the Unanderra site.

The students were encouraged to review critically each process and assess their potential contribution to the overall site goals.

Although focused on reduction in carbon intensity, students were also encouraged to review other potential benefits such as water efficiency and contribution to wellness. This led to benchmarking and borrowing ideas from a range of sustainability benchmark tools, including NABERS, Green Star, WELL and BASIX.

The students explored a range of technologies based on simple building improvements to mechanical system design and took inspiration from similar projects around the world.

Most students explored common and typical solutions to standard design problems.



During research, inspiration was taken from a range of sources including the UN Sustainable Development Goals and Living Building Challenge

Task 3 Proposals

Each student finally worked on assessing in detail their proposed initiatives. This included where appropriate energy modelling of the facility to identify the potential carbon saving benefit.

Students built Dynamic 3D models of the spaces, and tested each initiative to work towards improving the overall outcome.

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.

Some students were able to demonstrate a REF of >1 meaning the site was achieving net zero under modelled conditions.

Figure 32. North Elevation Improved Existing Building (NTS).

Figure 33. South Elevation Improved Existing Building (NTS).

Figure 34. West Elevation Improved Existing Building (NTS).

Figure 35. East Elevation Improved Existing Building (NTS).

Images: Student 1 Assignment 3, IDS12

Existing Building Improved (With Solar Generation)		
Total Solar Generation	45214.33 kWh	
Total Annual Net Energy Requirements	9344.907 kWh (Produces more solar energy than required)	
REF Values Hourly	No. Hrs	% Of Year
0	4197	47.91096
0<REF<0.30	620	7.077626
0.30<REF<0.95	1088	12.42009
0.95<REF<1.05	126	1.438356
REF>1.05	2729	31.15297
Annual REF Value	1.020174	

Table 3. Improved Existing Building Simulation Results.

Improved Existing Building Energy Breakdown		
	kWh	% Of Demand
Room (Equipment)	12382.15	34.52008
Lighting	10504.86	29.28638
Heating	340.8829	0.950344
Cooling	3881.528	10.82127
Hot Water	8760	24.42192

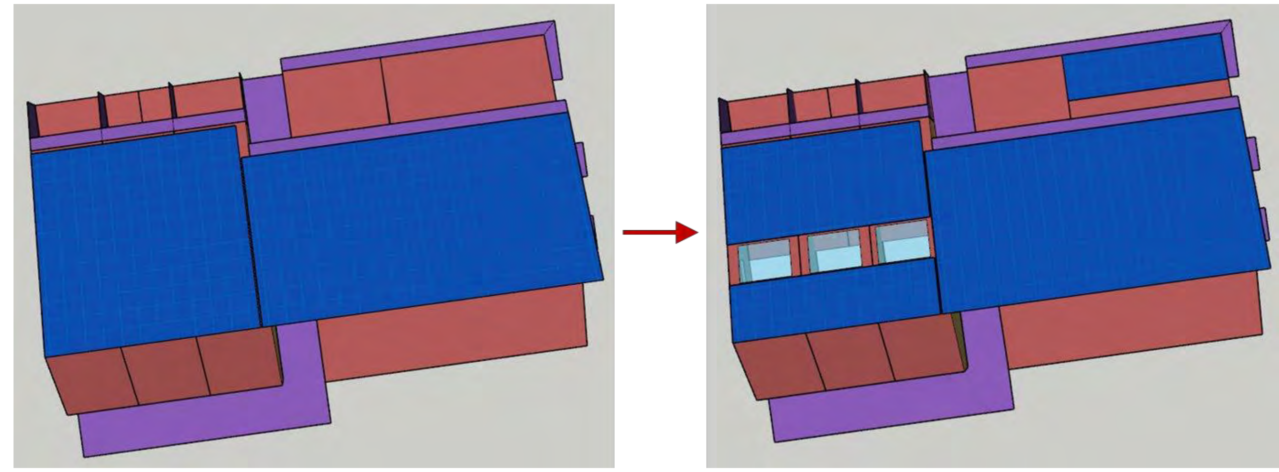
Table 4. Improved Exiting Building Energy Breakdown.

Images: Student 1 Assignment 3, IDS12

Studio

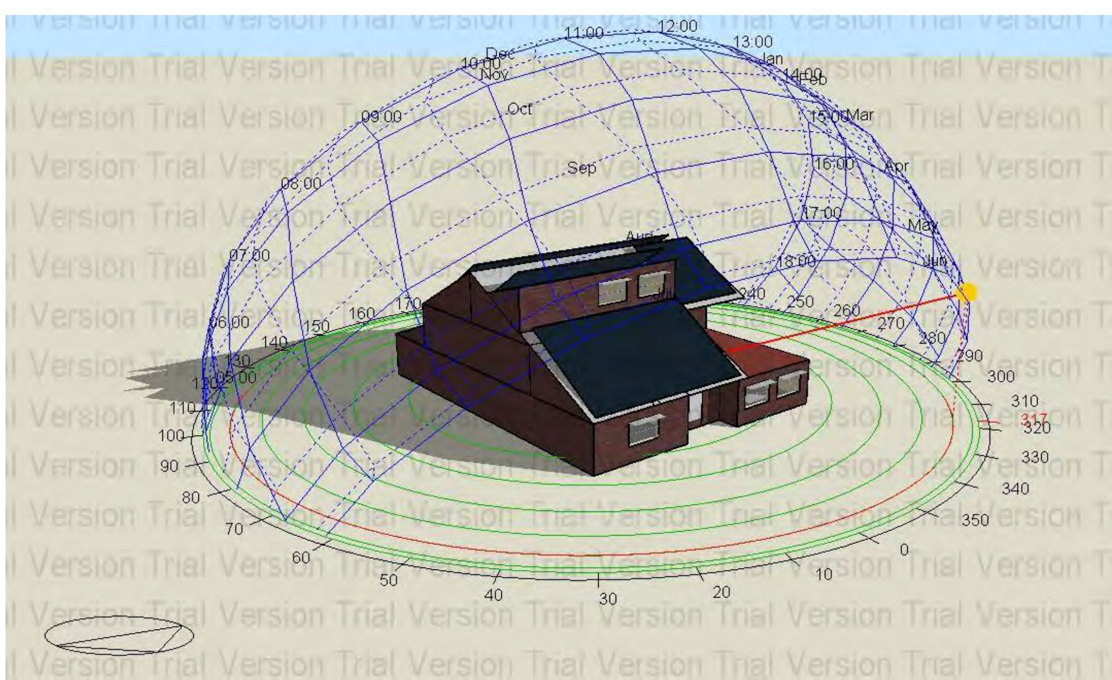
Task 3 Proposals

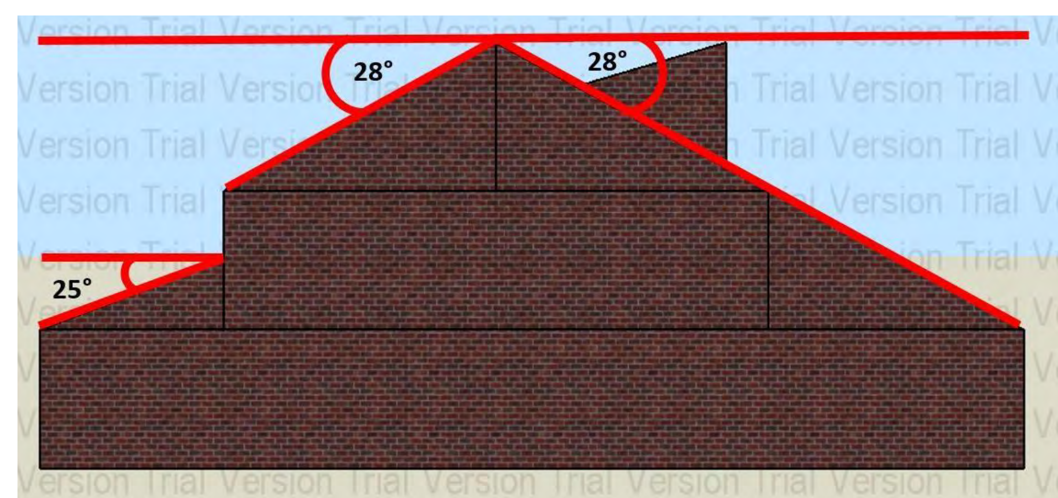
Further detailed information from a student's work is shown here including energy models, trying different orientations and assessing different PV arrays with the aim to maximise the overall performance outcome and improve the REF.



Case	Heating (GJ)	Cooling (GJ)	Lighting (GJ)	Equipment (GJ)	Total (GJ)	PV AC Output (GJ)	Site Net (GJ)	REF
Base	185.3	92.3	64.8	56.1	398.5	311.6	86.9	0.79
Insulation	167.3	86.6	64.8	56.1	374.8	311.6	63.3	0.79
Skylights	143.6	79.2	64.8	56.1	343.8	311.6	32.2	0.89

Images: Student 9 Assignment 3, IDS12 – Skylight and insulation assessment





Images: Student 7 assessed roof pitch as a design solution

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 the Lightning Ridge Development.

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
(P) Using PV Systems as Shade
(I) Power Purchase Agreement
(P) Optimising the arrangement of Façade
(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
(P) Cool Roofs
(P) Shading
(P) Thermal mass
(P) Thermal Labrinth
(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) Native Planting below Solar Panels
(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

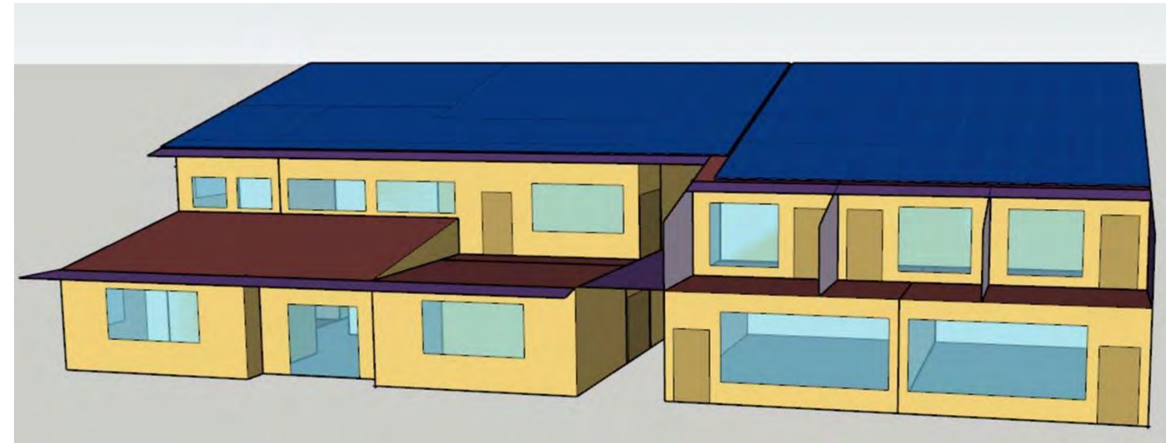
Energy models were developed by the students to assess their proposed improvements across the year. This design stage of verification allows the support of the development of the technology.

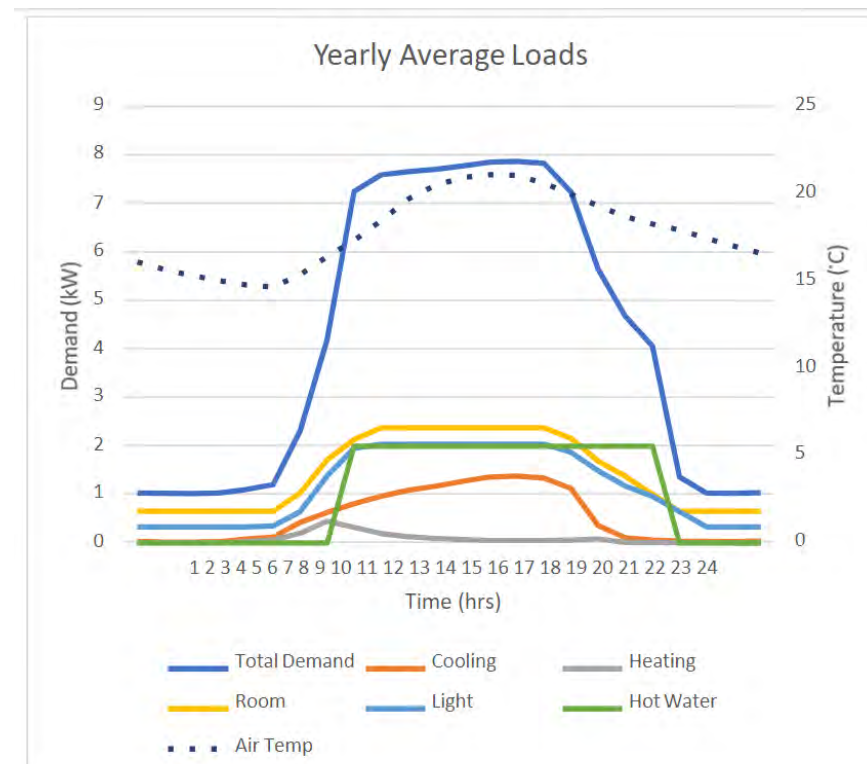
This was typically completed in either Google Sketchup and assessed using OpenStudio through the EnergyPlus energy modelling engine, or using DesignBuilder with their built-in engines which runs on EnergyPlus.

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 >1.0 - indicating the overall development had achieved net-zero.





Studio

Passive Design

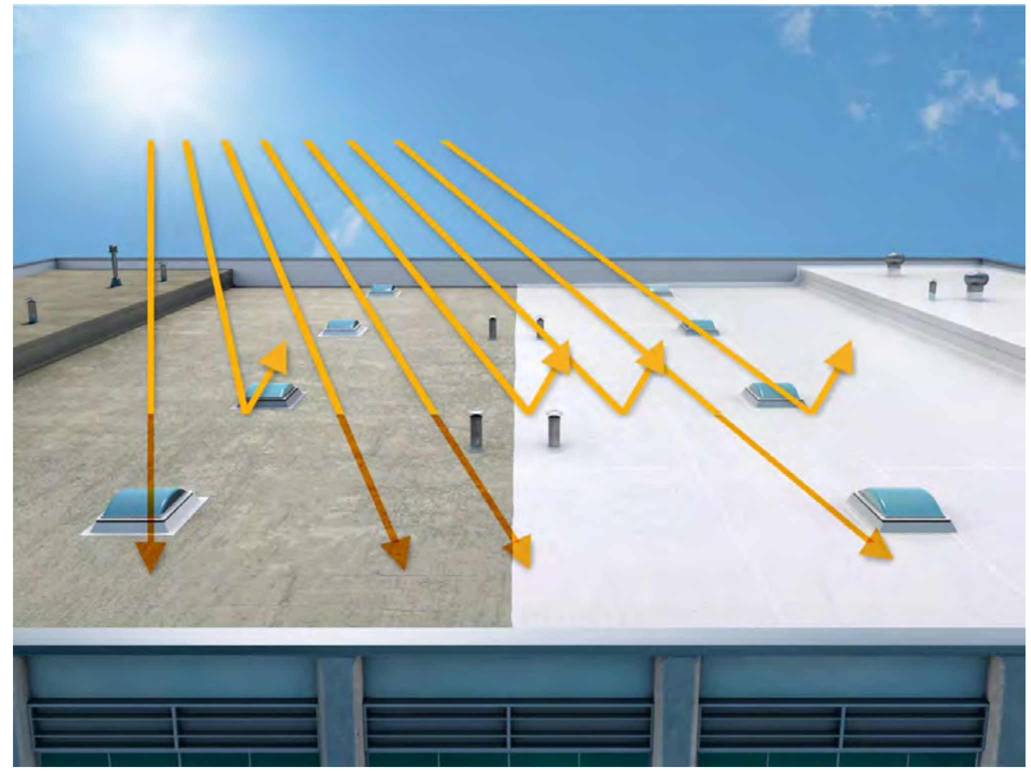
Students identified early on that there are significant opportunities to integrate passive design for new build designs.

