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INTRODUCTION TO CALCULATING WHOLE-OF-LIFE CARBON FOOTPRINTS OF HOUSES

December 2022

- Within the next few years, it is likely that calculating the carbon footprint of a proposed building will become a required part of a building consent application.
- This bulletin is an introduction to the topic, specifically calculating whole-of-life carbon footprints of houses.
- This bulletin is not a comprehensive guide for how to calculate a carbon footprint for a house.

1 INTRODUCTION

1.0.1 A carbon footprint is a metric that provides an understanding of the potential climate change impact of a building's design, construction, use and end-of-life management. The whole-of-life carbon footprint of a house is the sum of all significant greenhouse gas (GHG) emissions produced to build, use and dispose of it. It is calculated by identifying the resources that a building will use (materials, energy and water) and estimating the GHG emissions from using those resources – for example, from the manufacture of building materials and their transport to a construction site and the energy and water used in the building by the occupants. There are international standards and guidelines for making these calculations, which categorise groups of activities and their GHG emissions (Figure 1).

1.0.2 The GHG emissions from a building can be divided into two main categories:

- Embodied GHG emissions – due to manufacture, delivery and use of the building materials.
- Operational GHG emissions – due to water and energy use by the building occupants.

1.0.3 Within the next few years, it is likely that the carbon footprint of a proposed building will be a required part of a building consent application. There are likely to be caps on the embodied carbon allowable in new buildings.

1.0.4 There are already limitations on carbon emissions that a new building must comply with under Homestar, Green Star and other voluntary schemes.

1.0.5 In practical terms, calculating a carbon footprint is carried out with digital tools. The person making the assessment enters the amount of resources (materials, energy and water) used in a potential design and, in some cases, makes assumptions about how those resources are used. The tool then calculates a carbon footprint. The units used to describe a house's carbon footprint are kilograms or metric tonnes of carbon dioxide equivalent (CO_2eq). The 'carbon dioxide equivalent' concept takes into account the fact that some GHGs are more potent than CO_2. This is commonly measured using the global warming potential (GWP) indicator.

1.0.6 There is currently no standardised tool for measuring carbon footprints of buildings and no single comprehensive national database of the carbon associated with building materials. The Ministry of Business, Innovation and Employment (MBIE) has indicated that it will be holding consultations around the design and implementation of these resources. However, there are already a number of tools and databases available that architects and designers can use to develop their skills and knowledge in the area (see section 4).

1.0.7 Calculating the carbon footprint of a building should begin early in the building design process, well before final decisions are made. Designers can assess the carbon implications of multiple design alternatives to see which have the lowest impacts. If carbon footprinting is left until later in a project when crucial design decisions are locked in, it can be difficult, expensive or even impossible to make changes.

1.0.8 There is an urgency around this process. Under the UN Paris Agreement, New Zealand is committed to reducing its emissions, with a target to reduce net emissions to 50% below gross 2005 levels by 2030 and a commitment to reach a net-zero carbon economy by 2050.

1.0.9 Many other countries are already taking big steps in this area. For example:

- the Netherlands has required a calculation of building environmental impacts for new buildings since 2013
- the Nordic countries and France have regulations on embodied carbon in new buildings

