Cost-neutral, low-carbon residential construction

On behalf of MBIE

Document Approval and Revision

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Executive Summary

The challenge

To reach our climate goals, we need to build houses with smaller carbon footprints. The Building for Climate Change (BfCC) programme of Aotearoa New Zealand's Ministry for Business, Innovation and Employment (MBIE) calls for caps on both operational and embodied carbon. MBIE wanted to know if building lower-carbon homes would cost more. While buildings with better thermal design often have lower whole-of-life costs, this project focused on the upfront capital costs only.

MBIE commissioned thinkstep-anz, engineering consultancy Mott MacDonald, and quantity surveyors Prendos to investigate if it is possible to achieve BfCC's proposed carbon savings without increasing the upfront cost of construction.

What we did

We used a single reference building as the basis for analysis. The building selected from the LCAQuick reference library is a single-level home that features four bedrooms, two bathrooms, two living areas, one kitchen, one laundry, and a two-car internal garage.

We then modelled operational energy/carbon and embodied carbon for the reference building with different levels of thermal performance and different material combinations. All modelling was done at the system level (floors, roofs, walls, windows) rather than the material level.

Overall, this study considered 22,032 unique combinations of building elements, comprising:

- 6 roof options,
- 17 envelope wall options,
- 6 internal wall options,
- 12 floor options, and
- 3 window/door options.

The study also looked at three regional scenarios (Auckland, Wellington, Christchurch) for the operational energy/carbon modelling.

Operational carbon

Carbon emissions that occur during the use stage of a building. They stem mainly from the energy required to heat and cool the building, to heat water, and to power devices plugged in at the wall.

Embodied carbon

Carbon emissions stemming from the materials and products the building is made from, the construction process itself, construction waste disposal, maintenance and refurbishment throughout the building's life, and final disposal of a building at the end of its life.

Upfront carbon

Embodied carbon up to the point of practical completion, but excluding maintenance, refurbishment and building end-of-life.

What we found

New Zealand's residential buildings already have a relatively low carbon footprint due to the use of timber framing.

This study shows that timber products have low upfront and embodied carbon, even when we exclude stored biogenic carbon. New Zealand's widespread use of timber framing means that the potential to reduce embodied carbon is more limited than if other materials were used. Reductions of carbon footprint per square metre are therefore likely to be small, unless removals of carbon dioxide from the atmosphere (e.g., by trees that are converted into timber products and then used in buildings) are allowed in the calculations.

Without smart design, BfCC may increase the initial cost of construction by 5-10%.

This study shows that most residential buildings should be able to achieve BfCC's initial proposed operational efficiency cap, and that some can also meet the intermediate cap. Achieving these caps while also reducing embodied carbon (but without optimising the design) would likely result in construction costs increasing by roughly 5-10% per square metre of floor area.

However, there is significant variation in upfront costs for the same level of decarbonisation. By choosing the best solution, significant savings can be made for no additional upfront cost as long as the embodied carbon caps are not set too stringently.

Smart design can deliver lower carbon buildings at no additional cost.

We found that savings of up to 36% in upfront carbon and 12% in whole-of-life embodied carbon (compared with the reference building selected for this study) were possible for no additional upfront cost. However, because the reference building selected for this study was one of the cheapest options available, only 2.8% of all options considered delivered a lower upfront carbon footprint for a lower upfront cost. Only 1.0% delivered a lower whole-of-life embodied carbon footprint (excluding biogenic carbon and recycling credits) for a lower upfront cost. This means that the building industry can achieve low-carbon and low-cost construction, but only deliberate optimisation is likely to achieve both outcomes together.

There can be trade-offs between operational efficiency and embodied carbon.

We found that moving from a concrete slab to a suspended timber floor was one of the most effective strategies to reduce embodied carbon in the reference building. However, the lower thermal mass led to decreased thermal performance for the reference building considered, particularly in climates with larger swings in temperature (e.g., Auckland and Christchurch).

BfCC's final proposed operational efficiency cap will likely require changes in building design that achieve better thermal performance.

None of the scenarios modelled in this study achieved the proposed final cap for thermal performance or services efficiency. To reach these, optimised building design for better thermal performance and higher efficiency (e.g., heat pump) hot water systems are needed.

Our recommendations

This study highlights the need for credible data to design and build homes that are both highly energy efficient and have a low embodied carbon footprint without adding a higher price tag. Optimisation is made easier if there are high quality databases and easy-to-use tools available.

We found that differences in approach (which can include definitions, calculation methods, underlying data and scope of assessment) can be as important to the outcome as the active changes made to decarbonise buildings.

Given that BfCC may apply to all new buildings in New Zealand, it will be very important to standardise the methods and data sources used to provide clarity and consistency to the building and construction market. Doing so will provide a solid foundation when optimising for low carbon and low cost.

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1. Goal of the study

1.1. Goal

The primary goal of this project is to understand if it is possible to reduce operational and embodied carbon significantly for new standalone residential buildings in New Zealand without increasing the initial cost of construction. More specifically, the goal is to try to meet the caps proposed by the Ministry of Business, Innovation and Employment's (MBIE's) Building for Climate Change (BfCC) programme without adding to upfront building costs. Given that no cap is yet proposed for embodied carbon, this project aims to understand what cap would be possible without higher initial costs.

If it is not possible to achieve the proposed caps without additional costs, a secondary goal of this project is to understand what the likely increase in upfront cost will be.

1.2. Context

MBIE's BfCC programme aims to tackle the two major sources of greenhouse gas (GHG) emissions from buildings:

1. operational emissions ("operational carbon") (MBIE, 2020a), and
2. embodied emissions ("embodied carbon") (MBIE, 2020b).

BfCC proposes to cap both operational energy and embodied carbon per square metre of floor area. One way to operationalise this cap is through the Building Code and the building consent process. The intention is to create buildings that are both highly energy efficient and have a low embodied carbon footprint.

As part of the preparatory work for BfCC, MBIE wishes to understand what – if any – effect achieving its proposed caps will have on the upfront cost of construction. While it is widely recognised that improving energy efficiency will lower whole-of-life building costs, the focus of this work is deliberately on upfront costs only given public concern regarding the cost of construction. While a focus on whole-of-life carbon (as opposed to upfront carbon) could be considered a mismatch with upfront cost, it is the upfront cost of buildings that is most noticeable to people, as ongoing costs of operation and maintenance are spread out over many years.

The focus of this report is detached residential buildings only. While there has been a move towards attached residential buildings in many of New Zealand's major cities, this project deliberately does not consider any possible benefits of moving from detached to attached buildings. Standalone houses are still very common in greenfield developments throughout New Zealand and are still the building type of choice for most large residential home builders (e.g., G.J. Gardner Homes). As such, they are an important focus for decarbonisation.

2. Scope of the study

2.1. Reference building

This study uses a single reference building as the basis for all analysis.

The following criteria were considered when selecting the reference building:

- It must be a standalone new-build residential house.
- It must be suitable for a family of, say, 2 adults and 2-3 children. As such, the desired house was 3-4 bedrooms, 1-2 bathrooms (with a preference for 2), relatively large living areas, and a 1-2 car internal garage (with a preference for 2-car).
- It must use common materials for each major element of the building.
- It must have been built on a greenfield site with good ground conditions. The goal was to avoid sites that require significant clearing and/or a complex foundation.

The building selected (Table 2-1, Figure 2-1 and Table 2-2) comes from the LCAQuick reference library (Dowdell, et al., 2020). It is a house built in north Waikato in 2013. The building has four bedrooms, two bathrooms, two living areas, one kitchen, one laundry, and a two-car internal garage. Water heating comes from an internal electric hot water cylinder. All cooking appliances are electric. It is assumed the building has an electric heat pump. The building does not use fossil fuels for heating, nor does it have a wood burner.

Table 2-1: Information on the selected reference building from LCAQuick (Dowdell, et al., 2020)

Parameter	Value
Building Name	4_M_SS
Country	NZ
Location	Zone 1
No. of Building Occupants	5
No. of Annual Occupied Hours per Person	8760
Use	R-SS
Building Lifespan	90
GFA Approx.	194
NLA	156
Number of Storeys	1
Strata	Strata 1
Structural System (Type)	NZS3604
Structural System (Material)	Timber
Design Process Stage	Building Consent
HVAC Type	Typical - HVAC
Scope of Construction Work	New Build

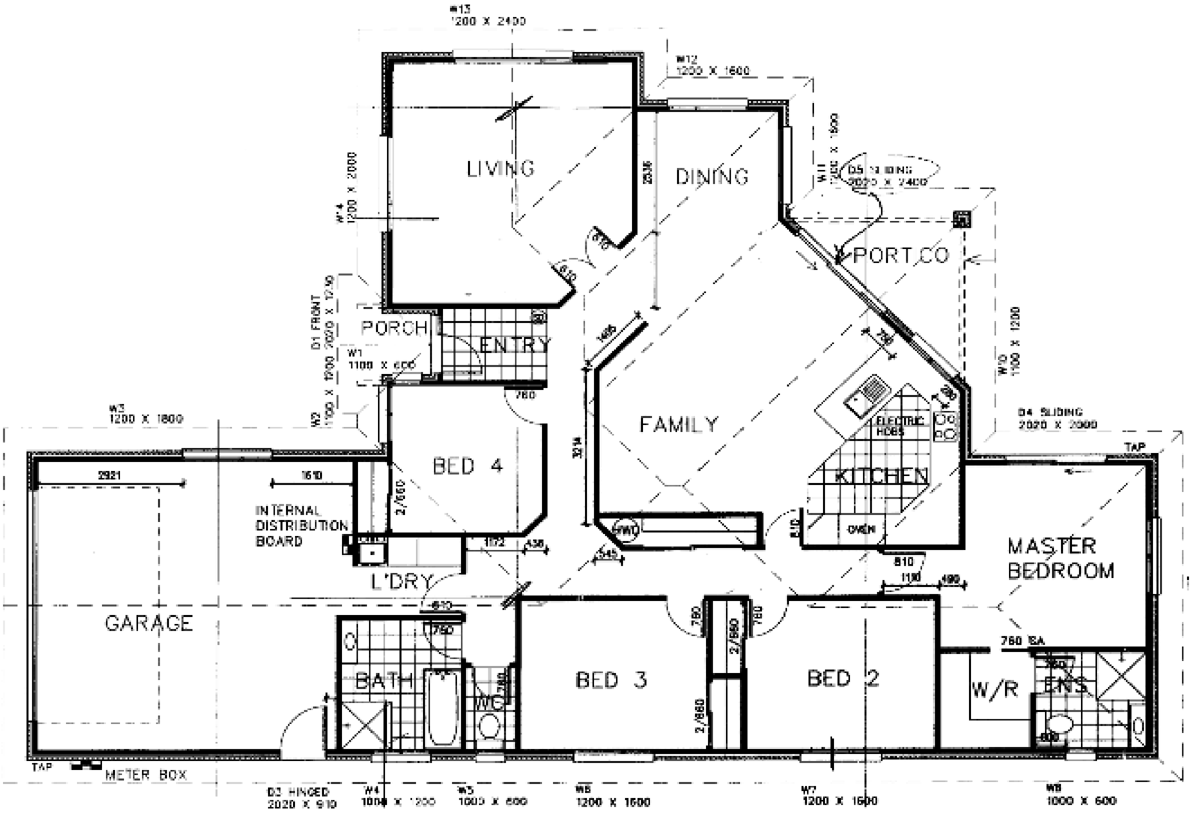


Figure 2-1: Floor plan of the selected reference building

Table 2-2: Building materials and areas for the selected reference building

Building element	Description	Area (m^2)	Source
Roof	Corrugated steel on timber roof trusses (70x45mm SG8 H1.2 treated purlins) with R3.2 ceiling insulation and a 10mm plasterboard interior ceiling lining	263	Drawing
Envelope wall	Brick veneer (70 series) with 50mm cavity over timber frame (90x45mm SG8 H1.2 treated) with R2.2 wall insulation and 10mm plasterboard as the inside lining	156	QS
Internal walls	Timber frame (90x45mm) with 10mm plasterboard lining on both sides	169	QS
Windows and exterior doors	Aluminium frame (powder coated) with double-glazed IGU	36	QS
Garage door	Double garage door (corrugated steel)	10	Drawing
Floor	Concrete slab on grade (100mm thick, 17.5 MPa) with 500E grade steel reinforcing mesh (uninsulated)	209	QS
Conditioned area	Living areas	170	Drawing
Unconditioned area	Double garage	39	Drawing
Gross internal area	Total floor area to inside edge of external wall	209	Drawing
Gross floor area	Total floor area to outside edge of external wall	218	Drawing

Apart from its cladding, this building uses the most common building elements in New Zealand residential construction (Lockyer & Clarke, 2021):

- Roof: Metal roofing has a market share of >70%.
- Envelope wall: Brick veneer was the most popular wall cladding when the reference building was built in 2013 (then around 45% market share), though weatherboards (timber, fibre cement, PVC) are now the main wall cladding used in New Zealand.
- Wall framing: Timber wall framing has a market share of >80%.
- Floor: Concrete slab floors have a market share of >65%. This percentage is likely an understatement as it includes upper floors, which are predominantly timber.

2.2. Regions considered

This study considers the reference building in Auckland, Wellington and Christchurch. This allows a range of heating and cooling loads in populous areas to be modelled.

2.3. Building life

The building's lifetime is assumed to be 90 years. This building life is used by BRANZ for its residential construction LCA work (Dowdell, et al., 2020). While BRANZ cite a paper from 1991 as the source of this assumption, stock-flow modelling conducted internally by thinkstep-anz in 2018 found the same figure (thinkstep-anz, unpublished). A 90-year life is therefore assumed to be typical for detached dwellings in New Zealand.

2.4. Carbon and energy caps

The proposed caps for operational energy under BfCC (MBIE, 2020a, p. 8) are:

- Initial cap: 120 kWh/(m^2.a) for thermal performance and services efficiency.
- Intermediate cap: 60 kWh/(m^2.a) for thermal performance and services efficiency.
- Final cap: 30 kWh/(m^2.a) for thermal performance and services efficiency.

These caps apply to the thermal performance and services only. An additional allowance is given in BfCC for plug loads. The caps are measured in kilowatt hours per square metre of floor area per annum.

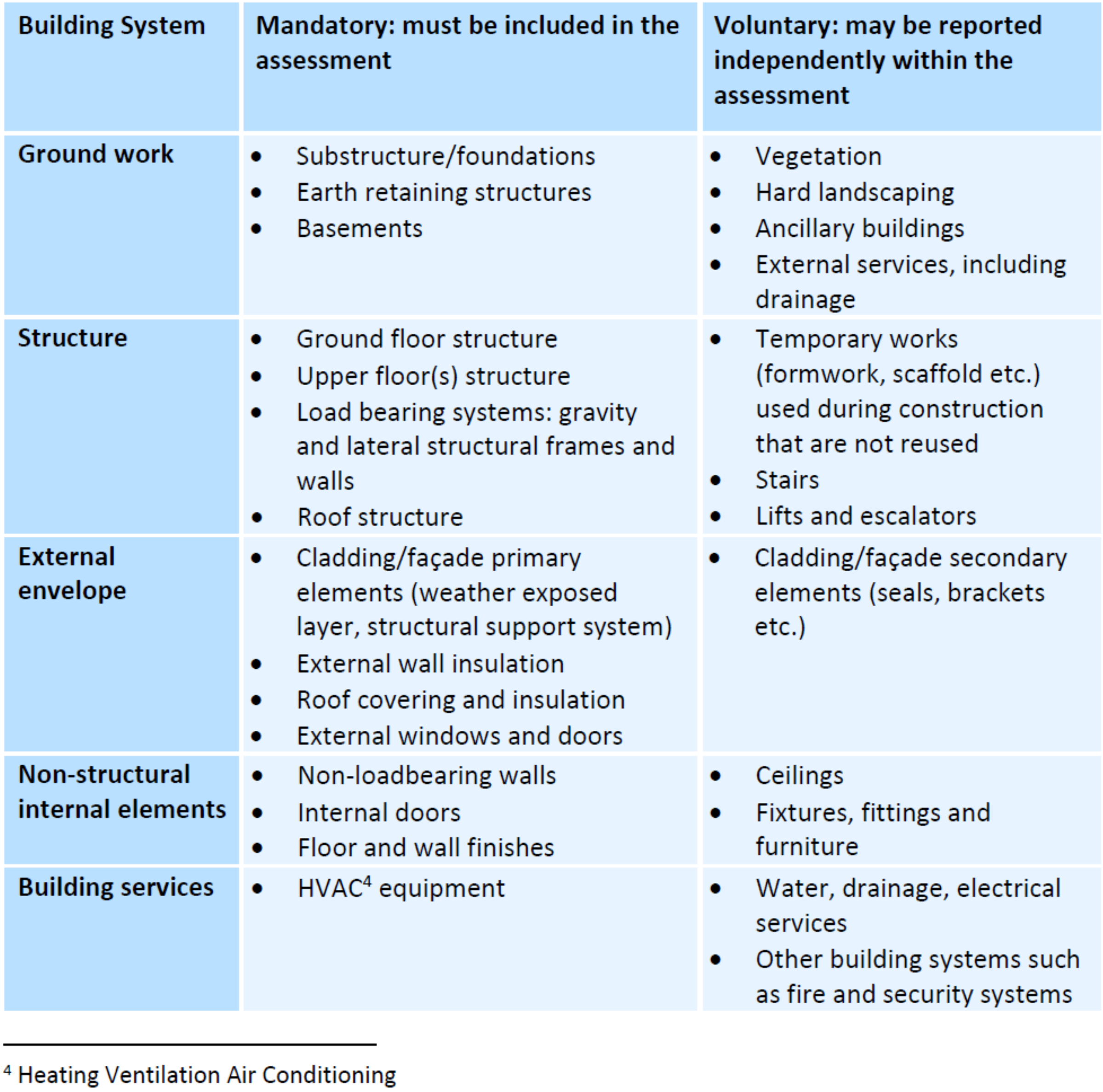
For this project, these caps have been interpreted as follows:

- Building services includes lighting and water heating.
- Thermal performance includes space heating and cooling.
- Plug loads are excluded, i.e., excluding energy for appliances plugged in at the wall.
- The conditioned floor area – and *not* the gross floor area – should be used as the divisor when calculating compliance with the caps. This interpretation follows the definition of "Energy Use Intensity" as "a measure of energy demand or use per square meter of usable floor area within a building per annum" (MBIE, 2020a).

2.5. Scope of building assessed

The items listed in Table 2-3 were included in this study, as required by the *Whole-of-Life Embodied Carbon Assessment: Technical Methodology* for BfCC (MBIE, 2022a). The only exceptions were items not needed for this building (earth retaining structures and basements). Also included in the analysis were some of the voluntary items that were difficult to separate from the rest of the building (notably ceilings and fixtures).

Table 2-3: Scope of building elements (MBIE, 2022a, section 4.1)



Building System	Mandatory: must be included in the assessment	Voluntary: may be reported independently within the assessment
Ground work	• Substructure/foundations • Earth retaining structures • Basements	• Vegetation • Hard landscaping • Ancillary buildings • External services, including drainage
Structure	• Ground floor structure • Upper floor(s) structure • Load bearing systems: gravity and lateral structural frames and walls • Roof structure	• Temporary works (formwork, scaffold etc.) used during construction that are not reused • Stairs • Lifts and escalators
External envelope	• Cladding/façade primary elements (weather exposed layer, structural support system) • External wall insulation • Roof covering and insulation • External windows and doors	• Cladding/façade secondary elements (seals, brackets etc.)
Non-structural internal elements	• Non-loadbearing walls • Internal doors • Floor and wall finishes	• Ceilings • Fixtures, fittings and furniture
Building services	• HVAC[4] equipment	• Water, drainage, electrical services • Other building systems such as fire and security systems

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[4] Heating Ventilation Air Conditioning

2.6. Reporting results

Results are reported using the format suggested in MBIE's *Whole-of-Life Embodied Carbon Assessment: Technical Methodology* (Figure 2-2). Given that the value to be capped is yet to be determined – and that the way to sum results at the building level is not specified by EN 15978:2011 or ISO 21930:2017 – this report considers four options:

- **GWP Upfront:** Global Warming Potential Upfront (EN 15978 modules A1-A5, excluding biogenic carbon). This approach is in line with ISO 14067:2018 for a partial product carbon footprint. It is also the approach adopted in Green Star Design & As Built NZ v1.1 (NZGBC, 2022) (NZ), Green Star Buildings (GBCA, 2021) (Australia), and WLCN/LETI for “Upfront Carbon” (WLCN & LETI, 2021) (UK).
- **GWP A-C EB:** Global Warming Potential for modules A-C Excluding Biogenic carbon (EN 15978 modules A1-A5, B1-B5, C1-C4).
- **GWP A-C IB:** Global Warming Potential for modules A-C Including Biogenic carbon (EN 15978 modules A1-A5, B1-B5, C1-C4). This approach is adopted by WLCN/LETI for “Embodied Carbon” (WLCN & LETI, 2021) and Finland (FME, 2019).
- **GWP A-D IB:** Global Warming Potential for modules A-D Including Biogenic carbon (EN 15978 modules A1-A5, B1-B5, C1-C4, D). This approach is used in France (Légifrance, 2020) and the Netherlands (Rijksoverheid, 2021).

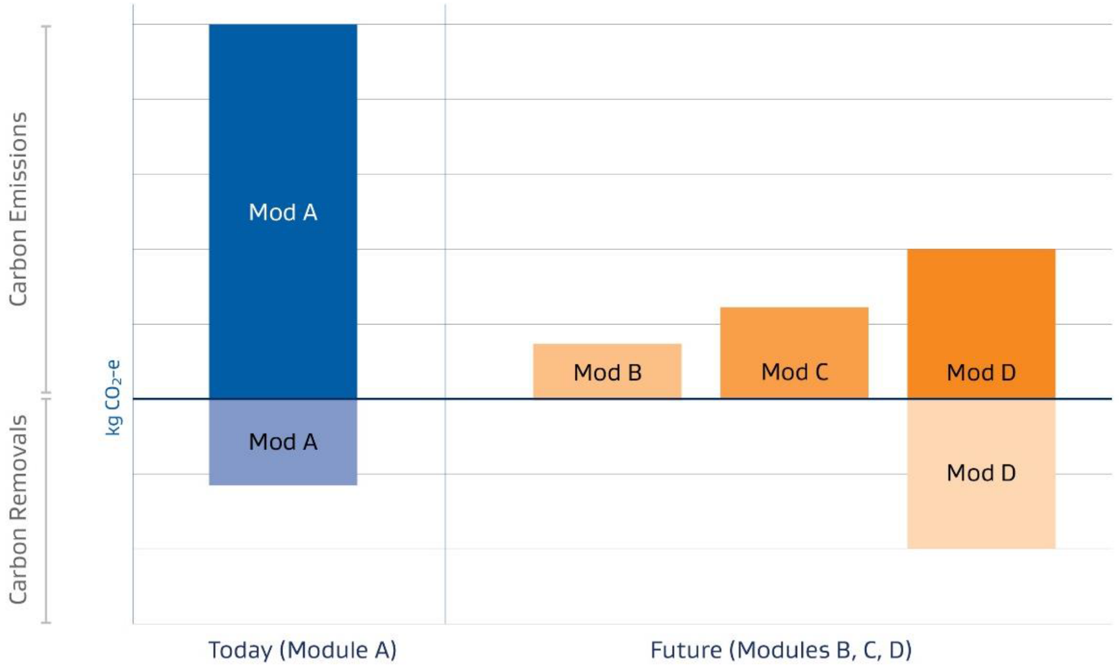

Figure 2-2: Example reporting format for Building for Climate Change (MBIE, 2022a, section 4.5)

3. Definitions and standards

3.1. Embodied carbon versus upfront carbon

This report adopts the World Green Building Council (WorldGBC) definition of embodied carbon as “carbon emissions associated with materials and construction processes throughout the whole lifecycle of a building or infrastructure” (WorldGBC, 2019, p. 5). Carbon emissions are calculated as the “sum of greenhouse gas emissions and greenhouse gas removals in a product system, expressed as CO_2-equivalent (CO_2e) and based on a life cycle assessment using the single impact category of climate change” (ISO, 2018).

