Centre for Building Performance Research

Holistic Carbon Accounting:

Extending the design life of the existing commercial scale building stock.

Emily Howell
Nilesh Bakshi
Marc Woodbury

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Authors: Emily Howell, Nilesh Bakshi and Marc Woodbury

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Centre for Building Performance Research,
Victoria University of Wellington,
P.O. Box 600, Wellington, New Zealand.

Phone + 64 4 463 6200 Facsimile + 64 4 463 6204

Contents

FIGURES

TABLES

1 ABSTRACT

This study critically examined the carbon accounting method designers use when considering how to interact with New Zealand's existing commercial buildings as they end their design life. A comparative carbon analysis was carried out using Life Cycle Assessments (LCA) of a commercial scale case study. This study aimed to establish the efficacy of refurbishing a commercial building at the end of its design life. The overarching question sought to identify whether a low-carbon new building would be more sustainable than increasing the design life of existing high-carbon commercial-scale buildings.

Employing a Life Cycle Assessment, a method of assessing the environmental impact of buildings throughout their lifetime, this study examined a single case study building. Two comprehensive practice-based design proposals were prepared for the case study in question. The first design proposal was for refurbishing the existing high-carbon building on site, and the second was for a new building comprised predominantly of commercial-scale timber.

This research tested creating a practice-based calculator, which identified various barriers that caused delays and highlighted significant flaws in LCA databases and modelling workflows. The critical database issues were inconsistencies in environmental impact values and a lack of consideration for local factors. This study also identified a lack of consistency and accuracy in existing workflows as the most significant issue.

This research found that existing assessments of refurbished buildings typically did not account for the carbon associated with reused or demolished materials. As a result, designers do not consider the carbon they are responsible for when making design decisions about an existing building.

This study found that a holistic carbon accounting approach must be considered, which would entail designers thinking about the embodied carbon of the existing materials. The existing embodied carbon would then be added to the carbon account of the new materials required to create another building with a new design life (60 years).

Comparing this holistic carbon account for each building scenario highlighted that the refurbishment produces a lower carbon density in a low-carbon new build. This holistic carbon account demonstrated that increasing the design life by 60 years would require half the embodied carbon of a new low-carbon build. Furthermore, over 120 years, the refurbishment is responsible for 25.8% less embodied carbon over the new design life.

To better understand the implications of these design decisions over the life of the building, this study also conducted a series of building energy simulations. The operational energy simulations identified that the refurbishment performed better than the timber new build, reducing the CO2 produced over the life of the building in its operation by 16%.

2 INTRODUCTION

How to interact with a building at the end-of-life (EoL) stage of its life cycle is a topic that is gaining popularity in both academic literature and in practice. It is believed by many that moving forward, we should be implementing "urban development as modification of the built environment," as opposed to demolition and new build scenarios (Schittich, 2012).

The Royal Institute of British Architects recently stated, "The most effective way to avoid embodied carbon emissions is to refurbish, retrofit, and extend the lives of existing buildings, instead of demolishing them and building new" (RIBA, 2021). However, newer technology allows for the design and construction of mass timber buildings.

Given that timber sequesters carbon throughout its lifetime, a fundamental question arises in the current emissions climate: Could commercial-scale timber be a viable, lower-carbon way to interact with buildings as they reach the end of their functional life?

2.1 Background

This study aimed to critically review one methodology for accounting for carbon specific to one case study. The project was centred around two design scenarios for a case study building in Wellington, New Zealand – one involving refurbishment and one a new build.

The study considered environmental impact in raw materials extraction and initial production of the building components, maintenance, and end-of-life. Both the carbon sequestration of timber and the environmental benefits of retaining an existing structure were considered and compared. A vital issue was deciding how to acknowledge and award points for retaining materials and where the responsibility lies for materials sent to landfill. Additionally, a simple LCA calculator for use and development in-house was proposed.

This study aimed to compare two design scenarios' environmental impacts (embodied carbon) for an existing concrete commercial office building in central Wellington. The proposed scenarios considered what to do with the existing building at the end of its functional lifetime. The comparison was between a refurbishment of the existing structure. The existing structure included an additional three floors constructed of mass timber, a scenario in which the existing structure was demolished, and a new structure built of mass timber. The only exception is a new concrete core.

This case study was chosen as it was a particularly unique opportunity. The lead architects completed a full timber design and an entire refurbishment scenario. These were both fully detailed as opposed to conceptual models. It is one of the few New Zealand-based buildings with two design options that are both fully costed in terms of price and materiality. The designs, therefore, have a higher level of detailed information available, making for a more holistic LCA study. The supposed benefits of this are improved accuracy and validity of results.

2.2 Data Sources and Case Studies

The following is a review of literature that speaks to critical issues that notably impact the validation of many LCA-based studies. The importance of consistency and further database development is a common theme that is highlighted.

A lack of consistency between LCA databases can cause significant variation in comparing results. This lack of consistency is an issue that has been noted not only in older studies (Anand & Amor, 2017; Takano, Winter, Hughes, & Linkosalmi, 2014) but also in very recent New Zealand-based research (Dani, Roy, Masood, Fang, & Lim, 2022), as well as recent international studies (AzariJafari, Guest, Kirchain, Gregory, & Amor, 2021). Emami et al. (2019) found a "huge variation in the published results which is not explicable by building characteristics but rather by the subjective choices of the LCA practitioner" (Emami et al., 2019). The subjective choices that impact the results are essential to consider when less experienced practitioners carry out LCAs, as the choices made may significantly impact the outcome.

Frischknecht (2006) highlighted that confidentiality issues have, in the past, made the sharing of primary data difficult. Frischknecht's finding is supported by Martinez-Rocamora et al. (2016) and AzariJafari (2021), who all highlight a lack of transparency (in documentation and references) across many databases. As a result, numerous diverse international LCA databases were developed to keep up with international LCA demand. However, the impacts of individual materials reported in these databases can differ dramatically (Frischknecht, 2006). Various databases meant results were seldom comparable.

Martinez-Rocamora et al. (2016) highlight the mismatch between the LCA database's location and the project's location. The critical issue is the variation in manufacturing processes between locations (Martínez-Rocamora, Solís-Guzmán, & Marrero, 2016). This is supported throughout the literature examined in this study, emphasising the importance of using country-specific environmental impact values based on local factors (R. Frischknecht et al., 2020; Öztaş & Tanaçan, 2017; Teng, Pan, & Li, 2018). Significant environmental influences come from the local material extraction and electricity generation processes. Hence, local factors are essential when creating an LCA database (Teng et al., 2018).

A vital issue for this study, in particular, is that both the industry and the research sector lack a unified, NZ-based LCA database (Dani et al., 2022). In order to optimise LCAs, it would be helpful to have a validated, accessible database of available information. Improving the consistency of LCA databases is urgent work that needs to be done to utilise LCA in building design and provide validated results (Emami et al., 2019).

A database was created which complied different results from previous LCAs. These were intended to be used as a means of quality assurance from the results of this study. This data showed that studies typically found the total impact between 15.4 and 24.4 kg CO2 eq/m2/yr (Fig 1). The Scion building was considered an outlier – with an impact of only 8.7 kg CO2 eq/m2/yr. Upon further analysis, it became apparent that there was a lack of consistency in this data. Figure 1 demonstrates that there is no real trend in results across ten NZ-based case studies. It also shows that three different LCA databases were utilised among the case studies. These were; eTool, which is a global database developed in Perth, Australia; LCAQuick, which is an NZ-specific database developed by BRANZ (Building Research Association of New Zealand); and another database that was developed using European and New Zealand environmental impact values in combination with Gabi 4.3 – another global LCA calculator (John & Mulligan, 2011). The years in which the studies were completed varied, which could further cause inconsistencies.

As a result, no accurate comparisons regarding a trend between environmental impact and construction type for these ten NZ-based studies could be drawn. This reiterates the above issue of a lack of consistency among studies, making it challenging to gather validated information in Life Cycle Assessments of buildings.

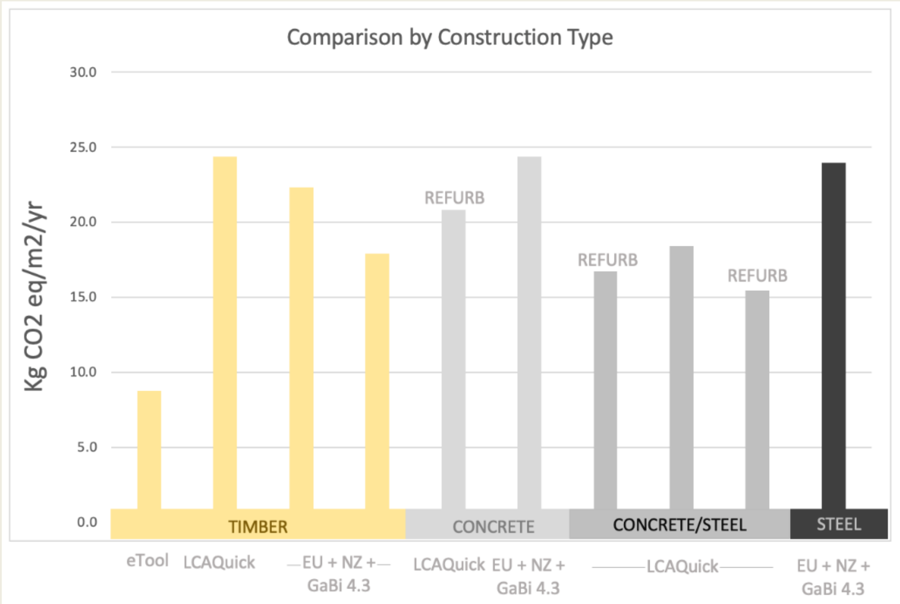

Figure 1: Case Study Comparison by Construction Type

However, John and Mulligan (2011) conducted a study comparing the different construction types. Their research used the LCA database developed using European and New Zealand environmental values in combination with Gabi 4.3. ScionResearch Limited did the actual LCA research, so assumptions could be made that the results are quality assured (John & Mulligan, 2011). This data could be used as a guideline for what could be expected from an LCA of Case Study A. However, neither refurbishment nor demolition of an existing building is considered. Figure 2 highlights the different environmental impacts of each material scenario.