Massing of the building can be adjusted to optimise solar load for both cooling and heating, which offsets the need for actives systems.

Students had a significant push on optimising the overall layout to minimise energy use. Students assessed several arrangements and passive elements to improve the overall performance, including:

- Window Arrangement
- Insulation performance
- Shading
- Air Tightness
- Passive Ventilation
- Window Performance and window treatments
- Cool roofs

Students typically found savings of up to 20% can be achieved through these passive methods while not impacting the building outcomes.



Cool Roofs reflect heat and significantly reduce heat loads in the space.
https://aus.sika.com/en/knowledge-hub/cool-roofs-and-energy-efficiency.html

Greenery below solar panels keeps the roof cool and can improve PV output by 4%.
https://www.pv-magazine-australia.com/2021/08/24/green-roof-improves-solar-panel-efficiency-by-3-6-on-average-peaking-at-16-study-finds/

Passive Design

Reducing loads passively was the key first step to achieving the reduction and assisting with the REF.

Key passive solutions focussed on the geometry, but also took inspiration from nature to cool air. In-depth conversations were had to develop pragmatic proposals in keeping with the architecture and targets for the project.

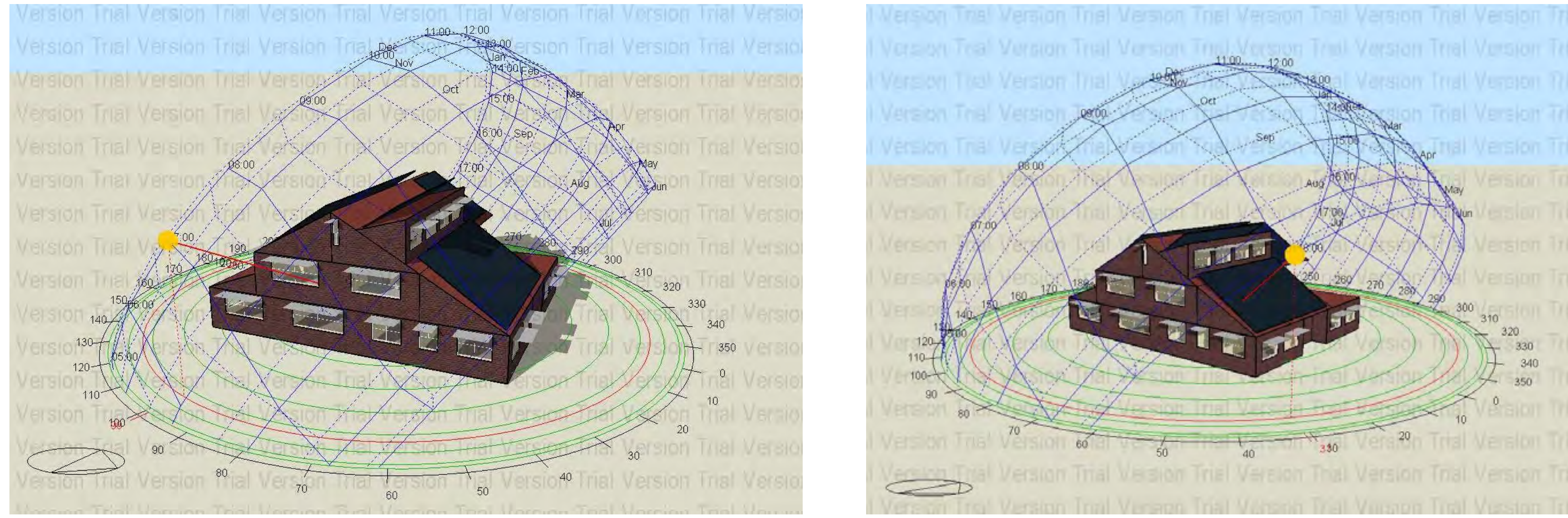
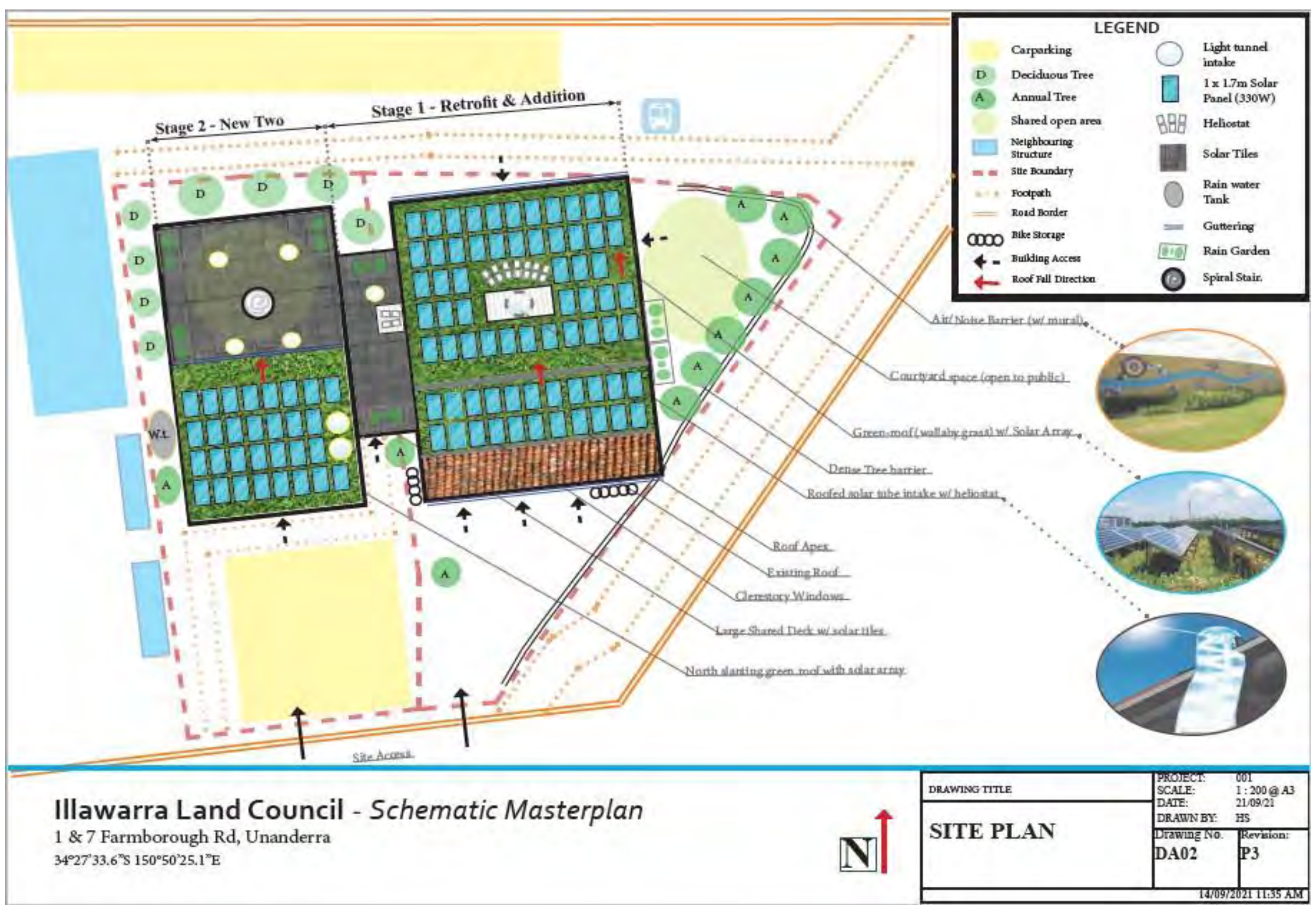


Image: Student 4 Assignment Submission, IDS12



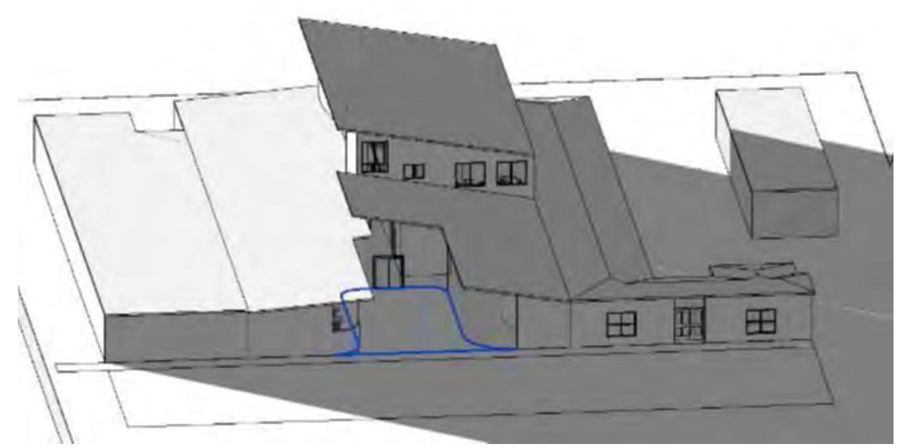


Image: Student 1 Assignment Submission, IDS12

Studio

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.

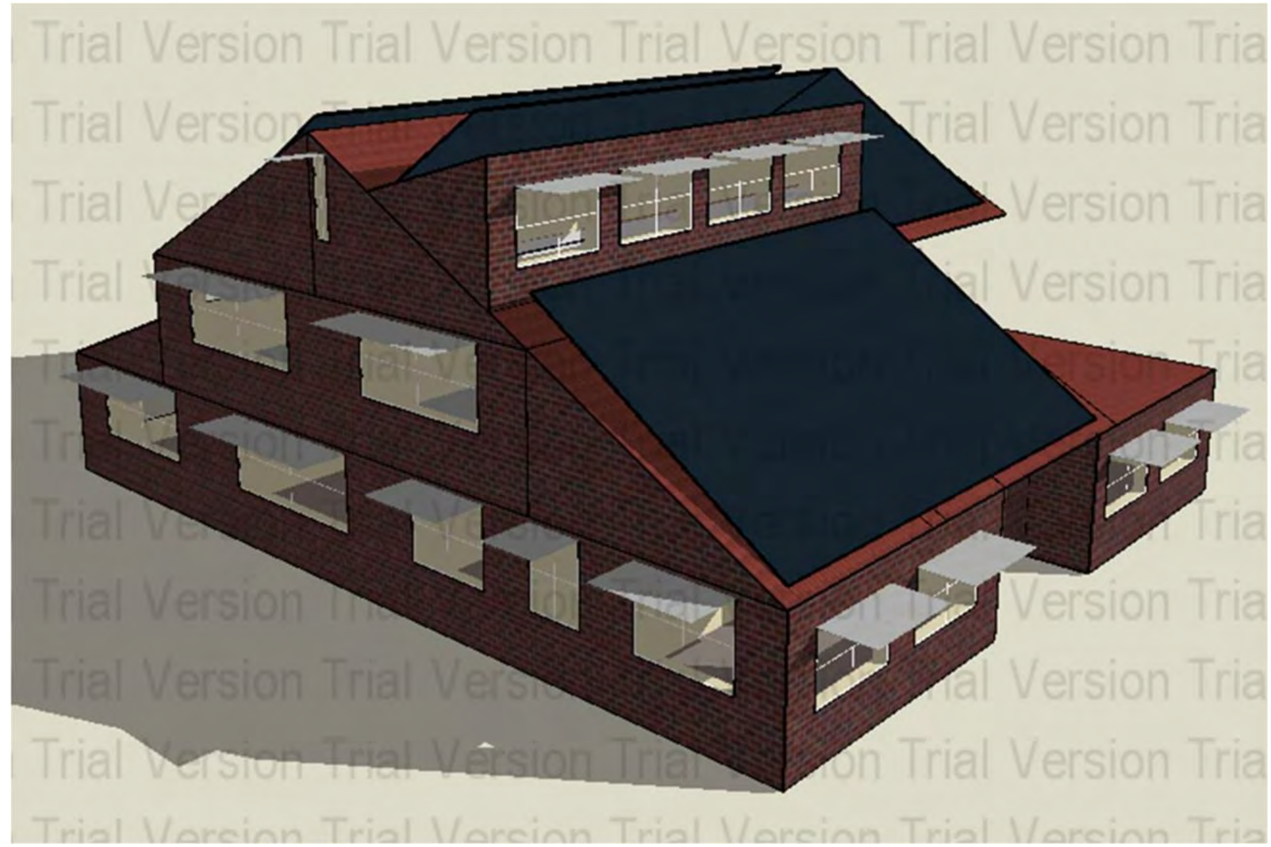
The return on investment is typically high with relatively short payback periods, making it an attractive option.

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 were considered beyond just the building and sought opportunities beyond the roof.

Students often found that with adequate PV, a REF of >1.0 could be demonstrated through modelling.



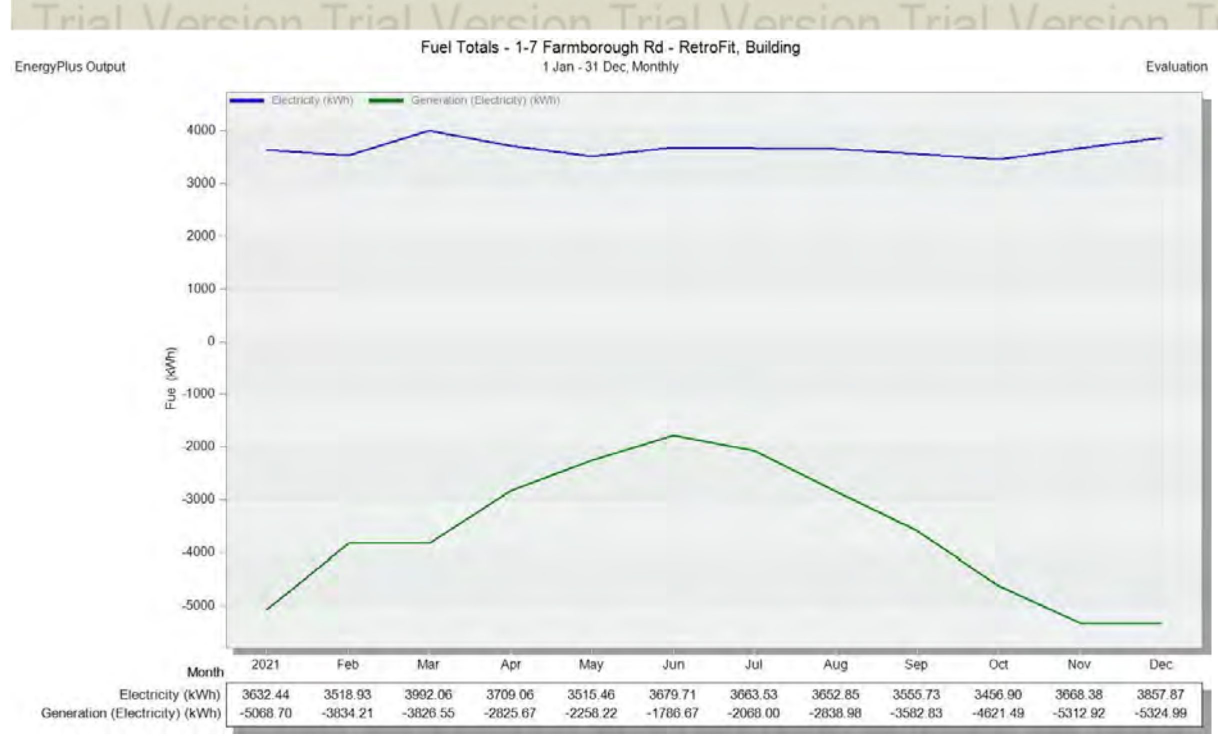


Image: Student 4 Assignment Submission, IDS12
Top: Model showing the PV
Bottom: Graph showing PV production across a typical day

Operational

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. Operable Blinds
3. Energy management systems

High efficiency:

Typically examples of this include enhanced efficiency of systems compared to business as usual. Business as usual defined by either code (NCC) or standards (AS, MEPS, etc.)