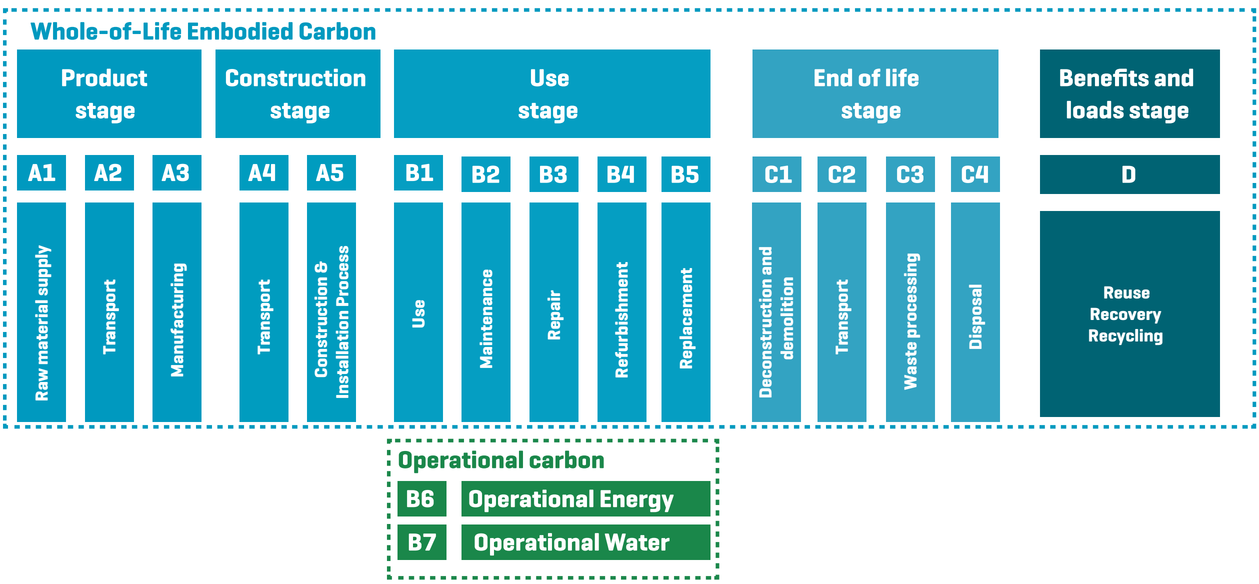

Figure 1. Components of whole-of-life embodied and operational carbon footprints.
Table from *Whole-of-Life Embodied Carbon Emissions Reduction Framework*, MBIE, August 2020.

- Denmark will shortly require a calculation of building environmental impacts for all new buildings, with progressively reduced allowances for embodied carbon
- changes to the United Kingdom Building Regulations introduced on 15 June 2022 will effectively result in CO_2 emissions from new-build homes that are around 30% lower than under the previous standards, with a 1-year transition period
- the European Union is revising its Energy Performance of Buildings Directive to require that, from 2030, all new buildings should be net-zero carbon and the worst-rated 15% of the existing building stock be improved from energy efficiency class G to at least F.

2 BUILDING FOR CLIMATE CHANGE

2.0.1 Launched in 2020, the MBIE *Building for climate change* programme is developing initiatives to reduce whole-of-life embodied carbon emissions, transform operational efficiency and support adaptation work that will enhance the resilience of the building stock.

2.0.2 In its published timelines, MBIE has said that, subject to government funding, it will:

- develop carbon calculation tools and resources (2021–2023)
- make available a new Building Code compliance pathway for operational efficiency (2024–2029)
- introduce mandatory disclosure of embodied carbon for new buildings (2024–2029)
- phase in caps for embodied carbon in new buildings (2024–2029)
- confirm an emissions reduction approach for existing buildings (2024–2029)
- progress towards final emissions reductions caps (2030 onwards).

2.0.3 In practical terms, this means that carbon footprints will become a mandatory part of building consent applications. Eventually, there will be caps placed on the allowable emissions in a new building, and the caps will be reduced over time.

2.0.4 In early 2022, MBIE published a technical methodology for assessing whole-of-life embodied carbon of new buildings in New Zealand. This is an important step on the path to the regulation of embodied carbon in new buildings. The published methodology follows a life cycle assessment approach in assessing the embodied carbon over the life cycle of a building. A basic model was proposed (Figure 2), which shows in simple terms how design choices contribute to the embodied carbon footprint of a building.

2.0.5 MBIE's methodology covers a suggested approach in five key areas of:

- what building elements should be included in assessments
- what life cycle stages should be included
- how carbon emissions and carbon benefits should be reported
- how data sources should be used in assessments
- how assessments should be formatted.

3 HOW IS A CARBON FOOTPRINT CALCULATED?

3.0.1 Calculating a carbon footprint is part of a wider process called life cycle assessment (LCA). LCA models activities that occur throughout a building's life cycle, the resources used to perform those activities and the environmental impact of performing those activities. Examples of activities within the building life cycle include materials extraction, processing, manufacturing, transportation, use, reuse, maintenance, recycling and eventual disposal. Climate change is just one of the environmental issues that LCAs typically consider. Examples of other issues are acidification of land and water, eutrophication (waterways damaged by the release of nitrogen and other chemicals) and stratospheric ozone depletion.

3.0.2 Both LCA and carbon footprinting of buildings are guided by international standards and protocols, such as:

- EN 15804+A2 *Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products*
- EN 15978 *Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method*

Figure 2. MBIE's proposed model for assessing whole-of-life embodied carbon.