A comparison of the results from the BRANZ studies is difficult as some are refurbishments, and some are new builds. However, taking note of the timber and concrete refurbishment scenarios assessed in LCAQuick, it is apparent that concrete refurbishment has a lower impact (Fig 1). This could be something to compare with in the analysis of Case Study A.

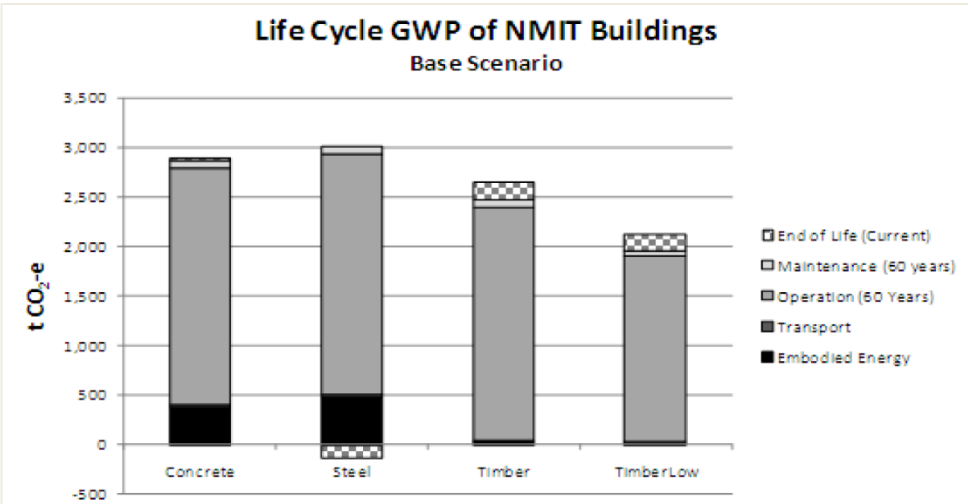

Figure 2: Comparison of Material Scenarios (John & Mulligan, 2011)

3 HOW ARE MATERIAL REUSE AND DEMOLITION CURRENTLY ACCOUNTED FOR?

A significant discussion throughout this study was the strategy used to account for the reuse or demolition of existing materials. There are various methods for assessing the environmental impact of building refurbishment – most of which are relatively new, being developed only within the last few years. How the demolition of materials can be accounted for carbon is unknown when a new building is being built.

3.1 Dealing with Material Reuse in Refurbishment

Obrecht et al. (2021) state that refurbishment is typically treated as the beginning of a new building cycle, making it difficult to assess the impact of specific reused components after refurbishing. They go on to say that the impacts must be distributed correctly both before and after refurbishment. Their research involved developing a new methodology that "enables a correct distribution of the environmental impacts between life cycles" (Obrecht, Jordan, Legat, Ruschi Mendes Saade, & Passer, 2021). They state that the impact of building components that remain in the building after refurbishments are currently neglected. However, this neglection is scientifically questionable (Obrecht et al., 2021). LCAQuick excludes existing materials entirely because the scope of the recycled materials would be part of the assessment of the original building itself.

3.2 Dealing with Demolition to Make Way for a New Building

This is an aspect of a new building that is not accounted for in an LCA. Again, LCAQuick excludes demolished materials for the same reasons– the impact from demolition and disposal should be considered in an assessment of the existing building. However, it would be beneficial to visually represent the benefits/avoided burden of reuse or the impacts/added burden of disposal. This is especially important when an assessment has not been completed for an existing building. This is a more holistic approach to carbon accounting

4 TESTING THE CONCEPT OF DEVELOPING A PRACTICE-BASED CALCULATOR

A practice-based calculator would be a valuable tool for practitioners as it could be integrated into decision-making for future projects. A simple in-house LCA calculator could be crafted to fit into how the individual practice operates. It could also be integrated into the CAD user interface to extract and sort quantities automatically. The following outlines the steps followed and some issues that caused difficulty throughout the process.

4.1 Data Extraction from User Interface – ArchiCAD 24

The calculations were done using material quantities extracted from the lead architect's ArchiCAD models. This model information was combined with environmental impact values (kg CO2 eq) gathered from academic references. The idea was to provide a ballpark figure of data sets to indicate how the final results may look regarding a carbon comparison between the two designs. A benefit of this process was that it allowed for the clarification of material quantities. This ensured that the input data was correct and validated when a more developed LCA tool was used. This provided a faster LCA as all the data was already gathered and ready to be put straight in.

Material quantities were extracted by volume (m3) from ArchiCAD by creating a Components by Layer schedule and exporting this as an excel file. While analysing the materials in the BIM model, it became apparent that there were several issues – one being that some of the floor structures were assigned to different layers. This made it challenging to group materials together. Missing structural elements and incorrectly labelled information highlighted that the IFC file from the structural engineers had not been used within the architect's BIM model. An IFC file is a unilateral model format which is used as a way to integrate other BIM software with ArchiCAD. To gain more precise quantities about the timber model's structural elements, the IFC file was used to extract quantities instead of the architect's ArchiCAD model. The architect's model was then used to gather quantities of components unrelated to the main structural elements. This was particularly important for the exterior cladding materials because glass and aluminium are relatively carbon-intensive materials. Neither model had much, if any, information regarding internal finishes. For this reason, and due to the time constraints of this project, the embodied carbon of internal finishes was not included in this study.

Once the schedule was created, the location of these materials in the 3D model could be found by selecting the material within the schedule and then selecting the 'find in 3D model' button. This highlighted the selected material in green, allowing the schedule to be quality assured against the structural and architectural plans. The process was relatively slow as there were 14 different groups of materials to locate and check.

A benefit of this was that it showed an issue with floors being included in the total timber volume, which meant it was labelled as 'LVL' instead of 'CLT'. The Glulam beams were also labelled as 'LVL', while a lot of the plywood was labelled as 'Wood'. An unknown material also appeared in the schedule, despite being hidden in the 3D model – 'IFC Building Material'. Upon further inspection and consultation with the architect's ArchiCAD specialist, it appeared that this was the material that is commonly assigned to objects used to create voids in other objects. An example of this was the blocks used to create the openings in the walls of the concrete core or a rebate in a concrete slab.

All 'IFC Building Materials' were excluded from the final material quantities schedule and should likely be excluded in future LCAs. However, a cross-check is recommended.

Another issue highlighted was that the concrete specification (i.e. the strength and type of concrete used) was not outlined in the model or the plans. The structural engineer's specifications were analysed for this information; however, this also fell short. The specifications (Appendix 1) contained the grade (and strength) of specific concrete types used in the new build. However, the required level of detail was more significant than this. Typically, an LCA requires the strength, amount of reinforcing steel, and mix (i.e. 50% GGBS cement). This information was complicated to find with the documentation provided. An assumption was made that most of the concrete used was 50% GGBS with 50kg of reinforcing steel for the various concrete grades. The piles were assumed to have 100kg of steel.

Any materials that were not assigned correctly were re-labelled. The table below outlines the materials that had to be reassigned.

Table 1: Reassigned materials for a timber scheme

COMPONENT AS PER PLANS	ASSIGNED AS	REASSIGNED AS
Timber 145 XL5 CLT Floor Panel	Wood	Wood - CLT
400x90 GL8 Glulam	Wood - LVL	Wood - Glulam
Plywood Box Beam	Wood	Wood - Plywood
New Pile	Concrete - Conc30	Concrete – N40, 50% GGBS, 100kg steel
Existing Pile	Concrete – Conc20	Concrete – N20, 50% GGBS, 100kg steel
400 thick concrete walls	Concrete – Conc20	Concrete – S30, 50% GGBS, 50kg steel
20 Series Block Wall Typical	Masonry Block	Masonry - 20 Series

This process required more specific building materials to be added to the ArchiCAD library. To achieve this, a component was selected, and the following steps were completed: Options > Element Attributes > Building Materials. From here, an existing material was selected, duplicated, and renamed. This added new material to the selection library. The 'Object Selection Library' was used to reassign the materials in the 3D Representation tab. In addition, an identical new surface was created and assigned. This was done by selecting the 'Surfaces' tab, creating a duplicate, and renaming it. An entire day was dedicated to tidying up the model and renaming components. These were then exported and sorted into four categories;

1. Wood
2. Concrete, cement, stone
3. Aluminium joinery, Glass
4. Steel, Metals

A visual walkthrough of the data extraction process can be found in Appendix 2.