This can also include the application of systems that a non-typical for the proposed application, e.g. the use of centralised heating and cooling for an aged care facility is not standard as it would have a higher capital and maintenance costs which dependent on project specific parameters (climate, location, building design) may not have a good return on investment.

Similarly, items such as high volume, low speed (HVLS) fans which provide cooling comfort to offset air conditioning use were discussed but not analysed – this may require changes to the project brief to enable inclusion.

Operable Blinds:

More Buildings these days are exploring climate-responsive blinds on the outside of buildings. These can be programmed to drop down and block the sun on a schedule or based on an absolute value of solar gains on the façade.

This technology is a simple and effective way to significantly reduce solar gains.

Energy Management Systems

There were discussions in the studio which identified potential savings by managing the use of energy in the facility. These proved harder to assess as they required detailed modelling of both system and occupant behaviour. These are included as they do show good opportunity for carbon savings.

Relaxed cooling and heating setpoints, and occupancy/daylight control of lighting are examples of systems that can be used to manage energy use. Human operation and education is also a critical step to reducing energy. Having users who know how the systems work and can manage their uses around the building's systems is a key step to reducing the building's energy use.

Operational

Relaxed Setpoints

Traditional office design temperature ranges have not changed since comfort models were designed in the 1960's. Design elements, including temperature, humidity, airspeed, clothing and the like are based on a 40-year-old male weighing 70kg in a three-piece suit. Accordingly, the current design of 22.5 ± 1.5°C is an archaic, outdated and sexist temperature range. It also leads to additional wasted energy use consumption.

Adjusting the space to maintain temperature for both males and females equally would result in a step-change in the philosophy of design as well as be an inclusive, modern and responsible change. This could occur in multiple ways to provide greater comfort to all.

- Set a wider temperature range, allowing the space to float between 20.5 - 25°C. Even this slightly warmer temperature could reduce cooling loads by 10%
- Allow different heat zones across the floorplate. Spaces could vary by up to 5°C from the North to South, allowing people to find their sweet spot based on their preference and individual physiology.

The additional comfort, leadership, energy savings and holistic inclusion through this measure would demonstrate a great position in changing the way society sets office temperature ranges.

Operational

Two-Tone Lighting

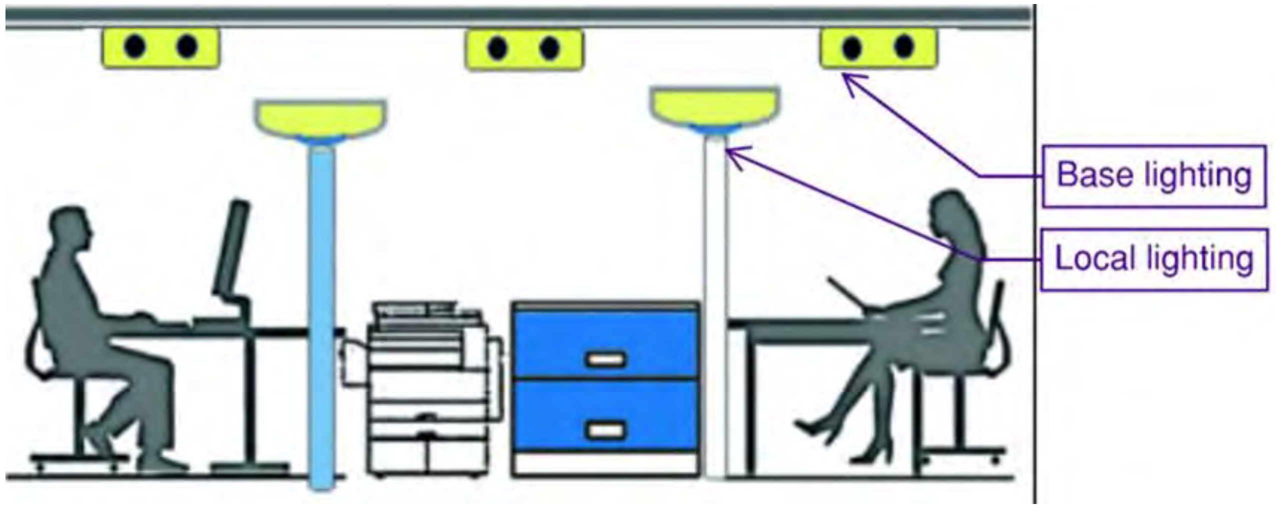
Within the space, lighting is typically one of the largest energy-consuming elements along with small power. Students found this could be up to 40% of the total. A standard lighting design follows AS1680.1, which for an office environment requires 320 Lux to be maintained across the working plane. This is achieved by lighting the entire floorplate to a continuous 320 lux. Such a system consumes approximately 4.5-5.0 W/m2 with even the best LED light fittings available.

The code as a baseline for simple tasks however only requires 160 lux, which requires far lower lighting levels. This level would not be acceptable for working tasks for a long period of time, but is acceptable for most daily tasks.

As a design alternate, significant energy can be saved by implementing a two-tone lighting system. This can be done in a couple of different ways:

Having the ceiling grid designed to achieve 320 lux on all workstations only, with walkways and other spaces lit to only 160 lux.

Having the ceiling grid only designed to 160 lux, and installing specialist lighting within the desks that can light the space to 320 lux. This has the added benefit that individual desks are turned off when no one is at the desk.



Studio

On-Site Renewables

Once loads have been minimised, efficiency has been driven as far as possible and unnecessary loads removed, the last opportunity to drive towards net zero is through renewable power.

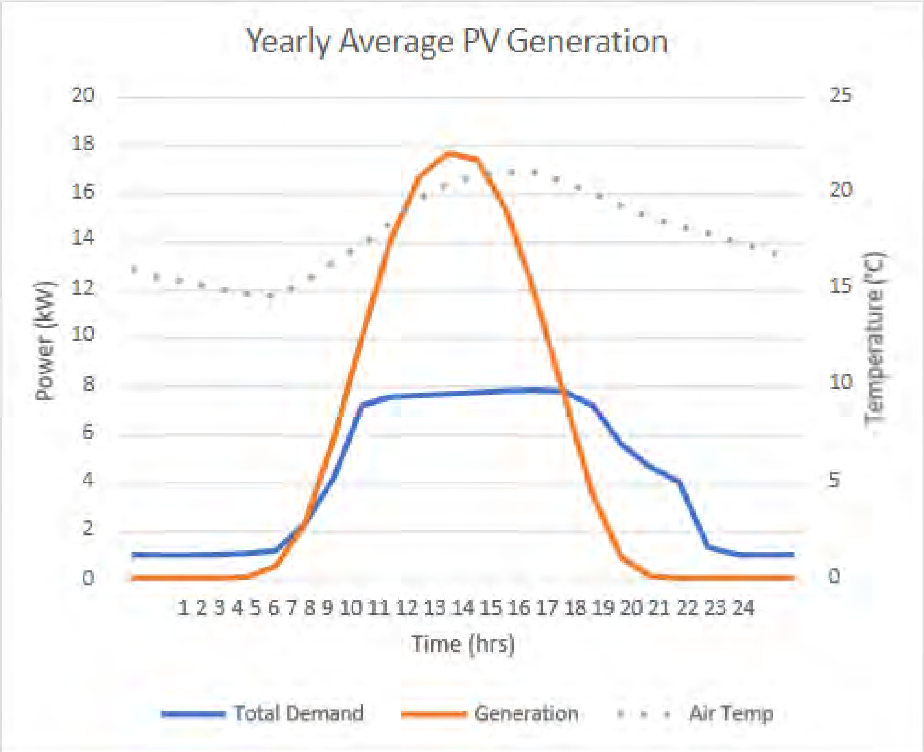
On-site renewables a simple and incredibly effective way to offset electricity consumption within the built form. All buildings providing amenity will consume energy. Once the building's energy consumption has been reduced as far as possible, the next step is to offset it through renewables.

Return on investment is typically high with relatively short payback periods, making it an attractive option.

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.

Students' assignments have found that the roof area should be sufficient at Unanderra to drive the project to a net-zero position, including achieving a REF of >1.0

IDS12 Assignment 3: Student 5



IDS12 Assignment 3: Student 8 showing annual generation exceeds demand.

Studio

Embodied Carbon

Modular Systems

Modular construction can generally be described as any form of construction where some form of prefabricated component or module is brought to site pre-assembled and erected into the final structural form.

Modular wall design may allow reduced cost, increased flexibility and improved embodied carbon in the space. The key to adjustability is designing wall systems that can be relocated, assembled and disassembled through a kit of parts relatively simply. Partnering with companies that have modular assemblies in place limit the flexibility in design, but can save significant cost, time, material and deliver real sustainability.

Components of the building (such as wet areas) or whole upgrades can be undertaken using prefabricated parts, which can have great end of life properties and a simple yet effective kit of parts.

Studio

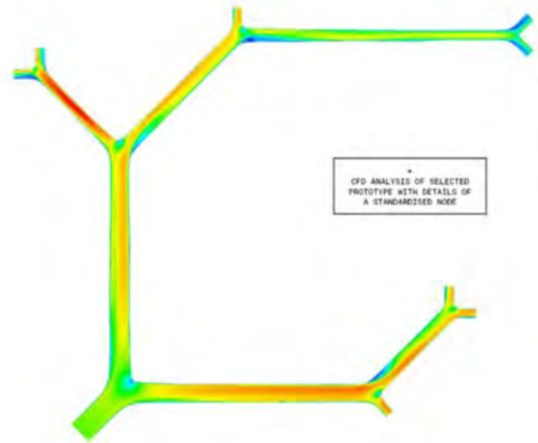
Embodied Carbon

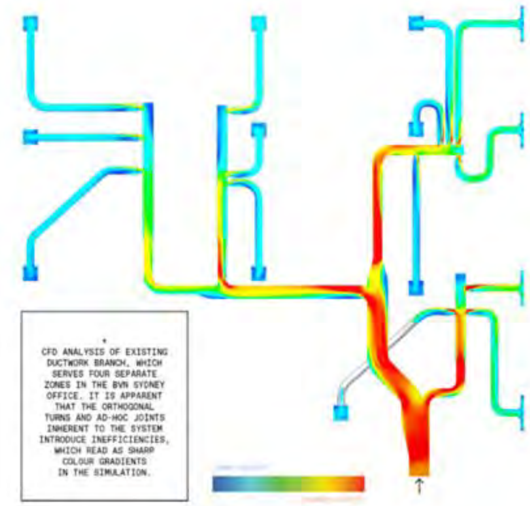
3-D Printed Ductwork

Sydney designed, novel and efficient, the world’s first robotically 3D-printed air-diffusion system will improve the operational efficiency and reduce the embodied carbon of the fitout. Air doesn’t move at right angles, yet ductwork and air distribution systems are designed this way.

The architectural practice BVN in collaboration with the UTS School of Architecture have designed a 3D printed solution, called Systems Reef 2 (SR2). SR2 reinvents air distribution: replacing steel with recycled plastic, square corners with aerodynamic curves, and large vents with fine pores.

It offers a 90 per cent reduction in embodied carbon when compared to existing systems. Made from recycled plastic waste, it can be fully recycled at the end of its life, exemplifying circular economy principles.





3D Printed Ductwork in BVN's Offices: https://www.hvacrnews.com.au/news/is-this-the-hvac-system-of-the-future/

Studio

Embodied Carbon

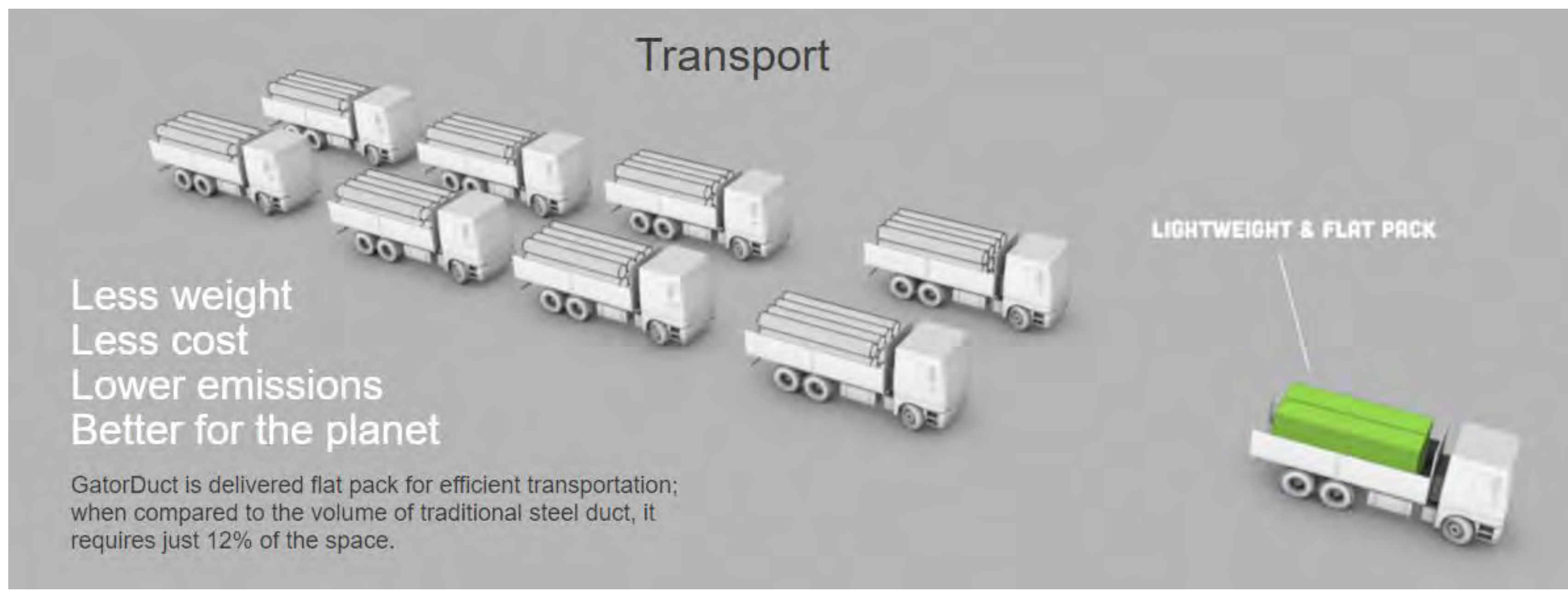
Cardboard Ductwork

The embodied carbon in ductwork could be reduced significantly by replacing it with natural materials such as cardboard. GatorDuct, a maker of engineered cardboard, has developed a low-weight, low-carbon ductwork solution that meets the flexibility and design needs of commercial offices. The system is designed to be fire-retardant, moisture-resistant, water-repellent and completely functional.

Cardboard is 80% lighter and guaranteed to last a lifetime. Cutting and assembly on site is very simple, as can be achieved with just a regular jigsaw.