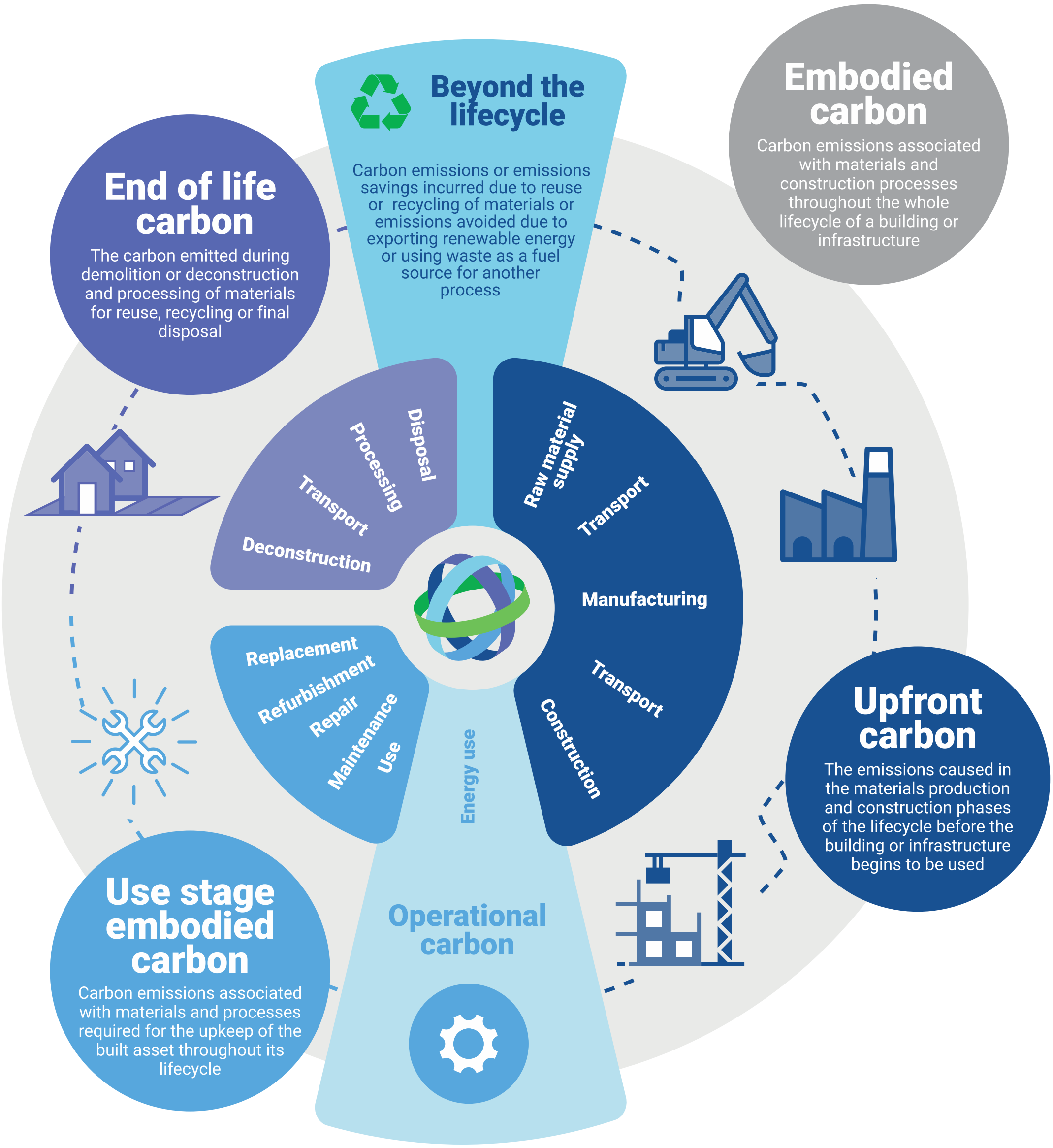

Figure 3-1: Embodied, upfront, use stage, and end-of-life carbon – reproduced from (WorldGBC, 2019)

Embodied carbon can be broken into three parts (Figure 3-1) (WorldGBC, 2019, p. 6):

- **Upfront carbon:** "The [carbon] emissions caused in the materials production and construction phases (A1-5) of the lifecycle before the building or infrastructure begins to be used."
- **Use stage embodied carbon:** "[Carbon] emissions associated with materials and processes needed to maintain the building or infrastructure during use such as for refurbishments [(B1-B5)]."
- **End of life carbon:** "The carbon emissions associated with deconstruction/ demolition (C1), transport from site (C2), waste processing (C3) and disposal (C4) phases of a building or infrastructure's lifecycle which occur after its use."

The life cycle stages included within each term are shown in Figure 3-2. The naming convention applied by WorldGBC follows European standards EN 15804 and EN 15978 for building products and whole buildings, respectively. Modules A1-A5 focus on manufacture of the building products (A1-A3), transport to site (A4) and installation (A5), modules B1-B7 focus on emissions during the building's operating life (including maintenance and repair), modules C1-C4 focus on end-of-life, and module D focuses on credits for avoided production of primary (virgin) materials in future product life cycles due to recycling or reuse.

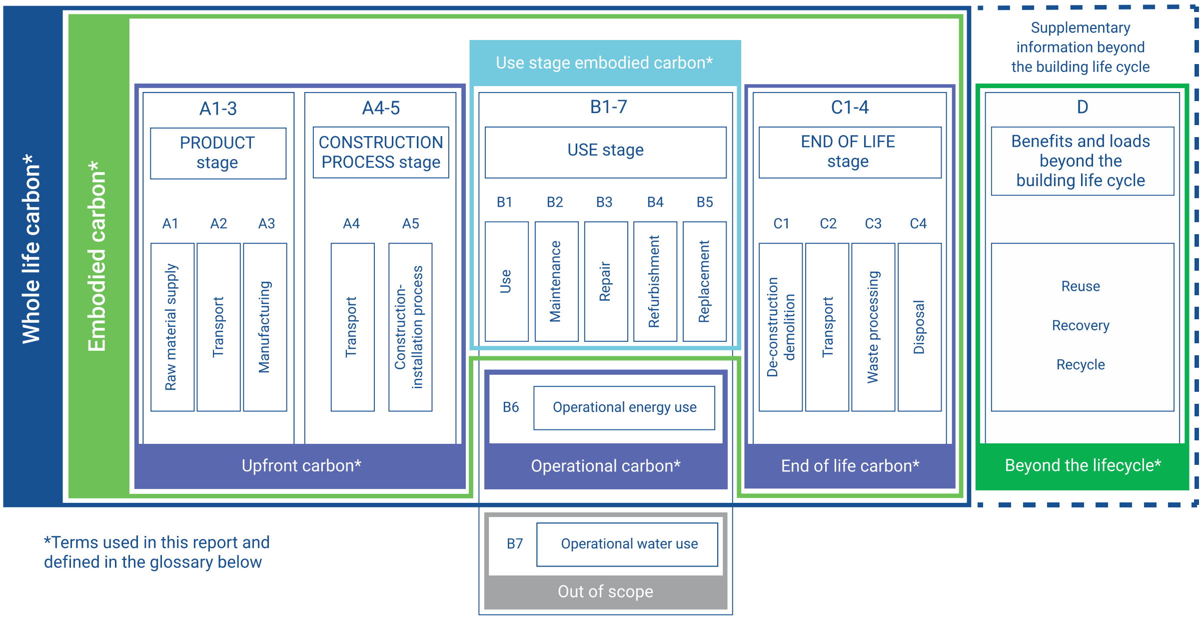

Figure 3-2: Terminology and related life cycle stages – reproduced from (WorldGBC, 2019)

3.2. Operational carbon

Operational carbon is the greenhouse gas emissions caused by operating the building. Following Building for Climate Change's *Transforming Operational Efficiency* (MBIE, 2020a), operational carbon includes:

- Operational energy use (module B6), and
- Operational water use (module B7).

The focus of this report is on operational energy use (module B6) only.

3.3. LCA versus carbon footprinting

Life cycle assessment (LCA) is the “[compilation] and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle” (ISO, 2006a). The LCA method inherently tries to prevent burden shifting – from one time to another, from one place to another, and from one environmental compartment (air, soil, freshwater, saltwater, etc.) to another. As such, LCA always considers multiple footprints: a carbon footprint, a water footprint, a waste footprint, etc.

A **carbon footprint (CF)** is an LCA using Global Warming Potential (GWP) as the sole indicator (ISO, 2018). Both methods share the same framework and approach – the key difference is that LCA considers multiple environmental indicators where a CF only considers climate change.

Importantly, the ISO standards for LCA (ISO 14040 and ISO 14044) and carbon footprinting (ISO 14067) provide a framework for conducting LCA and carbon footprint studies of any product or service. As a result, detailed product-specific rules are needed to be able to make fair comparisons between LCA or CF studies.

3.4. Building LCA and building product EPDs

The terminology for LCA and carbon footprinting of buildings and building products is defined by the following European standards:

- EN 15978:2011 – Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method (CEN, 2011), and
- EN 15804:2012+A2:2019 – Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products (CEN, 2019).

These two standards define the modular structure for reporting life cycle impacts shown in Figure 3-2.

Under these two standards, a building’s life cycle is broken down into life cycle stages:

- “Product stage” (modules A1-A3)
- “Construction process stage” (modules A4-A5)
- “Use stage” (modules B1-B7)
- “End of life stage” (modules C1-C4)

A further module – module D – is added to account for potential credits to future product systems (be they buildings or other products) by reusing, recycling, or recovering (with energy capture) elements of the building at end-of-life.

EN 15978 (CEN, 2011) states:

> “Modules A1 to C4 cover environmental impacts and aspects that are directly linked to processes and operations taking place within the system boundary of the building, while module D provides the net benefits relating to exported energy and secondary materials, secondary fuels or secondary products resulting from reuse, recycling and energy recovery that take place beyond the system boundary.”

EN 15804 is a sister standard for EN 15978. It provides a set of rules – known as a Product Category Rules (PCR) – for creating Environmental Product Declarations (EPDs) of construction products. An EPD is an LCA independently verified against a given PCR.

Importantly, both standards use the same modular structure so that the quantity of each building product installed in a building can simply be multiplied by the impact per unit from an EPD and then added up to get to the building total. (Calculating the total life cycle impacts of the building also requires accounting for energy and water use during construction, construction waste, operational energy use, and maintenance/repair/refurbishment.)

The previous version of EN 15804 – EN 15804+A1 (CEN, 2013) – was the basis for the 2017 update to its international equivalent ISO 21930:2017 (ISO, 2017). As a result, the two standards are very similar. Since this time, EN 15804+A1 has been revised as EN 15804+A2 (CEN, 2019), while ISO 21930 remains as it was. The new version of EN 15804 is similar to the old one, but there are several important changes, e.g., in the choice of environmental indicators, and in how the carbon footprint of bio-based materials such as wood is accounted for.

3.5. Biogenic carbon

Biogenic carbon is “carbon derived from biogenic (plant or animal) sources excluding fossil carbon” (ISO, 2018). More specifically, biogenic carbon is carbon dioxide removed from the atmosphere through photosynthesis by living things that is then transformed into other carbon-based compounds and stored within a plant or animal – be it the trunk of a tree, or the wool of a sheep (through eating grass). The process of removing carbon dioxide from the atmosphere helps to mitigate climate change. For short-lived products, such as food, this process is typically short-lived, with the stored carbon being released back to the atmosphere as either carbon dioxide (CO_2) or methane (CH_4) relatively quickly, effectively cancelling out any net benefit. For long-lived products such as those used in buildings, this atmospheric CO_2 will often be stored within the building for several decades, and sometimes hundreds of years. While this is a temporary effect, removing carbon dioxide from the atmosphere and storing it for several decades can help to buy time for further carbon reduction technologies and methods to be developed.

Biogenic carbon stored in wood products within buildings is governed by EN 16485:2014 (CEN, 2014), a sister standard to EN 15804+A1. A new version is currently in preparation to partner with EN 15804+A2, but it is not yet finalised.

4. Carbon and cost modelling

4.1. Introduction

Decarbonising a building typically requires:

- Optimising the thermal envelope of the building for the local climate to minimise energy used for heating/cooling over the building's design life.
- Installing high efficiency building heating/cooling and water heating systems, such as heat pumps.
- Reducing the embodied carbon in building materials, while ensuring that they are still durable enough not to lead to a higher carbon footprint over the building's life.

Embodied carbon can be reduced in two ways:

- Demand-side measures, such as reducing the size of the building, substituting high-carbon materials for low-carbon materials, and reducing construction waste on-site.
- Supply-side measures, such as manufacturers switching to renewable energy, using lower-carbon raw materials, and switching to lower carbon manufacturing processes.

This report focuses on one demand-side measure: material substitution. The potential benefits of material substitution are based primarily on published EPD data available through BRANZ's LCA databases. Reducing the floor area of the building was explicitly out of the scope of this analysis because BfCC's proposed caps were designed on a per square metre basis. Reductions in building waste on site were also out of scope as the savings were not considered to be large enough to materially impact the embodied carbon of the building. (For evidence of this final point, see Figure 6-1 of thinkstep-anz (2019) where construction waste is 6% of total upfront carbon and 7% of whole-of-life embodied carbon for a residential building. These figures include manufacture, transport and disposal of wasted materials. Even if waste was halved, this would only reduce the whole-of-life carbon footprint by 3%.)

Supply-side measures were investigated in detail through an earlier project conducted by thinkstep-anz for the New Zealand Green Building Council (thinkstep-anz, 2019). Supply-side and demand-side measures can be complementary in some cases, which can increase the savings made.

In the presence of embodied carbon caps set through BfCC in the future, it must be expected that building product suppliers will take action to decarbonise their products more rapidly. As a result, many of the assemblies available through BRANZ's LCA databases will start to decarbonise rapidly (where this is technically feasible), which may change the preference order for some materials over time.

4.2. Method

This study uses assembly-level modelling (rather than elemental-level modelling) to calculate operational energy/carbon and embodied carbon for the reference building with different levels of thermal performance and different material combinations.

The embodied carbon modelling considers 22,032 unique combinations of building elements, comprising:

- 6 roof options,
- 17 envelope wall options,
- 6 internal wall options,
- 12 floor options, and
- 3 window options.

Changes are applied for the whole area of each building element. One exception is for the double internal garage, which is always modelled as an uninsulated concrete slab.

The embodied carbon of the building is assumed to be identical, regardless of where it is built in New Zealand. The author considers this to be a reasonable assumption given that embodied carbon in the building is largely due to the building products themselves (which are sold nationally), with transport to site playing a relatively minor role in the building's whole-of-life carbon footprint.

The operational energy/carbon modelling considers a reduced number of scenarios. A total of 13 groups were identified from the 22,032 combinations above, where roof/floor/wall assemblies were grouped by similar R values. On top of this, three regional scenarios are applied (Auckland, Wellington, Christchurch) for a total of 39 scenarios.

4.3. Primary data sources

- LCAQuick (Dowdell, et al., 2020) was used for the reference building, with additional data supplied directly by BRANZ.
- BRANZ CO_2RE v1.0 (known as MaCC during the beta testing phase) was used for carbon footprint and thermal resistance (R-value) data for common residential roof, wall, and floor assemblies (BRANZ, 2021).
- BRANZ LCA Quick v3.5 was used to calculate the embodied carbon in internal wall assemblies (BRANZ, 2021).
- Homestar Embodied Carbon Calculator (HECC) was used to calculate the embodied carbon in the window assemblies (NZGBC & BRANZ, 2021).
- Building energy modelling was conducted by Mott MacDonald for the reference building (Mott MacDonald, 2022).
- Quantity surveying for the reference building was conducted by Linda Lodetti at Prendos (Lodetti, 2021).
- Future electricity grid emissions intensities (kg CO_2e/kWh) were supplied by MBIE for all years until 2050 (see Figure 4-2).

4.4. Key assumptions

- Cost data reflects the final quarter of 2021 (October to December 2021). Given that New Zealand (like many other countries) is currently experiencing rapid price inflation and supply chain shortages, the goal was not to try to predict future prices, but rather to reflect prices in late 2021.
- All replacement cycles follow BRANZ's defaults, shown in Table 4-1.
- Long-run steel is zinc/aluminium coated with a 0.4mm base metal thickness (modelled as COLORSTEEL ENDURA) in exposure zone C. Exposure zone C was selected as it contains most of New Zealand's housing stock (including most of Auckland, Wellington, Tauranga, Christchurch, and Dunedin). Hamilton is the only large New Zealand city that falls inside exposure zone B. Based on BRANZ's default lifetime assumptions, a zinc/aluminium coated steel roof will have a 30-year life in exposure zone C (i.e., two replacements during the building's life) versus 45 years in exposure zone B (i.e., only one replacement).
- All windows and doors have been modelled based on square metre rates calculated from a 'typical' window in New Zealand (Figure 4-1). (As New Zealand does not have standardised dimensions for windows, there is no true typical window.)
- Electricity (which determines operational carbon) decarbonises following Figure 4-2. The grid is assumed to remain constant after 2050. (Compliance with BfCC is not affected by energy decarbonisation as the caps are set based on energy.)

Table 4-1: Material replacement cycles assumed

Material	Lifetime (years)	Replacements
Roofing		
Long-run steel with zinc/aluminium metal coating	30	2
Concrete and clay tile	75	1
Membrane	25	3*
Envelope wall		
Bevel-back weatherboard	60	1
Fibre-cement weatherboard	50	1
Long-run steel	15-30	3
Brick veneer	60-100	0
Exterior Insulated Cladding and Finishing System (EIFS)	50	1
Windows and external doors		
Aluminium framed	30**	2**
Timber framed	30**	2**
uPVC	30**	2**

* Despite its lower life, many membrane roofs can be repaired by laying new material over the old material, reducing the impact of the replacement when compared to other roofing materials.

** BRANZ indicates a 60-year life for aluminium and timber windows and 45 years for uPVC. However, BRANZ's carbon calculator developed for NZGBC for use in Homestar v5 uses a 30-year replacement cycle for windows which use an Insulated Glazing Unit (IGU). All windows in this study use IGUs and, as such, a 30-year life from the Homestar Embodied Carbon Calculator was applied in this study.

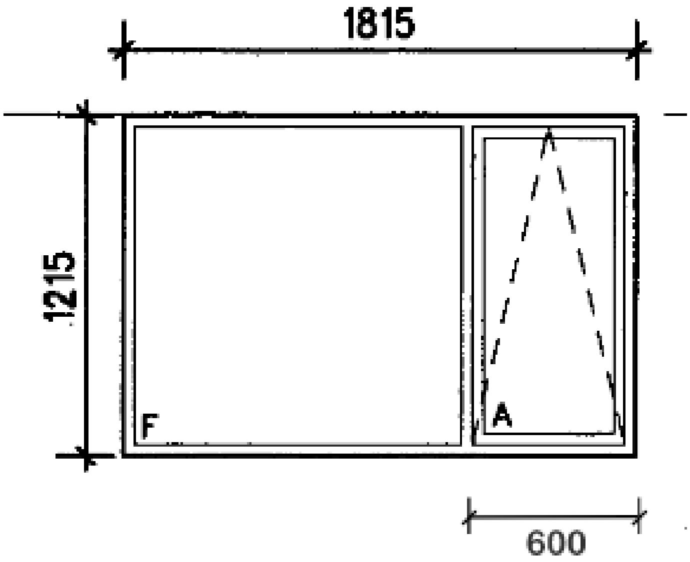

Figure 4-1: Assumed dimensions of a 'typical' window in New Zealand

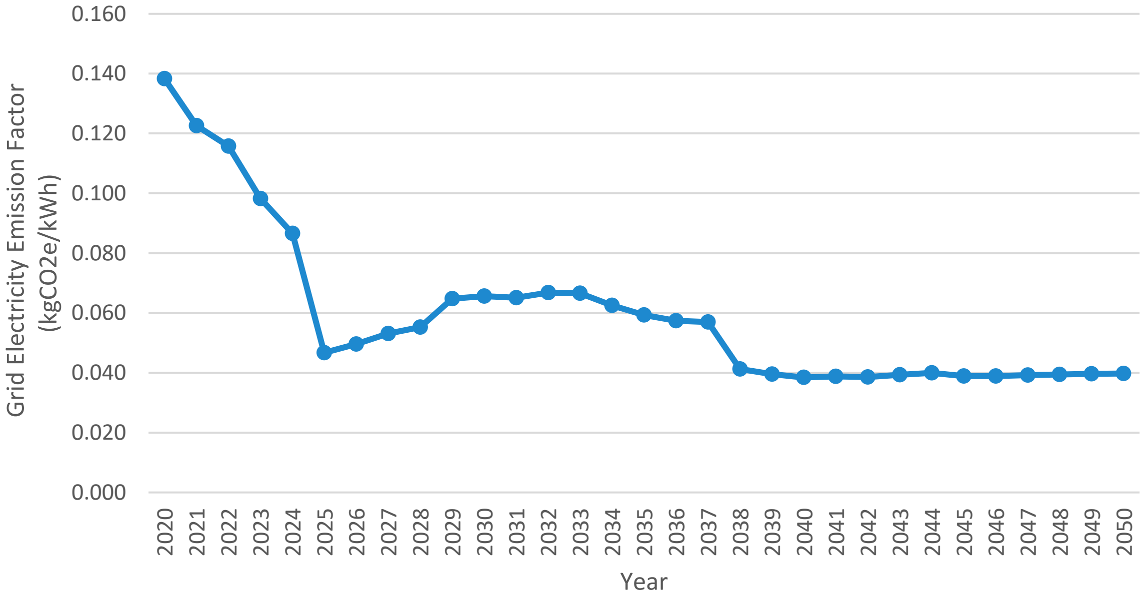

Figure 4-2: Electricity grid carbon emissions until 2050, based on data supplied by MBIE for this project

4.5. Energy modelling scenarios

Energy modelling was conducted by Mott MacDonald using the dimensions of the reference house in three different cities (Auckland, Wellington, Christchurch) (Mott MacDonald, 2022). All operational energy simulations were conducted following NZS 4218:2009 using the Integrated Environmental Solutions Virtual Environment (IES VE) software version 2021. All energy modelling was done at a building system level (rather than an elementary level).