4.2 Environmental Impact Values Used

Initially, data was gathered from various academic sources to gain rough figures for each material's environmental impact. The issue was that there were inconsistencies in what life cycle stages the values included. An essential reference was Alcorn (2003), a study that only considered a cradle-to-gate impact. This focused only on the embodied carbon involved in the extraction and manufacture of the materials (Alcorn, 2003). Additionally, the timber sequestration value only considered manufacture, meaning it did not include any carbon emissions from turning the timber into a product, demolition, or landfilling. It was essential to consider all life cycle stages of the materials (cradle-to-cradle or cradle-to-grave) to gain a more holistic and accurate assessment. This reiterates key barriers that come with creating bespoke LCA databases. Due to these issues, values extracted from an assessment done in LCAQuick were used to produce the desired graphs, which are found in Section 5.4

4.3 Holistic Carbon Accounting for Reused and Demolished Materials

There was much discussion with the lead architects about how to represent this issue. A holistic approach to carbon accounting was taken in creating the graphs presented in the practice-based calculator. This was to give reused materials a negative impact (CO_2 eq.) value because they already existed. Hence, the carbon had already been sunk. All new materials (excluding wood) were given a positive impact value as they were considered additional carbon. Any demolished materials were also given a positive impact value. An assumption had been made that the refurbishment or new build was responsible for the carbon of any materials sent to the landfill.

This approach was different to what other research had previously done. However, the value in it comes from being able to see the added burden of demolition and the avoided burden of reuse.

4.4 Accounting Input: Limitations and Assumptions

Seeing as the BIM model was created by someone else, it was hard to know what certain materials were supposed to be. This meant that much communication regarding the characteristics of materials was required. Structural plans and specifications were also consulted to figure out what type of concrete was used and where the different types of structural timber were used. This was key in tidying up the ArchiCAD model. This process also highlighted common things that were not modelled correctly or consistently, as outlined above.

There were also limitations in identifying appropriate environmental impact values that were consistent in what lifecycle stages they accounted for. This comes back to the issues outlined in Section 2 regarding the consistency and availability of environmental impact values for the creation of LCA databases

5 COMPARATIVE LIFECYCLE CALCULATION

When the initial calculator was created, there were significant differences between the results and those of LCAQuick. A key finding was that the total LCA difference was not dramatically different. However, the difference from one material to another was significant. This is essential as designers typically look at individual materials to reduce embodied carbon. This can be linked to the inconsistencies in the environmental impact values used for each material.

Following the experimental creation of an LCA calculator, it was necessary to have calculated figures from a more detailed calculator. LCAQuick has had a significant investment in time put into it by BRANZ. However, the BRANZ spreadsheet is an educational and research tool. It is not meant for accurate carbon accounting but was primarily designed for teaching and learning. LCAQuick was used for this study as it is the only current NZ-specific tool in which a comparative assessment can be done regarding the carbon accounting of materials due to the extensive, validated database.

5.1 LCAQuick 24

To begin, the 'Summary Analysis' section was filled out. This outlined the characteristics of the project, i.e. new build, commercial office, number of storeys, timber structural system, GFA, located in Wellington.

Materials were then selected from tab 1a – Material Codes. The information found within the Product/Material Code, Product/Material Description, and Required Building Material Quantities were copied into Parameters 3 – 5 in tab 1c INPUT – Material Quantities. Parameter 2 and the 'Column being Summed' was also filled in depending on the Unit Quantity requirement. All of the materials were volume dependent. This meant the volumes exported from ArchiCAD were easily transferred into LCAQuick. This made the whole process quick and easy, producing results for each scenario within approximately 30 minutes. The results were then found within the various results tabs. A visual walkthrough documenting this process can be found in Appendix 3.

5.2 Component Inclusion and Exclusion

Due to the time constraints of this project, it would have been challenging to alter all of the BIM models to a level of detail high enough to complete an entire building LCA. Instead, only the impact of key building materials was assessed. This included the four material categories outlined in section 4.1. The primary structural materials, along with the materials that were found within the building fabric, were considered the most important to include. The models were not detailed enough to produce accurate quantities of components such as internal linings or internal finishes. All services were excluded due to a lack of validated information in terms of material quantities and environmental impact values. The lack of environmental data for services is an issue that has been highlighted within the N.Z. building research sector (Butler, 2021).

5.3 Accounting for Reuse or Demolition

LCAQuick excludes demolished and reused materials entirely as the impact of these would be considered in the scope of an existing building LCA – assuming an assessment is completed for the original building. For this reason, the assessments done on the refurbishment and timber scheme in LCAQuick have only additional materials.

The assessments consider the environmental impacts of the materials from stage A-D. This includes manufacture, construction, maintenance & replacement, demolishing and disposal, and benefits of reuse and recycling.

5.4 Results

The results in the graphs below used the GWP (Global Warming Potential) values for each material once analysis was done in LCAQuick. Only the additional materials were included in the analysis for the above reasons. However, these results provide an idea of the impact of the most prominent new materials used in each scenario. The total material impact was taken and divided by its volume to gather the GWP values for each material. The original graphs from LCAQuick can be found in Appendix 4. These show the total impact values by material. These results include the impact for every life cycle stage. This means they are values specific to this case study's location, building type, and building use. These values vary slightly between the refurbishment and the new build. This is likely due to assumptions LCAQuick makes regarding the reuse and disposal of materials. A table showing the environmental impact values for each material in both the refurbishment and timber scheme can be found in Appendix 5.

Interestingly, the timber scheme has a reasonably sizeable total impact. Figure 3 shows that this is mainly due to the amount of aluminium and glass. The BIM model and building plans show the curtain wall on all four sides of the building. In the refurbishment, there were only two sides of the building to cover, as the other two backed onto existing structures. The data within the graphs represent this. The timber scheme also added four 30-meter-deep concrete piles and a concrete core. While the carbon sequestration of the timber used does provide some reduction in the total impact, it does not outweigh the impact of the carbon-intensive materials in this case study.

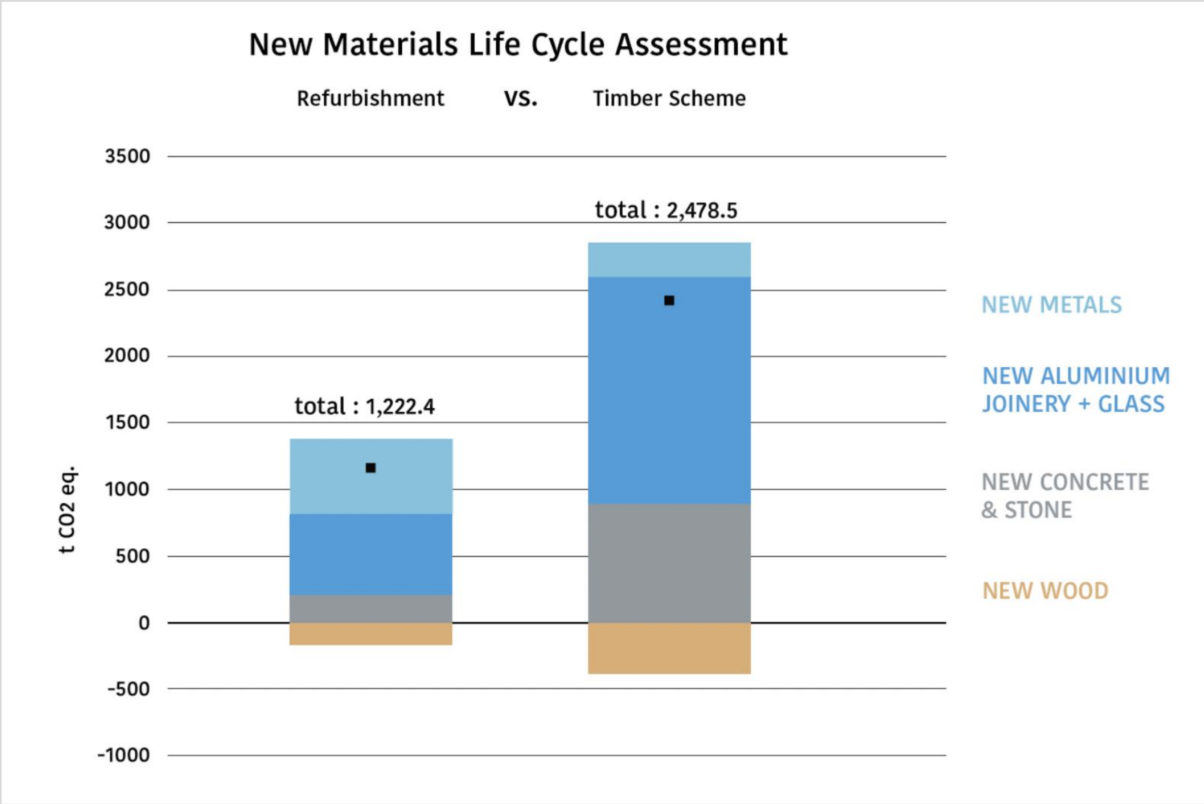

Figure 3: Comparison of LCA of New Materials

The graph below outlines a holistic approach to carbon accounting. All reused materials were given a negative impact value since they already existed. Hence, the carbon had already been sunk. All new materials (excl. wood) were assigned a positive impact value as they added embodied carbon. Any demolished materials were also given a positive impact value as the refurbishment, or new build would be responsible for this carbon (Fig 4).

Presenting the data in this way made it possible to visualise the avoided burden of materials when these were reused instead of demolished. Figure 4 highlights that the avoided burden of the reuse of the majority of the materials, in combination with the additional use of timber structure, is more than enough to outweigh the impact of the additional carbon-heavy materials. The primary materials emitting carbon were the new concrete, steel, glass, and aluminium joinery and the demolition of a small amount of concrete.

The graph representing the timber scheme highlights the added burden where materials are demolished while also representing the avoided burden of a small amount of

reused concrete. This demonstrates that the most significant impact comes from the embodied carbon of the demolished concrete, new aluminium joinery, and glass (Fig 4).