Shipping and manufacture costs and carbon are significantly reduced, as the low-carbon product can be shipped as a flatpack. This reduces the space required and the number of trucks by up to 88%. Further, branding is simple as any brand, word or symbol can be printed on the duct.

An aboriginal artwork could run through the entire space, painted on the ductwork.



Cardboard ductwork is light, recyclable, low carbon and available: https://www.gatorduct.com/

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 it's existing form.

The average Sydney office fitout diverts 21% of waste from landfill. 400,000m^2 of commercial office space is refitted each year in Sydney CBD alone, which drives approx. 55,000 tonnes of waste to landfill. Reducing strip-out waste can be achieved by creating clever policies to avoid churn and finding locations for the equipment in the space. This will have multiple benefits:

- Save and make money – monetise unwanted resources and avoid expensive landfill costs
- Reduce landfill – help eliminate the 55,000 tonnes of strip-out waste sent to Sydney landfills each year
- Create a closed-loop economy – support charities by donating materials or help businesses make new products from your waste

Strip out waste guidelines set parameters for fitout tenants to reduce their impacts. More valuably, the Better Buildings Partnership provide a resources workbook, which includes inventory Matrices, reuse directories, calculators to assist with hitting targets and wider project advice.

Creating clever end of life solutions and seeking to find homes for equipment is incredibly important.
https://www.betterbuildingspartnership.com.au/resource/stripout-waste-guidelines-procurement-systems-and-reporting/

Improvement on Business as usual

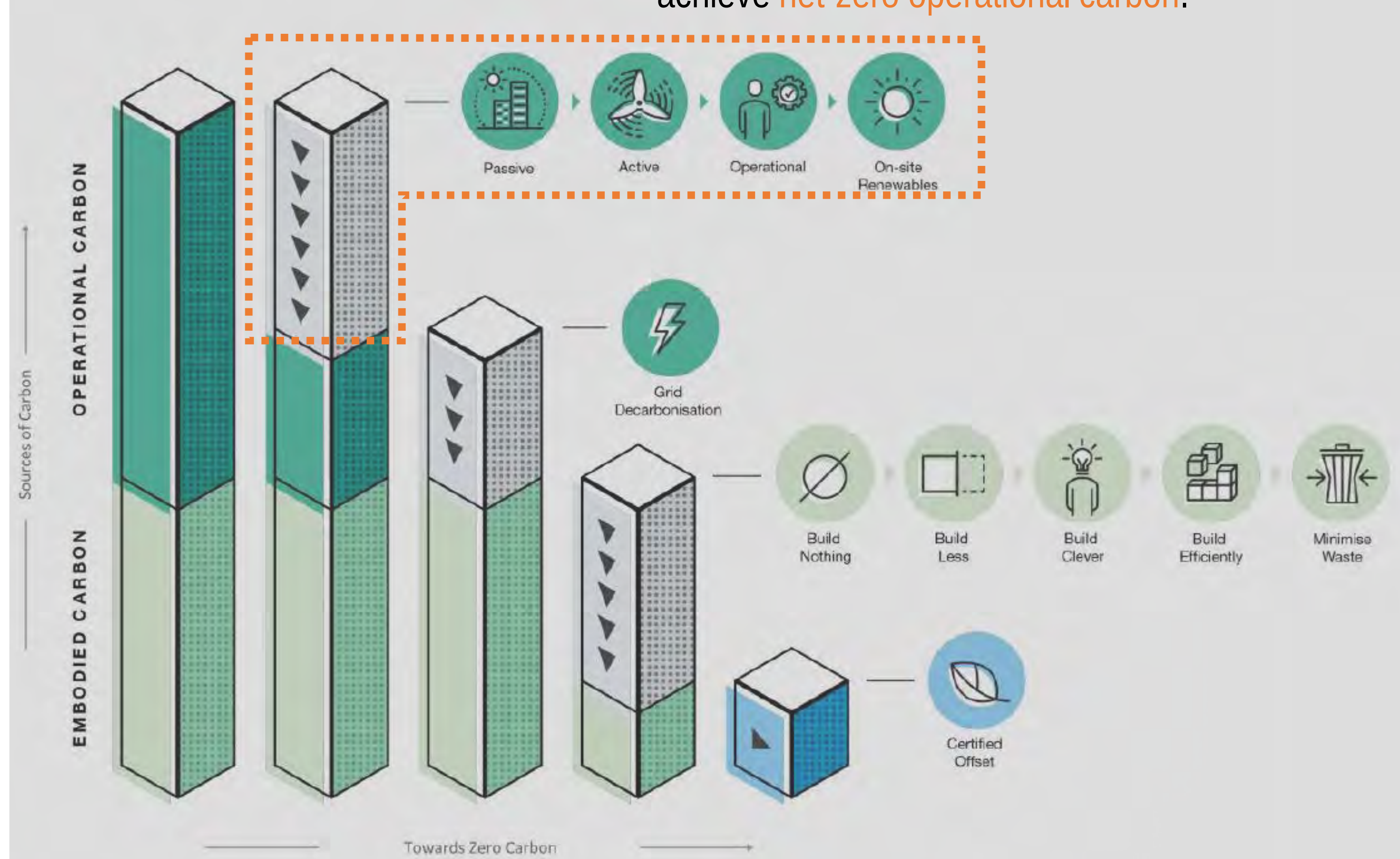
The variability in design of the size and usage of community facilities means there is no single, definitive benchmark available for end of use energy. Functional spaces, building services, size, location, climate, typology are all significant influences on energy and there are large variations of these parameters in comparisons to similar buildings.

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.

Passive design features (daylighting, natural ventilation, envelope improvements, etc.) have been found to decrease building services loads in the temperate climate by up to 25%.

Introducing PV onto a site such as this has the capability to achieve a net-zero outcome. This however will still draw power from the grid, but give back an equivalent amount over the 12-month period. Dependent on investment, the savings may be even greater. 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.

Many of the proposed initiatives have sympathetic relationships that would enhance their performance – for example, increased envelope performance may reduce fabric loads enough to remove cooling and provide only passive ventilation. Detailed studies into this would unlock even greater savings. Combined with onsite renewable the development could achieve net-zero operational carbon.



Adapted from: Arup.com - net-zero carbon buildings: three steps to take now (2020)

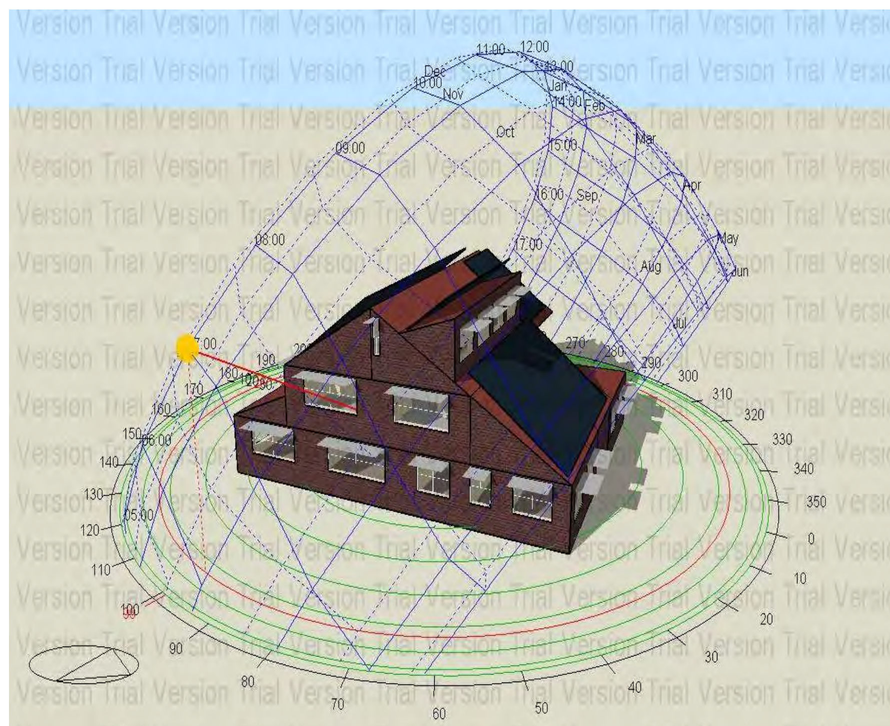
Conclusions

This studio concluded that there are many opportunities to reduce the Unanderra LALC building's carbon during construction, end of life 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 cover the remainder, looking onsite first and potentially integrating energy storage and where a shortfall exists, there may be potential to source power from off-site.

As a facility which focusses on communal spaces, consideration should been 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.
Reconciliation and Aboriginal Heritage was deemed to be of high importance for the site.

No overarching pathway for net-zero has been presented in the students work, through the individual reports do show a high level of savings is available. Renewable energy will play a key part in finalising the net-zero goal - it has been found that a REF of >1.0 is achievable through considered design and on-site renewables.



Images: Student 4 Assignment, IDS12

Images: Group 2 Assignment, IDS12

APPENDIX H – ARCHITECTUAL DESIGN DEVELOPMENT

Integrated Design Studio Unanderra

Corner of Farmborough Road & Princes Highway, Unanderra NSW

21-0051

UOW DEV - IDS 12, Unanderra

4 March 2022

This work was prepared by
undergraduate students during
Semester 2, 2021 at the
University of Wollongong (UOW)

ENGG210
Building Physics and
Building Services

Faculty of Engineering and
Information Sciences
University of Wollongong

Unanderra Group IU1

Jordan Janos

Josie-Rae Ross-Whitehouse

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Rami Yousef

Unanderra Group IU2

Caitlin Battersby

Nathan Cowgill

Jeremy Jones

Jackson Partridge

Kane Rodwell

Revision	Date	Description
A	14 March 2022	First Draft
B	25 March 2022	Final Issue

Prepared by:	lf/gm	
Position:	Architectural Graduate	
Date:	25 March 2022	

Approved by:	lq	
Position:	Architect	
Date:	25 March 2022	

UNIVERSITY OF WOLLONGONG AUSTRALIA

Integrated Design Studio
Unanderra

Address:
Corner of Farmborough Road & Princes Highway
Unanderra NSW 2526

Drawing title:
X

Site appreciation

<u>Site Background</u>

1. The traditional Custodians of the land on which the site sits are the Dharawal people.

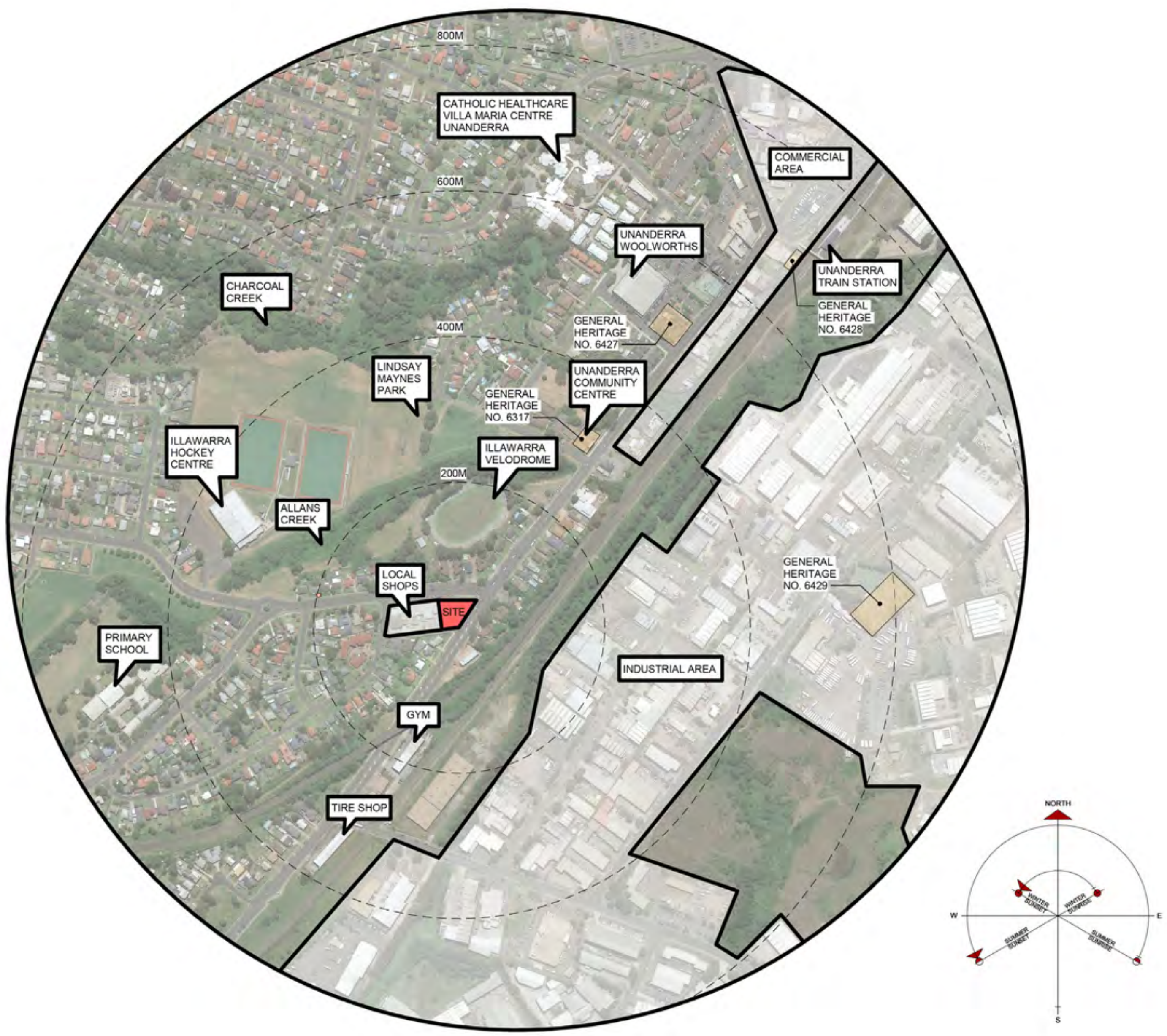
2. 'Unanderra' is an adapted form of the aboriginal word meaning 'meeting place of the creeks, in reference to Alan's Creek and Charcoal Creek (www.heritage.nsw.gov.au, accessed 2021).

3. Prior to to 1881, European settlers called the township 'Charcoal' in reference to both the burning of charcoal and a nickname used for an Aboriginal stockman known as Throsby Smith.

4. The building of interest was previously used as a Police station for training exercises, temporary imprisonment and office-work. Using an AHIMS search, there was no Aboriginal sites or places declared on the site (www.environment.nsw.gov.au, accessed 2021).

5. Special consideration should be taken with the treatment of any native trees on site, as they could carry great significance to the local Indigenous peoples.

6. The site is surrounded by low density residential and small neighbourhood shops. There is a large industrial area to the East and South of the site.