13 combinations of building elements ("scenarios") were modelled for each city, for a total of 39 scenarios. The 13 scenarios for Auckland and Wellington are the same as the thermal

requirements are identical, meaning the only difference was the climate simulation. Different base case R values were used for Christchurch due to different thermal requirements. The base case analysis used 2020 weather data. Sensitivity analyses were run using forecast weather data for 2050 (with +1.5°C climate shift) and 2080 (with +3.0°C climate shift) based on the Climate Change World Weather File Generator (CCWorldWeatherGen) tool, published by the University of Southampton.

A summary of the modelling inputs used by Mott MacDonald is provided below in Table 4-2. The scenarios included for each region were:

1. **H1: Benchmark scenario for H1 2019 compliance.** It is important to note that the analysis was conducted to Building Code H1 4th Edition (MBIE, 2019) and does not account for the more recent H1 5th Edition (MBIE, 2022b).
2. **H1 Roof 1:** H1 2019 scenario with increased **roof insulation** only.
3. **H1 W1:** H1 2019 scenario with increased **wall insulation** only.
4. **H1 F1:** H1 2019 scenario with increased **floor insulation** only.
5. **H1 F2:** H1 2019 scenario with increased **floor insulation** and **timber floor**.
6. **H1 Window 1:** H1 2019 scenario with improved **window frame** only.
7. **S1:** Combination of scenarios 2 to 4. Broadly representative of a typical house in September/October 2021 when the modelling was conducted.
8. **S2 Concrete:** Scenario 7 with increased **floor insulation** only.
9. **S2 Low G Concrete:** Scenario 7 with increased **floor insulation** and improved **solar control glass**.
10. **S3:** Scenario 7 with increased **floor insulation** and **timber floor**.
11. **S3 High R frame:** Scenario 7 with increased **floor insulation**, **timber floor** and improved **window frame**.
12. **S3 Low G value:** Scenario 7 with increased **floor insulation**, **timber floor** and improved **solar control glass**.
13. **S4:** Scenario 7 scenario with increased **floor insulation**, improved **window frame** and improved **solar control glass**.

Table 4-2: Scenarios considered in building energy modelling

Region	Scenario	Roof R	Wall R	Floor R	Window R
AKL	H1 AKL	3	1.9	1.2	0.26
AKL	H1 AKL Roof 1	4.3	1.9	1.2	0.26
AKL	H1 AKL W1	3	3.1	1.2	0.26
AKL	H1 AKL F1	3	1.9	2.1	0.26
AKL	H1 AKL F2	3	1.9	2.8	0.26
AKL	H1 AKL Window1	3	1.9	1.2	0.36
AKL	S1 AKL	4.3	3.1	2.1	0.26
AKL	S2 AKL Concrete	4.3	3.1	2.8	0.26
AKL	S2 Low G Concrete	4.3	3.1	2.8	0.26
AKL	S3 AKL	4.3	3.1	2.8	0.26
AKL	S3 High R frame	4.3	3.1	2.8	0.36

Region	Scenario	Roof R	Wall R	Floor R	Window R
AKL	S3 AKL Low G value	4.3	3.1	2.8	0.26
AKL	S4	4.3	3.1	2.8	0.36
WLG	H1 WLG	3	1.9	1.2	0.26
WLG	H1 WLG Roof 1	4.3	1.9	1.2	0.26
WLG	H1 WLG W1	3	3.1	1.2	0.26
WLG	H1 WLG F1	3	1.9	2.1	0.26
WLG	H1 WLG F2	3	1.9	2.8	0.26
WLG	H1 WLG Window1	3	1.9	1.2	0.36
WLG	S1 WLG	4.3	3.1	2.1	0.26
WLG	S2 WLG Concrete	4.3	3.1	2.8	0.26
WLG	S2 Low G Concrete	4.3	3.1	2.8	0.26
WLG	S3 WLG	4.3	3.1	2.8	0.26
WLG	S3 High R frame	4.3	3.1	2.8	0.36
WLG	S3 Low G Value	4.3	3.1	2.8	0.26
WLG	S4	4.3	3.1	2.8	0.36
CHC	H1 CHC	3.1	2	1.2	0.26
CHC	H1 CHC Roof 1	4.3	2	1.2	0.26
CHC	H1 CHC W1	3.1	3.1	1.2	0.26
CHC	H1 CHC F1	3.1	2	2.1	0.26
CHC	H1 CHC F2	3.1	2	2.8	0.26
CHC	H1 CHC Window1	3.1	2	2.8	0.36
CHC	S1 CHC	4.3	3.1	2.1	0.26
CHC	S2 CHC Concrete	4.3	3.1	2.8	0.26
CHC	S2 Low G concrete	4.3	3.1	2.8	0.26
CHC	S3 CHC	4.3	3.1	2.8	0.26
CHC	S3 High R frame	4.3	3.1	2.8	0.36
CHC	S3 Low G Value	4.3	3.1	2.8	0.26
CHC	S4	4.3	3.1	2.8	0.36

5. Operational energy and carbon

The key outputs from the energy modelling conducted by Mott MacDonald are presented in Table 5-1 below. All thermal performance results are based on 2020 weather data. Services efficiency includes both lighting and water heating, though in practice almost all is water heating (calculated as 5 MWh for water heating vs. 0.19 MWh for lighting).

Table 5-1: Key outputs from energy modelling

Region	Scenario	Thermal performance (kWh/m².a)	Services efficiency (kWh/m².a)	Electricity excl. plug-loads (kWh/m².a)
AKL	H1 AKL	28.44	29.49	57.93
AKL	H1 AKL Roof 1	27.87	29.49	57.36
AKL	H1 AKL W1	28.07	29.49	57.56
AKL	H1 AKL F1	28.04	29.49	57.53
AKL	H1 AKL F2	38.25	29.49	67.74
AKL	H1 AKL Window1	28.44	29.49	57.93
AKL	S1 AKL	27.19	29.49	56.68
AKL	S2 AKL Concrete	27.13	29.49	56.62
AKL	S2 Low G Concrete	26.59	29.49	56.08
AKL	S3 AKL	36.87	29.49	66.36
AKL	S3 High R frame	38.34	29.49	67.83
AKL	S3 AKL Low G value	34.06	29.49	63.55
AKL	S4	26.88	29.49	56.37
WLG	H1 WLG	24.23	29.49	53.72
WLG	H1 WLG Roof 1	23.13	29.49	52.62
WLG	H1 WLG W1	23.10	29.49	52.59
WLG	H1 WLG F1	22.98	29.49	52.47
WLG	H1 WLG F2	32.46	29.49	61.95
WLG	H1 WLG Window1	22.16	29.49	51.65
WLG	S1 WLG	20.77	29.49	50.26
WLG	S2 WLG Concrete	20.26	29.49	49.75
WLG	S2 Low G Concrete	21.16	29.49	50.65
WLG	S3 WLG	29.49	29.49	58.98
WLG	S3 High R frame	30.17	29.49	59.66
WLG	S3 Low G Value	28.15	29.49	57.64
WLG	S4	19.15	29.49	48.64
CHC	H1 CHC	27.93	29.49	57.42
CHC	H1 CHC Roof 1	26.76	29.49	56.25

Region	Scenario	Thermal performance (kWh/m².a)	Services efficiency (kWh/m².a)	Electricity excl. plug-loads (kWh/m².a)
CHC	H1 CHC W1	26.39	29.49	55.88
CHC	H1 CHC F1	26.19	29.49	55.68
CHC	H1 CHC F2	38.45	29.49	67.94
CHC	H1 CHC Window1	26.36	29.49	55.85
CHC	S1 CHC	22.39	29.49	51.88
CHC	S2 CHC Concrete	21.59	29.49	51.08
CHC	S2 Low G concrete	22.07	29.49	51.56
CHC	S3 CHC	37.13	29.49	66.62
CHC	S3 High R frame	37.10	29.49	66.59
CHC	S3 Low G Value	33.72	29.49	63.21
CHC	S4	20.74	29.49	50.23

The results of the energy modelling (Table 5-1) relative to BfCC's thermal performance and services efficiency caps (excluding plug loads) can be summarised as follows:

- **Auckland:** All scenarios modelled meet the initial cap proposed by BfCC. No scenarios meet the final proposed cap. All scenarios with concrete slab floors meet the intermediate proposed cap (though they are mostly quite close to the cap). All scenarios with a suspended timber floor do not meet the intermediate proposed cap, with scenario "S3 AKL Low G value" being the closest to meeting the cap but still not meeting it. The reason for this appears to be predominantly the higher cooling loads in Auckland during warm months to keep the building at or below 25°C. This reflects modelling to NZS 4218:2009. While it is important to have clear thermal comfort targets to make modelling consistent, it is quite possible that many building occupants would not always have their air conditioning on when the temperature is above 25°C.
- **Wellington:** All scenarios modelled meet the initial and intermediate proposed caps, except for scenario "H1 WLG F2" which narrowly misses it. No scenarios meet the final proposed cap.
- **Christchurch:** All scenarios modelled meet the initial cap proposed by BfCC. No scenarios meet the final proposed cap. Like Auckland, those scenarios with concrete slab floors meet the intermediate proposed cap and those with suspended timber floors do not. This is predominantly due to winter heating loads and to a lesser extent due to summer cooling loads.

Three general findings can also be drawn from the energy modelling results:

- **Achieving BfCC's final proposed services efficiency cap will likely require high efficiency (e.g., heat pump) water heating.** All scenarios in this study used direct electric hot water cylinders. As can be seen in Table 5-1, direct electric water heating consumes approximately as much energy as building heating and cooling for the reference building.

- **Changes in building design to optimise the thermal envelope will be needed to achieve BfCC's final proposed thermal performance cap.** This study took a conventional freestanding residential house and improved the R values of the components, with no changes to building design. The outcome was that none of the scenarios modelled in this study met the final proposed cap and most were not close to doing so.
- **Concrete slab floors outperformed suspended timber floors for thermal performance.** This was most noticeable in cities where there is greater variation in temperature across the year (Auckland and Christchurch) and least noticeable in Wellington where the temperature is more stable throughout the year. From discussions with Mott MacDonald, this was because the thermal mass in the concrete provides a buffer to changing air temperatures due to external radiation, allowing for greater passive smoothing of indoor air temperatures.

To simplify the remaining modelling, operational and embodied carbon are treated as independent variables for optimisation in the next two chapters, with the two brought back together in the conclusions and interpretation. The full database provided in Excel format alongside this report does allow each building configuration to be tested against both operational energy/carbon and embodied carbon.

6. Embodied carbon at the assembly level

This section presents the carbon footprint results per building element (roofs, external walls, internal walls, floors, windows). The results are first presented at the building level and then as square metre rates with a greater level of breakdown. GWPIB is the Global Warming Potential including biogenic carbon. GWPEB is the Global Warming Potential excluding biogenic carbon. Both indicators include all fossil carbon releases. The difference between them is that GWPIB includes the removal of carbon dioxide from the atmosphere during tree growth, assuming sustainably managed forestry (i.e., a negative carbon footprint a start-of-life), and corresponding emissions at end-of-life (i.e., a positive carbon footprint at end-of-life). GWPEB follows national carbon accounts and excludes carbon removals at start-of-life and carbon emissions at end-of-life, only accounting for non-neutral emissions of greenhouse gases (such as releases of methane from landfills). Refer to section 2.6 for further discussion of these indicators.

The BRANZ reference numbers in the tables in this section refer to the numbers in BRANZ's CO_2RE tool (known as MaCC through the beta testing process). All data derive from CO_2RE v1.0, except for windows (which come from NZGBC's Homestar Embodied Carbon Calculator) and internal walls (which were calculated in LCAQuick v3.5).

Key findings at the building element level are:

- **Roofs:** All roofs with a timber frame have similar upfront carbon. However, tiles and membrane outperform long-run corrugated steel over the full building life cycle. For tiles, this is because they are longer lasting, requiring only one replacement over the building's assumed 90-year life, versus two for steel (in exposure zone C). While the membrane roof is not longer-lasting than steel, a new waterproofing layer can typically be laid over the top of the old one – a repair with low embodied carbon. The one roof considered with steel trusses had a considerably higher carbon footprint than those with wooden trusses for both upfront carbon and embodied carbon. For long-run corrugated steel, one option seems to be to move from zinc-aluminium metal coating (currently the most common coating) to zinc-aluminium-magnesium (ZAM) as ZAM offers better corrosion resistance. Fletcher Steel already has a ZAM coated product on the market (under the brand name ColorCote MagnaFlow).
- **External walls:** Bevel-back weatherboards on a timber frame have the lowest upfront and embodied carbon. Fibre-cement weatherboard on a timber frame performs similarly well. Brick veneer performs reasonably well, particularly over the full life cycle due to its inherent durability. The Exterior Insulation Finishing System (EIFS) performs reasonably well for both upfront and life cycle embodied carbon. Long-run steel has a low upfront carbon footprint but has poor life cycle embodied carbon due to multiple replacements in exposure zone C (as assumed for this project) – it would perform better in exposure zone B. Concrete block has the highest upfront carbon and among the highest whole-of-life carbon footprints. Steel framing

has a higher carbon footprint than timber framing for both upfront and embodied carbon.

- **Internal walls:** Most internal wall systems are reasonably similar. 9 mm thick ply over steel stud has the worst performance. Steel frame has a somewhat higher upfront carbon footprint than timber frame, but it performs similarly over the full life cycle if biogenic carbon is excluded.
- **Floors:** Suspended timber floors have an upfront carbon footprint approximately three times lower than concrete systems (concrete slab and waffle pod), while also offering considerable improvements over whole-of-life.
- **Windows:** The carbon footprint of windows is broadly comparable. Timber has slightly lower upfront carbon than the others. uPVC has slightly lower whole-of-life carbon. When biogenic carbon is included, timber is far lower carbon.
- **Other:** The total of other items outside the scope of these main assemblies is quite significant, particularly over the full life over the building due to the number of replacement cycles.

6.1. Results per building element at the building level

Table 6-1: Roof assemblies for the reference building

BRANZ Reference	Description	R Value (m^2 °C/W)	GWP Upfront (kg CO$_2$e)	GWP A-C EB (kg CO$_2$e)	GWP A-C IB (kg CO$_2$e)	GWP A-D IB (kg CO$_2$e)
49.0	Concrete or clay tile - Timber-framed roof with roof space, 90 mm ceiling joists or bottom chords 15 degree pitch, Pink® Batts® Classic R3.2 Ceiling insulation, 70 x 35 mm timber battens	3.1	8,204	18,492	11,636	10,807
49.4	Concrete or clay tile - Timber-framed roof with roof space, 90 mm ceiling joists or bottom chords 15 degree pitch, Pink® Batts® Ultra® R5.0 Ceiling insulation, 70 x 35 mm timber battens	4.43	8,535	18,825	11,970	11,126
29.8	Profiled steel - Timber-framed roof with roof space, 90 mm ceiling joists or bottom chords 15 degree pitch, timber trusses, Pink® Batts® Ultra® R5.0 Ceiling insulation, 70 x 35 mm timber battens @ 600 mm centres	4.3	8,763	25,586	20,896	15,919
29.0	Profiled steel - Timber-framed roof with roof space, 90 mm ceiling joists or bottom chords 15 degree pitch, timber trusses, Pink® Batts® Classic R3.2 Ceiling insulation, 70 x 35 mm timber battens @ 600 mm centres	3.1	8,470	25,290	20,601	15,636
29.7	Profiled steel - Timber-framed roof with roof space, 90 mm ceiling joists or bottom chords 15 degree pitch, steel trusses with thermal breaks, Pink® Batts® Classic R3.2 Ceiling insulation, steel battens @ 600 mm centres	3	13,426	29,107	28,274	22,476
59.2	Membrane - Low slope timber framed, 140 mm rafters and battens 1.5 mm butyl rubber membrane, Pink® Batts® Classic R3.6 Ceiling insulation, rafters @ 600 mm centres	3.4	6,386	16,626	8,803	8,277

Table 6-2: External wall assemblies for the reference building

BRANZ Reference	Description	R Value (m^2 °C/W)	GWP Upfront (kg CO_2e)	GWP A-C EB (kg CO_2e)	GWP A-C IB (kg CO_2e)	GWP A-D IB (kg CO_2e)
67.2	Bevel-back weatherboard - Timber-framed, cavity, 140 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R4.0 140 mm Wall insulation	3.2	3,063	9,845	-1,315	-2,598
66.0	Bevel-back weatherboard - Timber-framed, cavity, 90 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Classic R2.2 Wall insulation	2	2,545	8,871	-963	-2,086
74.0	Bevel-back weatherboard - Steel-framed, direct-fixed, 90 mm frame steel studs @ 600 mm centres, dwangs @ 800 mm (14.4% framing ratio), Pink® Batts® Steel R2.2 Wall insulation	2	4,248	9,672	2,681	1,337
83.0	Sheet cladding - Timber-framed, cavity, 140 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R3.2 140 mm Wall insulation	2.6	3,532	9,167	4,885	4,284
97.2	Fibre-cement weatherboard - Timber-framed, cavity, 140 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R4.0 140 mm Wall insulation	3	4,403	10,726	6,444	5,784
96.0	Fibre-cement weatherboard - Timber-framed, cavity, 90 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R2.8 Wall insulation	2.1	4,076	9,944	6,989	6,480
100.0	Fibre-cement weatherboard - Steel-framed, direct-fixed, 90 mm frame studs @ 600 mm centres, dwangs 800 mm centres (14.4% framing ratio), Pink® Batts® Ultra® R2.8 Wall insulation	2	5,948	11,102	10,990	10,248
91.4	Masonry veneer - Timber-framed, cavity, 140 mm frame 70 mm clay brick masonry, studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R4.0 140 mm Wall insulation	3.1	7,990	10,934	7,007	6,323
91.5	Masonry veneer - Timber-framed, cavity, 140 mm frame 90 mm clay brick masonry, studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R4.0 140 mm Wall insulation	3.1	9,763	12,772	8,844	8,097
90.4	Masonry veneer - Timber-framed, cavity, 90 mm frame 70 mm clay brick masonry, studs @ 400 mm centres, dwangs 800	2.1	7,662	10,152	7,552	7,020

BRANZ Reference	Description	R Value (m^2 °C/W)	GWP Upfront (kg CO_2e)	GWP A-C EB (kg CO_2e)	GWP A-C IB (kg CO_2e)	GWP A-D IB (kg CO_2e)
	mm centres (18% framing ratio), Pink® Batts® Classic R2.8 Wall insulation					
92.0	Masonry veneer - Steel-framed, cavity, 90 mm frame 70 mm clay brick masonry, studs @ 600 mm centres, dwangs 800 mm centres (14.4% framing ratio), Pink® Batts® Ultra® R2.8 Wall insulation	2	9,464	11,174	11,061	10,268
105.2	Metal - Timber-framed, cavity, 140 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R4.0 140 mm Wall insulation	3.1	5,247	25,940	22,012	16,464
104.0	Metal - Timber-framed, cavity, 90 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R2.8 Wall insulation	2.1	4,920	25,158	22,557	17,160
106.0	Metal - Steel-framed, cavity, 90 mm frame studs @ 600 mm centres, dwangs 800 mm centres (14.4% framing ratio), Pink® Batts® Ultra® R2.8 Wall insulation	2	6,807	26,345	25,997	20,313
107.0	EIFS - Timber-framed, cavity, 90 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Classic R2.2 Wall insulation	2.4	4,211	13,691	9,865	9,363
107.2	EIFS - Timber-framed, cavity, 90 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R2.8 Wall insulation	2.6	4,402	13,884	10,057	9,547
111.1	Concrete block - Strapped and lined/false wall 200 series masonry, studs @ 600 mm centres, dwangs 1200 mm centres (12% framing ratio), Pink® Batts® Classic R2.2 70 mm Wall insulation	1.9	14,612	19,368	17,377	16,694

Table 6-3: Internal wall assemblies for the reference building

BRANZ Reference	Description	R Value (m^2 °C/W)	GWP Upfront (kg CO_2e)	GWP A-C EB (kg CO_2e)	GWP A-C IB (kg CO_2e)	GWP A-D IB (kg CO_2e)
n/a (#1)	10 mm thick GIB both sides, Timber framed, 90 mm wall frame, Dwangs @ 800 mm centres, studs @ 400 mm centres	n/a	1,061	2,437	276	33

BRANZ Reference	Description	R Value (m^2 °C/W)	GWP Upfront (kg CO_2e)	GWP A-C EB (kg CO_2e)	GWP A-C IB (kg CO_2e)	GWP A-D IB (kg CO_2e)
n/a (#2)	13 mm thick GIB both sides, Timber framed, 90 mm wall frame, Dwangs @ 800 mm centres, studs @ 400 mm centres	n/a	1,285	2,721	561	317
n/a (#3)	10 mm thick GIB both sides, steel stud wall system, 92.1x33.1 0.55 BMT @ 450ctrs, 1 nogging row	n/a	1,763	2,435	2,435	2,160
n/a (#4)	13 mm thick GIB both sides, steel stud wall system, 92.1x33.1 0.55 BMT @ 450ctrs, 1 nogging row	n/a	1,987	2,719	2,719	2,444
n/a (#5)	9 mm thick ply both sides, Timber framed, 90 mm wall frame, Dwangs @ 800 mm centres, studs @ 400 mm centres	n/a	1,963	3,003	-1,516	-1,770
n/a (#6)	9 mm thick ply both sides, steel stud wall system, 92.1x33.1 0.55 BMT @ 450ctrs, 1 nogging row	n/a	2,665	3,002	642	356

Table 6-4: Floor assemblies for the reference building*

BRANZ Reference	Description	R Value (m^2 °C/W)	GWP Upfront (kg CO_2e)	GWP A-C EB (kg CO_2e)	GWP A-C IB (kg CO_2e)	GWP A-D IB (kg CO_2e)
118.8	Suspended timber - Open perimeter, bulk insulants with lining, 190/290 mm joists 290 x 45 mm joists @ 600 mm centres, 19 mm CD ply flooring with slip tongues (no dwangs to joints), Pink® Batts® SnugFloor® R2.6 insulation	3	7,511	11,433	3,160	2,243
120.24	Suspended timber - Closed perimeter, bulk insulants with lining, 190/290 mm joists 290 x 45 mm joists @ 600 mm centres, 19 mm CD slip tongue ply flooring (no dwangs), Pink® Batts® SnugFloor® R2.6 insulation, A/P ratio 2.5	2.8	7,311	11,057	1,821	827
118.11	Suspended timber - Open perimeter, bulk insulants with lining, 190/290 mm joists 290 x 45 mm joists @ 450 mm centres, 20 mm T&G flooring (to suit joists @ 450 mm centres), Pink® Batts® SnugFloor® R2.6 insulation	3	8,069	13,296	2,328	929

BRANZ Reference	Description	R Value (m^2 °C/W)	GWP Upfront (kg CO_2e)	GWP A-C EB (kg CO_2e)	GWP A-C IB (kg CO_2e)	GWP A-D IB (kg CO_2e)
120.27	Suspended timber - Closed perimeter, bulk insulants with lining, 190/290 mm joists 290 x 45 mm joists @ 450 mm centres, 20 mm T&G flooring (to suit joists @ 450 mm centres), Pink® Batts® SnugFloor® R2.6 insulation, A/P ratio 2.5	2.8	7,869	12,919	988	-488
117.4	Suspended timber - Open perimeter, bulk insulants with lining, 90/140 mm joists 90 x 45 mm joists @ 600 mm centres, 19 mm CD ply flooring with slip tongues (no dwangs to joints), Pink® Batts® SnugFloor® R1.6 insulation	1.7	6,818	9,755	4,356	3,768
119.2	Suspended timber - Closed perimeter, bulk insulants without lining, 90/140 mm joists 90 x 45 mm joists @ 600 mm centres, 19 mm CD slip tongue ply flooring (no dwangs), Pink® Batts® SnugFloor® R1.6 insulation, A/P ratio 2.5	1.8	7,395	10,086	2,413	1,723
124.4	Concrete slab on ground - With thermal break 100 mm EPS throughout, 140 mm wall framing with A/P ratio of 2.5	3.1	15,786	17,632	16,285	15,335
124.2	Concrete slab on ground - With thermal break 50 mm EPS throughout, 90 mm wall framing with A/P ratio of 2.5	2.1	15,328	17,239	15,893	14,917
126.2	Concrete slab on ground - With no thermal break, either full or perimeter insulation under slab 50 mm EPS throughout, 90 mm wall framing with A/P ratio of 2.5	1.7	15,348	17,261	15,915	14,939
127.6	Concrete slab on ground - 90 mm deep wall frame no edge insulation, no underfloor insulation with A/P ratio of 2.5	1.2	15,770	18,148	16,862	15,880
131.0	Waffle pod - 90 mm deep wall frame 30 mm XPS edge insulation, A/P ratio of 2.5	2.1	17,611	20,388	20,016	18,688
131.2	Waffle pod - 90 mm deep wall frame no edge insulation, A/P ratio of 2.5	1.5	16,861	18,970	18,599	17,716

* The floor assembly is a combination of the living areas (modelled row by row within the table above) and the garage (always modelled as item 127.6).