- ISO 21931-1 *Sustainability in buildings and civil engineering works – Framework for methods of assessment of the environmental, social and economic performance of construction works as a basis for sustainability assessment – Part 1: Buildings*
- ISO 21930 *Sustainability in buildings and civil engineering works – Core rules for environmental product declarations of construction products and services.*

3.0.3 LCA draws on data provided from many sources, but environmental product declarations (EPDs) are considered one of the most reliable sources. EPDs are documents published by manufacturers declaring the environmental impact of their product and are developed and independently verified according to standards such as those listed above and others. Databases giving information about the carbon profile of different building materials frequently draw on EPDs. For example, the BRANZ CO_2NSTRUCT tool provides values for embodied GHG (as kg CO_2 equivalent) and energy (MJ) for a range of construction materials, including concrete, glass, timber and metals, as well as products such as lifts and fittings for bathrooms and kitchens. Much of this data comes from EPDs.

3.0.4 A full building carbon footprint also requires consideration of water and energy use (the operational carbon footprint), which requires energy simulation. Again, digital tools are available to calculate operational carbon such as IES, EnergyPlus, Passive House Planning Package (PHPP) or the New Zealand Green Building Council's ECCHO tool (which is accessible to those who have done Homestar v5 designer training). MBIE is also planning to provide guidance for the assessment of operational carbon.

3.0.5 As the research and understanding around embodied carbon and operational carbon develops, the tools and the data behind them will also change.

3.0.6 Always bear in mind the total overall picture. Operational and embodied carbon considerations interact with each other. Placing too much emphasis on reducing the embodied carbon can inadvertently increase the operational carbon and potentially lead to poorer long-term outcomes. For example, it would be possible to keep the embodied carbon in a house low by only using the minimum of insulation materials to comply with Building Code clause H1 *Energy efficiency*. However, if you improve the thermal performance of the building envelope – which may require more insulation materials and hence a higher amount of embodied carbon – you could significantly reduce the long-term energy use in the house, reducing its overall carbon footprint and more than compensating for the slightly higher embodied energy from the higher-performing insulation. Similarly, too much focus on operational carbon may come at the detriment of embodied carbon.

3.0.7 The power of using these tools and making these calculations is in helping building owners, designers, developers and managers to make the best material, systems and operational decisions for the whole life of a building.

4 TOOLS FOR ASSESSING CARBON FOOTPRINTS OF HOUSES

4.0.1 There are a number of tools that can help. It is likely that, in coming years, the existing tools will be updated and further developed and new tools will be introduced. The choice of tool depends partly on the stage in the design process. Some tools are more suited to providing estimates during the preliminary stages of a design, and other tools can provide more-precise estimates later when the final building design is clearer and more settled.

4.0.2 To complete a detailed carbon footprint, you will need to know the quantities of construction materials. This can come from a building information modelling (BIM) tool (Revit, ArchiCAD or similar) or a schedule from a quantity surveyor or an estimate from the plans.

4.0.3 BRANZ has developed four carbon tools that can be used to help assess the carbon in house designs:

- LCAQuick – a life cycle assessment tool that can be used to produce carbon footprints on more-complex dwellings.
- CO_2NSTRUCT – a database of embodied carbon data for the manufacture of various materials used in the New Zealand built environment.
- CO_2RE – a simpler tool that compares the impact and construction R-values of a range of common residential roof, wall and floor constructions.
- CO_2MPARE – provides building carbon benchmarks and carbon budgets based on BRANZ analysis of reference buildings. This information can help in setting targets at the start of a new project. The residential reference buildings are four stand-alone houses ranging from 120 m^2 to 192 m^2, an 8-unit medium-density housing complex totalling 887 m^2 and one apartment building of 108 units.

4.1 LCAQUICK

4.1.1 LCAQuick is free to use and is the main BRANZ tool for carrying out a life cycle assessment of a planned building and understanding the potential environmental impacts, including GHG emissions across its life cycle. Although it calculates the impact for a range of environmental issues, it can also be used for carbon footprinting alone. LCAQuick gives carbon footprint details with embodied and operational contributions shown separately. Users don't need BIM tools to use LCAQuick, but LCAQuick is most commonly used with them.

4.1.2 The full version is an Excel spreadsheet. Data for this full working version can be entered directly, pasted from LCAQuick Data Entry or loaded from a file saved by LCAQuick Data Entry. As LCAQuick does a number of calculations in the background, users may find that using LCAQuick Data Entry may speed up the process.

4.1.3 LCAQuick Data Entry is a complementary tool that allows data entry but does not have the functionality to calculate the environmental impacts of a building. Once data is in the correct format in LCAQuick Data Entry, it can be saved into a small file or copied and pasted into the full version of LCAQuick.