Site context diagram
Edmiston Jones Architects

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Address:
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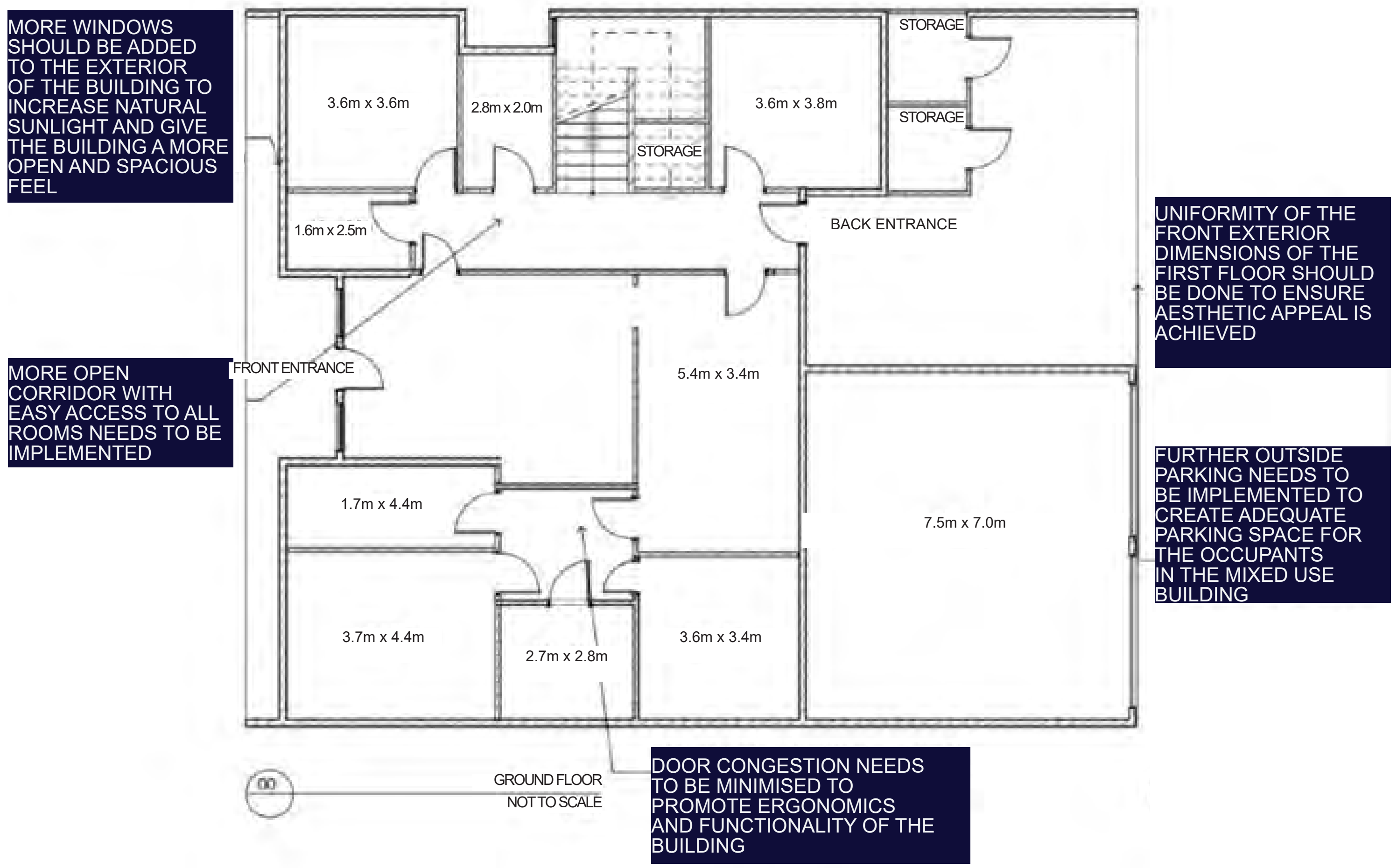
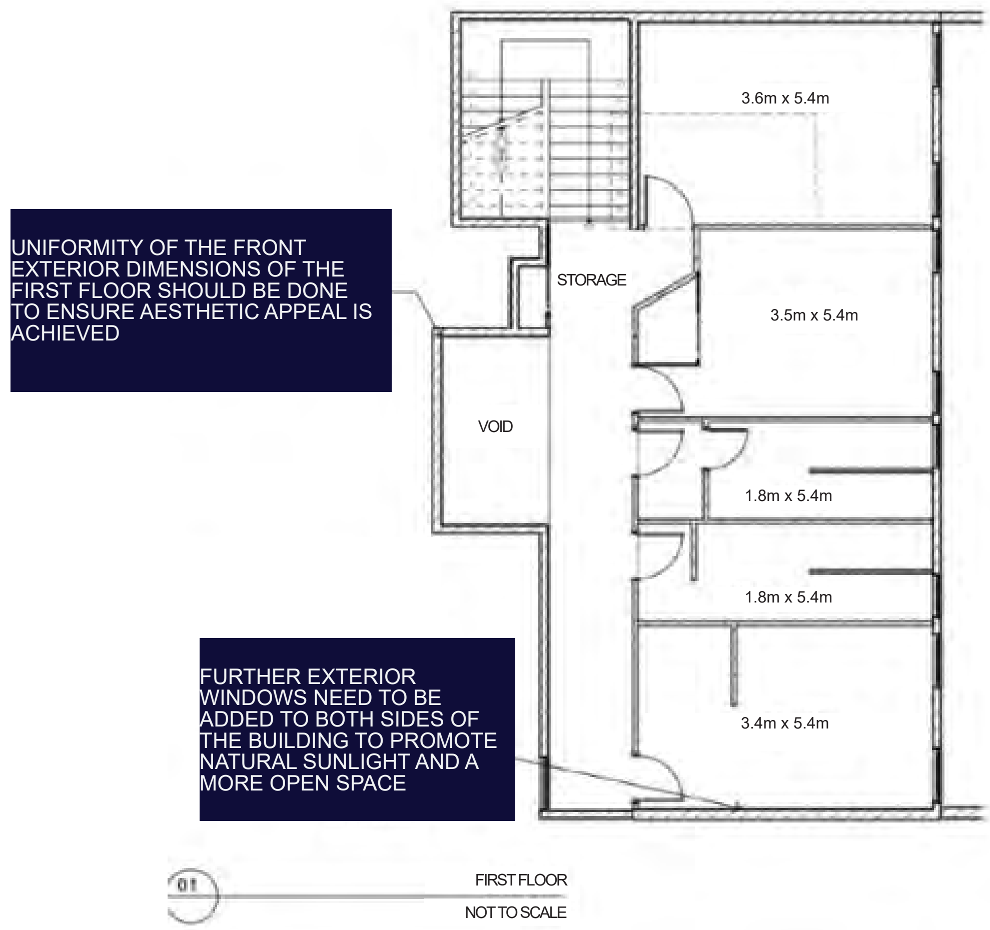
Unanderra NSW 2526

Drawing title:
1. Site appreciation
1.1 Site context



Existing Plan - Ground
NOT TO SCALE
GROUP 2 - ASSIGNMENT 2



Existing Plan - Level 1
NOT TO SCALE
GROUP 2 - ASSIGNMENT 2

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Integrated Design Studio
Unanderra

Address:
Corner of Farmborough Road & Princes Highway
Unanderra NSW 2526

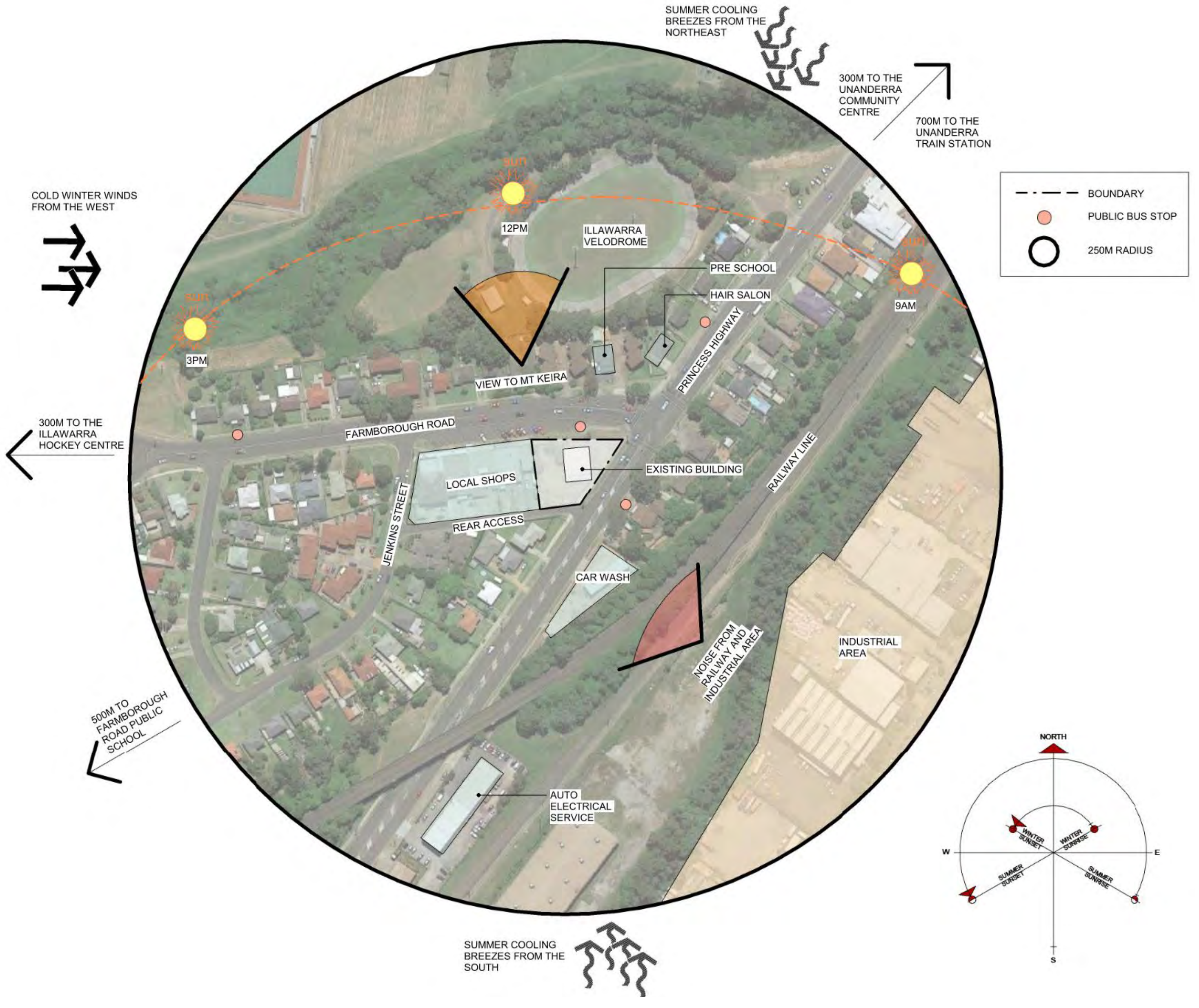
Drawing title:
1. Site appreciation
1.1 Site context

Assessment Site Opportunities		Comments
SITE CONSTRAINTS		
ZONING	R2 Low Density Residential zones	Council Maps
SITE AREA	1250m^2	From Students Report
HEIGHT LIMIT	9m - 2 storeys where development occurs within the 8m rear setback the development is limited to single storey, so as not to adversely impact on the amenity of the adjoining property	Council Maps
MAXIMUM FSR	0.5:1	
MAXIMUM FLOOR AREA	625m^2	
SETBACKS FRONT	1. A 6m setback requirement applies from the front property boundary to the front facade of the building 2. On corner allotments a minimum setback of 3m to the secondary street frontage from the dwelling facade must be provided 3. Balconies, front courtyard fences and other building extrusions may be set back up to 900mm closer than the required front or secondary set back. 4. An increase in setbacks may be required to retain existing trees or respect adjacent heritage items.	Wollongong DCP - B1 - Clause 5.3
SIDE and REAR	Minimum side and rear setback: 0.8 x Ceiling Height Minimum side and rear setbacks where balconies or windows of living areas face the rear boundary at first floor level or above: 1 x Ceiling Height	Wollongong DCP - B1 - Clause 5.4
BUILDING CODE REQUIREMENTS		
CLASS & TYPE ACCESSIBLE/ ADAPTABLE UNITS	Depends on design brief Depends on design brief	Reference BCA Clause
COUNCIL CODE REQUIREMENTS		Check BCA and DCP requirements
FLOOD RESTRICTIONS BUSHFIRE PRONE FORESHORE HERITAGE RESTRICTIONS	Not known n/a n/a No heritage item in site area General heritage items 6317, 6427, 6428 and 6429 in the neighbouring communities	Council Maps
ACID SULPHATE SOILS PRIVATE OPEN SPACE	n/a 1. Private open space must be provided at the ground level or podium level. The courtyard or terrace must have a minimum dimension of 4 metres x 5 metres. This area must be separated from boundaries by at least 1.5 metres with a vegetated landscaping bed and must not en-croach upon deep soil zone landscaping areas. Where a level courtyard is not possible, a deck or split level courtyard must have a minimum depth of 3 metres. 2. The primary private open area of at least 70% of the dwellings within a multi dwelling housing development must receive a minimum of three hours of direct sunlight between 9.00am and 3.00pm on June 21. 3. Private open space areas (courtyards) must not extend forward of the front building setback by greater than 900mm.	
LANDSCAPED AREA	375 m^2. Min. 30% of the site area. A minimum of 50% of the landscaped area is deep soil zone.	
OTHER REQUIREMENTS		
BIODIVERSITY OFFSET SCHEME STORAGE	n/a n/a	
PARKING REQUIREMENTS		
RESIDENTIAL ACCESSIBLE VISITOR	Refer to DCP E3 Schedule 1 Refer to DCP E3 Schedule 2 -	Check Council DCP Check BCA for Accessible Spaces

SITE INFORMATION CURRENTLY AVAILABLE

SITE SURVEY	SITE MODEL	SITE PHOTOS
SITE ANALYSIS	SITE SECTIONS	LOCATION PLAN (Google Maps)

Issues to be addressed
-
-



Site analysis diagram
Edmiston Jones Architects

UNIVERSITY OF WOLLONGONG AUSTRALIA

Integrated Design Studio Unanderra

Address:
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Unanderra NSW 2526

Drawing title:
1. Site appreciation
1.2 Site analysis

General Information

The Illawarra Local Aboriginal Land Council (ILALC) aims to develop a mixed-use building that allows the entirety of the council's staff to relocate as well as providing retail and office spaces which local businesses can lease. The site exists on two lots (1 and 7 Farmborough Road, Unanderra), with an existing structure in place on 1 Farmborough Road. The two lots have a total area of approximately 1200m2 with the rear laneway giving vehicular access to the site.

Due to the ILALC existing as a statute authority, and the building having prior use on crown land, a Development Application (DA) is not required to modify the existing structure. Unless the structure is demolished, or an additional structure is added.

The existing structure on the Ground Floor consists of a concrete slab and double brick walls. The Upper Level consists of timber floor and stud walls, with a ceramic tile roof. The external facade with the exception of boarded windows and the front, rear and garage doors; is brickwork.

Design Requirements

1. The existing structure may be retrofitted or demolished and rebuilt, dependant on the analysis of the design team. There are benefits and drawbacks to the decision, with these being:

i. Retrofit – No DA will be required, however structural alterations may be necessary, with the structure also requiring retrofitting to be more passively sustainable. Consideration will also be required as to how to integrate renewables and services.

ii. Reconstruction or Addition - A DA will be required. The ILALC is heavily invested in environmental efficiency, meaning that if the structure were to be demolished or addition were to be made a Statement of Environmental Effects which would included a Waste Minimisation Plan amongst other reports.

2. The Land Council receives no funding from the government, so revenue streams are extremely important. A focus should be placed on maximizing potential revenue for the land Council. One example as to how this could be achieved is through maximizing lettable spaces.

3. Lot 7 may be used to expand the development site or construct and additional structure. This site may be suitable for mixed use commercial/residential. The ILALC currently has a shortage of 1500 dwellings for social housing. 95% of this demand is for single occupant residences.

4. The Land Council has no preference over residential or commercial spaces.

5. If Lot 7 is not developed, then consideration may be given as to the use of the site as an outdoor space (e.g. meeting place, garden etc.)