Table 6-5: Window assemblies for the reference building

BRANZ Reference	Description	R Value (m^2 °C/W)	GWP Upfront (kg CO_2e)	GWP A-C EB (kg CO_2e)	GWP A-C IB (kg CO_2e)	GWP A-D IB (kg CO_2e)
n/a (Timber)	Timber joinery 20mm (4/12/4) IGU	0.36	1,202	4,565	-212	-629
n/a (Al)	Aluminium joinery 20mm (4/12/4) IGU	0.26	1,614	4,928	4,928	3,239
n/a (uPVC)	uPVC joinery 20mm (4/12/4) IGU	0.36	1,516	3,854	3,854	3,411

Table 6-6: Other items in the reference building in scope of BfCC for which no scenarios are considered

QS No.	Item	BRANZ CO_2NSTRUCT Code	BRANZ CO_2NSTRUCT Description*	kg CO_2/ Unit	Quantity	Unit	Replacements over life?	Upfront (kg CO_2e)	Replacements (kg CO_2e)
	Substructure								
3	Pad footing for portico	PR_20_31_16_1_2_2_1	Reinforced concrete, 17.5 MPa, in-situ, inc. 100 kg/m³ steel reinforcing, (OPC)	0.27	1825.20	kg	0	493	0
	Frame								
5	Lintel beam for garage	PR_20_85_8_33_2_B	Engineered wood, glulam, Radiata pine softwood (H1.2 boron treated) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry]	0.28	48.00	kg	0	13	0
	Windows and Exterior Doors								
12	Double garage door	PR_25_71_51_91_1_1_1	ZinaCore™ and ZinaCore X™ (pre-painted steel with hot-dipped aluminium/zinc alloy), ColorCote® 0.4 mm BMT (150 g/m² coating weight), all profiles (wall, roof) (Pacific Coilcoaters, Fletcher Steel Ltd)	13.90	9.60	m²	0	133	0

QS No.	Item	BRANZ CO$_2$NSTRUCT Code	BRANZ CO$_2$NSTRUCT Description*	kg CO$_2$/ Unit	Quantity	Unit	Replacements over life?	Upfront (kg CO$_2$e)	Replacements (kg CO$_2$e)
	Interior Doors								
14	Double door complete	PR_25_71_97_53_1_B	MDF floor (E0 and E1, moisture resistant (MR) melamine coated) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], imported	1.21	15.00	kg	1	18	18
15	Single door complete	PR_25_71_97_53_1_B	MDF floor (E0 and E1, moisture resistant (MR) melamine coated) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], imported	1.21	135.00	kg	1	163	163
16	Single door cavity slider	PR_25_71_97_53_1_B	MDF floor (E0 and E1, moisture resistant (MR) melamine coated) [from unsustainable forest management practices, don't know or won't ensure from sustainable forestry], imported	1.21	15.00	kg	1	18	18
	Floor finishes								
17	Tiled floors	PR_35_93_96_19	Tiles (ceramic), imported (Asia)	9.98	22.00	m²	1	220	220
18	Carpets	PR_35_57_11_64_1_2	Carpet - woven broadloom (pile material 700 - 800 g/m² polyamide 6.6, woven textile backing)	13.80	140.00	m²	5	1,932	9,660
20	Tiling to porch and patio	PR_35_93_96_19	Tiles (ceramic), imported (Asia)	9.98	8.00	m²	1	80	80

QS No.	Item	BRANZ CO_2NSTRUCT Code	BRANZ CO_2NSTRUCT Description*	kg CO_2/ Unit	Quantity	Unit	Replacements over life?	Upfront (kg CO_2e)	Replacements (kg CO_2e)
	Heating and Ventilation								
36	Heat pump complete	PR_70_60_37_2_1	Heat pump (air source), 10kW, HFC 32 refrigerant, imported (Thailand)	997.00	1.00	unit	5	997	4,985
37	Extract fans	PR_70_60_37_2_1	Heat pump (air source), 10kW, HFC 32 refrigerant, imported (Thailand)	997.00	0.43	unit	5	427	2,136
							Total	**4,495**	**17,280**

* Timber has been modelled as “from unsustainable forest management practices, don't know or won't ensure from sustainable forestry” even though this is very unlikely to be true simply because this is the only way to get the GWP excluding biogenic carbon (GWPEB) values from BRANZ’s databases.

6.2. Results per building element per square metre

Table 6-7: Roof assemblies per unit area (kg CO_2e/m^2)

BRANZ Ref.	GWP Upfront	GWP A-C EB	GWP A-C IB	GWP A-D IB	GWPIB A1-A3	GWPIB A4-A5	GWPIB B4	GWPIB C1-C4	GWPIB D	GWPEB A1-A3	GWPEB A4-A5	GWPEB B4	GWPEB C1-C4	GWPEB D
49.0	31.19	70.31	44.24	41.09	-3.24	8.37	27.35	11.77	-3.15	20.45	10.74	27.35	11.77	-1.97
49.4	32.45	71.58	45.51	42.30	-2.15	8.54	27.35	11.78	-3.21	21.55	10.91	27.35	11.78	-2.03
29.8	33.32	97.28	79.45	60.53	12.81	2.68	55.31	8.65	-18.93	29.02	4.30	55.31	8.65	-18.12
29.0	32.21	96.16	78.33	59.45	11.85	2.53	55.31	8.64	-18.88	28.06	4.15	55.31	8.64	-18.07
29.7	51.05	110.67	107.50	85.46	45.27	2.61	55.31	4.31	-22.04	48.15	2.90	55.31	4.31	-21.90
59.2	24.28	63.22	33.47	31.47	-9.29	3.82	29.27	9.67	-2.00	18.95	5.33	29.27	9.67	-1.25

Table 6-8: External wall assemblies per unit area (kg CO_2e/m^2)

BRANZ Ref.	GWP Upfront	GWP A-C EB	GWP A-C IB	GWP A-D IB	GWPIB A1-A3	GWPIB A4-A5	GWPIB B4	GWPIB C1-C4	GWPIB D	GWPEB A1-A3	GWPEB A4-A5	GWPEB B4	GWPEB C1-C4	GWPEB D
67.2	19.63	63.11	-8.43	-16.65	-33.23	3.37	3.87	17.56	-8.22	11.76	7.87	25.92	17.56	-4.99
66.0	16.31	56.86	-6.17	-13.37	-27.50	2.82	3.87	14.64	-7.20	9.76	6.55	25.92	14.64	-4.35
74.0	27.23	62.00	17.19	8.57	2.08	2.39	3.87	8.85	-8.62	22.78	4.46	25.92	8.85	-6.59
83.0	22.64	58.77	31.32	27.46	-10.74	5.93	24.54	11.58	-3.86	14.22	8.43	24.54	11.58	-2.62
97.2	28.22	68.76	41.31	37.08	-6.22	7.00	28.84	11.69	-4.23	18.73	9.49	28.84	11.69	-2.99
96.0	26.13	63.74	44.80	41.54	0.57	6.61	28.84	8.77	-3.26	17.79	8.33	28.84	8.77	-2.41
100.0	38.13	71.17	70.45	65.69	30.88	6.52	30.03	3.01	-4.76	31.54	6.59	30.03	3.01	-4.74
91.4	51.22	70.09	44.91	40.53	12.64	13.40	6.85	12.03	-4.38	35.53	15.69	6.85	12.03	-3.25
91.5	62.58	81.87	56.69	51.90	20.84	16.56	6.85	12.44	-4.79	43.73	18.85	6.85	12.44	-3.66
90.4	49.12	65.08	48.41	45.00	19.44	13.01	6.85	9.11	-3.41	34.59	14.53	6.85	9.11	-2.66
92.0	60.67	71.63	70.91	65.82	47.27	12.68	6.85	4.11	-5.09	47.92	12.75	6.85	4.11	-5.06
105.2	33.63	166.28	141.10	105.54	5.64	2.81	121.66	10.99	-35.56	28.53	5.10	121.66	10.99	-34.43
104.0	31.54	161.27	144.60	110.00	12.44	2.42	121.66	8.07	-34.59	27.60	3.94	121.66	8.07	-33.85

BRANZ Ref.	GWP Upfront	GWP A-C EB	GWP A-C IB	GWP A-D IB	GWPIB A1-A3	GWPIB A4-A5	GWPIB B4	GWPIB C1-C4	GWPIB D	GWPEB A1-A3	GWPEB A4-A5	GWPEB B4	GWPEB C1-C4	GWPEB D
106.0	43.63	168.88	166.65	130.21	39.24	2.16	121.66	3.59	-36.44	41.27	2.36	121.66	3.59	-36.35
107.0	26.99	87.76	63.24	60.02	-1.94	4.40	50.14	10.63	-3.22	20.36	6.63	50.14	10.63	-2.11
107.2	28.22	89.00	64.47	61.20	-0.88	4.56	50.14	10.64	-3.27	21.42	6.79	50.14	10.64	-2.17
111.1	93.67	124.15	111.39	107.01	53.34	27.56	19.03	11.45	-4.38	64.94	28.72	19.03	11.45	-3.81

Table 6-9: Internal wall assemblies per unit area (kg CO_2e/m^2)

BRANZ Ref.	GWP Upfront	GWP A-C EB	GWP A-C IB	GWP A-D IB	GWPIB A1-A3	GWPIB A4-A5	GWPIB B4	GWPIB C1-C4	GWPIB D	GWPEB A1-A3	GWPEB A4-A5	GWPEB B4	GWPEB C1-C4	GWPEB D
n/a (#1)	6.28	14.42	1.63	0.20	-8.45	1.95	0.00	8.14	-1.44	3.17	3.11	0.00	8.14	-0.86
n/a (#2)	7.60	16.10	3.32	1.88	-7.47	2.29	0.00	8.50	-1.44	4.15	3.46	0.00	8.50	-0.86
n/a (#3)	10.43	14.41	14.41	12.78	8.84	1.59	0.00	3.97	-1.63	8.84	1.59	0.00	3.97	-1.63
n/a (#4)	11.76	16.09	16.09	14.46	9.82	1.93	0.00	4.33	-1.63	9.82	1.93	0.00	4.33	-1.63
n/a (#5)	11.61	17.77	-8.97	-10.47	-16.97	1.84	0.00	6.16	-1.50	8.61	3.01	0.00	6.16	-0.92
n/a (#6)	15.77	17.76	3.80	2.11	0.32	1.48	0.00	1.99	-1.69	14.28	1.48	0.00	1.99	-1.69

Table 6-10: Floor assemblies per unit area (kg CO_2e/m^2)

BRANZ Ref.	GWP Upfront	GWP A-C EB	GWP A-C IB	GWP A-D IB	GWPIB A1-A3	GWPIB A4-A5	GWPIB B4	GWPIB C1-C4	GWPIB D	GWPEB A1-A3	GWPEB A4-A5	GWPEB B4	GWPEB C1-C4	GWPEB D
118.8	26.87	47.34	0.08	-4.23	-25.36	4.97	6.83	13.63	-4.31	18.88	7.99	6.83	13.63	-2.80
120.24	25.70	45.12	-7.80	-12.56	-31.50	4.28	3.90	15.53	-4.76	17.89	7.81	3.90	15.53	-3.00
118.11	30.16	58.29	-4.82	-11.97	-39.41	6.46	6.83	21.30	-7.15	17.96	12.20	6.83	21.30	-5.21
120.27	28.98	56.07	-12.70	-20.30	-45.56	5.76	3.90	23.20	-7.60	16.96	12.02	3.90	23.20	-5.41
117.4	22.79	37.46	7.12	4.73	-11.79	4.24	6.83	7.84	-2.38	17.08	5.72	6.83	7.84	-1.65
119.2	26.19	39.41	-4.31	-7.29	-20.80	3.27	2.44	10.78	-2.98	18.94	7.25	2.44	10.78	-1.89

BRANZ Ref.	GWP Upfront	GWP A-C EB	GWP A-C IB	GWP A-D IB	GWPIB A1-A3	GWPIB A4-A5	GWPIB B4	GWPIB C1-C4	GWPIB D	GWPEB A1-A3	GWPEB A4-A5	GWPEB B4	GWPEB C1-C4	GWPEB D
124.4	75.55	83.80	77.29	72.78	57.58	11.46	0.00	8.25	-4.51	64.09	11.46	0.00	8.25	-4.51
124.2	72.86	81.49	74.98	70.32	54.92	11.43	0.00	8.63	-4.66	61.43	11.43	0.00	8.63	-4.66
126.2	72.97	81.62	75.11	70.45	55.03	11.43	0.00	8.64	-4.66	61.54	11.43	0.00	8.64	-4.66
127.6	75.45	86.83	80.68	75.98	57.70	11.60	2.08	9.30	-4.70	63.85	11.60	2.08	9.30	-4.70
131.0	86.29	100.01	99.23	92.50	76.57	8.94	4.50	9.22	-6.73	77.34	8.94	4.50	9.22	-6.73
131.2	81.87	91.67	90.89	86.78	72.33	8.77	0.64	9.16	-4.11	73.10	8.77	0.64	9.16	-4.11

Table 6-11: Window assemblies per unit area (kg CO_2e/m^2)

BRANZ Ref.	GWP Upfront	GWP A-C EB	GWP A-C IB	GWP A-D IB	GWPIB A1-A3	GWPIB A4-A5	GWPIB B4	GWPIB C1-C4	GWPIB D	GWPEB A1-A3	GWPEB A4-A5	GWPEB B4	GWPEB C1-C4	GWPEB D
n/a (Timber)	33.38	126.81	-5.88	-17.46	-12.09	1.42	-1.97	6.76	-11.58	30.55	2.83	86.49	6.93	-5.59
n/a (Al)	44.83	136.89	136.89	89.98	43.63	1.20	91.26	0.80	-46.91	43.63	1.20	91.26	0.80	-46.91
n/a (uPVC)	42.12	107.05	107.05	94.76	41.71	0.41	64.18	0.76	-12.30	41.71	0.41	64.18	0.76	-12.30

7. Embodied carbon and cost analysis

7.1. Results

This section focuses on the upfront/embodied carbon and upfront capital cost of construction across the different building element combinations (“scenarios”) outlined in section 4.1. Altogether, 22,032 scenarios were considered across four indicators:

- **GWP Upfront:** Global Warming Potential Upfront
  (EN 15978 modules A1-A5, excluding biogenic carbon).
- **GWP A-C EB:** Global Warming Potential for modules A-C Excluding Biogenic carbon (EN 15978 modules A1-A5, B1-B5, C1-C4).
- **GWP A-C IB:** Global Warming Potential for modules A-C Including Biogenic carbon (EN 15978 modules A1-A5, B1-B5, C1-C4).
- **GWP A-D IB:** Global Warming Potential for modules A-D Including Biogenic carbon (EN 15978 modules A1-A5, B1-B5, C1-C4, D).

The reference building used for this project was one of the cheapest scenarios possible, making its upfront cost difficult to beat. Its upfront cost was in the 5th percentile, meaning that 95% of the scenarios considered had a higher upfront cost. This restricts the pool of options available for the same or lower upfront cost. There are several possible reasons why the reference building may have a low upfront cost. One is that the market has tended towards lower upfront cost as this makes new houses easier to sell. Another is that there is a greater economy of scale in the market for common material choices.

Table 7-1 presents the high-level results of the scenario analysis. This table shows that most scenarios had a lower carbon footprint than the reference building, irrespective of which of the carbon footprint metrics were considered. 57% of scenarios had a lower carbon footprint than the reference building across all four carbon footprint metrics. However, because only 5% of scenarios were cheaper than the reference building (for upfront cost), this limited the pool of options that were both lower cost and lower carbon. Only 2.8% of scenarios had lower upfront cost and lower upfront carbon, while only 0.9% of scenarios had lower upfront cost and lower carbon footprint across all carbon footprint metrics.

Table 7-1: Results of scenario analysis

Proportion of buildings with…	Lower carbon	And lower cost
Lower upfront cost than reference building	n/a	5.0%
Lower GWP Upfront than reference building	78.5%	2.8%
Lower GWP A-C EB than reference building	64.1%	1.0%
Lower GWP A-C IB than reference building	75.9%	1.7%
Lower GWP A-D IB than reference building	74.8%	1.9%
Lower across all GWP criteria	**57.2%**	**0.9%**

The charts presented in this section (Figure 7-1, Figure 7-2, Figure 7-3, and Figure 7-4) should be interpreted as follows:

- There are four charts, one for each GWP indicator
- The left vertical axis shows the change in upfront cost relative to the reference building. A value of $0 means the scenario is the same cost as the reference building. A positive number (top part of the graph, shown in red) means the scenario is more expensive than the reference building.
- The right vertical axis shows the change in carbon relative to the reference building. A value of 0 kg CO_2e means the scenario has the same carbon footprint as the reference building. A positive number (top part of the graph, shown in red) means the scenario has a higher carbon footprint than the reference building.
- All charts are presented with the carbon footprint (right vertical axis) ordered from lowest (largest carbon footprint reduction) to highest (largest carbon footprint increase) relative to the reference building (solid blue squares). Cost is presented on the left vertical axis, with data points shown as charcoal-coloured hollow circles. The black line shows the overall trend in cost data, calculated using linear regression.
- The reference building is marked with a white “x” on the graph, positioned on the line that is both 0% change in upfront cost and 0% change in carbon footprint.
- Any scenario that is positioned to the bottom-left of the white “x” (the green area) has both a lower upfront cost and a lower carbon footprint than the reference building.
- Cost changes are relative to the full cost of construction including builder’s margins and GST (i.e., the price the homeowner would pay to build the house) but excluding land costs. Carbon changes are relative to the reference building’s carbon footprint covering all mandatory building elements from BfCC.

An example of how to read these charts is shown in Figure 7-5 on page 46. To estimate the change in upfront cost to achieve a given carbon footprint reduction, draw a vertical line from the solid blue squares (carbon footprint line) to the solid black line (average cost line) and then project from the point of intersection left to the vertical axis (the upfront cost axis). In this example, achieving an upfront carbon reduction of 25% would lead to an increase in upfront cost of approximately 8%, on average.

Across all GWP metrics in Figure 7-1, Figure 7-2, Figure 7-3, and Figure 7-4, upfront cost is on average 3% to 11% higher than the baseline scenario. This is true even when the carbon footprint is higher than the reference building. This is because the upfront cost of the reference building is among the lowest of all scenarios (in the 5th percentile for upfront cost), meaning that almost any change – whether it is to reduce carbon footprint or not – will typically lead to a higher upfront cost. Those scenarios that have a lower carbon footprint have an upfront cost in the order of 5% to 11% higher than the reference building, on average. Yet for all GWP metrics, there are always some scenarios with both a lower carbon footprint and a lower upfront cost – it is simply that these scenarios are in the minority.