4.1.4 BRANZ offers free support for using LCAQuick. The best place to start is by watching these online webinars, then contact LCAQuick.help@branz.co.nz for further support:

- LCA Overview
- LCAQuick

4.1.5 LCAQuick was the tool used to produce the carbon footprints of 10 newly built houses (Figure 3), a project undertaken to help assess the carbon footprint of typical new house construction in New Zealand today.

4.1.6 The NZ Passive House Institute publication ER70 *PHINZ High-performance construction details handbook* (2022) also has embodied carbon rates for different construction types and junctions that could be used for a simple calculation.

4.2 OTHER TOOLS

4.2.1 There is a range of other tools that can be used either to calculate the carbon footprint of a building or give an indication of the carbon footprint of different building materials and elements. Of the large number of carbon footprinting tools available, eTool and One Click LCA are currently among the most widely used in New Zealand. Like LCAQuick, they are LCA tools that cover both whole-of-life embodied carbon and operational carbon.

- eTool is a proprietary product founded by two Australian engineers and is now used in countries around the world. It is web based, and a basic version can be used free of charge, with more features being available through a subscription model. eTool can also provide assessments and certifications for a charge. eTool also has a plugin for Autodesk Revit and is able to import data directly from a .csv file.
- The developers behind eTool also have another product available called RapidLCA designed specifically for housing.
- One Click LCA is also a web-based proprietary product that was originally developed in Europe but is also now used worldwide. It integrates with a range of other tools or types/categories of tools such as BIM (including a plugin for Autodesk Revit), BEM and others such as Excel. It offers a range of different subscriptions plans.

4.2.2 The New Zealand Green Building Council has the Homestar Embodied Carbon Calculator (HECC) tool. Developed by BRANZ, the HECC tool is based on a CO_2RE tool platform and facilitates calculation of an estimated carbon footprint of a dwelling. HECC requires a user to select constructions and input the areas of those construction elements. It is a tool that can be used by anyone.

4.2.3 The BRANZ CO_2RE and NZGBC HECC tools do not calculate a detailed carbon footprint but are an easy way to get a sense of the likely climate change impact of a house design. They compare the impact and construction R-values of a range of common residential roof, wall and floor constructions. They can give estimated embodied carbon figures for different types of constructions based on the choice of material and type of system. CO_2RE can also compare constructions that deliver a desired construction R-value to illustrate lower embodied carbon options.