6. The entire roof needs to be replaced, with the Council open to the idea of a small rooftop terrace/garden suitable for small gatherings/meetings.

7. The existing structure has issues with natural light, with the top floor having multiple windows, whereas the ground floor only receiving light from the front of the structure, and a central light well.

8. A lift well will need to be included to provide disability access to the top floor.

9. The existing building has been vacant for 25 years, with the interior having been heavily vandalized (e.g. all internal plumbing and electrical cabling has been removed). The entire interior will need replacing.

10. The council is heavily invested in environmental efficiency and environmental impact. The inclusion of renewable energy sources and passive design strategies is greatly encouraged.

Client goals

1. The Illawarra Local Aboriginal Land Council (ILALC) aims to "improve, protect and foster the best interests of all Aboriginal persons within the Council.
   The ILALC is separate from the government and therefore funding is independent. This project will serve as cash-flow for their organisation as well as relocation for the staff.

2. Budget $1,000,000.

3. Renovate and refurbish the existing building in order to save on cost and avoide a development approval (DA).

4. Take advantage of the mountain views to the east.

UNIVERSITY OF WOLLONGONG AUSTRALIA

Integrated Design Studio
Unanderra

Address:
Corner of Farmborough Road & Princes Highway
Unanderra NSW 2526

Drawing title:
2. Client brief
2.1 Overview & Client goals

Spatial analysis

Spatial requirements

1. General: Office spaces for ILALC staff, Retail spaces, bathrooms, café/retail.

   ii. Entry/Hallways: Entrance retained off Farmborough Road, easily accessible and open to the road, large enough to fit common furniture through, Umbrella storage, Main entrance accessible from street front.

   iii. Studios: Appropriate spaces for meeting rooms, reception, office rooms (10sqm is the minimum size for office spaces) and open desks for the ILALC staff, Multiple studios 10m−2 or larger. Space for 8+ ILALC staff.

   iv. Toilets/Bathroom: Bathrooms on both levels to cater for ILALC staff as well as retail staff and customers. Ideally, the top bathroom located directly above the bottom for piping ease. Man/woman toilets separated for cultural requirements, vanity and no bath. Provide a disabled toilet.

   v. Storage: Bike racks facilities to encourage riding to work, Storage rooms of 10m^2 on both floors.

   vi. Carpark: Parking spaces for the building staff and customers. Provide accessible car parking space closest to the entry. Number of car and motorbike spaces to be confirmed.

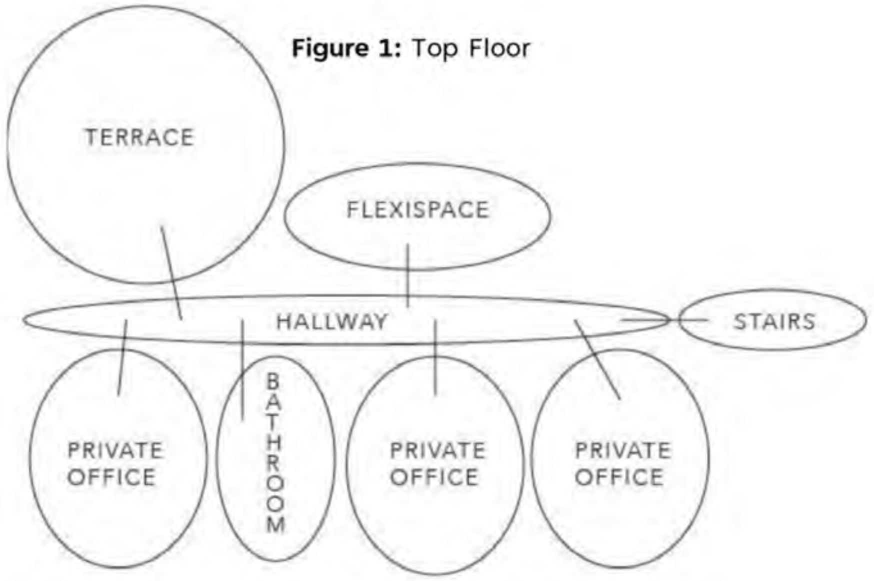
   vii. Café/retails places: Cafe / lunch facilities off main entry on ground floor, Provide seating for people to take a break from work, Important for ILALC cash-flow therefore 200-300m^2 should be allocated to retail spaces. Active uses are encouraged on the street level.

Energy use

1. Proposed Existing Building Redesign, Total Floor Area 442m^2, Estimated Energy use from energy intensity factor is 393.4GJ per year.

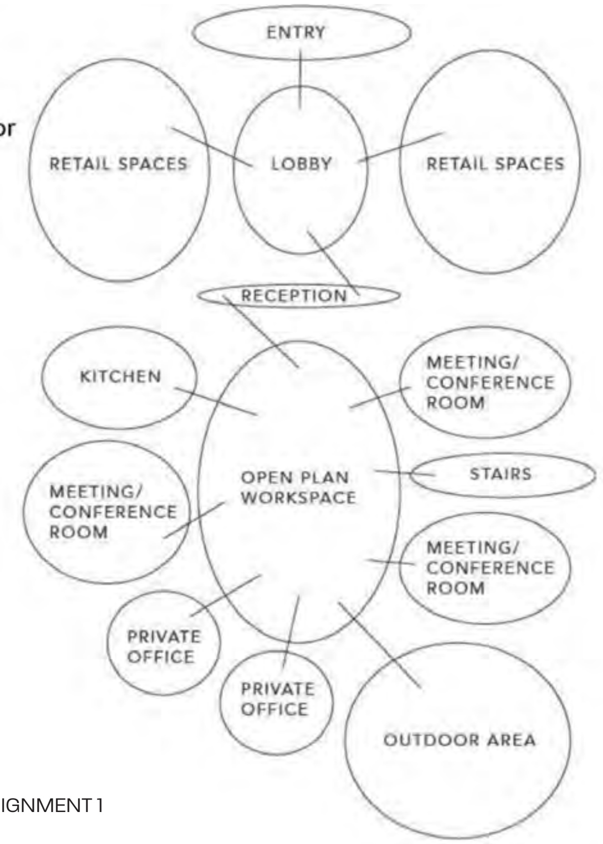
2. Proposed Secondary Development, Total Floor Area 280m^2, Estimated Energy use from energy intensity factor is 249.2GJ per year.

Figure 1: Top Floor



NOT TO SCALE
GROUP 2 - ASSIGNMENT 1

Figure 2:
Ground Floor



NOT TO SCALE
GROUP 2 - ASSIGNMENT 1

UNIVERSITY OF WOLLONGONG AUSTRALIA

Integrated Design Studio
Unanderra

Address:
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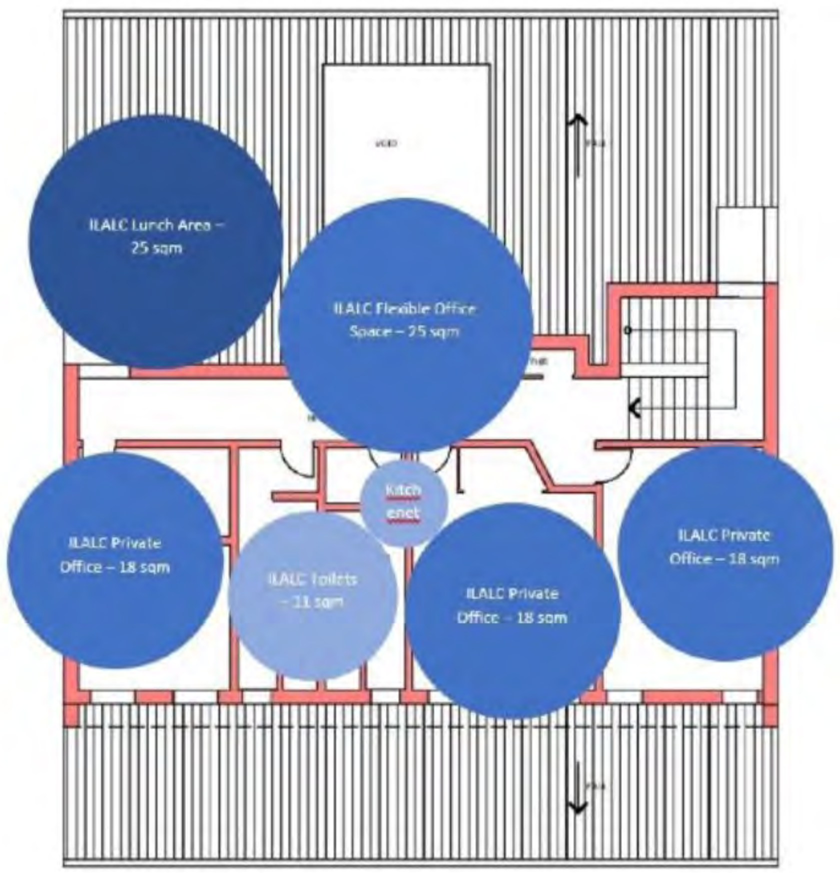
Unanderra NSW 2526

Drawing title:
2. Client brief

2.2 Spatial analysis

Spatial analysis

NOT TO SCALE
GROUP 2 - ASSIGNMENT 2



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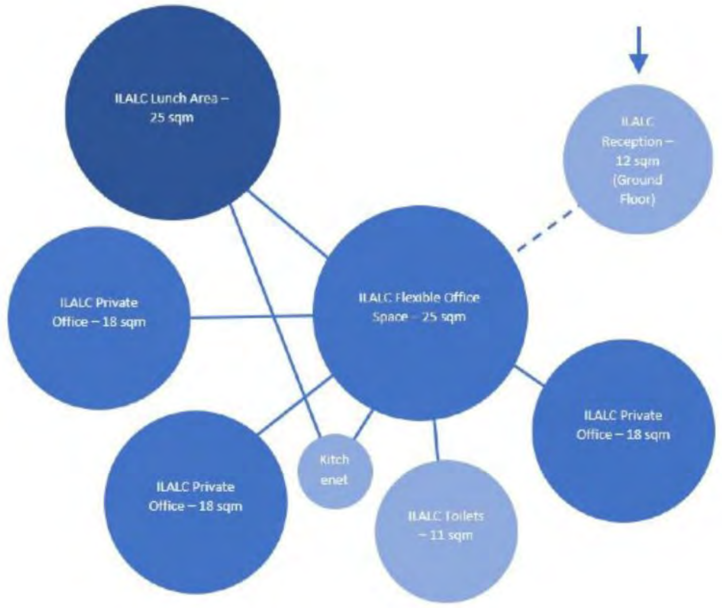
GROUP 2 - ASSIGNMENT 2



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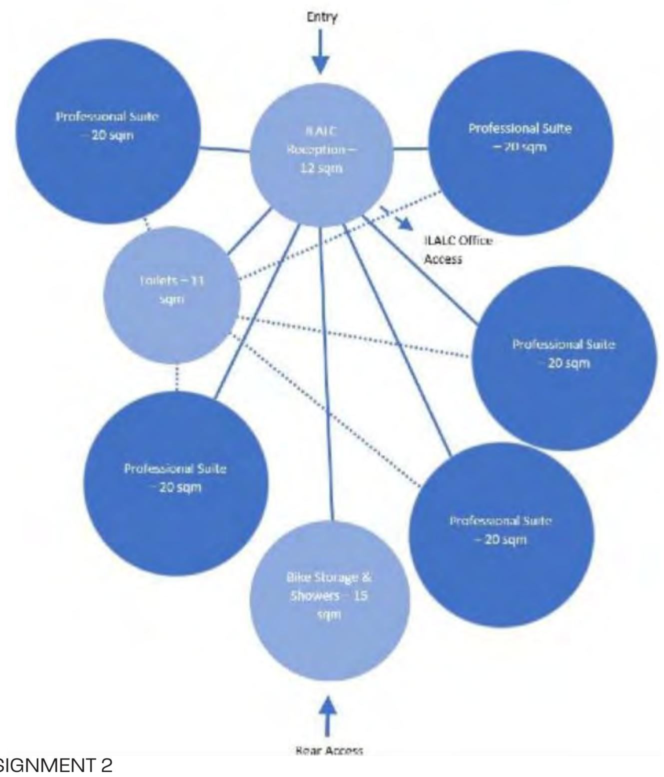
GROUP 2 - ASSIGNMENT 2



NOT TO SCALE
GROUP 2 - ASSIGNMENT 2

UNIVERSITY OF WOLLONGONG AUSTRALIA

Integrated Design Studio
Unanderra

Address:
Corner of Farmborough Road & Princes Highway
Unanderra NSW 2526

Drawing title:
2. Client brief

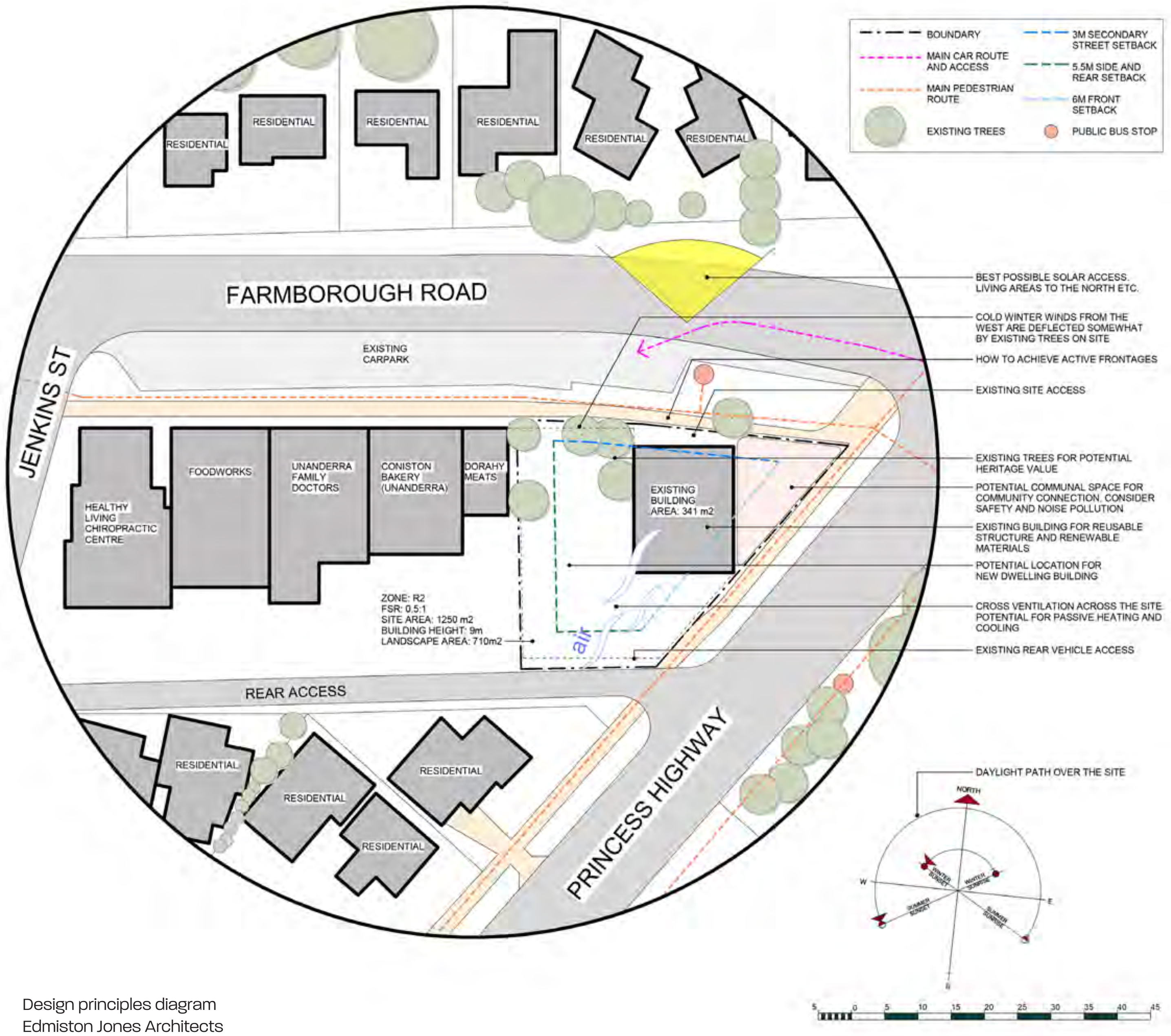
2.2 Spatial analysis

Design principles

1. Response to Place
   i. Think beyond the site,
   ii. What is the sequential experience of approaching the site?

2. Functional/ Spatial Requirements and Spatial Association
   i. WSustainable
   ii. Reusable and multi purpose

3. Environmental Sustainable Design (ESD)
   i. Passive design that includes;
      - Embodied energy
      - Reuse/ recycle/ retain
      - Orientation
      - Material choice and suitability
      - Solar access
      - Daylighting
      - Cross ventilation
      - Thermal mass
      - Heating and cooling
      - Water conservation
      - Biodiversity
      - Canopy cover
      - Native endemic species selection