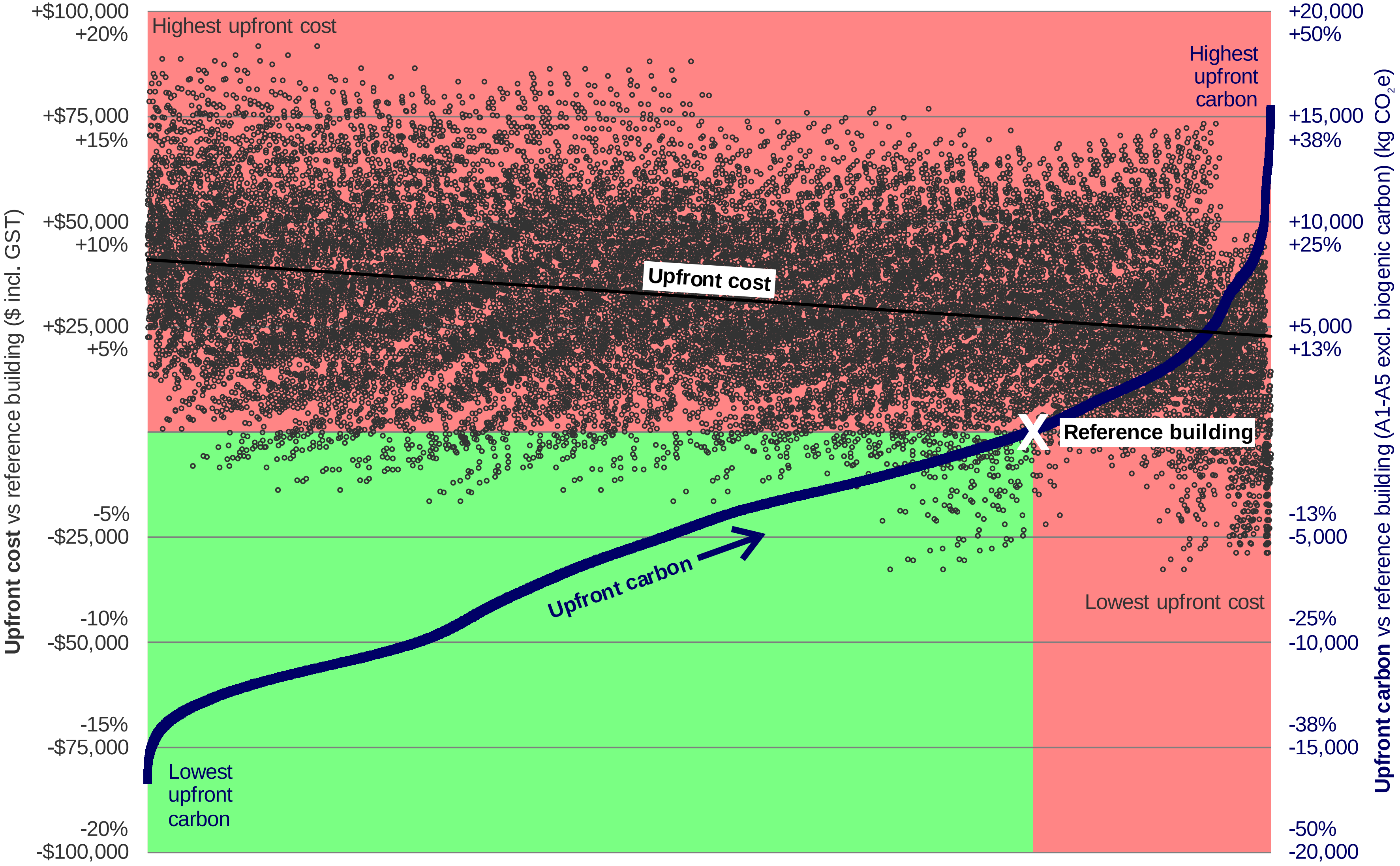

Figure 7-1: Upfront cost and upfront carbon excluding biogenic carbon vs. reference building (Auckland scenario)

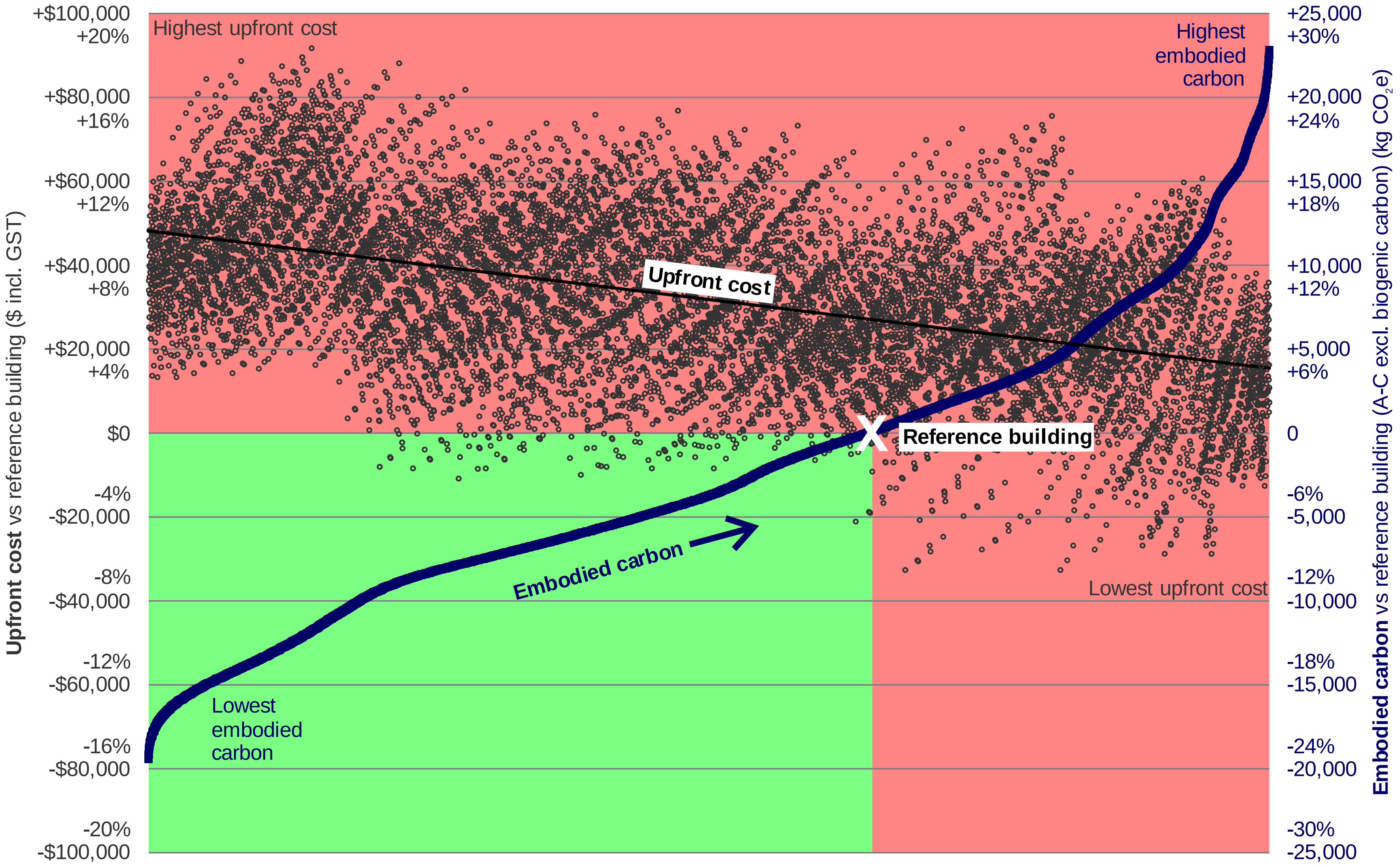

Figure 7-2: Upfront cost and life cycle carbon (A+B+C excluding biogenic) vs. reference building (Auckland scenario)

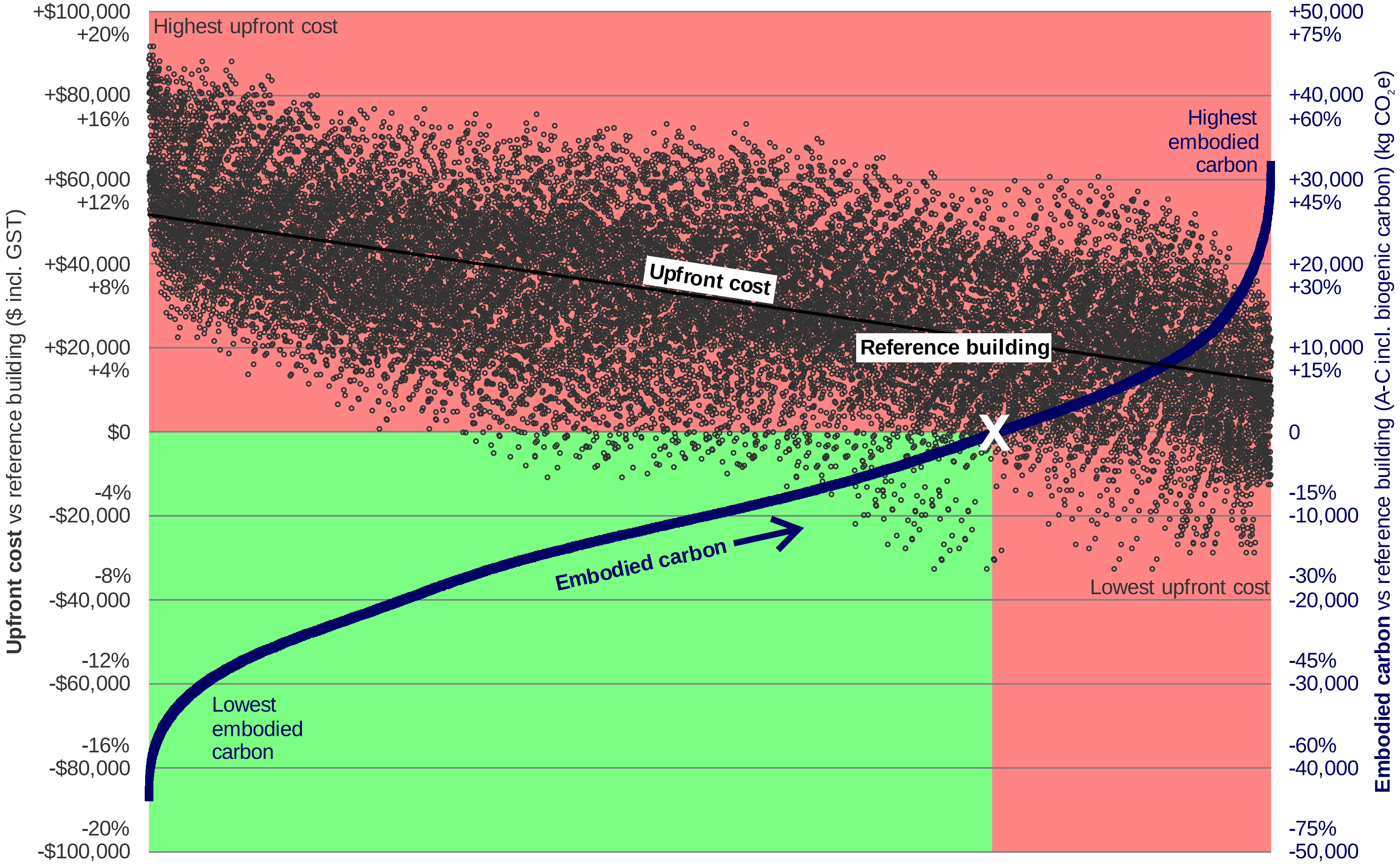

Figure 7-3: Upfront cost and life cycle carbon (A+B+C including biogenic) vs. reference building (Auckland scenario)

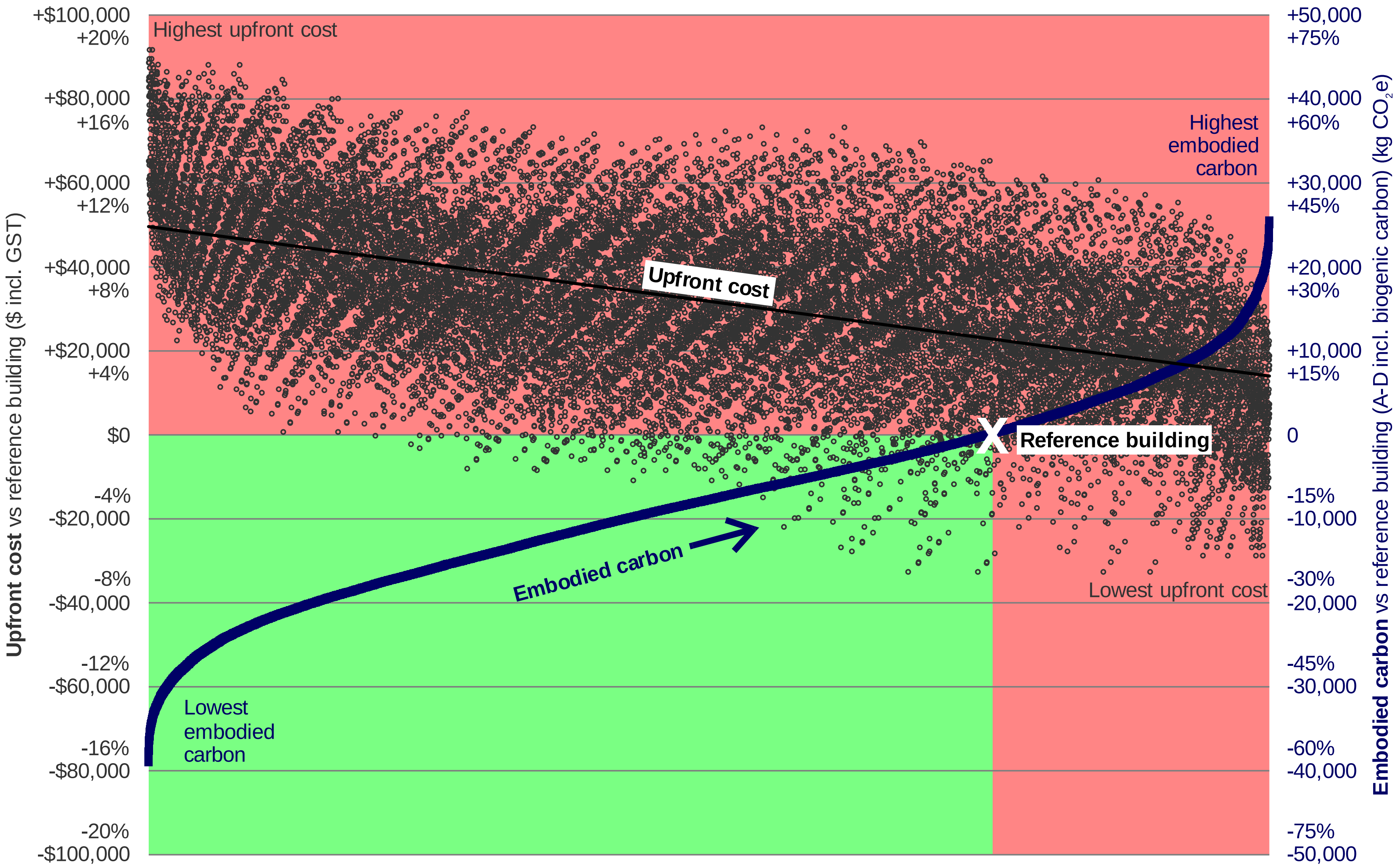

Figure 7-4: Upfront cost and life cycle carbon (A+B+C+D including biogenic) vs. reference building (Auckland scenario)

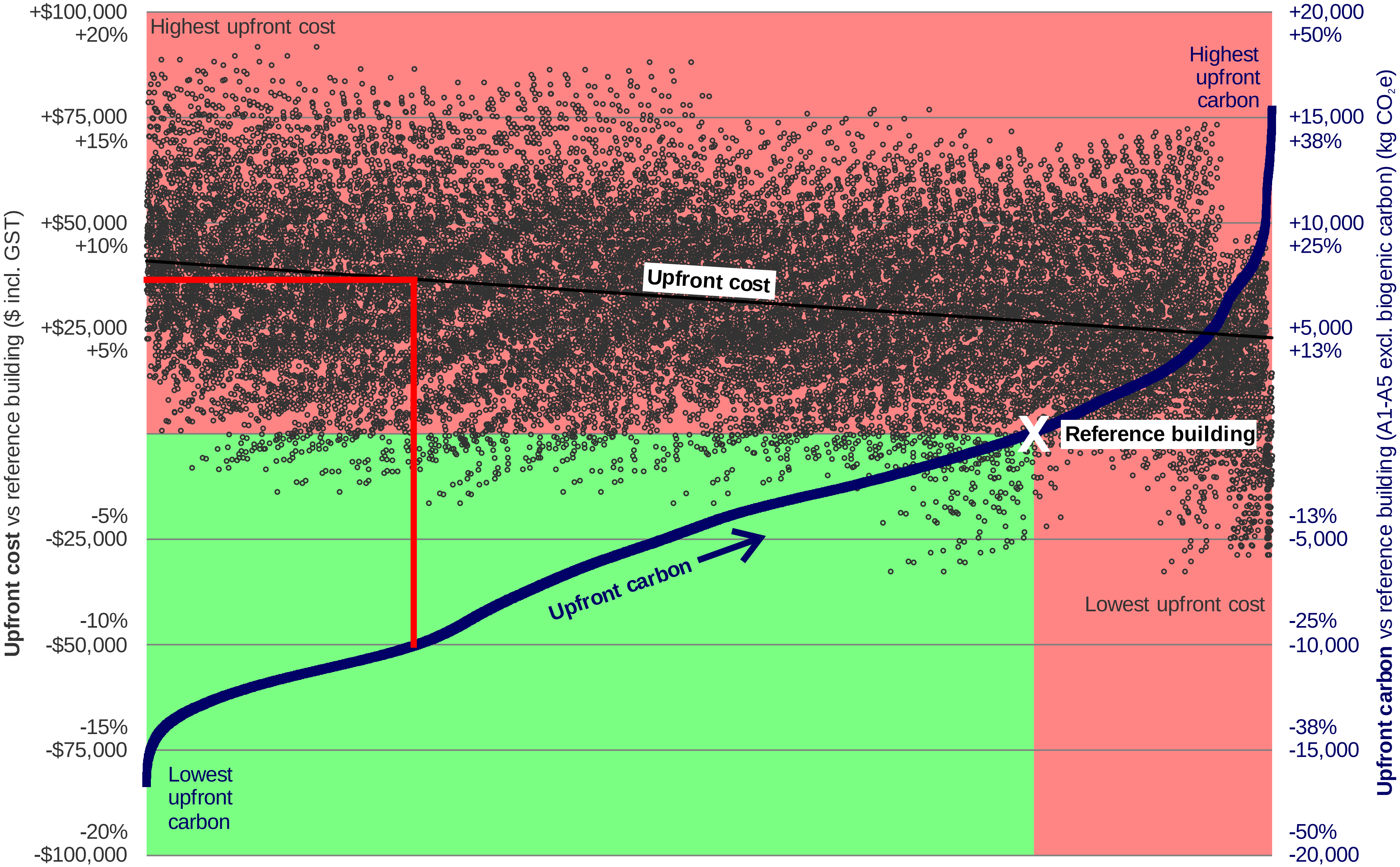

Figure 7-5: Example of interpreting upfront cost and upfront carbon chart (Auckland scenario)

7.2. Interpretation

All charts show that upfront/embodied carbon and upfront cost are inversely correlated to some extent (the blue line and black line move in different directions). This means that lower embodied carbon buildings are typically more expensive than higher embodied carbon buildings upfront, based on the sample of building element types considered in this study. However, there is significant variation in upfront costs for the same level of decarbonisation, meaning that significant carbon savings are often possible for no additional upfront cost.

When considering the maximum improvement/reduction, the average change (without any weighting for market share), and the maximum increase (Table 7-2), the results highlight that upfront carbon footprint reductions of up to 42% are achievable, or up to 23% over the whole building life cycle (excluding biogenic carbon and recycling credits). Inclusion of biogenic carbon allows for dramatically larger savings owing to the timber effectively providing a carbon offset for the remainder of the building. Across all scenarios, the upfront cost of construction varied from $32,600 (6%) cheaper to $91,700 (17%) more expensive than the reference building.

Table 7-2: Change in embodied carbon and cost compared to the reference building

vs. reference	Max. carbon reduction	Average change in carbon footprint	Max. carbon increase
Upfront v ref (kg CO_2e)	**-16,566 (-42%)**	**-4,523 (-12%)**	**15,351 (39%)**
…at a cost of ($ inc. GST)	$42,220 (+8%)	$31,838 (+6%)	-$5,279 (-1%)
GWP A-C EB v ref (kg CO_2e)	**-19,414 (-23%)**	**-2,573 (-3%)**	**22,816 (28%)**
…at a cost of ($ inc. GST)	$34,080 (6%)	$31,838 (+6%)	$10,868 (2%)
GWP A-C IB v ref (kg CO_2e)	**-43,471 (-60%)**	**-9,473 (-13%)**	**31,715 (44%)**
…at a cost of ($ inc. GST)	$88,719 (16%)	$31,838 (+6%)	$7,369 (1%)
GWP A-D IB v ref (kg CO_2e)	**-39,014 (-61%)**	**-7,785 (-12%)**	**25,525 (40%)**
…at a cost of ($ inc. GST)	$88,719 (16%)	$31,838 (+6%)	$18,919 (3%)

For upfront carbon:

- The largest upfront carbon saving was 42% for a cost increase of 8%. The saving over the whole building life cycle was 23%, excluding biogenic carbon. This was for a home built on a suspended timber floor, with timber framing, a membrane roof, weatherboard wall cladding, double-glazed timber joinery, and 10mm plasterboard.
- The building above would be visually different to the reference building due to the flat membrane roof. However, a similar saving could be achieved using a pitched tiled roof, with a 38% reduction in upfront carbon for an upfront cost increase of 8%.
- A 36% saving in upfront carbon (12% over whole-of-life, excluding biogenic carbon) could be achieved upfront cost neutral. This building had a suspended timber floor, timber framing, a long-run corrugated steel roof, weatherboard wall cladding, double-glazed aluminium joinery, and 10mm plasterboard throughout.

- The suspended timber floor was the single most important change. The top 6,930 scenarios modelled featured this floor system. The next best performer was a concrete slab building for a 21% upfront carbon reduction but a 9% cost increase.
- The choice of roof cladding, envelope wall, internal wall and windows was much less important for upfront carbon as most systems performed similarly. (The biggest differentiator is for whole-of-life embodied carbon due to differences in expected replacement cycles.)

For embodied carbon (modules A+B+C) excluding biogenic carbon:

- The largest carbon saving was 23% for a cost increase of 6%. The upfront carbon saving was 40%. This was for a home built on a suspended timber floor, with timber framing, a membrane roof, weatherboard wall cladding, double-glazed uPVC joinery, and 10mm plasterboard throughout (over either timber or steel studs).
- The building above would be visually different to the reference building due to the flat membrane roof. However, a similar saving could be achieved using a pitched tiled roof, with a 21% reduction in upfront carbon for an upfront cost increase of 6%.
- An 12% saving could be achieved upfront cost neutral. This building had a suspended timber floor, a long-run corrugated steel roof, long-run steel cladding, double-glazed aluminium joinery, and 10mm plasterboard throughout.
- The suspended timber floor was the single most important change. The top 3,137 scenarios featured this floor system. The next best performer was a concrete slab building for a 14% embodied carbon reduction but an 8% cost increase.
- The next most important change was to the roof system. Membrane roofs performed best due to their low-carbon maintenance regime. Concrete/clay tile roofs were also low-carbon due to their durability, minimising the number of replacement cycles.
- The choice of envelope wall, internal wall and windows was much less important.

For embodied carbon (modules A+B+C) including biogenic carbon:

- The largest carbon saving was 60% for a cost increase of 16%. This was for a home built on a suspended timber floor, with timber framing, a membrane roof, timber weatherboard wall cladding, double-glazed timber joinery, and 9mm plywood as a wall covering.
- A 24% saving could be achieved upfront cost neutral. This building had a suspended timber floor, timber framing, a long-run corrugated steel roof, timber weatherboard cladding, double-glazed aluminium joinery, and 10mm plasterboard throughout.
- This calculation tracks similarly to the previous option, except that the use of timber becomes even more important (e.g., plywood over plasterboard for wall linings) due to the net sequestration of atmospheric CO_2 in the building and later in landfill.

For embodied carbon (modules A+B+C+D) including biogenic carbon:

- The largest carbon saving was 61% for a cost increase of 16%. This was for the same home identified for modules A+B+C including biogenic carbon above.
- A 28% saving could be achieved upfront cost neutral. This building had a suspended timber floor, timber framing, a long-run corrugated steel roof, timber weatherboard cladding, double-glazed aluminium joinery, and 10mm plasterboard throughout.

- This option is similar to the one above, except that corrugated steel gains slightly because the steel can be recycled at end-of-life and provide a credit in module D.