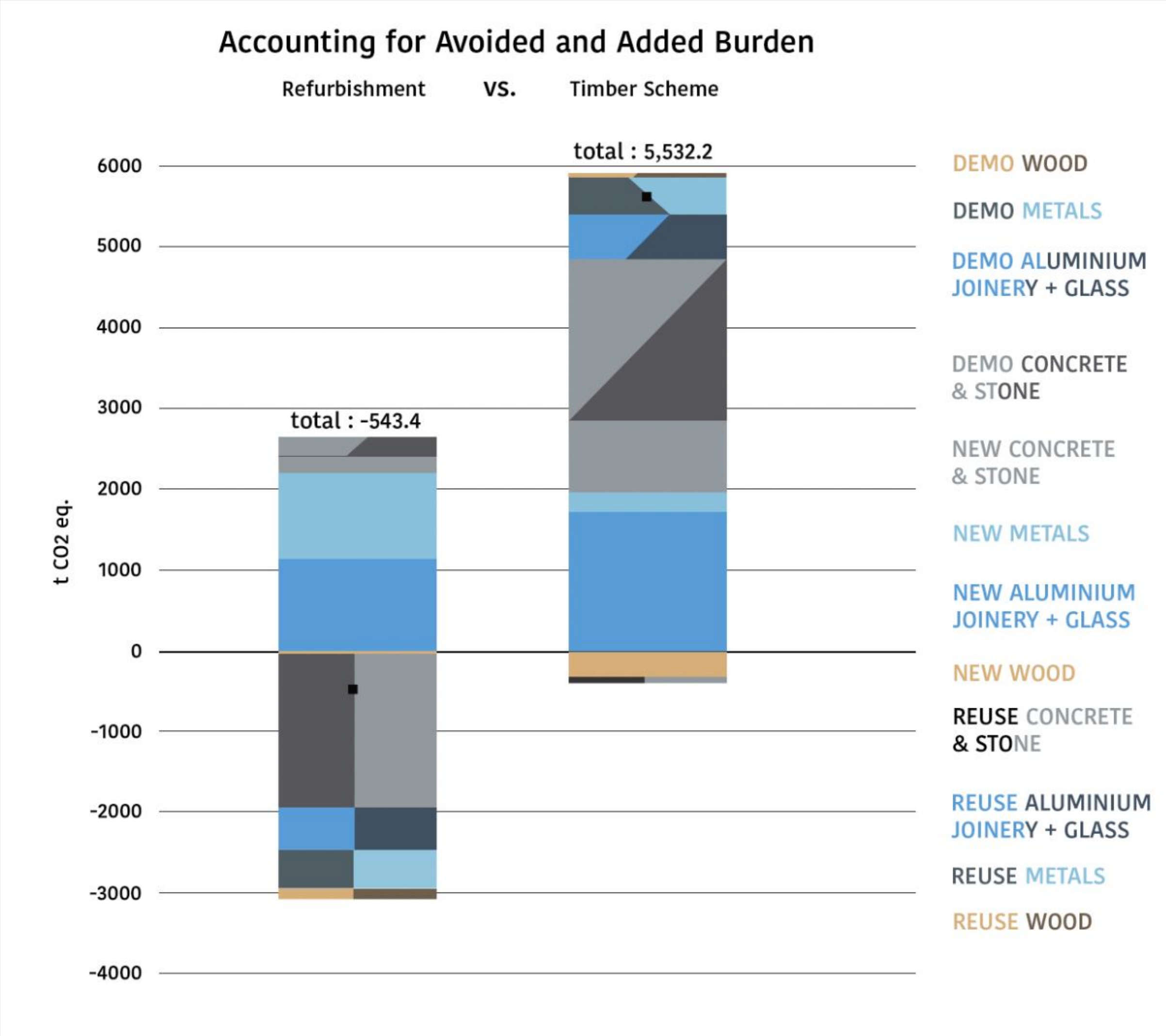

Figure 4: LCA Comparison Accounting for Demolished and Reused Materials

5.5 Limitations and Assumptions

An LCA study with time constraints comes with numerous limitations and assumptions. Some critical limitations of this study were as follows:

- A lack of material quantities for the whole building due to models that were not at a high enough level of detail.
- Inconsistencies in the level of detail between models.
- Time constraints meant ArchiCAD models could not be thoroughly cleaned up and brought to a greater level of detail.
- Material assumptions, such as the ratios in the mix of concrete used, had to be made.
- The lead architects also made assumptions about the amount of new concrete. This was assumed to be 10% of the total amount contained in the refurbishment.

As for assumptions that LCAQuick makes – most of these can be found in BRANZ study report 418. LCAQuick makes assumptions regarding the percentage of materials being reused, going to landfills, or being recycled. One fundamental assumption is that LCAQuick only accounts for the impacts of demolition of the three primary materials (timber, steel, or concrete) (Dowdell, Berg, Butler, & Pollard, 2020). Report 418 also outlines assumptions around the environmental impact values used in LCAQuick.

6 OPERATIONAL ENERGY

Operational energy was essential to consider, given the differences in material characteristics of the two scenarios. Concrete, a thermal mass, can help reduce building heating and cooling loads. However, the timber structure may reduce the cooling load, with commercial offices typically being cooling dominated due to high internal heat gains. To gain a more holistic carbon analysis, an energy simulation was done to compare the energy densities of each scenario.

The simulation can be considered quality assured as all modelling parameters were cross-checked with the building plans and services specifications. In addition, a base model using typical N.Z. constructions was simulated. The BRANZ BEES study was used to quality assure the results of the simulated energy density. The BEES study is an analysis of building energy end use in N.Z. The floor area and use of Case Study A fall into Strata 4, which means the simulated energy consumption should be around 201 kWh/m2.yr, with a confidence interval of 73 kWh/m2.yr (BRANZ, 2014). The table outlining this can be found in Appendix 6. The simulation of a typical building produced an EUI of 130.2 kWh/m2/yr, which falls within the confidence interval.

A description of the modelling methodology and a table of modelling parameters for Case Study A can be found in Appendix 7.

6.1 Energy End Use Results Comparison

The energy simulation of the refurbishment produced an Energy Use Index (EUI) of 52.7 kWh/m2.yr. Simply changing the constructions and adding the additional windows for the timber scheme produced an EUI of 62.4 kWh/m2.yr. Figure 5 shows an EUI breakdown by use and month. These graphs demonstrate that the refurbishment (concrete structure) requires less cooling in warmer months than the new build. The heating required between April and October is also notably less. These differences are due to concrete being a thermal mass, heat loss in the timber building through additional windows, and Wellington being a reasonably cool climate during winter. During summer, the additional windows in the new building would let more sunlight in, resulting in increased solar heat gains and, as a result, a more significant cooling load. Additional data gathered from the simulation can be found in Appendix 8, along with a short description of what each graph highlights. Appendix 8 contains; floating (unconditioned) temperatures of the two buildings; energy balance graphs; and daily energy use profiles. These graphs emphasise the above points regarding reasons for increased energy consumption. It is essential to mention that the EUI results are accurate relative to the two simulated scenarios, and no claims are made regarding the actual CO2 savings.

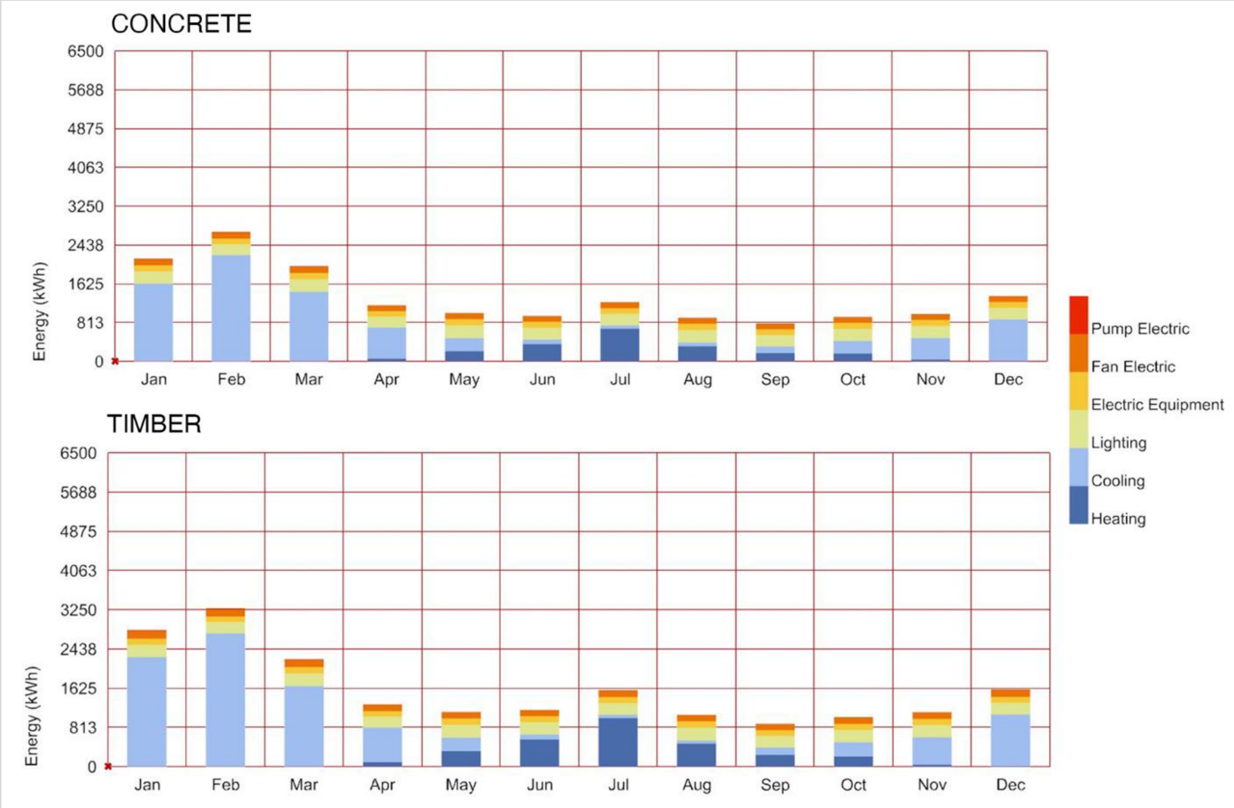

Figure 5: Energy Breakdown by Use and Month

6.2 Carbon Calculations Using Simulated Energy Density

The carbon calculations were done using an impact value of 380g CO2 eq./kWh (Coelho, 2011). This value was calculated in 2011 using information gathered regarding the impact of energy generation and distribution. With New Zealand's increase in renewable energy generation and the recent decarbonisation of the grid, this value has likely decreased and will continue to do so. The table below identifies the impact in the CO2 associated with operational energy for each scenario if this number stays the same over the building's lifetime.