Design principles diagram
Edmiston Jones Architects

UNIVERSITY OF WOLLONGONG AUSTRALIA

Integrated Design Studio
Unanderra

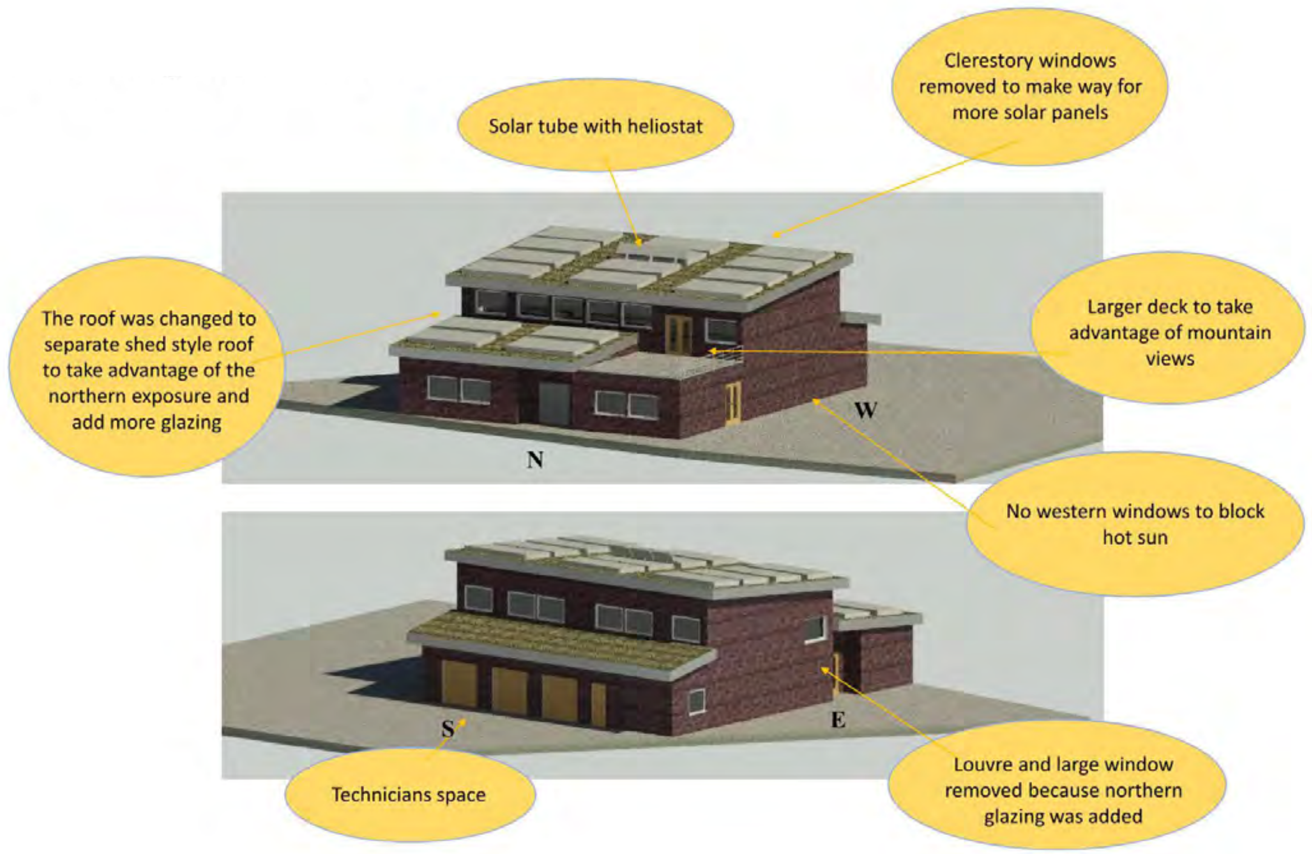
Address:
Corner of Farmborough Road & Princes Highway
Unanderra NSW 2526

Drawing title:
3. Design principles

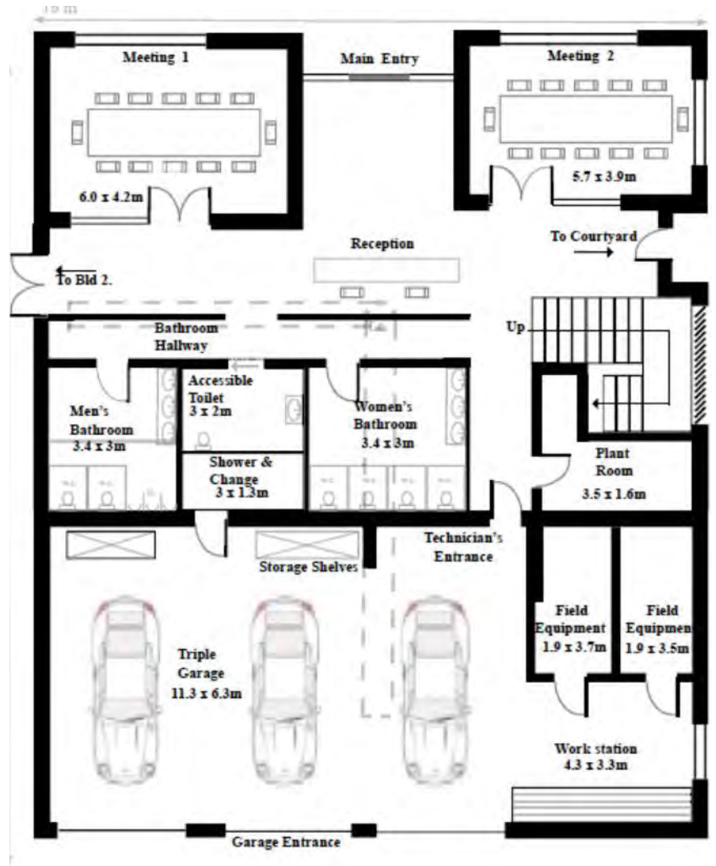
Assessment II: Design Proposal

Group 1 Student Work

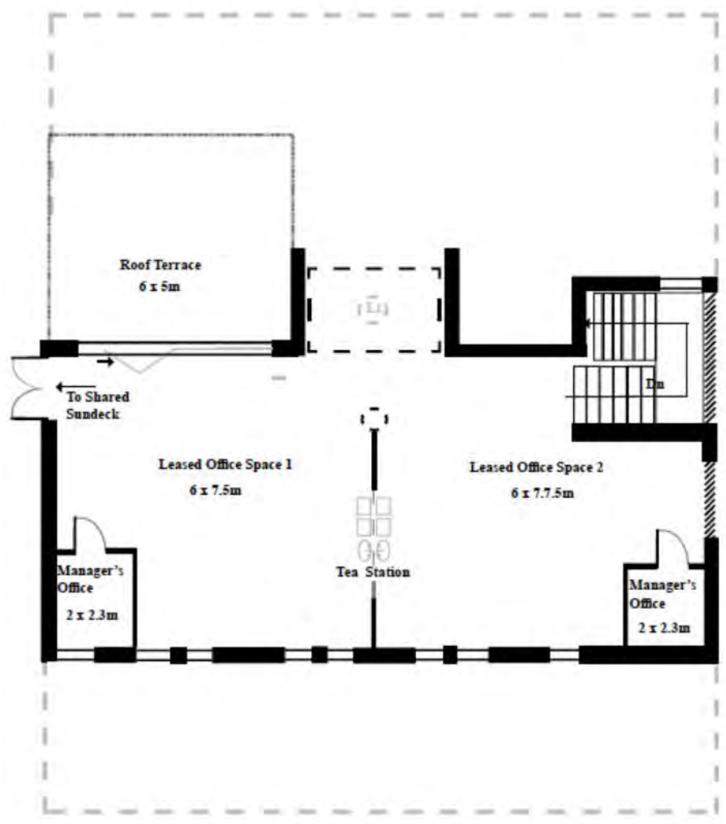
Stage 1



Stage 1 - Ground Floor
NOT TO SCALE



Stage 1 - Level 1
NOT TO SCALE



Schematic Design Proposal – Stage 2 Floor Plans – Group 2

UNIVERSITY OF WOLLONGONG AUSTRALIA

Integrated Design Studio Unanderra

Address:
Corner of Farmborough Road & Princes Highway
Unanderra NSW 2526

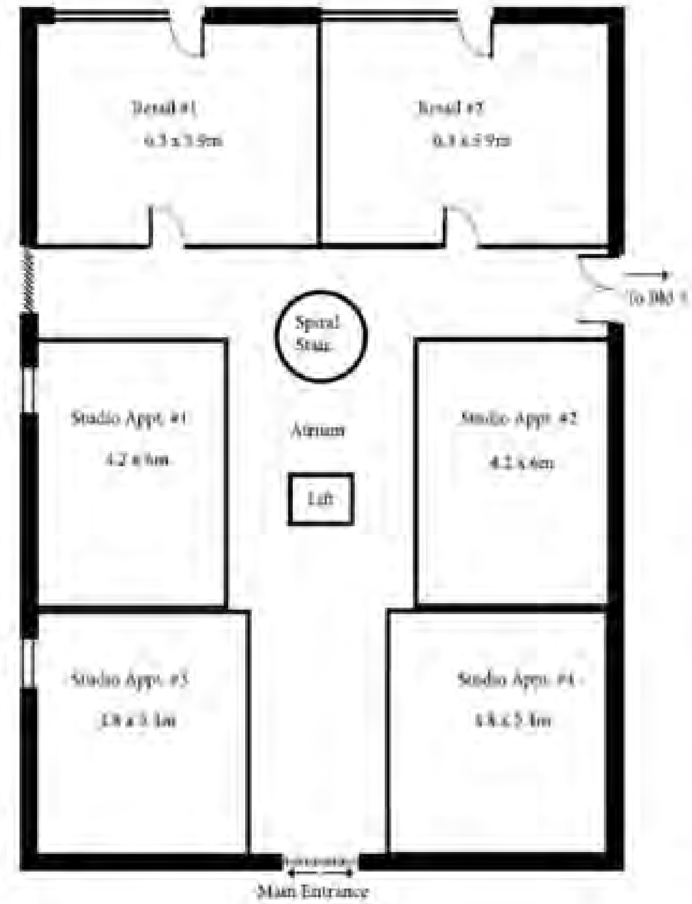
Drawing title:
3. Design Proposal
3.1 UOW Group 1

Assessment II: Design Proposal

Group 1 Student Work

Stage 2

Stage 2 - Ground Floor
NOT TO SCALE



Stage 2 - Level 1
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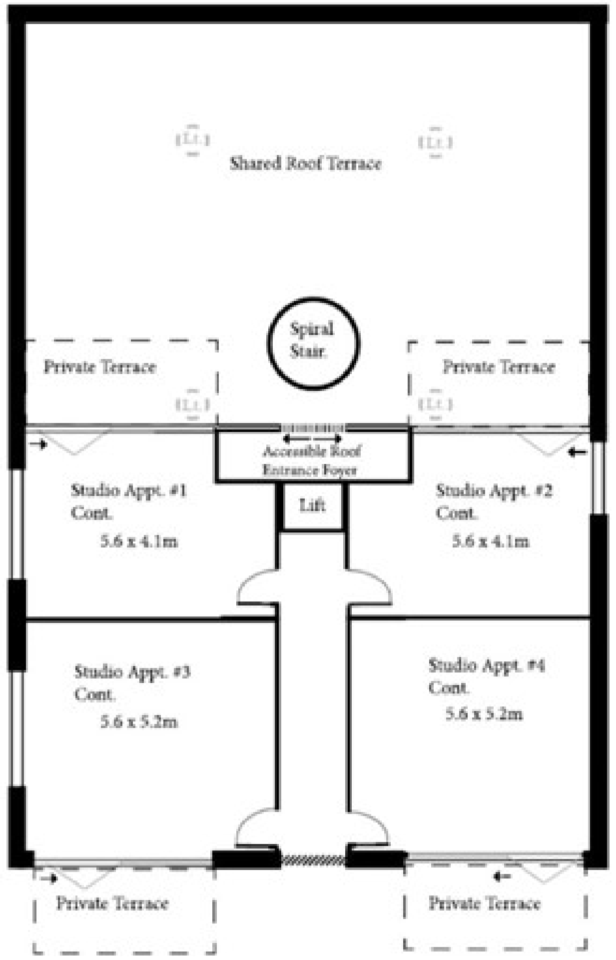

Schematic Design Proposal – Stage 2 Floor Plans – Group 2

UNIVERSITY OF WOLLONGONG AUSTRALIA

Integrated Design Studio
Unanderra

Address:
Corner of Farmborough Road & Princes Highway
Unanderra NSW 2526

Drawing title:
3. Design Proposal

3.1 UOW Group 1

Assessment II: Design Proposal

Group 2 Student Work

Skylights can be placed in to assist with natural lighting and ventilation

Community garden to be placed on intersection between farmbrorgh road and princes highway

Natural light colours have been chosen to assist with passive cooling

Terrace space which can be used for small gatherings/meetings

Additional windows have been placed around the building for additional natural lighting and ventilation

Green walls proposed to be used on side go the building

Skylights can be placed in to assist with natural lighting and ventilation

Roof sloping at 10 degrees in order to maximise solar gains

Terrace space which can be used by the emergency housing residents

Green walls proposed to be used on side go the building

Natural light colours have been chosen to assist with passive cooling

Large windows have been placed around the building for additional natural lighting and ventilation

Roof sloping at 10 degrees in order to maximise solar gains

Large Glass doors for studio 5 for additional lighting and ventilation

Drive way can be used for additional off-road parking

Additional opening skylight window across top of building enabling additional ventilation and solar gains (Not pictured)

Storage Rooms placed at rear near driveway for easy access

Community Garden assist's with being a noise barrier from main roads

Approx. 40 m2 Appartments

Come equip with living space, bathroom and kitchen

Assist's with the shortage of emergency single resident home within the Illawarra

Large windows enabling with natural lighting and ventilation

Light colours used to make the space seem larger and assist with passive cooling

Versatile space, could also be used as rentals or more studio spaces if desired

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Integrated Design Studio Unanderra