7.3. Comparing the reference building to alternative designs

The purpose of this section is to compare several archetypal building element scenarios identified as good performers in the previous sections alongside the reference building. Table 7-3 presents key carbon footprint data for these scenarios. The subsections that follow provide a fuller profile of each scenario.

Table 7-3: Carbon footprint data for archetypal building element scenarios

Parameter	Reference	Upfront Min. Sloped Roof	Upfront $ Neutral	Embodied A-C EB Min. Slope. Roof	Embodied A-C EB $ Neutral	Embodied A-C/A-D IB Min. Sloped
Structure						
Roof	Steel	Tile	Steel	Tile	Steel	Tile
Envelope wall	Brick veneer	Timber w/board	Timber w/board	Timber w/board	Sheet	Timber w/board
Internal wall	Plasterboard 10mm	Plasterboard 10mm	Plasterboard 10mm	Plasterboard 10mm	Plasterboard 10mm	Plywood 9mm
Floor	Concrete (uninsulated)	Suspended timber	Suspended timber	Suspended timber	Suspended timber	Suspended timber
Windows	Aluminium	Timber	Aluminium	uPVC	uPVC	Timber
GWPIB A1-A3	22,844	-4,976	998	-115	6,467	-14,346
GWPIB A4-A5	5,492	3,908	2,364	3,810	2,759	4,162
GWPIB B2, B4	36,615	26,433	37,144	28,814	39,393	25,515
GWPIB C1-C4	7,043	8,635	7,599	7,716	6,417	11,807
GWPIB D	-8,411	-3,111	-8,519	-3,169	-6,783	-4,297
GWPEB A1-A3	32,721	16,601	19,071	17,963	20,657	17,426
GWPEB A4-A5	6,351	5,669	3,877	5,324	3,884	7,001
GWPEB B2, B4	36,615	33,057	40,583	32,253	39,393	32,138
GWPEB C1-C4	7,043	8,642	7,599	7,716	6,417	11,814
GWPEB D	-7,984	-1,887	-7,608	-2,259	-6,223	-2,729
GWP Upfront	39,072	22,270	22,949	23,287	24,540	24,427
GWP A-C EB	82,730	63,968	71,130	63,256	70,351	68,380
GWP A-C IB	71,994	34,000	48,104	40,225	55,037	27,138
GWP A-D IB	63,582	30,889	39,586	37,055	48,254	22,841
Upfront per m^2	179	102	105	107	113	112
A-C EB per m^2	379	293	326	290	323	314
A-C IB per m^2	330	156	221	185	252	124
A-D IB per m^2	292	142	182	170	221	105

7.3.1. Reference building

The reference building features a long-run steel roof, brick veneer cladding over a timber frame, internal timber walls with 10mm plasterboard on both sides, aluminium double-glazed joinery, all on an uninsulated 100mm concrete floor slab. Figure 7-6 and Figure 7-7 present the embodied carbon for this building per building element and module, respectively. Both figures use the GWP A-D IB carbon footprint indicator.

In Figure 7-6, “Others” represents all elements of the building that were not modelled at the elemental level. This includes the carpet, tiles, garage door, the heat pump, and concrete footings for the portico. The significant impact of Module B for “Others” is largely due to replacements of the carpet and heat pump over the estimated life of the building. Figure 7-6 presents the carbon footprint of all building elements using GWP excluding biogenic carbon and then uses the “Removals” categories to present the total carbon footprint over the whole life cycle. This is done to show the fossil carbon emissions of each building element, as otherwise the carbon footprint of timber building elements would partly cancel out or become negative. The “Removals” category is the net carbon removal due to a combination of sequestered biogenic carbon in timber products over the full building life cycle (blue colour) and recycling credits at the end of the building’s life (yellow colour).

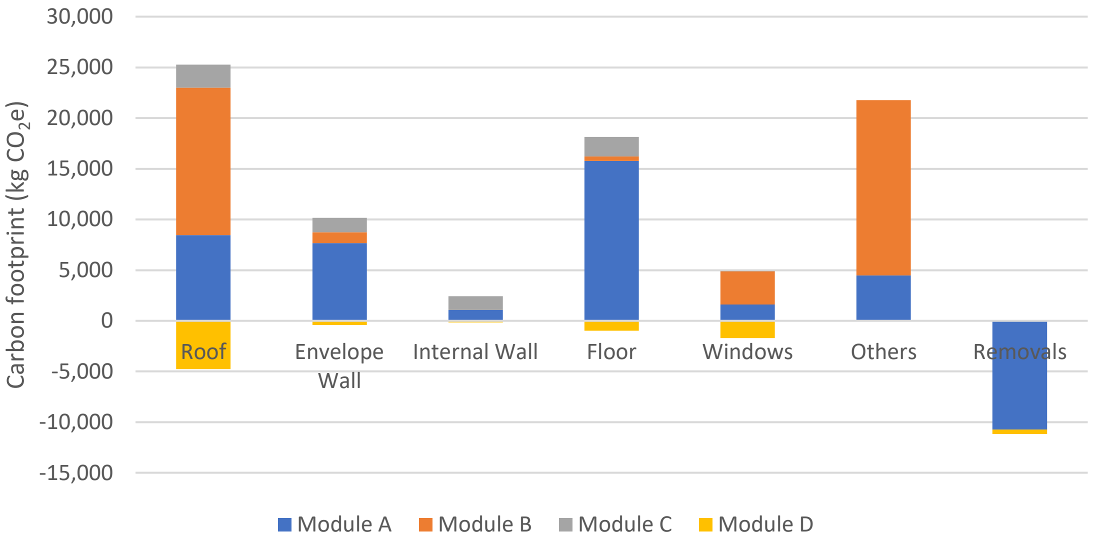

Figure 7-6: Embodied carbon per building element for the reference building (GWP A-D IB)

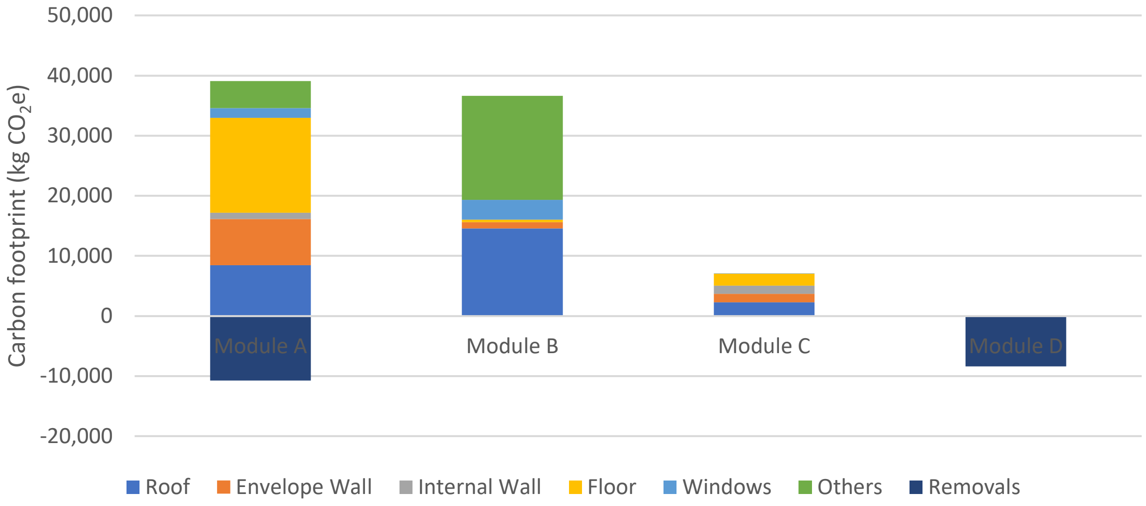

Figure 7-7: Embodied carbon per module for the reference building (GWP A-D IB)

7.3.2. Minimum upfront carbon building while still retaining a sloped roof

This building features a concrete or clay tile roof, timber weatherboards over a timber frame, internal timber walls with 10mm plasterboard on both sides, timber double-glazed joinery, all on a suspended timber floor. Figure 7-8 and Figure 7-9 present the embodied carbon for this building per building element and module, respectively.

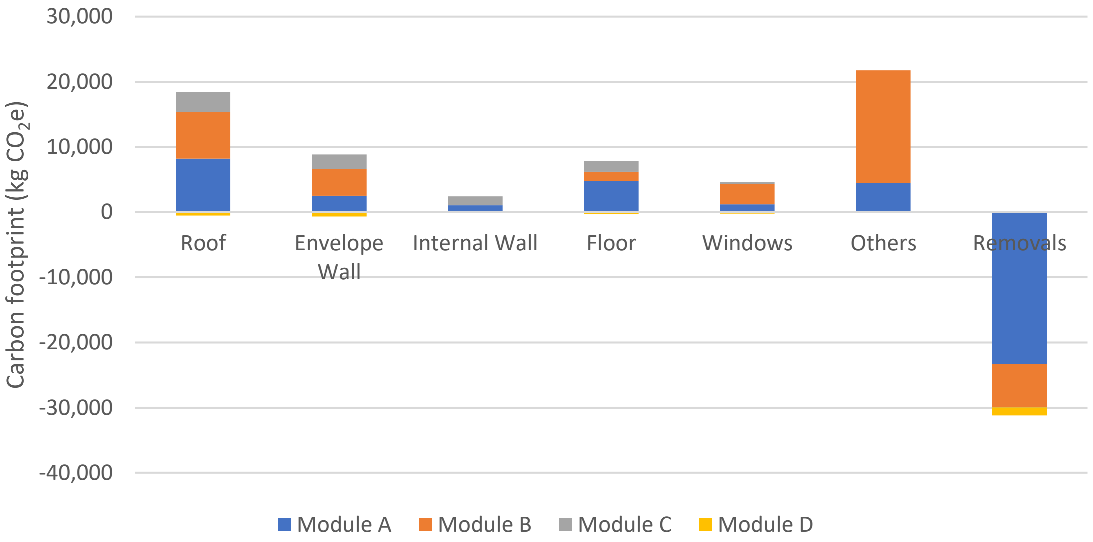

Figure 7-8: Embodied carbon per building element for low upfront carbon building with a sloped roof (GWP A-D IB)

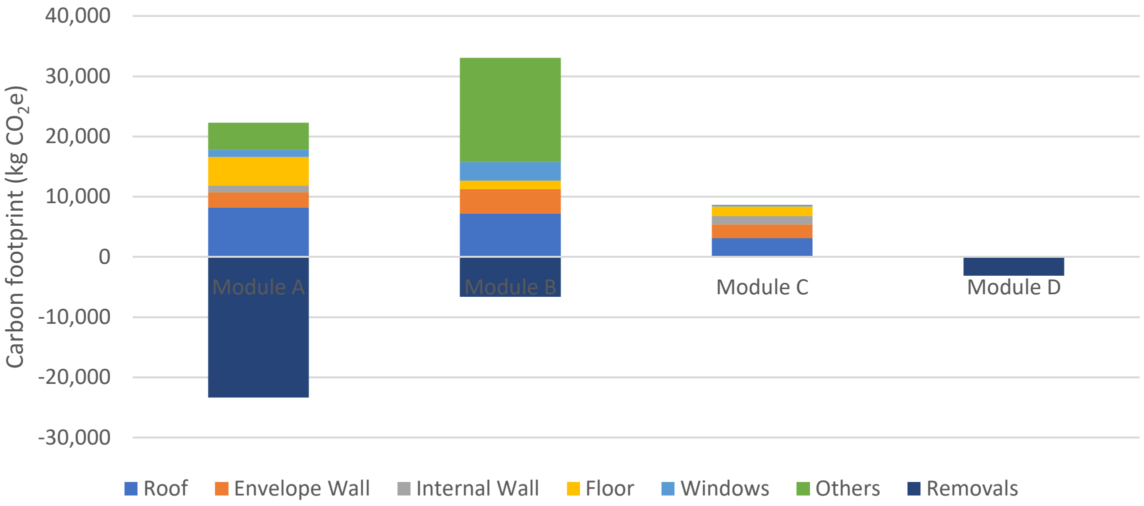

Figure 7-9: Embodied carbon per module for low upfront carbon building with a sloped roof (GWP A-D IB)

7.3.3. Minimum upfront carbon while being upfront cost neutral

This building features a long-run steel roof, timber weatherboard cladding over a timber frame, internal timber stud walls with 10mm plasterboard on both sides, aluminium double-glazed joinery, all on a suspended timber floor. Figure 7-10 and Figure 7-11 present the embodied carbon for this building per building element and module, respectively.

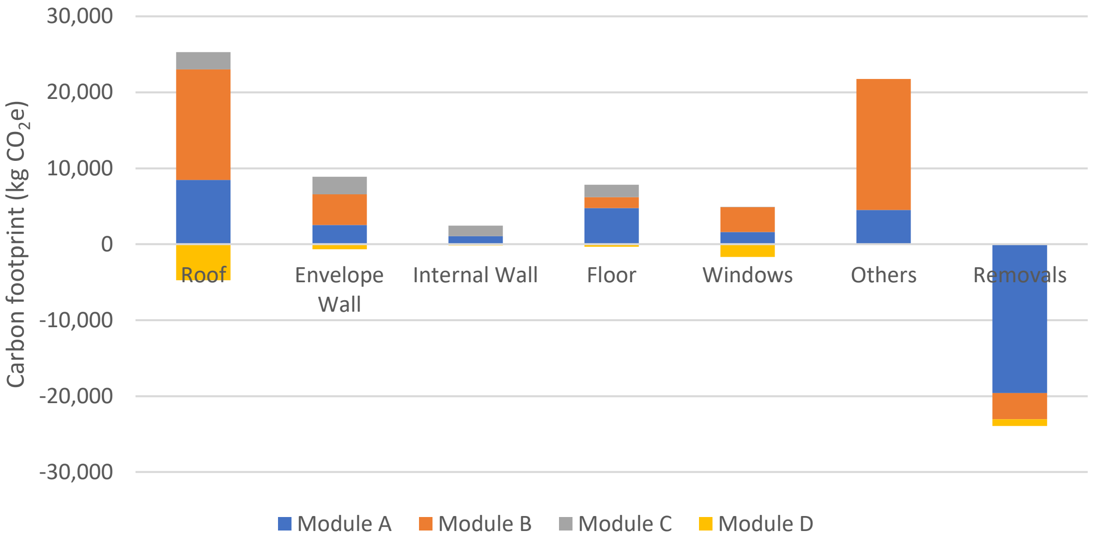

Figure 7-10: Embodied carbon per building element for low upfront carbon building (cost neutral) (GWP A-D IB)

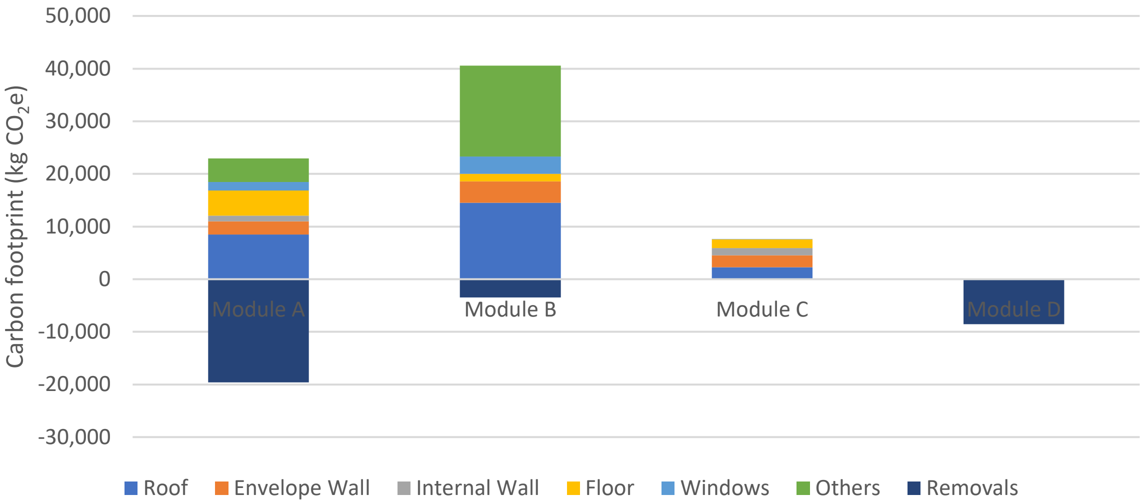

Figure 7-11: Embodied carbon per module for low upfront carbon building (cost neutral) (GWP A-D IB)

7.3.4. Minimum embodied carbon building while still retaining a sloped roof

This building features a concrete or clay tile roof, timber weatherboard cladding over a timber frame, internal walls with steel or timber stud with 10mm plasterboard on both sides, uPVC double-glazed joinery, all on a suspended timber floor. Figure 7-12 and Figure 7-13 present the embodied carbon for this building per building element and module, respectively.

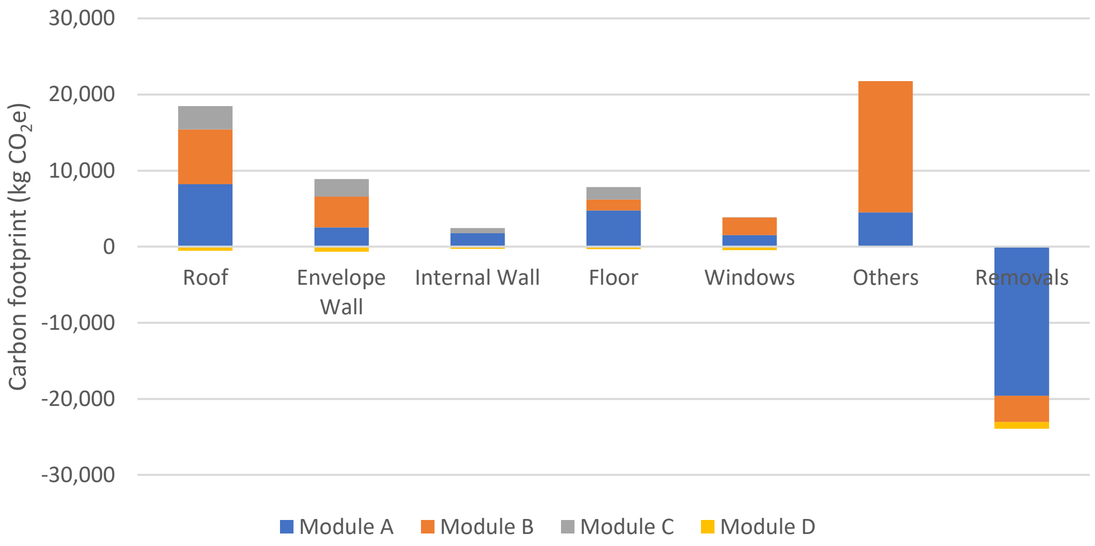

Figure 7-12: Embodied carbon per building element for low embodied carbon building with a sloped roof (GWP A-D IB)

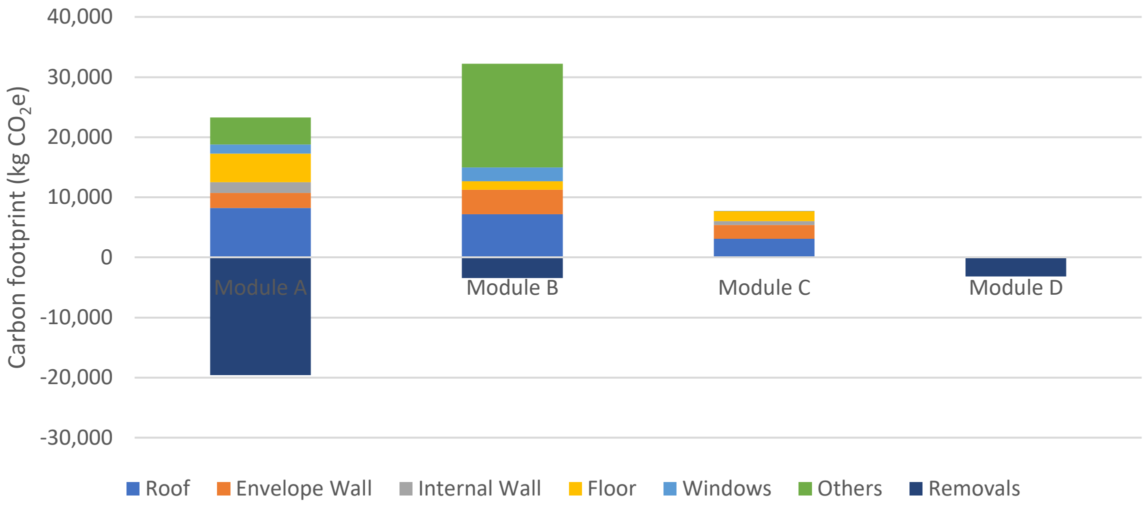

Figure 7-13: Embodied carbon per module for low embodied carbon building with a sloped roof (GWP A-D IB)

7.3.5. Minimum embodied carbon (A-C, IB) while being upfront cost neutral

This building features a long-run steel roof, sheet cladding over a timber frame, internal walls with steel or timber stud with 10mm plasterboard on both sides, uPVC double-glazed joinery, all on a suspended timber floor. Figure 7-14 and Figure 7-15 present the embodied carbon for this building per building element and module, respectively.