Table 2:Carbon associated with operational energy

BUILDING	GFA	kWh/m2.yr	kWh/m2	IMPACT (kg CO2 eq.)/yr
Refurbishment	3995	52.7	210,596.4	75,814.7
New Build	4020	62.4	250,779.7	90,280.7

Table 2 shows that the refurbishment performs better than the new build, saving 14,466 kg CO2 eq. per year. This is a 16% reduction in carbon emissions from operational energy. This means that throughout the building's life cycle, this saves 867,598 kg CO2 eq. Again, if this is accounted for in relative terms and regardless of the gradual decarbonisation of the electricity grid, the saving would be 16%.

7 CRITICAL ASSESSMENT OF COMPARATIVE ANALYSIS

The results of this research highlight the importance of holistic carbon accounting in building life cycle assessment. Current practice does not acknowledge this importance. As Obrecht et al. (2021) noted, the neglection of the impact of reused components in refurbishment is scientifically questionable. It can also be said to negate the impact of landfilled components.

To further these findings, the results can be considered and scaled relative to the two life cycles of the building. This is representative of how the industry will interact with the current commercial building stock in the near future.

The assumption regarding the lifetime of a commercial office building in N.Z. is 60 years. In the refurbishment scenario, the total embodied carbon of the existing building is partially reused to gain another life cycle (another 60 years). The building still contains the original carbon. However, only a fraction of this is required to gain another 60 years of life out of it. This means the carbon footprint of the building for the further 60-year lifetime may be notably smaller. Even when refurbishing with carbon-intensive materials such as glass, aluminium, and steel, the lifetime of the existing materials has doubled, making their impact lesser. Figure 6 shows the result of taking the impact of the existing building and adding it to the impact of the new materials required to provide another 60-year lifetime. This sum can then be divided by 120 years to represent the multiple building cycles.

The timber scheme also had a lifetime assumption of 60 years. Suppose a holistic carbon accounting approach is taken. In that case, all the carbon from the existing building and the embodied carbon of the new building can be added together and divided by 120 years.

Table 3 shows that a refurbishment would require 50% of the existing building's carbon to gain another 60-year lifetime, whereas building new would require an extra 100%. The impact of new materials in the refurbishment is less than 1/2 of that in the new build. In addition, the refurbishment results in 10.4 t CO_2 eq. (or 25.8%) less embodied carbon over two life cycles compared to the new timber build. Accounting for avoided and added burdens makes the impact dramatically different. However, it further emphasises that refurbishment results in lower carbon intensity.

The data gathered from this case study analysis suggests that instead of building new buildings, the construction industry should focus on extending the life of existing buildings. The carbon implications appear less significant when interacting with and refurbishing the current building stock.

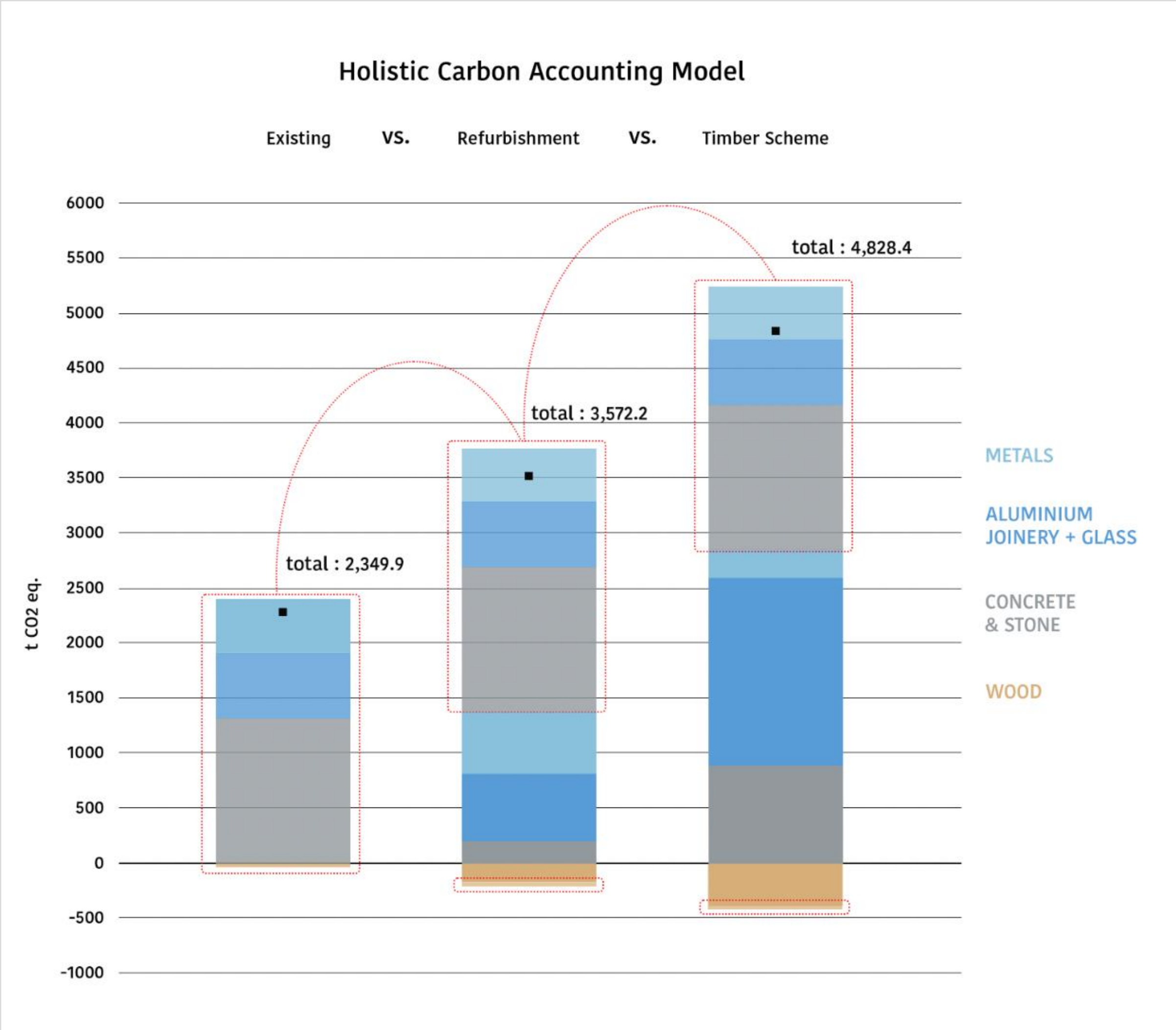

Figure 6: Holistic Carbon Accounting Approach

Table 3: Carbon Intensity When Considering Multiple Life Cycles

NEW MATERIALS ONLY	IMPACT (t CO2 eq.)	IMPACT/60 YEARS
Existing	2349.9	39.2
Refurbishment	1222.4	20.4
Timber	2478.5	41.3
HOLISTIC APPROACH 2X LIFE CYCLES	**IMPACT (t CO2 eq.)**	**IMPACT/120 YEARS**
Existing + Refurbishment	3572.2	29.8
Existing + Timber	4828.4	40.2
AVOIDED AND ADDED BURDEN	**IMPACT (t CO2 eq.)**	**IMPACT/120 YEARS**
Existing reuse + Refurbishment	-543.4	-4.5
Existing demo + new Timber	5532.2	46.1

As the industry moves forward, the focus will fall more heavily on the embodied carbon of the materials. There has been and continues to be an emphasis on reducing operational energy. With technological advances, passive design, and stricter regulations, this area has dramatically improved and will continue to do so.

As a building becomes efficient and energy consumption decreases, the relative significance of embodied energy increases. This notion is supported by recent research (Kapoor, 2017; Koezjakov, Urge-Vorsatz, Crijns-Graus, & van den Broek, 2018). In addition, Vickers et al. (2021) state, "Over time, as the electricity grid decarbonises, embodied carbon will become a greater percentage of a building's emissions profile." Their research predicts that as the industry continues to reduce emissions associated with operational energy, embodied carbon will be responsible for 85% of building emissions by 2050 (Vickers et al., 2021). Regardless, it was essential to consider operational energy for Case Study A as it still accounts for most of the carbon emissions throughout a building's lifecycle in N.Z.

8 DISCUSSION OF FINDINGS

Four key findings resulted from this study. These are outlined in the sections below.

8.1 Fundamental Database Issues

This research highlighted fundamental issues and database inconsistencies that are important to consider for any LCA study. Despite using environmental impact values from published and peer-reviewed academic references, significant differences between the calculator created during this study and BRANZ's LCAQuick were noted. These differences suggested that the numbers sourced were different for CO2 emissions per material.