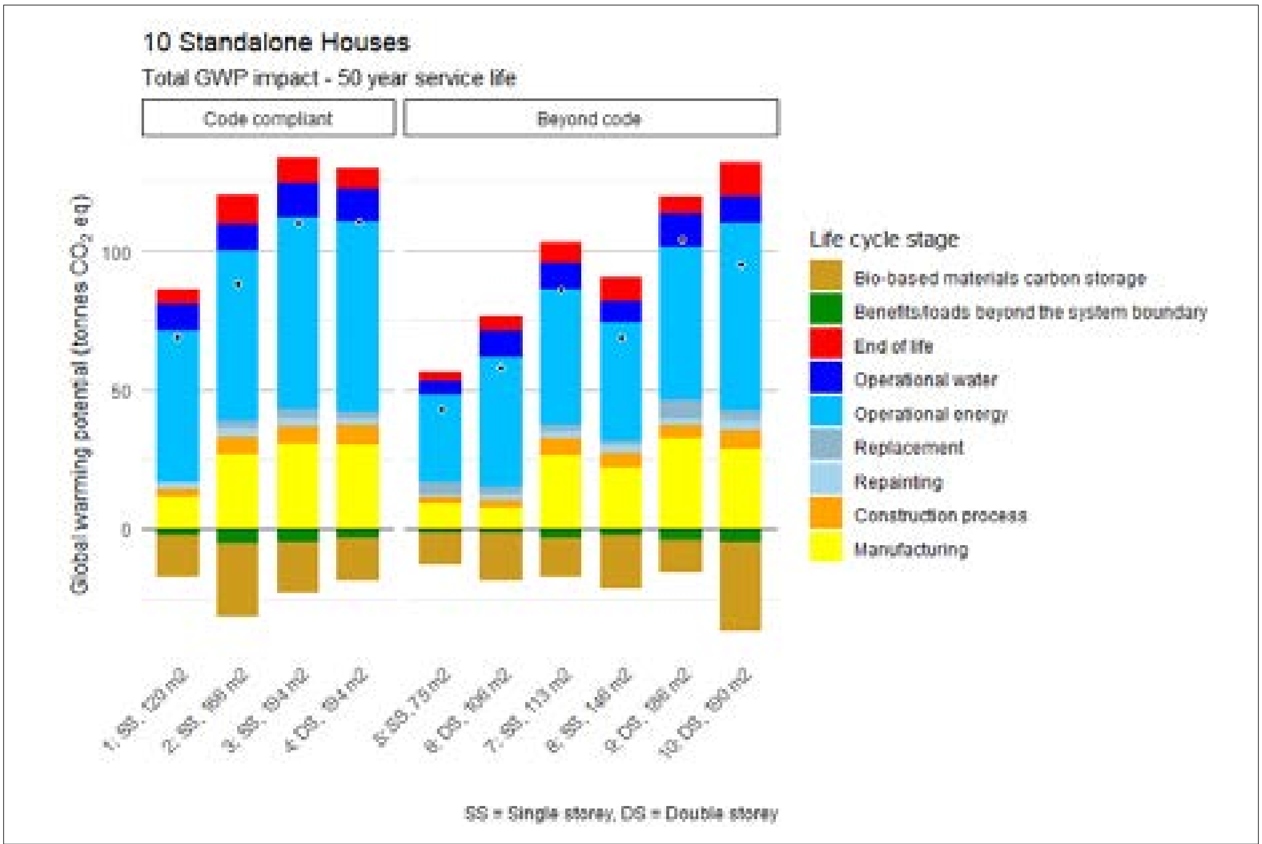

Figure 3. Carbon footprints (in tonnes CO_2eq) calculated for 10 recently built stand-alone houses over a 50-year service life.

5 CUTTING CARBON

5.0.1 With no specific legal requirements around carbon footprints or carbon caps in new-build homes at the moment, a good general approach is to avoid focusing too much on specific numbers and instead focus on understanding the options for reducing carbon in a proposed building and the differences between them.

5.1 BRANZ MODELLING SHOWS POTENTIAL GAINS

5.1.1 Modelling already undertaken by BRANZ on a case study house indicates the savings possible from different design options. (Some are described below, and they are explained in more details in *Build* magazine issues 190 and 191). While the modelling was based on the thermal performance requirements in H1/AS1 4th edition, the overall findings are still relevant. The options considered in the modelling included:

- increasing construction R-values
- exposing a concrete floor slab
- adopting a more compact building form
- reducing house size.

5.1.2 Adding more insulation to a house adds embodied carbon. However, it provides a more comfortable, drier and healthier environment for the occupants and can reduce energy use (which reduces operational GHG emissions). The BRANZ modelling found that, despite a modest increase in embodied carbon of 1–2.5 tonnes CO_2eq to achieve higher construction R-values, overall carbon savings (from reduced operational GHG emissions) range from 5% in Auckland to 26% in Queenstown – more than enough to compensate for the higher embodied carbon.

5.1.3 Exposing a concrete floor slab can potentially provide two GHG emissions benefits:

- It avoids the use of floor coverings in the exposed floor areas, reducing the embodied carbon of the house over its lifetime.
- It exposes the thermal mass of the concrete, which can help the house make better use of solar gains (assuming it is well oriented and overheating is not a risk). The mass can moderate temperature spikes, storing the heat to be released later in the day when it is cooler. This reduces operational carbon because it reduces both heating and cooling needs.

5.1.4 Floor layouts can take all forms, from simple squares or rectangles to more complex L, U or H shapes and many other alternatives. A particular floor size can have a large range of area-to-perimeter (A/P) ratios (Figure 4). Complex shapes with lower A/P ratios require more wall materials and provide more opportunity for heat loss. Both the whole-of-life embodied carbon and heating/cooling carbon are affected. BRANZ modelling found that complex shapes with lower A/P ratios could result in up to 12% higher total GHG emissions. The results were similar in both Auckland and Queenstown climates. (Building form should also reflect the optimal depth for natural ventilation and daylighting, to further reduce emissions.)

5.1.5 Larger houses require more materials to be manufactured, transported, installed and maintained and (usually) more energy to maintain healthy indoor temperatures. The BRANZ modelling confirmed the impact of house size on emissions.