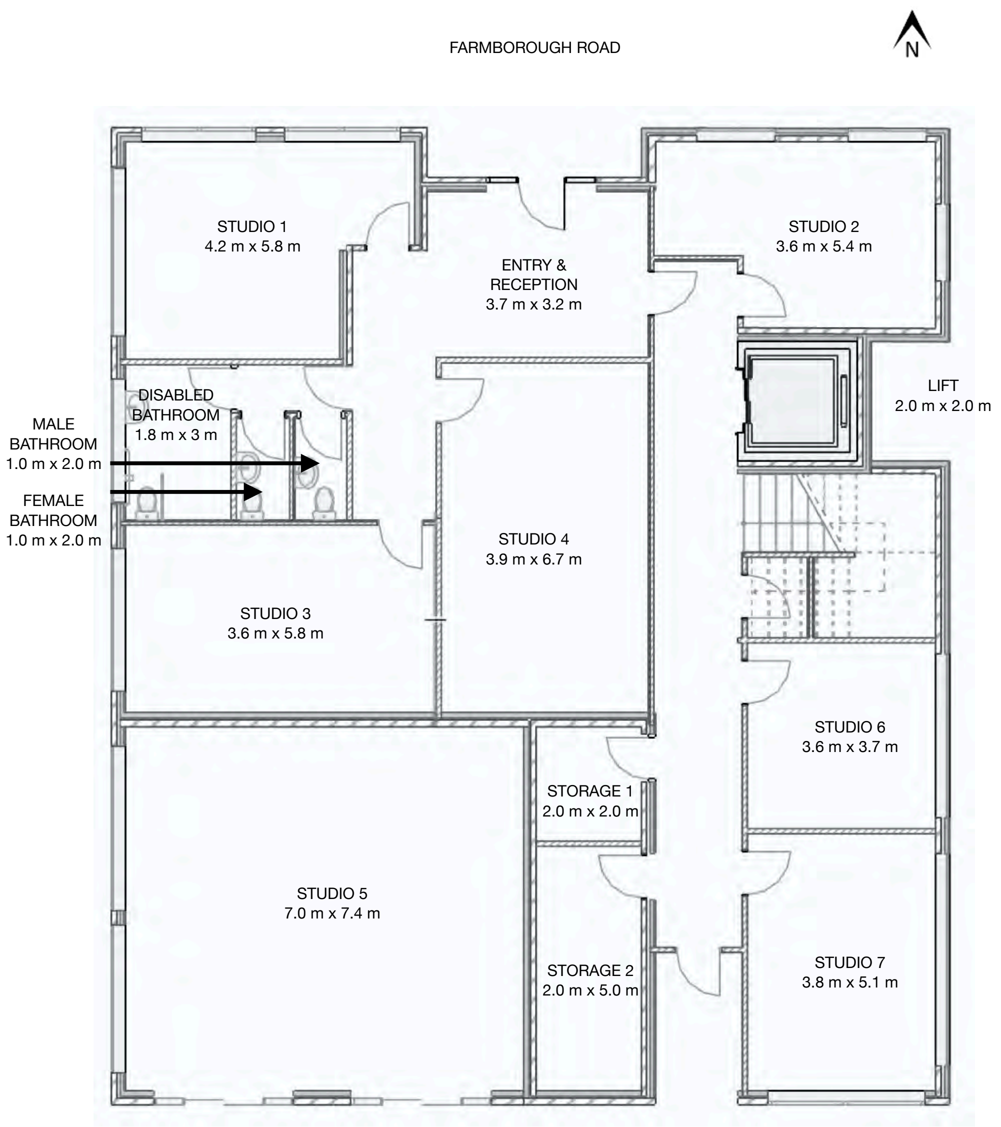
Address:
Corner of Farmborough Road & Princes Highway
Unanderra NSW 2526

Drawing title:
3. Design Proposal
3.2 UOW Group 2

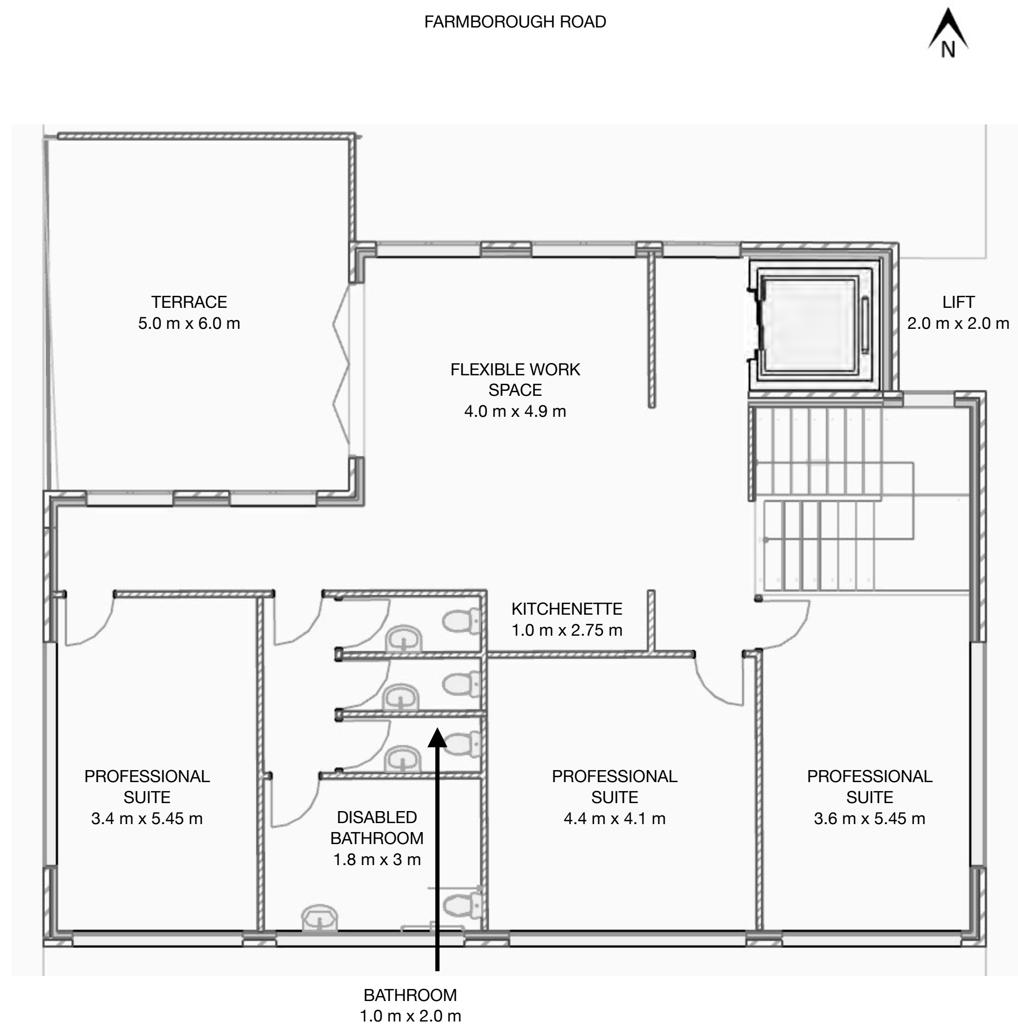
Assessment II: Design Proposal

Group 2 Student Work

Ground Floor
NOT TO SCALE



First Floor
NOT TO SCALE



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Integrated Design Studio
Unanderra

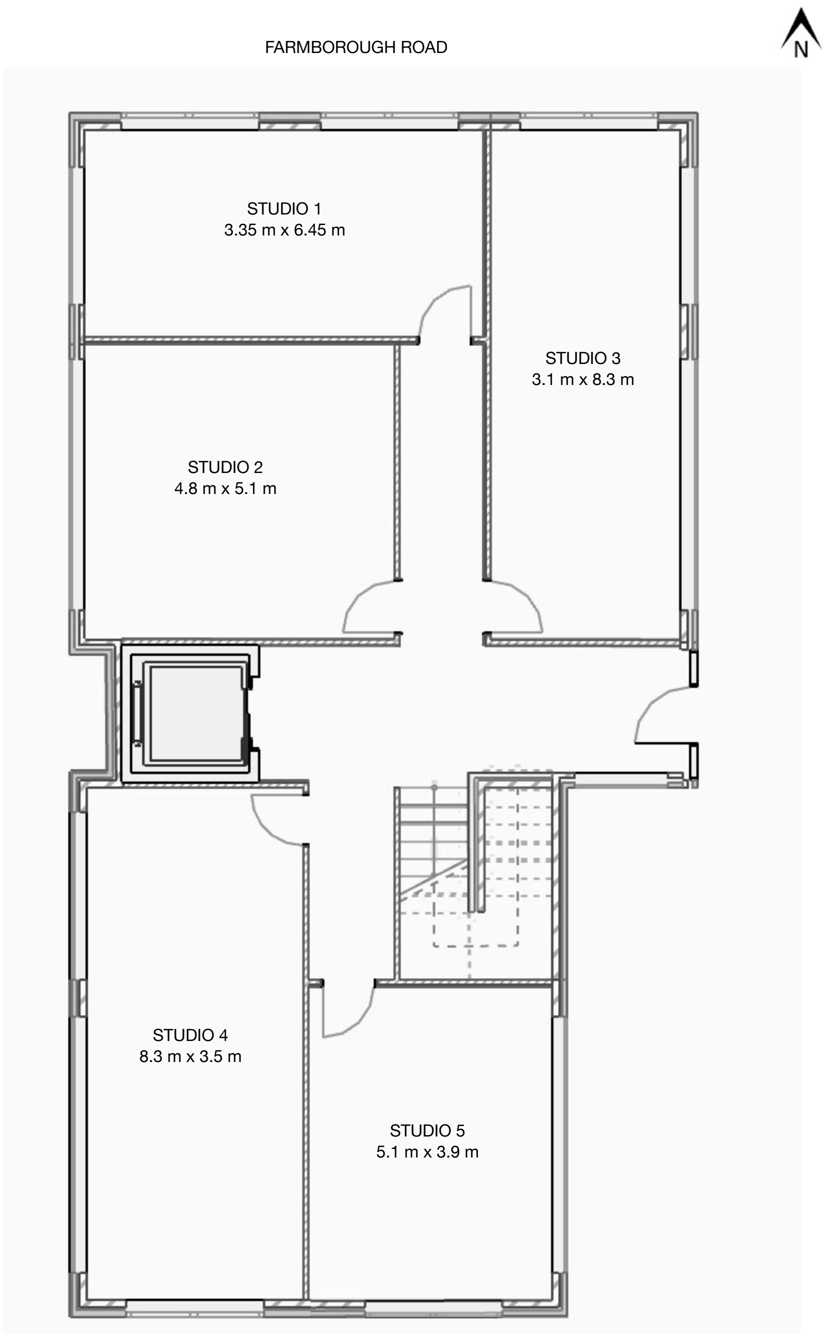
Address:
Corner of Farmborough Road & Princes Highway
Unanderra NSW 2526

Drawing title:
3. Design Proposal
3.2 UOW Group 2

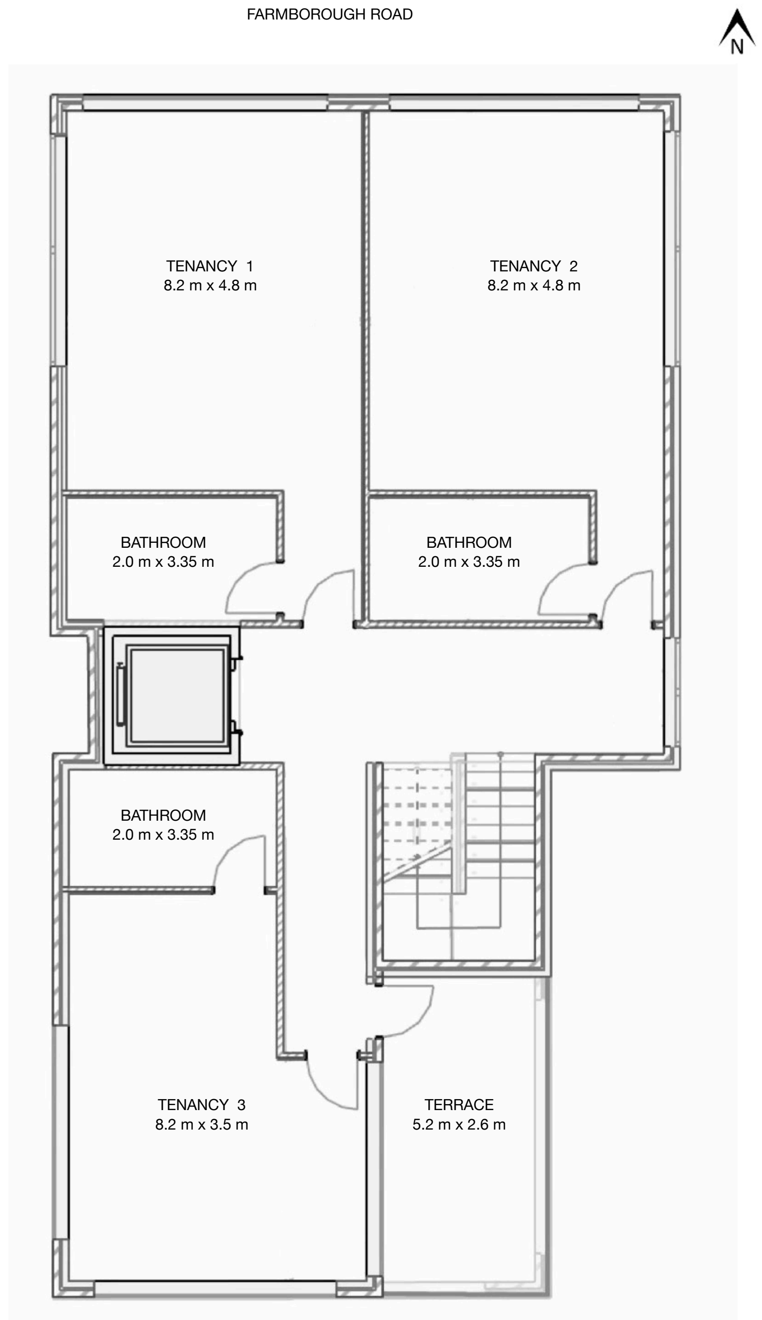
Assessment II: Design Proposal

Group 2 Student Work

Ground Floor
NOT TO SCALE



First Floor
NOT TO SCALE



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Integrated Design Studio
Unanderra

Address:
Corner of Farmborough Road & Princes Highway
Unanderra NSW 2526

Drawing title:
3. Design Proposal

3.2 UOW Group 2

Conslusion

Research:

1. Great insight on the history and heritage of the Land, People and Site.

2. The groups demonstrated an understanding of the importance of the surrounding context and didn't focus solely on the site in isolation.

3. The groups provided a good understanding of the opportunities and constraints that the site presented to them.

4. Graphical the groups presentation lacked formality and consistency in the set out of the work presented from page to page.

Brief and Schematic Design:

1. Each groups report had a disconnect from the research work and the design solution.

2. A greater investigation of the brief would have been beneficial to both groups.

3. To interrogate critical questions, such as:

    i. The number of current staff they are designing for.
    ii. The number of those staff requiring individual offices.
    iii. The number of meeting rooms required.
    iv. The number of people to be accommodated at any one time in the/ each meeting room.
    v. Any other spaces required apart from the usual staff amenities including lunchroom, toilets, storage etc.
    vi. Is there a preferred proportion of dwelling types and number required?
    vii. Is there a specific use anticipated with the commercial spaces?

Overall:

1. Both groups did well in gathering information, investigate the opportunities and constraints the site had to offer.

2. Both groups required a greater interrogation of the brief to get down to the specifics which would have aided in providing greater resolved design solutions.