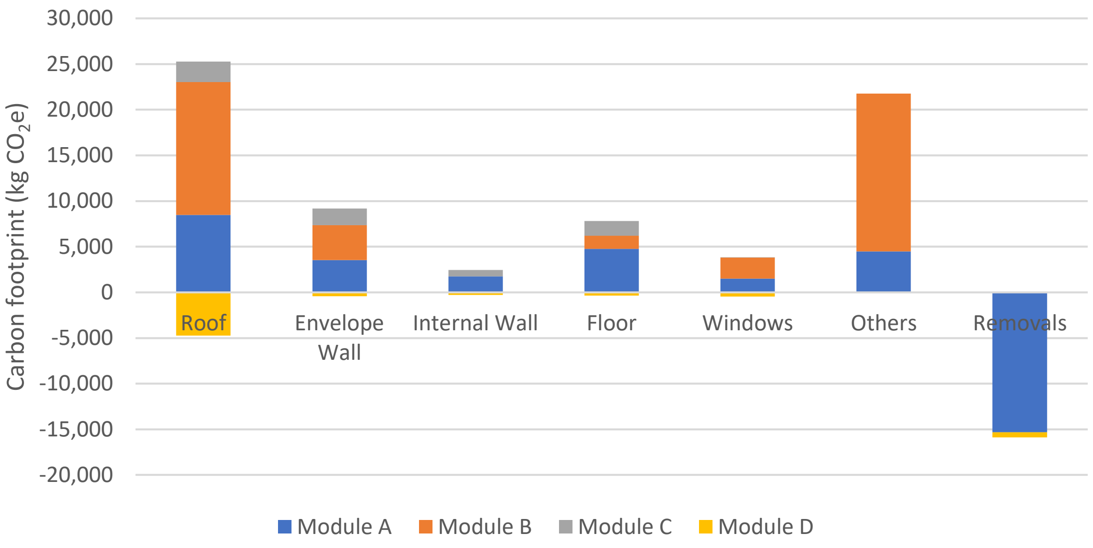

Figure 7-14: Embodied carbon per building element for low embodied carbon building (cost neutral) (GWP A-D IB)

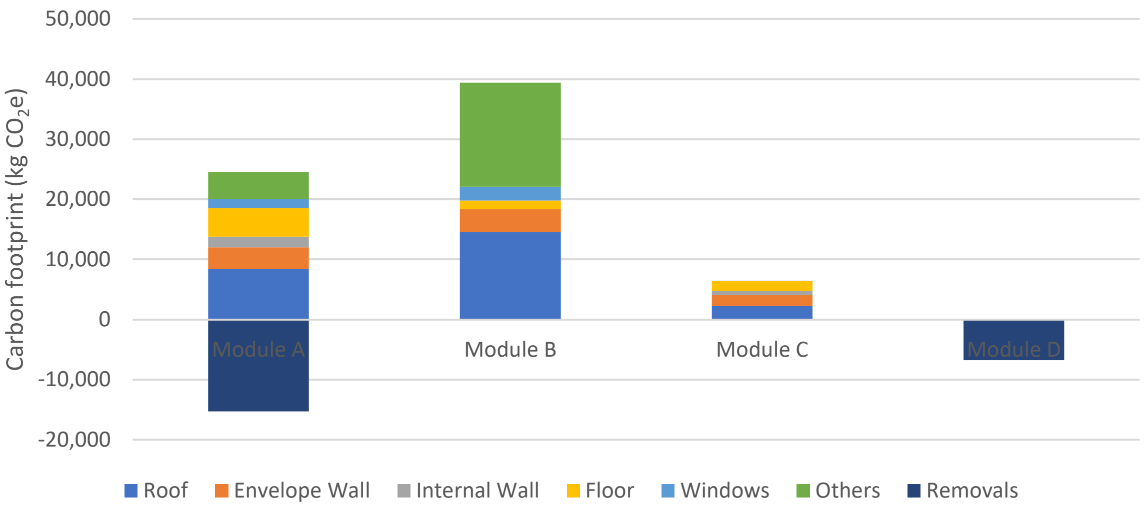

Figure 7-15: Embodied carbon per module for low embodied carbon building (cost neutral) (GWP A-D IB)

7.3.6. Minimum embodied carbon including biogenic carbon with a sloped roof

This building features a concrete or clay tile roof, timber weatherboard cladding over a timber frame, internal timber walls with 9mm plywood on both sides, timber double-glazed joinery, all on a suspended timber floor. Figure 7-16 and Figure 7-17 present the embodied carbon for this building per building element and module, respectively.

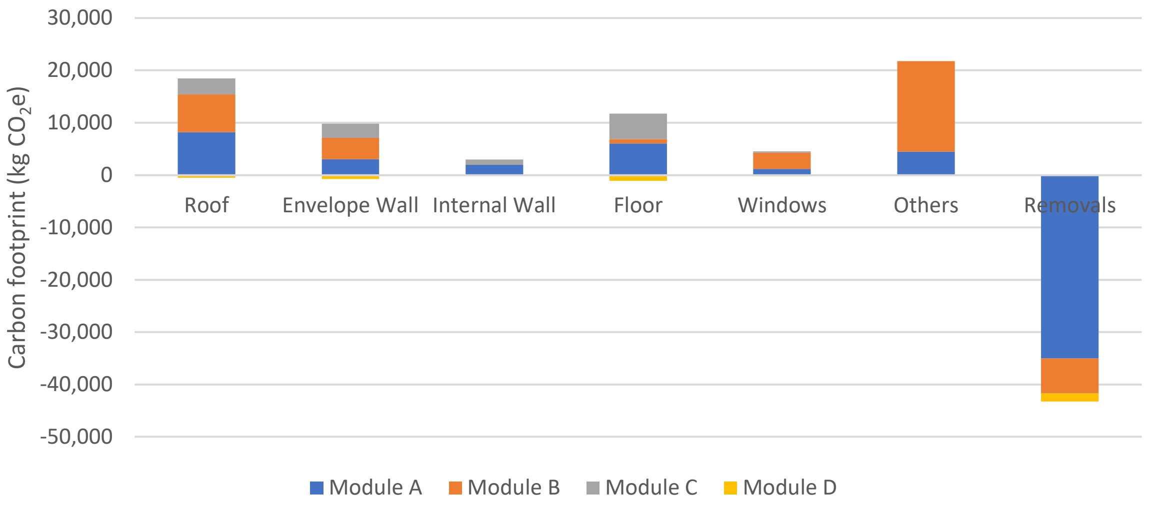

Figure 7-16: Embodied carbon per building element for min. embodied carbon building (incl. biogenic) (GWP A-D IB)

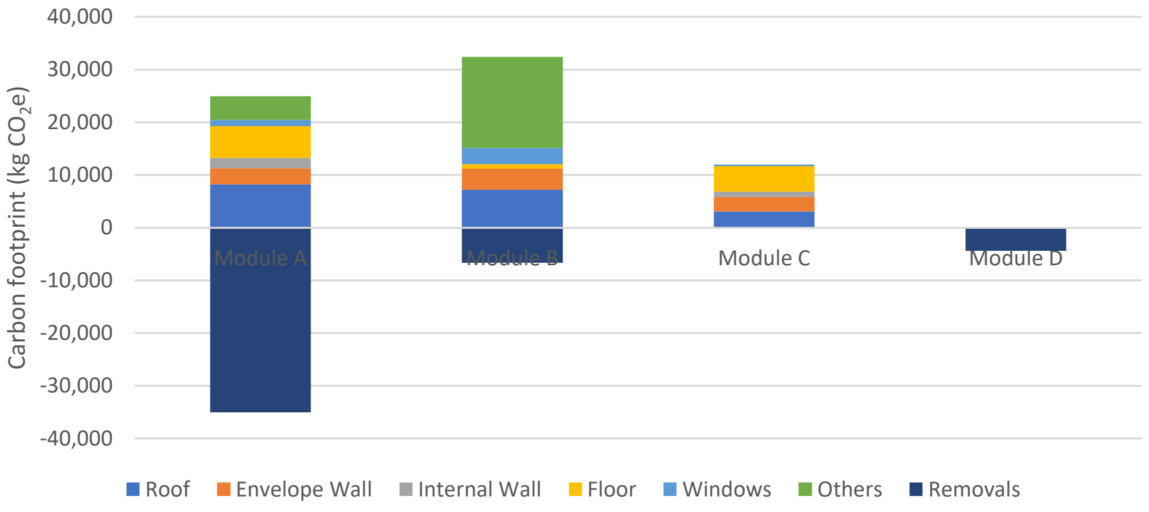

Figure 7-17: Embodied carbon per module for minimum embodied carbon building (incl. biogenic) (GWP A-D IB)

7.4. What about supply-side improvements?

The analysis above has found that substitution of a concrete slab for a suspended timber floor is one of the most significant improvements that can be made for residential construction. However, the concrete industry in New Zealand is well positioned to decarbonise itself quite quickly, which will reduce the significance of this. Previous analysis conducted by thinkstep-anz for NZGBC found that the carbon footprint of concrete could be reduced by 21-24% within the next few years due to the partial substitution of Portland cement by supplementary cementitious materials (SCMs) (thinkstep-anz, 2019). SCMs are not widely used in New Zealand yet due to a lack of local supply; however, they are widely used overseas and therefore well understood. It would also be possible to source low-carbon reinforcing steel from overseas to further bring down the carbon footprint of the concrete slab (though this is unlikely to reduce greenhouse gas emissions at the global level as low-carbon steel is typically recycled steel and recycling is limited by the availability of steel scrap.)

7.5. What embodied carbon saving is achievable for no additional upfront cost?

Given that Building for Climate Change has not set its caps on upfront/embodied carbon, the purpose of this section is to evaluate what savings can be achieved for no additional upfront cost. Before doing this, it is important to point out that the selected reference building is already among the cheapest of the building combinations considered in this project. Only 5% of the building element combinations (1,098 of 22,032) could be achieved for the same or lower cost, irrespective of their carbon footprint. Of the building elements considered, the reference building uses the cheapest-equal roof, the cheapest-equal internal wall, the third-cheapest floor, and the cheapest windows/doors. The only element that is not at the low end of the cost spectrum is the envelope wall (brick façade) which is in the upper half of that category’s price range.

Of the 1,098 scenarios that would achieve the same or lower upfront cost as the reference building, 619 (56% of the 1,098 scenarios) would achieve the same or lower upfront carbon. Looking at these remaining 619 scenarios, and considering possible reductions in whole-of-life embodied carbon (using the GWP A-D IB indicator):

- A ≥30% reduction in whole-of-life embodied carbon was not achieved by any scenario (while also having the same or lower upfront cost and the same or lower upfront carbon footprint).
- A ≥20% reduction in whole-of-life embodied carbon was achieved by 30 scenarios (2.7% of the 1,098 scenarios).
- A ≥10% reduction in whole-of-life embodied carbon was achieved by 156 building combinations (14% of the 1,098 scenarios).

These findings suggest that ambitious caps on embodied carbon will not be achievable without either a higher upfront cost of construction or a change in the design of the building. In the context of the reference building chosen for this study, a reduction of 20% below the current whole-of-life embodied carbon performance could be achieved for no additional upfront cost, but a reduction of 30% or more could not be.

8. Reducing upfront cost through design

The focus of this project was to achieve cost and carbon savings for a specific reference building. No changes were made to the building's design through this process. However, it would be possible to make some relatively small design changes to further reduce cost and potentially carbon too.

Several strategies to reduce the cost of the building were suggested by Linda Lodetti (MRICS NZIQS), the Quantity Surveyor appointed for this project (direct quotes below):

- A more regular floor plan with the same floor area could reduce the extent of the external and internal walls by approximately 2% to 2.5% of the costs at say $12,000 to $15,000.
- A less complex roof design for the same floor area, i.e. with less hips and valleys, could reduce the costs by approximately 1.2% to 1.3% of the costs at say $7,000 to $8,000.
- A new floor plan design that reduces the extent of corridors and which could be considered more cost effective could be achieved with the same room areas. Reducing the overall floor plan area by 3.7% to 5% or reducing the overall area by say 10m^2, could reduce overall costs by between $22,000 to $28,000.
- Using increased R-value insulation improves the performance of the house, reducing the need for alternative energy. The labour cost to install the various types of R-value insulation is essentially the same and the supply prices are only marginally different.
- House orientation to the sun, insulation specifications, thermally broken and double-glazed windows, designed ventilation and sealed houses, all contribute towards reducing the need for heat pumps and would minimise energy requirements.

Elrond Burrell of MBIE made several additional suggestions:

- Lightweight cladding instead of brick. This could be used to reduce the thickness of the foundation, to change cladding over windows and to reduce material and labour costs of cladding.
- Rationalise the junction between the house and garage. The garage is outside the thermal envelope. The back wall of the garage could be a straight line from the Bed 4 wardrobe to the bathroom with the laundry moved inside the thermal envelope and the door from the garage into the laundry. This will increase insulated floor area and ceiling area a small amount but simplify both and reduce insulated wall area and four wall junctions.
- Don't insulate the garage. (The drawings suggest the garage was insulated.)

9. Conclusions

Most combinations of alternative building elements considered in this study were more expensive than those used in the reference building, regardless of their embodied carbon footprint. As upfront costs were highly variable for the same level of decarbonisation, significant savings in upfront carbon were possible for no additional upfront cost.

Reducing the upfront carbon footprint of the reference building by over 30% was achievable, or 20% over the whole building life cycle (excluding biogenic carbon and recycling credits). These reductions would likely come with a price premium of approximately 5-10% unless optimisation is applied to find those building element combinations that are both low cost and low carbon. Including biogenic carbon allows for dramatically larger savings than these, owing to the timber effectively providing a carbon offset for the remainder of the building.

In the best case, a saving of 36% in upfront carbon and 12% in whole-of-life embodied carbon (compared with the reference building selected for this study) was found to be possible for no additional upfront cost.

This report also identifies the potential for trade-offs between operational efficiency and whole-of-life embodied carbon caps. One of the most effective strategies to reduce embodied carbon identified by this study was to move from a concrete slab to a suspended timber floor. However, this change meant that the reference building chosen for this study no longer met BfCC's intermediate proposed cap for thermal performance in Auckland or Christchurch.

Achieving BfCC's final proposed cap for services efficiency will likely require high efficiency water heating (e.g., heat pump water heating). All scenarios modelled in this study used direct electric hot water cylinders. These were able to meet the initial and intermediate proposed caps for services efficiency, but not the final proposed cap.

10. Recommendations

10.1. Standardise calculation of floor area

While seemingly simple, calculation of the floor area proved to be a problem throughout this project. One obvious point of difference was conditioned floor area versus gross floor area. In the author's opinion, the wording of *Transforming Operational Efficiency* (MBIE, 2020a) was unclear as to what floor area should be used, i.e., was it only the living areas, or should gross internal area or gross floor area be used instead?

Given that BfCC proposes to set caps per metre of floor area, providing greater clarity regarding which floor area is needed for the operational and embodied caps is important.

10.2. Consistency in building meta data

As the reductions in carbon footprint calculated through this project are reasonably modest, it will be very important to make sure that building meta data is collected in a consistent way to ensure that the improvements are real and not simply artefacts in the data.

The author of this report is an LCA practitioner, not a building industry expert. Even getting the basic details needed for this project (floor/wall/window areas, material types chosen, R-values, etc.) sometimes proved challenging, with different people providing different information. In addition to the modelling done specifically for this project, there were also 273 pages of code compliance paperwork for the selected reference building and often the values needed had to be measured or calculated from various drawings in this paperwork.

Examples of questions that arose through this project included:

- Is roof area the plan area or the sloped area? This was necessary when scaling the embodied carbon data from BRANZ's CO_2RE tool and CO_2NSTRUCT database.
- Do window/door areas include the frame?
- Do window/door areas include the garage door?
- Should floor area be measured to the internal wall edge, the outside edge of the concrete slab, or the outside of the exterior cladding?

While some of these differences may seem trivial, it is important to note that different building professionals often use these values for their purposes and there may be slight differences in their needs. Some examples observed in this project include the following:

- One of the engineers used a window/wall ratio to calculate the area of windows. The challenge with this is that the calculation included the garage door opening, which is large (as it is a double garage door) and does not contain any windows.
- One of the engineers initially used the sloped area of the roof, not the plan area.
- The QS split the roof area into two: the top area of the roof and the underside to be lined. This is because not all roof area is lined on the underside.

- Neither the engineers nor the QS used the gross floor area (GFA) for anything. The GFA was included in only one drawing in the 273 pages of compliance paperwork.
- The areas reported by BRANZ (Table 2-1) differ from those identified by the QS (Table 2-2). Both parties had the same plans and source data available to them.

10.3. Collect data on material quantities as well as carbon

This project was originally performed in LCAQuick v3.4, the previous version of the CO_2RE tool (then called MaCC) and the CO_2NSTRUCT v1.0 Database (Table 10-1). In December 2021, BRANZ released LCAQuick v3.5, CO_2NSTRUCT v2.0 and CO_2RE v1.0. Updating the analysis to reflect these new datasets resulted in the changes shown in Table 10-2. As can be seen, an update between versions of the BRANZ's databases was enough to reduce whole-of-life embodied carbon by 18% – a similar level of reduction to many of the savings identified through this project.

Table 10-1: Embodied carbon in reference building with LCAQuick v3.4 and sister tools

Assembly	Area (m2)	BRANZ Ref	GWP A-C EB (kg CO2e)	GWP A-C IB (kg CO2e)	GWP A-D IB (kg CO2e)
Roof	263	29	33,055	27,747	20,842
Envelope Wall	156	90.4	11,381	8,442	7,615
Internal Wall	169		3,178	733	343
Floor	209	127.6	18,227	16,870	15,085
Window	36		8,685	8,685	4,423
Total			**74,528**	**62,476**	**48,307**

Table 10-2: Embodied carbon in reference building with LCAQuick v3.5 and sister tools

Assembly	Area (m^2)	BRANZ Ref	GWP A-C EB (kg CO2e)	GWP A-C IB (kg CO2e)	GWP A-D IB (kg CO2e)
Roof	263	29	25,290	20,601	15,636
Envelope Wall	156	90.4	10,152	7,552	7,020
Internal Wall	169		2,437	276	33
Floor	209	127.6	18,148	16,862	15,880
Window	36		4,928	4,928	3,239
Total			**60,955**	**50,219**	**41,808**

As a result, thinkstep-anz strongly recommends that MBIE capture data on material quantities – in addition to carbon footprint – through implementation of the BfCC data, so that improvements in carbon footprinting databases can be separated from improvements due to changes in building material choices.

10.4. Greater transparency in building LCA databases

While BRANZ have made considerable effort to document their building LCA work to date, their work will come under increasing scrutiny if it does become the basis for BfCC. The previous section identified a reduction in upfront carbon of 18% due to a change in database alone. Trying to investigate the cause of the underlying changes proves challenging. The changelog for LCAQuick v3.5 simply states, “Updated materials data per LCAQuick_Material Library Format 10_2_exc concrete_MASTER_6 and LCAQuick_Material Library Format 10_2_concrete_MASTER_3”. Without having access to the raw data for the “LCAQuick_Material Library”, it is very difficult to understand what has changed.

thinsktep-anz recommends that if BRANZ’s databases do become the basis for BfCC, the database itself – including all raw data sources, all key assumptions, and all underlying calculations – should be made fully transparent. Many of the entries in LCAQuick, CO_2NSTRUCT and CO_2RE are assemblies based on BRANZ’s own material build-ups, construction waste rates (module A5), and assumed replacement rates (module B4). Without being able to see the key assumptions, raw data, and calculation steps to get to the output, it is difficult to be able to comment on the quality and appropriateness of data used and the assumptions made. This comment applies both to the current version of the database, and for historic versions.

10.5. Clearly defined building scope and calculation approach

Because the building selected is one from BRANZ’s reference library, it is possible to directly compare the results in this study with those from BRANZ study. The results of this study should be directly comparable with LCAQuick v3.5, except for differences in the scope of the building analysed. As can be seen in Table 10-3, differences in calculation method and scope yield quite large differences in building LCA results. (There are also some challenges in how biogenic carbon is dealt with, so only GWP including biogenic carbon is compared.)

Table 10-3: Building carbon footprint in the BRANZ LCAQuick reference library

Source	A1-A3	A4-A5	B2, B4	C1-C4	D	GWP A-C IB (kg CO2e)	GWP A-D IB (kg CO2e)
LCAQuick v3.4.4	16,728	5,345	36,767	9,897	-9,930	68,737	58,807
LCAQuick v3.5	30,900	6,370	44,500	9,180	-9,560	90,950	81,390
This study	22,844	5,492	36,615	7,043	-8,411	71,994	63,582

10.6. Standardise replacement cycles

Replacement cycles for major components of the building were found to be crucial in calculating good whole-of-life carbon footprints. As an example, BRANZ’s analysis typically shows that concrete/clay roof tiles outperform long-run steel roofing. This finding is solely due to the assumption that the tiles will last much longer than the steel, meaning the steel needs to be replaced more often. The steel would likely last longer in a lesser corrosion zone and/or if a zinc-aluminium-magnesium (ZAM) coating was used instead of zinc-aluminium. Further, the number of replacements needed also hinges on the building’s life.

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List of Acronyms

BfCC	Building for Climate Change
CF	Carbon Footprint
EAF	Electric Arc Furnace
EoL	End-of-Life
EPD	Environmental Product Declaration
GBCA	Green Building Council of Australia
GFA	Gross Floor Area
GIA	Gross Internal Area
GHG	Greenhouse Gas
GWP	Global Warming Potential
GWPEB	GWP Excluding Biogenic Carbon
GWPIB	GWP Including Biogenic Carbon
ISO	International Organization for Standardization
IGU	Insulated Glazing Unit
LC	Life Cycle
LCA	Life Cycle Assessment
MBIE	Ministry of Business, Innovation and Employment
NZGBC	New Zealand Green Building Council
PCR	Product Category Rules
QS	Quantity Surveyor
SCM	Supplementary Cementitious Material
UNFCCC	United Nations Framework Convention on Climate Change
WorldGBC	World Green Building Council

Applicability and Limitations

Restrictions and Intended Purpose

This report has been prepared by thinkstep-anz with all reasonable skill and diligence within the agreed scope, time and budget available for the work. thinkstep-anz does not accept responsibility of any kind to any third parties who make use of its contents. Any such party relies on the report at its own risk. Interpretations, analyses, or statements of any kind made by a third party and based on this report are beyond thinkstep-anz's responsibility.

If you have any suggestions, complaints, or any other feedback, please contact us at: feedback@thinkstep-anz.com.

Legal interpretation

Opinions and judgements expressed herein are based on our understanding and interpretation of current regulatory standards and should not be construed as legal opinions. Where opinions or judgements are to be relied on, they should be independently verified with appropriate legal advice.

Annex A Quantity Surveyor’s Report

PRENDOS.
Intelligent Property Solutions

28 September 2022 **Matter No.** 038319001

Thinkstep-anz (Australia & New Zealand)
11 Rawhiti Road
PUKERUA BAY 5026

Attention: Jeff Vickers

Dear Jeff

Re: MBIE LOW CARBON RESIDENTIAL STUDY - QUANTITY SURVEYING SERVICES IN RELATION TO ELEMENTAL ASSEMBLY RATES AND THE REFERENCE HOUSE IN WAIKATO

Please find attached our response to your instruction in relation to the required elemental rates and analysis of the reference house located in Waikato area.

We have reviewed the assembly items required, evaluated average rates for such assemblies and assessed the relevant quantities and build cost in relation to the reference house as per the consented design drawings provided.

A. ELEMENTAL RATES FOR 37 ASSEMBLIES

Please refer to **Appendix A** for the list of rates that apply to the 37 requested assemblies.

The rates are comprised of a composite build-up of material and labour to correlate with the elemental assembly descriptions as provided and as referenced.

Note we have provided an additional column that reflects the indicative supply price of the various insulation specification types being considered for your information and further analysis.

We highlight that market rates can vary depending on a range of factors however we have considered average current market rates as relevant to Waikato area.

B. COMPARISON OF THREE WINDOW TYPE OPTIONS

Please refer to **Appendix B** for the analysis and comparison of the three different window types and glazed doors for the reference house.

As an overview the rates are as follows:

i) Timber framed double glazed windows $1,496/m2

ii) Aluminium framed double-glazed windows $1,020/m2

iii) uPVC double glazed windows $1,300/m2

Prendos New Zealand Limited p. 0800 PRENDOS e. prendos@prendos.co.nz w. www.prendos.co.nz
Auckland (Head Office). 34 Barrys Point Road, Takapuna, PO Box 33700, 09 970 7070
Auckland CBD. PwC Tower, Level 17, 15 Customs Street West, Auckland, PO Box 33700, 09 970 7070; Hamilton. 539 Te Rapa Road, Te Rapa, Hamilton, 07 929 9540
Rotorua. Unit 1B, 1188 Whakaue Street, PO Box 12018, Rotorua, 07 929 9540; Tauranga. 96 Cameron Road, Tauranga, PO Box 12018, Rotorua, 07 929 9540
Wellington. Dell EMC House, 5-7 Willeston Street, PO Box 10278, 04 931 7070; Christchurch. 6/35 Sir William Pickering Drive, PO Box 8049, Burnside, 03 341 7570
Dunedin. L2, Vero House, 34 London Street, PO Box 6231, Dunedin, 03 940 2763

Note this was obtained by requesting quotes from suppliers based on the window and glazed doors schedule for the reference house and with the overall area of 35.48m2. A slightly different location address was used to protect the name and details of the actual reference house.