5.1.6 The BRANZ modelling found that, taken together, all the options considered in the project (including some not covered in this brief summary) had the potential to reduce the case study house's carbon footprint over 90 years by approximately:

- 34% in Auckland (32 tonnes CO_2eq embodied + 20 tonnes CO_2eq operational = total 52 tonnes CO_2eq saving)
- 39% in Wellington (33 tonnes CO_2eq embodied + 34 tonnes CO_2eq operational = 67 tonnes CO_2eq saving)
- 48% in Queenstown (33 tonnes CO_2eq embodied + 74 tonnes CO_2eq operational = 107 tonnes CO_2eq saving).

5.1.7 As a note of caution, when seeking to increase construction R-values, consider the embodied carbon of the elements making up the thermal envelope. The CO_2RE tool can help with selection of wall, floor and roof elements, and the HECC tool can help with calculating building carbon footprints. While the operational carbon savings provided by insulation can often outweigh the embodied carbon, this is not guaranteed. Higher-carbon materials should be approached with care, and consideration should also be given to the climate. In warmer regions, the potential energy savings are significantly lower and may not justify increased levels of insulation with a higher embodied carbon footprint.

5.2 OTHER EMISSIONS REDUCTION CONSIDERATIONS

5.2.1 Other questions to ask:

- Has the building been oriented on site to maximise the benefits of passive solar design?
- Has glazing been specified that maximises thermal performance, providing winter warmth through larger

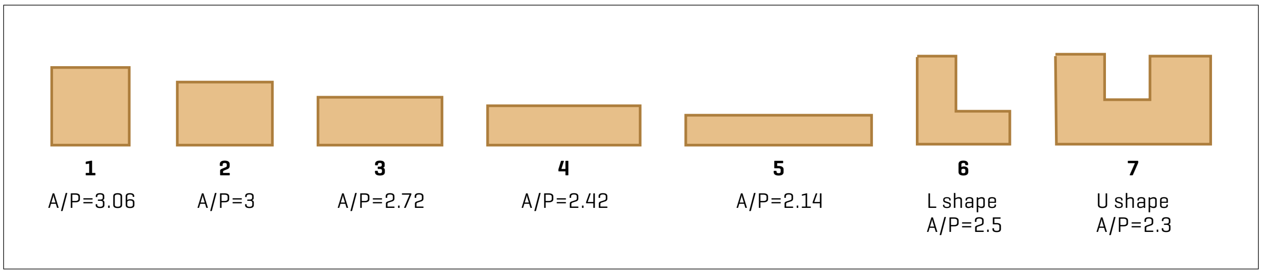

Figure 4. Examples of how the area-to-perimeter ratio of a house changes according to its form. These are individual cases – for example, not all L-shaped buildings will have an A/P of 2.5.

north-facing windows and reducing heat loss by minimising glazing on south walls?
- Have appropriate external shading devices been specified to reduce the risk of summer overheating?
- Will the building be sufficiently airtight?
- Has the risk of heat transfer through thermal bridging been minimised?
- Is a particular construction or a material needed at all?
- Are floor coverings really needed? Many of them have relatively high embodied carbon because they usually have shorter service lives than the house itself and may need replacing multiple times. Is flooring with low embodied carbon and a long serviceable life available?
- Can materials with a high recycled content be used?
- Is it possible to avoid waste during construction, and where waste is generated, can it be reused or recycled?
- Is it possible to specify materials with much longer durability than alternatives?
- Have high-efficiency space and water heating systems been specified?
- Has mechanical ventilation with heat recovery been specified?
- What design options can be adopted that will require less maintenance in the longer term?

6 RESOURCES

BRANZ

Bulletin BU596 *An introduction to life cycle assessment*

Bulletin BU608 *Building life cycle assessment*

Bulletin BU655 *Building blocks for new-build net-zero carbon houses*

Bulletin BU669 *Tools for measuring carbon in new-build houses*

Study Report SR418 *New Zealand whole-building whole-of-life framework: LCAQuick v3.4*

Calculators and tools

The Carbon Challenge (four webinars)

Carbon tools webinars

Reducing carbon videos

MBIE

Building for climate change programme

Whole-of-Life Embodied Carbon Emissions Reduction Framework

Transforming Operational Efficiency

Whole-of-Life Embodied Carbon Assessment: Technical Methodology

NEW ZEALAND GREEN BUILDING COUNCIL

Homestar

HECC tool

Embodied Carbon: Supporting Analysis

OTHER

eTool

RapidLCA

One Click LCA

Chandrakumar, C., McLaren, S., Dowdell, D. & Jaques, R. (2020). A science-based approach to setting climate targets for buildings: The case of a New Zealand detached house. Building and Environment, 169.

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Telephone 04 237 1170 - Fax 04 237 1171
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