Moreover, this study highlights that carbon implications depend on the quality of the environmental impact numbers that are sourced and used in any LCA database. The process of taking quantities and multiplying them by an environmental impact value is a relatively straightforward concept. However, defining the coefficient to multiply the quantities by was the single most significant barrier to completing any comparative LCA when testing the development of a practice-based calculator. Not only gathering reliable environmental impact values for New Zealand but also reliable numbers for specific materials is a challenging task.

One option is to rely on environmental product declarations (EPDs) as a critical source of information for use in LCA databases. The issue with this is that there are few N.Z.-based EPDs available. For practitioners looking to use LCA to guide design, there is a great deal of difficulty in decision-making when there is no reliable data source. This makes it difficult for those without LCA expertise to make these choices and produce reliable results. A comprehensive breakdown of materials is also crucial for the decision-making process. It is an aspect that needs to be considered in any LCA calculation tool.

Numerous calculators are coming onto the market that use international databases. The issues found in developing a calculator proved how dramatically LCAs could vary using numbers from different sources. This further emphasised that figuring out the appropriate values is the hardest part of this study.

8.2 Lessons Learned for Routine Implementation of LCA in Industry

Several barriers slowed the process of simply trying to carry out an LCA of the building. The complications of extracting material quantities from the ArchiCAD model were the most apparent issues. The accuracy and level of detail found varied within the three models provided. The existing building had little information, while the refurbishment and timber models were slightly more detailed. However, the IFC model not being used in the architect's model was time-consuming. This was dealt with by extracting structural quantities from one model and façade quantities from another. Setting up the material schedules here was difficult due to the inconsistent naming of materials and layer assignments.

If more care had been taken in the modelling process, the extraction of material quantities, and therefore the LCA process, would have been much less time-consuming. If there were to be a routine implementation of LCA in practice, it would be essential to have consistency and accuracy throughout the models. If models were created in a way that acknowledged and supported the idea of using it for an LCA, the process would be quicker and the accuracy greater. This would also help if the architects implemented a BIM-integrated LCA – where the data extraction process is done more automatically. These corrections would help to avoid similar errors in the future if this were the path they were looking to take

8.3 Dealing with Refurbished or Demolished Materials

Holistic carbon accounting needs to be considered in LCAs. Considering the reuse of materials as an avoided burden and demolishing materials as an added burden is an interesting take on carbon accounting. While it is typical for the reuse and demolition to be accounted for in an LCA of an original building, an assessment is not always done. The findings and critical assessment show what would happen if a holistic carbon accounting approach were used to assess Case Study A.

Practitioners must be aware of the carbon they become responsible for when interacting with a building. Taking a holistic approach emphasised carbon accountability in the built environment.

8.4 Refurbishment or New Build?

The results section of the report outlines that refurbishment is the most environmentally friendly option because it is the lowest embodied carbon alternative. Both sets of results – whether accounting only for new materials or accounting for avoided and added burden, emphasised that the new build scheme for Case Study A would have been surprisingly carbon intensive. This includes a 25% increase in $CO2$ associated with materials and a 16% increase in $CO2$ associated with operational energy compared to the refurbishment. Due to LCA limitations, it does not include the impact of components or the efficiency of building services. These are aspects that would need to be considered in future research.

This case study was fascinating as the timber scheme does contain additional concrete, which heavily outweighed the impact of the timber sequestration. While at a glance, one may consider the timber scheme to be the lower carbon option, it is relatively carbon intensive upon closer analysis.

This study aimed not to look at a representative sample but to produce a valuable critical review of one methodology for accounting for carbon specific to one case study. It assessed how data could be extracted from one user interface currently used in practice. As a result, the carbon results can be considered accurate relative to the various components that this study compared. From this, a comparison of holistic carbon for each building scenario can be used to make decisions that will positively impact carbon accounting across New Zealand's commercial building stock.

9 FUTURE WORK AND RECOMMENDATIONS

In order to optimise LCAs, it would be helpful to have a validated, accessible database of available information. Improving the consistency of LCA databases is work that needs to be done urgently to utilise LCA in building design and provide validated results.

Initially, the idea behind creating a practice-based LCAQuick calculator was that it would be more straightforward than LCAQuick. However, it is apparent that LCAQuick is already very simple after using the program. An advantage of creating a bespoke calculator is that it could be made to fit the way the firm works. A programme that learns from how the practice operates and allows them to estimate what the likely carbon impact would be ideal. However, it is unlikely this could be developed in-house at present. It would require an LCA specialist. Therefore, it would be interesting to look at proprietary systems that already exist and could be used. These would be particularly useful where there may be a simple and a more complex partnering in terms of LCA input and output.

If the LCA process were to be replicated for a future project, it would be important for the modelling workflow and component labelling to be consistent throughout ArchiCAD models. This would make the data extraction and LCA processes to be more efficient. This could be taught to practitioners in the future.

Future work could also involve a deeper analysis of building lifetime. The general assumption for commercial office buildings, which was used in this study, is 60 years. Due to this study's time constraint and limited resources, the reasons behind this and alternatives for this assumption could not be thoroughly considered.

Responsible disposal or reuse of materials is also essential and could be looked into in further studies. A standard/less responsible method of demolition and disposal of materials could cause even greater carbon emissions.

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11 APPENDICES

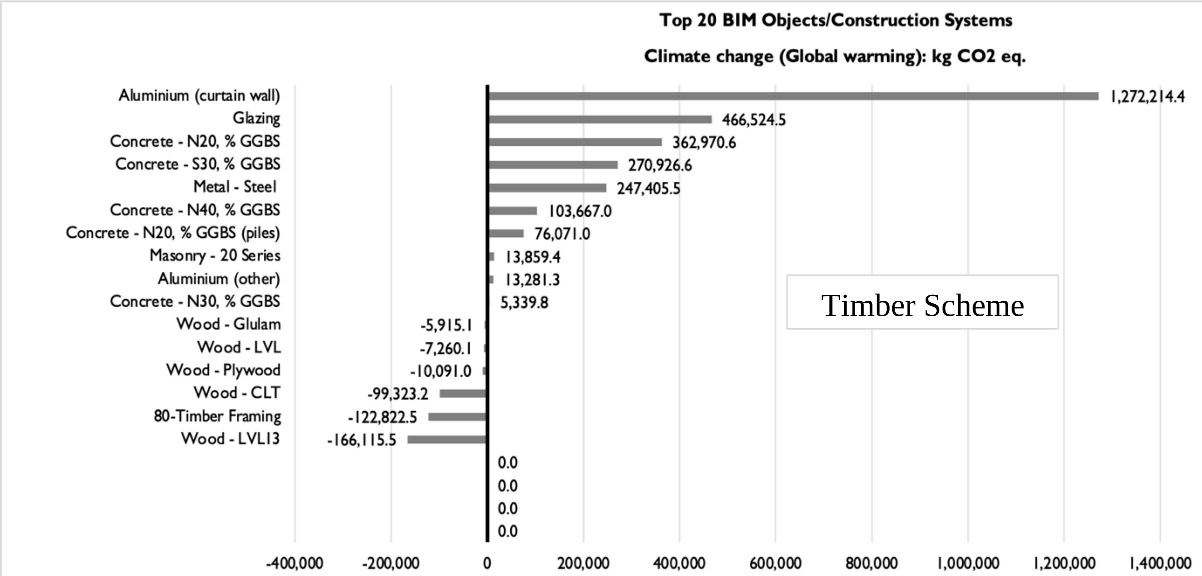
Note: Appendix 2,3, and 7 are available by contacting the research project lead Dr Nilesh Bakshi.

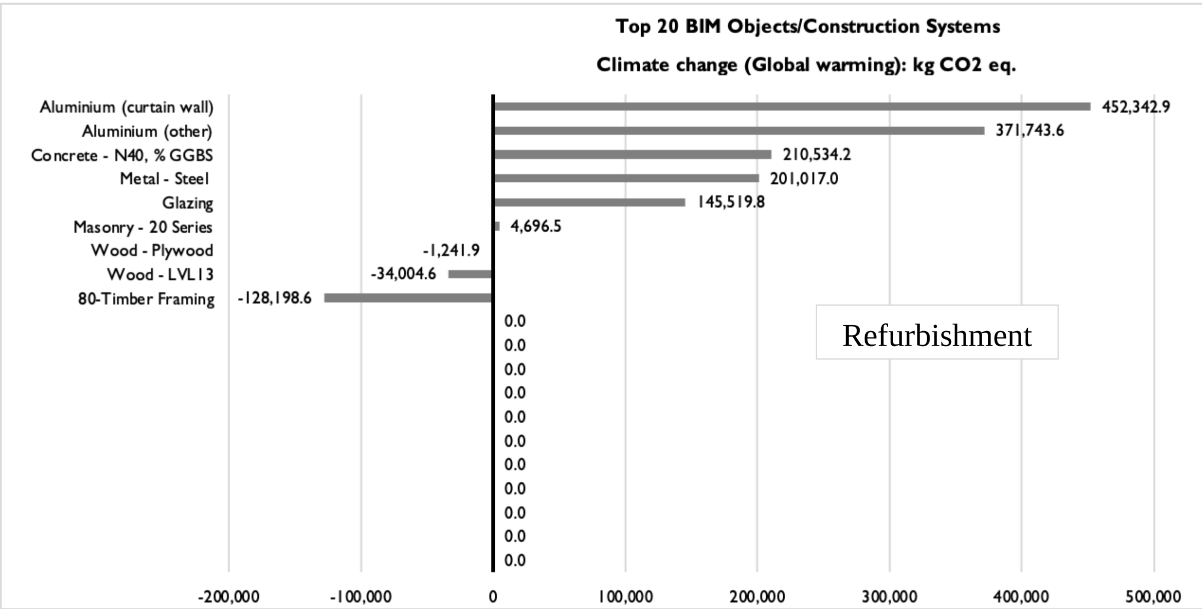
Due to open-source repository limitations, these could not be included in this publication's digital license.