The additional extra over cost for low E glass ranges from an additional 3.35% to 4% of the supply cost of the windows and glazed doors.

C.ELEMENTAL ESTIMATE OF REFERENCE HOUSE

Please refer to **Appendix 3** for the Summary and Breakdown of the full elemental estimate of the reference house as at 16 December 2021.

The overall build cost of the reference house is $553,442.38 including GST, which equates to $2,648/m2 overall including GST.

The specific assembly rates used have been based on the consented drawing specifications and the rates have been highlighted in the estimate.

- Concrete slab on grade with no insulation
- Timber roof trusses and coloursteel roofing
- 70 Series masonry veneer with R2.8 wall insulation
- Aluminium double-glazed windows and glazed doors
- GIB ceiling with R3.2 ceiling insulation

Please refer to the specific assumptions, exclusions, and inclusions stipulated below as qualification to our total estimated cost for the development of the reference house.

Estimate of other costs not covered by the 37 assemblies:

In considering the adjustment of omitting the elements covered by the assembly rates, results in the "balance of items not in the assemblies" totalling $199,022.80 including GST.

Thus, following the deduction, the rate for "the items not in the assemblies" equates to **$952.26/m2 including GST** and represents 33.82% of the overall project build costs.

Basis of rates and elemental estimate:

- Reasonably competitive market conditions for tender procurement.
- Our cost estimate is based on relevant market data at the date of the estimate, i.e. 16 December 2021.
- Our estimate does not propose to be a rated scope of works.
- The market rates can vary depending on numerous factors
- We have considered average market rates which could vary from what we have provided.

Inclusions:

- GST - 15%
- Scaffolding
- Preliminaries - 7%
- Margins (Off-site Overheads & Main Contractors Profit)- 8%

Exclusions:

- Demolition of any existing buildings for site preparation
- Design fees for consent drawings and construction issue.
- Cost of infrastructure including driveways, decks, paving's, landscaping etc.
- Contamination removal and ground remediation
- Project contingency allowance
- Connections of power, water, data services
- Local Authority Fees, fees for building consent, including council inspections, and Code Compliance.
- Allowance for development contribution.
- Professional fees for Project Management, Architectural, Engineering, Geotechnical and Quantity Surveying including procurement and contract administration.
- After hours or weekend works.
- Contract Work Insurance.
- LINZ, title registration.
- Legal, finance and marketing fees.
- Effects of Covid 19 restrictions and market disruptions or delays.
- Escalation in costs beyond the date of this estimate.

Overall Observation Comment:

The reference house has an overall area over the plates of 209m2 and this is the gross floor area that we have based our rates per m2 on. The floor plan has a number of recesses, angles and returns that contribute to additional labour and material costs. We would suggest that with some reconfiguration and optimization that the following potential savings could be achieved:

a) A more regular floor plan with the same floor area could reduce the extent of the external and internal walls by approximately 2% to 2.5% of the costs at say $12,000 to $15,000.

b) A less complex roof design for the same floor area, i.e. with less hips and valleys, could reduce the costs by approximately 1.2% to 1.3% of the costs at say $7,000 to $8,000.

c) A new floor plan design that reduces the extent of corridors and which could be considered more cost effective could be achieved with the same room areas. Reducing the overall floor plan area by 3.7% to 5% or reducing the overall area by say 10m2, could reduce overall costs by between $22,000 to $28,000.

d) Using increased R-value insulation improves the performance of the house, reducing the need for alternative energy. The labour cost to install the various types of R-value insulation is essentially the same and the supply prices are only marginally different.

e) House orientation to the sun, insulation specifications, thermally broken and double-glazed windows, designed ventilation and sealed houses, all contribute towards reducing the need for heat pumps and would minimise energy requirements.

f) In terms of Life Cycle Costings, it is worth noting what the maintenance regime is for the external or exposed products that are being considered. For example: Veneer block cladding requires the least maintenance costs over its lifetime compared to regular painting of other products such as weatherboard cladding.

We trust the above rates, analysis and comparison meet your requirements.

Please do not hesitate to contact us should you have any queries.

Prepared by

Linda Lodetti
BSc (Hons) Quantity Surveying
MRICS NZIQS
REGISTERED & CHARTERED QUANTITY SURVEYOR
CENTRAL NORTH ISLAND LEAD QUANTITY SURVEYOR

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REGISTERED & CHARTERED BUILDING SURVEYOR
DEPUTY CHAIR, SI MANAGER

Attachments:

Addendum A: Rates for 37 No Assemblies
Addendum B: Comparison of three different Window types options
Addendum C: Elemental Estimate of Waikato Reference House (With Assemblies identified)

APPENDIX 1
MBIE Low carbon residential study
Assembly rates
Housing unit, Waikato

Reference	Description	Insulation supply rate per m2	RATE PER ELEMENT AREA	COMMENTS
	Roofs			
49.0	Concrete or clay tile - Timber-framed roof with roof space, 90 mm ceiling joists or bottom chords 15 degree pitch, Pink® Batts® Classic R3.2 Ceiling insulation, 70 x 35 mm timber battens	7.18	370	
49.4	Concrete or clay tile - Timber-framed roof with roof space, 90 mm ceiling joists or bottom chords 15 degree pitch, Pink® Batts® Ultra® R5.0 Ceiling insulation, 70 x 35 mm timber battens	13.77	377	
29.8	Profiled steel - Timber-framed roof with roof space, 90 mm ceiling joists or bottom chords 15 degree pitch, timber trusses, Pink® Batts® Ultra® R5.0 Ceiling insulation, 70 x 35 mm timber battens @ 600 mm centres	13.77	302	
29.0	Profiled steel - Timber-framed roof with roof space, 90 mm ceiling joists or bottom chords 15 degree pitch, timber trusses, Pink® Batts® Classic R3.2 Ceiling insulation, 70 x 35 mm timber battens @ 600 mm centres	7.18	295	
29.7	Profiled steel - Timber-framed roof with roof space, 90 mm ceiling joists or bottom chords 15 degree pitch, steel trusses with thermal breaks, Pink® Batts® Classic R3.2 Ceiling insulation, steel battens @ 600 mm centres	7.18	295	Assumed light weight steel truss option at no cost difference to timber TBC
59.2	Membrane - Low slope timber framed, 140mm rafters and battens 1.5mm butyl rubber membrane, Pink® Batts® Classic R3.6 Ceiling insulation, rafters @ 600mm centres	7.86	367	Additional assembly
	Envelope Walls			
67.2	Bevel-back weatherboard - Timber-framed, cavity, 140 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R4.0 140 mm Wall insulation	9.44	455	All rates include $95/m2 for Internal painted Gib wall linings
66.0	Bevel-back weatherboard - Timber-framed, cavity, 90 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Classic R2.2 Wall insulation	5.94	431	
74.0	Bevel-back weatherboard - Steel-framed, direct-fixed, 90 mm frame steel studs @ 600 mm centres, dwangs @ 800 mm (14.4% framing ratio), Pink® Batts® Steel R2.2 Wall insulation	5.94	426	
83.0	Sheet cladding - Timber-framed, cavity, 140 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R3.2 140 mm Wall insulation	7.18	382	
97.2	Fibre-cement weatherboard - Timber-framed, cavity, 140 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R4.0 140 mm Wall insulation	9.44	395	

Reference	Description	Insulation supply rate per m2	RATE PER ELEMENT AREA	COMMENTS
96.0	Fibre-cement weatherboard - Timber-framed, cavity, 90 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R2.8 Wall insulation	14.88	380	
100.0	Fibre-cement weatherboard - Steel-framed, direct-fixed, 90 mm frame studs @ 600 mm centres, dwangs 800 mm centres (14.4% framing ratio), Pink® Batts® Ultra® R2.8 Wall insulation	14.88	380	
91.4	Masonry veneer - Timber-framed, cavity, 140 mm frame 70 mm clay brick masonry, studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R4.0 140 mm Wall insulation	9.44	425	
91.5	Masonry veneer - Timber-framed, cavity, 140 mm frame 90 mm clay brick masonry, studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R4.0 140 mm Wall insulation	9.44	435	
90.4	Masonry veneer - Timber-framed, cavity, 90 mm frame 70 mm clay brick masonry, studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Classic R2.8 Wall insulation	10.25	405	
92.0	Masonry veneer - Steel-framed, cavity, 90 mm frame 70 mm clay brick masonry, studs @ 600 mm centres, dwangs 800 mm centres (14.4% framing ratio), Pink® Batts® Ultra® R2.8 Wall insulation	14.88	410	
105.2	Metal - Timber-framed, cavity, 140 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R4.0 140 mm Wall insulation	9.44	365	
104	Metal - Timber-framed, cavity, 90 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R2.8 Wall insulation	14.88	350	
106	Metal - Steel-framed, cavity, 90 mm frame studs @ 600 mm centres, dwangs 800 mm centres (14.4% framing ratio), Pink® Batts® Ultra® R2.8 Wall insulation	14.88	335	
107.0	EIFS - Timber-framed, cavity, 90 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Classic R2.2 Wall insulation	5.94	391	
107.2	EIFS - Timber-framed, cavity, 90 mm frame studs @ 400 mm centres, dwangs 800 mm centres (18% framing ratio), Pink® Batts® Ultra® R2.8 Wall insulation	14.88	400	
111.0	Concrete block - Strapped and lined/false wall 200 series masonry, studs @ 600 mm centres, dwangs 1200 mm centres (12% framing ratio), Pink® Batts® Classic R2.2 70 mm Wall insulation	5.94	238	
111.1	Concrete block - Strapped and lined/false wall 250 series masonry, studs @ 600 mm centres, dwangs 1200 mm centres (12% framing ratio), Pink® Batts® Classic R2.2 70 mm Wall insulation	5.94	245	
	Floor			
120.24	Suspended timber - Closed perimeter, bulk insulants with lining, 190/290 mm joists 290 x 45 mm joists @ 600 mm centres, 19 mm CD slip tongue ply flooring (no dwangs), Pink® Batts® SnugFloor® R2.6 insulation, A/P ratio 2.5	10.47	281	

Reference	Description	Insulation supply rate per m2	RATE PER ELEMENT AREA	COMMENTS
120.27	Suspended timber - Closed perimeter, bulk insulants with lining, 190/290 mm joists 290 x 45 mm joists @ 450 mm centres, 20 mm T&G flooring (to suit joists @ 450 mm centres), Pink® Batts® SnugFloor® R2.6 insulation, A/P ratio 2.5	10.47	401	
119.20	Suspended timber - Closed perimeter, bulk insulants without lining, 90/140 mm joists 90 x 45 mm joists @ 600 mm centres, 19 mm CD slip tongue ply flooring (no dwangs), Pink® Batts® SnugFloor® R1.6 insulation, A/P ratio 2.5	5.86	276	
124.4	Concrete slab on ground - With thermal break 100 mm EPS throughout, 140 mm wall framing with A/P ratio of 2.5	17.44	263	Includes min 150mm hardfill
124.2	Concrete slab on ground - With thermal break 50 mm EPS throughout, 90 mm wall framing with A/P ratio of 2.5	9.73	255	
126.2	Concrete slab on ground - With no thermal break, either full or perimeter insulation under slab 50 mm EPS throughout, 90 mm wall framing with A/P ratio of 2.5	9.73	245	
127.6	Concrete slab on ground - 90 mm deep wall frame no edge insulation, no underfloor insulation with A/P ratio of 2.5		235	
131.0	Waffle pod - 90 mm deep wall frame 30 mm XPS edge insulation, A/P ratio of 2.5	11.04	325	
131.2	Waffle pod - 90 mm deep wall frame no edge insulation, A/P ratio of 2.5		320	
118.8	Suspended timber - Open perimeter, bulk insulants with linings, 190/290 mm joists 290x45mm joists @ 600mm centres, 19mm CD ply flooring with slip tongues (no dwangs to joints), Pink® Batts® SnugFloor® R2.6 insulation	10.47	240	Additional assembly
118.1	Suspended timber - Open perimeter, bulk insulants with linings, 190/290 mm joists 290x45mm joists @ 450mm centres, 20mm T&G flooring (to suit joists @ 450mm centres), Pink® Batts® SnugFloor® R2.6 insulation	10.47	360	Additional assembly. Note T&G ranges $200/m2 to $350/m2 depend on spec
117.4	Suspended timber - Open perimeter, bulk insulants with linings, 190/140 mm joists 90x45mm joists @ 600mm centres, 19mm CD ply flooring with slip tongues (no dwangs to joints), Pink® Batts® SnugFloor® R1.6 insulation	5.86	215	Additional assembly
	Internal Walls			
1	10 mm thick GIB both sides, Timber framed, 90 mm wall frame, Dwangs @ 800 mm centres, studs @ 400 mm centres		266	
2	10 mm thick GIB both sides, steel stud wall system, 92.1x33.1 0.55 BMT @ 450ctrs, 1 nogging row		266	Assumed no price difference in steel stud TBC
3	9 mm thick ply both sides, Timber framed, 90 mm wall frame, Dwangs @ 800 mm centres, studs @ 400 mm centres		296	
4	13mm thick GIB both sides, Timber framed, 90mm wall frame, Dwangs @ 800mm centres, studs @ 400mm centres		278	Additional assembly
5	13mm thick GIB both sides, steel stud wall system, 92.1x33.1 0.55 BMT @ 450ctrs, 1 nogging row		278	Additional assembly. Assumed no price difference in steel framing

APPENDIX 2

Dec-21

MBIE Low carbon residential study

Door window comparison

Housing unit, Waikato

Item Description	Type 1	Type 2	Type 3
	David - Timber	NT Joinery-Aluminium	Green Innovation - UPVC
MATERIAL			
Total supply Without Low e glass	37,210.00	21,810.66	31,144.35
Add for openable glass on slider		727.02	
Add for Flashing cost	1,650.00	1,650.00	1,650.00
LABOUR			
Add for Flashing labour	1,631.00	1,631.00	1,631.00
Add for fixing D/W	5,676.68	5,676.68	5,676.68
Total basic cost	46,167.68	31,495.37	40,102.03
Add for OH & Profit -15%	6,925.15	4,724.30	6,015.30
Grand total for supply and fixing of Doors and windows	**53,092.83**	**36,219.67**	**46,117.33**
Rate /m2 for supply and fixing of Doors and windows- overall area 35.5m2	1,496.45	1,020.87	1,299.84
Low e option			
Total supply amount With Low e glas	*38,455.00*	*22,649.42*	*32,390.12*
Extra cost for Low e	1,245.00	838.76	1,245.77
Additional % for Low e	3.35%	3.85%	4.00%

APPENDIX 3

Dec-21

SUMMARY

MBIE Low carbon residential study
Elemental estimate of reference house
Housing unit, Waikato

REFERENCE HOUSE WAIKATO

SUMMARY	$	Cost per m2
Site Preparation	2,400.00	
Substructure	50,315.00	
Frame	13,480.00	
Roof	63,755.00	
Exterior Walls and Exterior Finish	35,880.00	
Windows and Exterior Doors	40,220.00	
Internal Walls	13,520.00	
Interior Doors	11,100.00	
Floor finishes	16,740.00	
Wall Finishes	46,254.00	
Ceiling Finishes	18,810.00	
Fittings & Fixtures	30,500.00	
Sanitary Plumbing	33,900.00	
Heating and Ventilation	5,000.00	
Fire Services	300.00	
Electrical Services	26,080.00	
Drainage	1,200.00	
BWIC	1,000.00	
Sub Total	**410,454.00**	**1,963.89**
Scaffolding	6,000.00	
Preliminaries	29,151.78	
Margins (Off-site Overheads & Main Contractors Profit	35,648.46	
Sub Total	**481,254.24**	**2,302.65**
GST	72,188.14	
TOTAL BUILD	**553,442.38**	**2,648.05**

APPENDIX 3

Dec-21

BREAKDOWN

MBIE Low carbon residential study

Elemental estimate of reference house

Housing unit, Waikato

ELEMENTAL REFERENCE HOUSE ESTIMATE

			Unit	Qty	Rate	TOTAL	
		Site Preparation					
1		Clear site for proposed house build	m2	300	8.00	2,400.00	
							2,400.00
		Substructure					
2	127.6	Concrete slab on grade	m2	209	235.00	49,115.00	
3		Extra value for pad footing portico	No	1	1,200.00	1,200.00	
							50,315.00
		Frame					
4	90.4	90mm Timber wall framing	m2	156	80.00	12,480.00	
5		Extra value for lintel beam garage	sum	1	1,000.00	1,000.00	
							13,480.00
		Roof					
6	29.0	Timber roof trusses and corrugated colo	m2	263	205.00	53,915.00	
7		Fascia and bargeboards	m	52	120.00	6,240.00	
8		Gutters & downpipes	m	40	60.00	2,400.00	
9		Downpipes	Item	1	1,200.00	1,200.00	
							63,755.00
		Exterior Walls and Exterior Finish					
10	90.4	70 Series masonary veneer with R2.8 Wa	m2	156	230.00	35,880.00	
							35,880.00
		Windows and Exterior Doors					
11	Option	Aluminium double glazed windows	m2	36	1,020.00	36,720.00	
12		Double garage door	No	1	3,500.00	3,500.00	
							40,220.00
		Internal Walls					
13	1	90mm Timber wall framing	m2	169	80.00	13,520.00	
							13,520.00
		Interior Doors					
14		Double door complete	No	1	1,800.00	1,800.00	
15		Single door complete	No	9	900.00	8,100.00	
16		Single door cavity slider	No	1	1,200.00	1,200.00	
							11,100.00
		Floor finishes					
17		Tiled floors	m2	22	250.00	5,500.00	
18		Carpets	m2	140	60.00	8,400.00	
19		Sealed concrete	m2	40	15.00	600.00	
20		Tiling to porch and patio	m2	8	280.00	2,240.00	
							16,740.00
		Wall Finishes					
21	90.4	GIB linings, battens, painting and skirting	m2	156	95.00	14,820.00	
22	1	GIB linings, battens, painting and skirting	m2	169	186.00	31,434.00	
							46,254.00
		Ceiling Finishes					
23	29	GIB ceilings, battens, painting	m2	209	90.00	18,810.00	
							18,810.00
		Fittings & Fixtures					
24		Kitchen Joinery including appliances	P/S	1	20,000.00	20,000.00	
25		Laundry	P/S	1	1,500.00	1,500.00	
26		Linen cupboard	P/S	1	3,000.00	3,000.00	
27		Master W/R	P/S	1	2,000.00	2,000.00	

ELEMENTAL REFERENCE HOUSE ESTIMATE

		Unit	Qty	Rate	TOTAL		
28	Bedroom cupboards (No 3)	P/S	1	2,400.00	2,400.00		
29	Vanity including mirror (No 2)	P/S	1	1,600.00	1,600.00		
						30,500.00	
	Sanitary Plumbing						
30	General plumbing allowance	P/S	1	15,000.00	15,000.00		
31	WC complete	No	2	2,500.00	5,000.00		
32	Bath complete	No	1	3,000.00	3,000.00		
33	Shower set complete	No	2	3,500.00	7,000.00		
34	Washhand basin to vanity	No	2	1,200.00	2,400.00		
35	Laundry tub complete	No	1	1,500.00	1,500.00		
						33,900.00	
	Heating and Ventilation						
36	Heat pump complete	Item	1	3,500.00	3,500.00		
37	Extract fans	No	3	500.00	1,500.00		
						5,000.00	
	Fire Services						
38	Smoke detectors	No	2	150.00	300.00		
						300.00	
	Electrical Services						
39	General power and lighting	m2	209	120.00	25,080.00		
40	Heated towel rails	No	2	500.00	1,000.00		
						26,080.00	
	Drainage						
41	Gulley traps	Item	1	1,200.00	1,200.00		
						1,200.00	
	BWIC						
42	Builders work in connection with service	Item	1	1,000.00	1,000.00		
						1,000.00	
	SUBTOTAL				**410,454.00**	**1,963.89**	**per m2**
43	Scaffolding	Item	1	6,000.00	6,000.00		
44	Preliminaries	7	%		29,151.78		
45	Margins	8	%		35,648.46		
	TOTAL excl GST				**481,254.24**	**2,302.65**	**per m2**
	GST 15%				72,188.14		
	TOTAL incl GST				**553,442.38**	**2,648.05**	**per m2**

About thinkstep-anz

Our mission is to enable organisations to succeed sustainably. We develop strategies, deliver roadmaps, and implement leading software solutions. Whether you're starting out or want to advance your leadership position, we can help no matter your sector or size.

Why us? Because we are fluent in both languages of sustainability and business. We are translators.

We've been building business value from sustainability for 15 years, for small or large businesses, family-owned and listed companies, or government agencies.

Our approach is science-based, pragmatic, and flexible.

Our work helps all industries in Australia and New Zealand, including manufacturing, building and construction, FMCG, packaging, energy, apparel, tourism, and agriculture.

Our services range from ready-to-go packages to solutions tailored to your needs.

As a certified B Corp with an approved science-based target, we make sure we are walking the talk.

Our services cover:

Product

- Life Cycle Assessment (LCA)
- Environmental Product Declarations (EPD)
- Carbon footprint
- Circular Economy (CE)
- Cradle to Cradle (C2C)
- Water footprint
- Packaging
- Independent reviews

Carbon

- Carbon Footprint
- Scope 3 emissions
- Reduction strategy
- Carbon targets
- Science-based targets (SBT)
- Offsetting strategies
- Inventory verification

Strategy

- Materiality assessment
- Green Star
- Sustainable Development Goals (SDGs)
- Foresighting & regenerative futures
- Roadmaps & action plans
- Responsible procurement & supply chain engagement

Software & tools

- GaBi LCA software
- GaBi Envision
- Material Circularity Indicator (MCI)
- OpenLCA
- eTool
- Packaging calculator
- SoFi sustainability reporting

Reporting & disclosures

- Task Force on Climate-related Financial Disclosures (TCFD)
- Global Reporting Initiative (GRI) & Integrated reporting (<IR>)
- B Corp
- Voluntary & compliance reporting
- CDP

Communications

- Short form reports
- Case studies
- Infographics
- Workshops
- Storytelling
- Stakeholder engagement
- Sustainability reports

www.thinkstep-anz.com

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CLIMATE LEADERS COALITION
ON A MISSION TO REDUCE EMISSIONS IN NEW ZEALAND

UN GLOBAL COMPACT

SCIENCE BASED TARGETS
DRIVING AMBITIOUS CORPORATE CLIMATE ACTION

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BUSINESS OPERATIONS