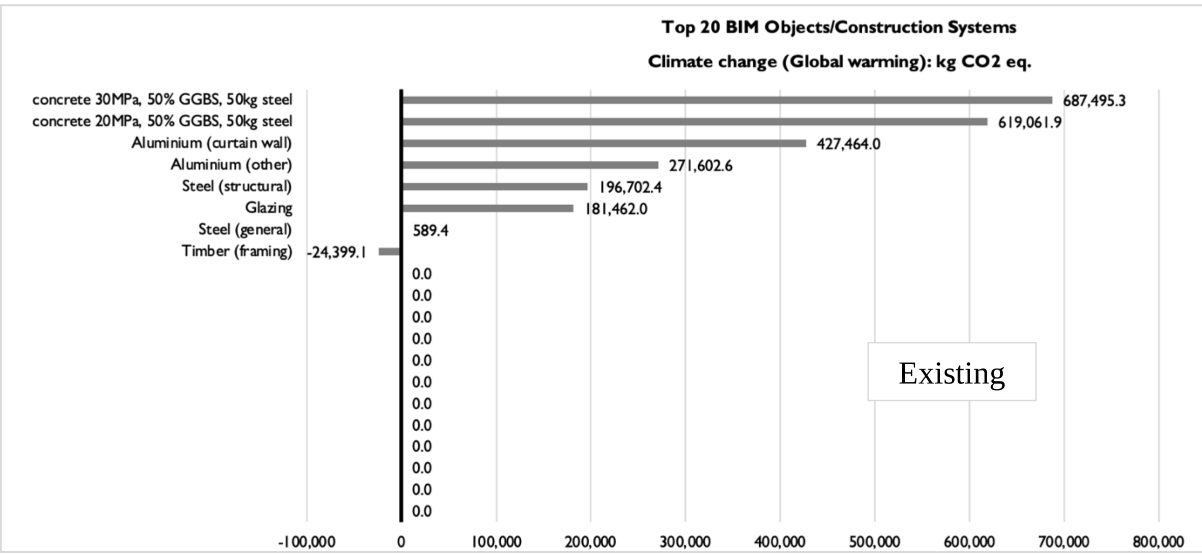
Appendix 1. Concrete Specifications.

Location	Concrete Grade	Max. Nominal Aggregate Size	Workability (Nominal Slump)	Pumping Permitted	Special Requirements
Pile concrete	N40	20 mm	100 mm T.B.C. by Contractor	Yes	
Raft Slab	S30 at 56 days	25mm	150 mm max.	Yes	2.35m thick slab. Mix to minimise heat of hydration. Refer CON.11 - Curing for additional requirements.
Jump Form Core	S30	20mm	T.B.C by contractor	Yes	Strength testing to be carried out on batched cylinders stored at site conditions.
Plant Room Screed	N30	13mm	T.B.C. by Contractor	With Eng. approval of Pour size and c.j. positions	
Steel Column Concrete encasement	N30	12mm	150mm	Yes	
Comflor Topping slab	N30	20mm	130 mm max.	Yes	

Appendix 4. Impact of Individual Materials from LCAQuick.







Appendix 5. Calculations of impact by material/volume.

Timber Scheme

Material	Volume (m3)	Impact (kg co2 eq.)	impact/m3
Timber (internal wall framing)	265	-114965	-434.4
Timber (LVL/structural)	400	-166115.5	-415.3
Plywood	76	-10091	-132.8
Timber (CLT)	256	-99323.2	-388.0
Timber (Glulam)	12	-5915.1	-492.9
N40 concrete (insitu)	148	103667	701.8
N20 concrete (insitu)	877	362970.6	413.8
N30 concrete (insitu)	12	124100.7	10341.7
S30 concrete (insitu)	609	270926.6	445.0
Masonry - Concrete Block	30	13859.4	469.7
Glazing	130	466524.5	3578.8
Aluminium (window joinery)	90	1272214.4	14159.2
Aluminium	2	13281.3	5569.8
Steel (general)	16	247405.5	15024.7

Refurbishment

Material	Volume (m3)	Impact (kg co2 eq.)	impact/m3
Timber (internal wall framing)	310	-128198.6	-413.5
Timber (LVL/structural)	79	-34004.6	-433.2
Plywood	10	-1241.9	-128.0
N40 concrete (insitu)	300	210534.2	701.8
Masonry - Concrete Block	10	4696.5	469.7
Glazing	41	145519.8	3588.7
Aluminium (window joinery)	32	452342.9	14135.7
Aluminium	56	371743.6	6640.7
Steel (general)	13	201017	15462.8

Appendix 6. Energy End Use Table (BRANZ, 2014)

Table C: $EnPI_{elec}$ by Building Size Strata and Building Use Strata.

Building size strata	$EnPI_{elec}$ (kWh/m².yr) Estimate	±95% confidence interval
S1: 0–649 m²	143	57
S2: 650–1,499 m²	153	53
S3: 1,500–3,499 m²	154	65
S4: 3,500–8,999 m²	201	73
S5: 9,000 m² +	223	66
Building use strata		
CO: Commercial Office	186	61
CR: Commercial Retail	176	45
Other BEES	158	36
Total	**173**	**28**

Appendix 7. Simulation Strategy

The simulation was completed using EnergyPlus, with Grasshopper as the interface in order to utilise the Ladybug plug-in. A 5-zone model was used to represent the interaction between the internal and external environment. Table 4 shows each input used.

The alteration of wall, floor, and roof constructions was the key area of interest. This was the only change made between the models, other than the addition of windows on the Southern and Eastern façades for the new build.

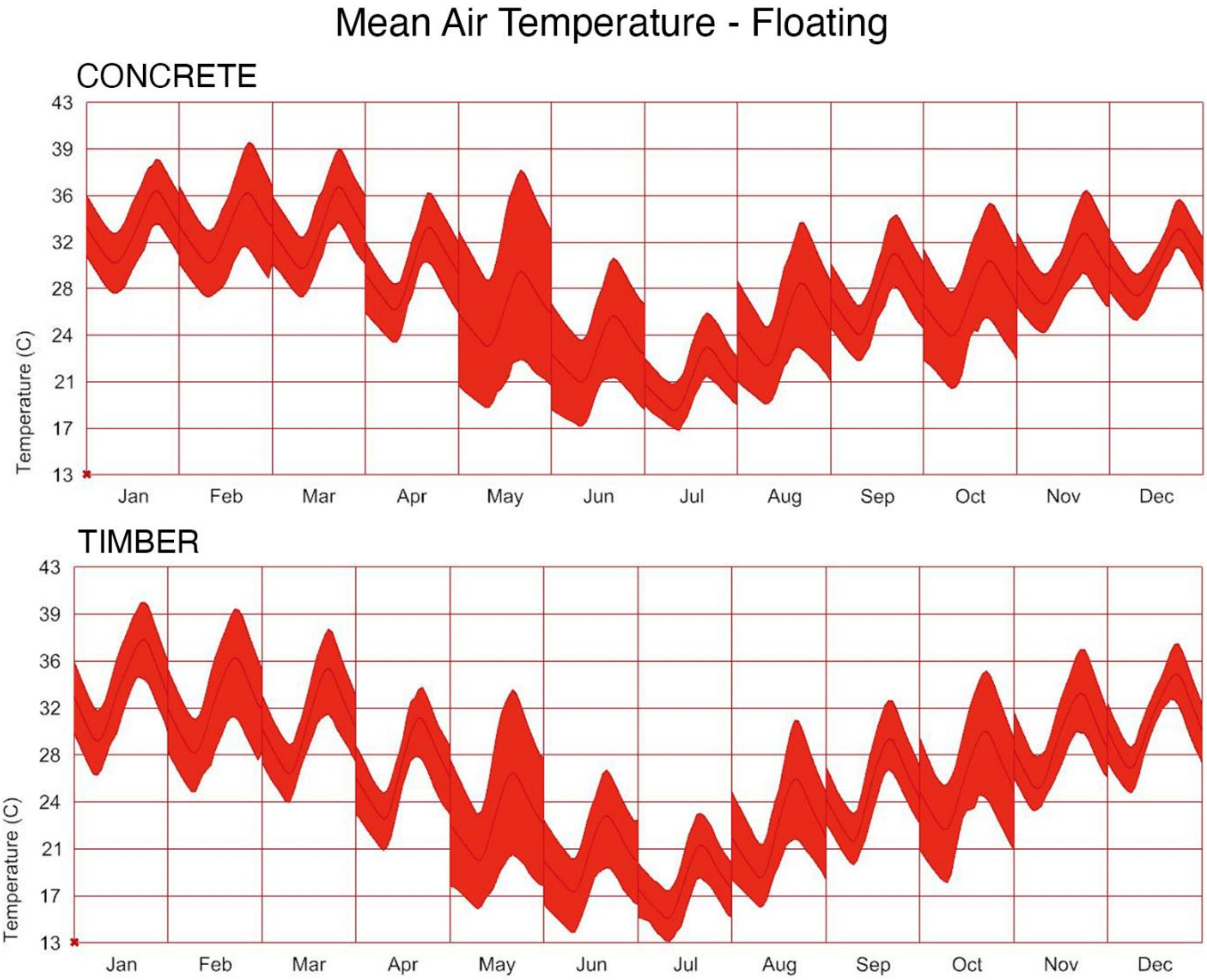
The simulation was run twice for each building. The first represented a middle floor, with the ceiling and floor set to adiabatic, meaning there is no heat loss through these surfaces. The second simulation was done to represent the top floor, with the roof outside boundary condition set to 'outside'. The means there is heat loss through the roof. This caused a slight increase in energy total energy use for that floor, which was accounted for in the final EUI.

PARAMETER	REFURBISHMENT	NEW BUILD
Heating & Cooling Setpoints	18°C & 26°C	
Ventilation (m3/s per person)	0.02 (perimeter zones) & 0.05 (core)	
Operable widows	N.A.	
Heat gains (people/ m2)	0.12	
Heat gains (Lighting Watts/ m2)	4	
Heat gains (Equipment Watts/ m2)	2	
Window-to-wall-ratio	85%	
Window locations	North, West	North, West, South, East

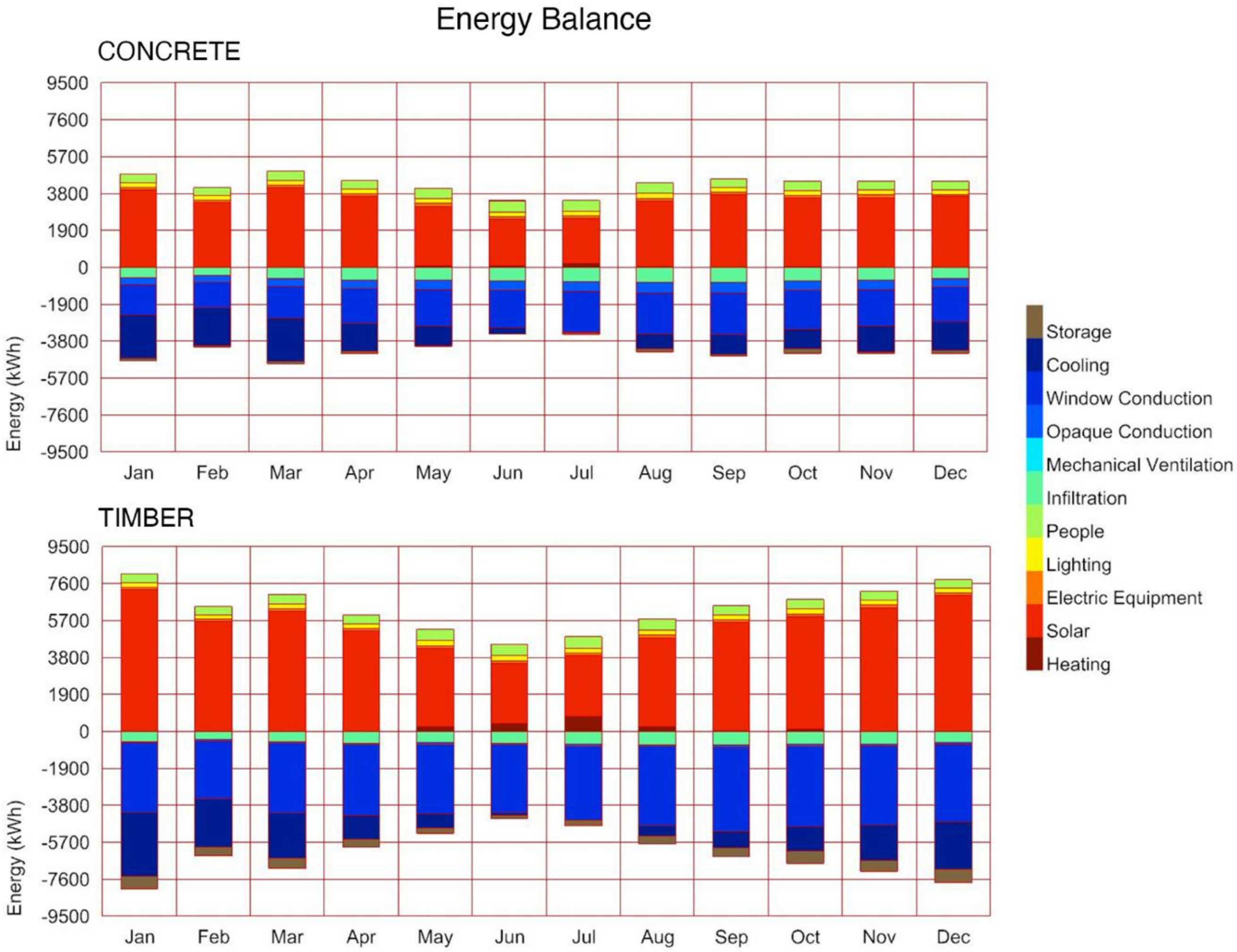
Window height	Floor to ceiling (3m)	
Perimeter zone depth	4.5m	
Building dimensions	22m (North-South), 14m (East- West)	
Roof construction	Concrete, timber frame	Timber shingle + frame
Wall construction	Reinforced concrete	Timber
Floor construction	Concrete, carpet	Timber, carpet
Glazing	Double glazed, thermally broken, aluminium frame, low E	
Services	VAV chilled water with central heat pump reheat	

Table 4 Modelling Parameters

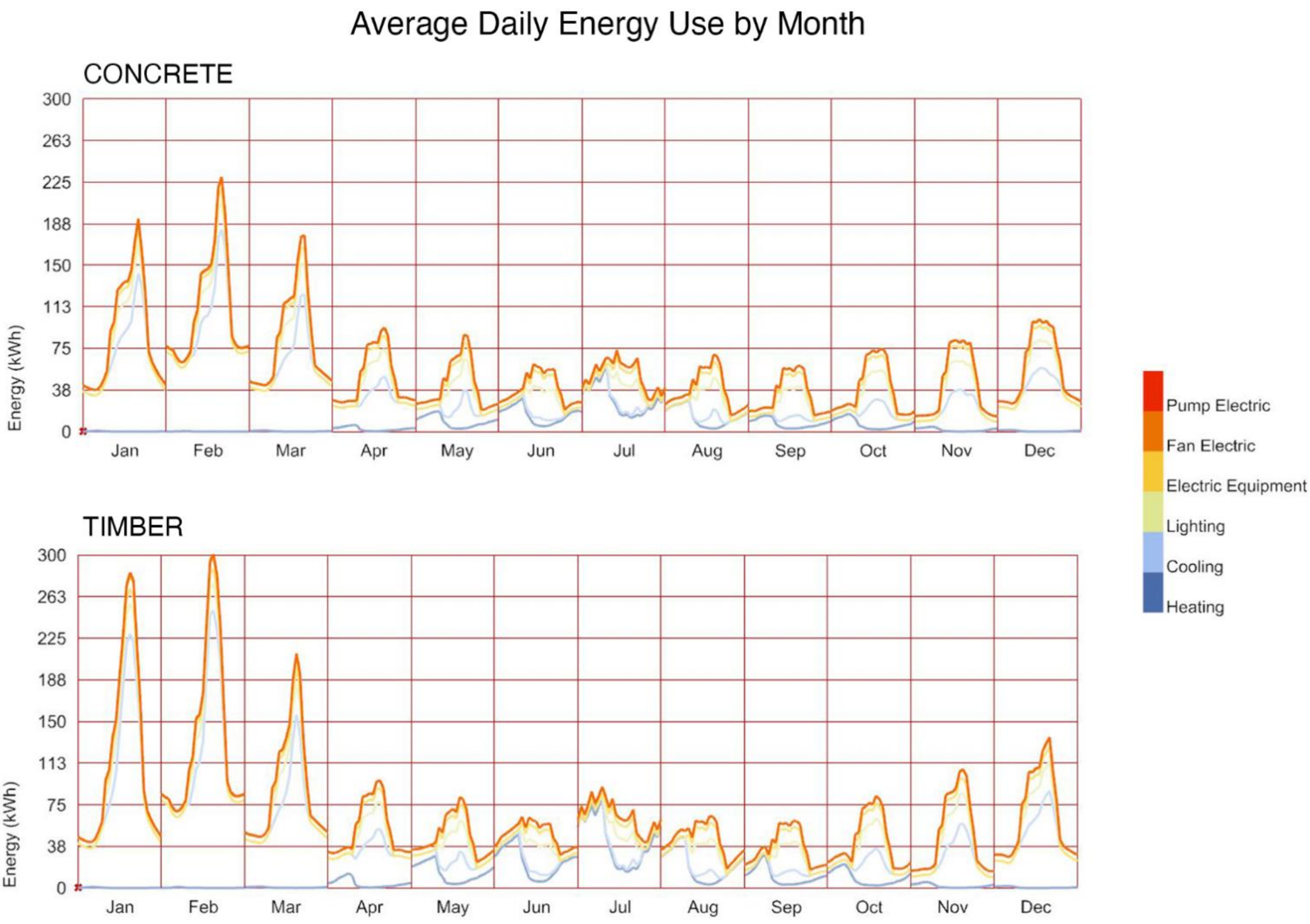
Appendix 8. Additional Simulation Data



The mean floating air temperature is the temperature when the building is not conditioned. These graphs highlight that the timber scheme is slightly warmer in summer and colder in winter. As mentioned in Section 6.1, this would be due to increased heat loss and solar heat gain through the windows, as well as heat loss through the walls.



The energy balance graphs further highlight the increased energy consumption in the timber scheme. The graph shows greater solar heat gains and window conduction, more cooling, and more heating compared to the concrete refurbishment.



The energy use profiles show the daily energy use. These show that when the services are turned on in the summer months in the morning, there is a large spike in energy demand, specifically cooling. This peaks around midday and gradually declines. The timber scheme shows notably more consumption during occupied hours across the entire year.

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Telephone +64 4 463 6200 Facsimile +64 4 463 6204