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BULLETIN

BUILDING BLOCKS FOR NEW-BUILD NET-ZERO CARBON HOUSES

December 2022

- Greenhouse gas emissions from new building work must be reduced for New Zealand to meet its commitment to a net-zero carbon economy.
- This bulletin gives an overview of the decisions that designers, builders and clients can take to reduce the carbon footprints of new houses.
- This is the second of two bulletins on net-zero carbon building. It follows Bulletin 651 *Climate change, net-zero carbon and the building industry.*

1 INTRODUCTION

1.0.1 One of New Zealand's key commitments against climate change, set out in the Climate Change Response (Zero Carbon) Amendment Act 2019, is to reduce net emissions of greenhouse gases (except methane from plants and animals) to zero by 2050.

1.0.2 Net-zero carbon is when human-caused greenhouse gas emissions are reduced to as close to zero as possible. Any remaining emissions produced would be offset with an equivalent amount of carbon removed from the atmosphere – for example, by on-site carbon storage or planting forests.

1.0.3 Bulletin 651 *Climate change, net-zero carbon and the building industry* sets out the estimated levels of greenhouse gas emissions produced by the built environment. It describes a 2019 study where Massey University and BRANZ scientists calculated how much carbon dioxide typical new 3-bedroom homes should emit in their lifetime as we move towards the 2050 net-zero carbon target. New Zealand house construction and operation currently produces too much carbon dioxide by several multiples.

1.0.4 This bulletin briefly outlines the practical issues that designers, builders and their clients should consider as we take steps towards designing and building net-zero carbon houses.

1.0.5 A great deal of research is currently under way in this area. BRANZ itself has an extensive programme of work, some with partner organisations.

1.0.6 Building a net-zero carbon home requires attention to every single area of the project – site selection, overall house design, room layout, materials selection, specification of fixtures, services and appliances, construction methods and waste reduction. In many cases, pluses and minuses of a construction method or material or element have to be balanced out. The key is to start considering the issues at the very earliest stages of planning a new house. Everyone – client, designer, builder, subcontractors, materials suppliers – needs to be involved.

1.0.7 This bulletin addresses only new-build houses. Retrofits and renovations will be dealt with separately.

2 THE SITE

2.0.1 A building site will often have already been chosen when designers or builders are contacted by clients, so they are unlikely to have much influence over site selection. The site itself, however, can have a big impact on the carbon footprint of a house. As a simple example, a house on a site with excellent solar access can be designed so it requires minimal purchased energy for space heating, while the same house on a site that sees little sun will require higher amounts of purchased energy (or higher-performance insulation and glazing).

2.0.2 There are two key considerations:

- Location – a site should ideally be within walking distance of shops and other services and/or regular public transport. This is likely to reduce fossil fuel consumption because fewer private vehicle journeys are needed.
- Solar access – a site should ideally have good solar access for at least 75% of the daily sunshine hours for its location. NIWA's online tool Solarview provides sun path diagrams for any particular location. The web tool SketchUp can help identify potential shading from trees, neighbouring buildings and so on. Solar access is not the only way to reach net-zero carbon, but it can be a big help.

2.0.3 Unfortunately, some new subdivisions have long and narrow north-south sections that make it difficult to achieve optimal orientation for a house for sun. Some developments have restrictive covenants that only allow houses over 200 m^2 or 250 m^2 to be built. This encourages houses that are more likely to have higher carbon footprints.

3 HOUSE SIZE

3.0.1 In general terms, the larger the house, the more greenhouse gas emissions it will be responsible for and therefore the larger the carbon footprint it will have (Figure 1). The evidence indicates that this applies even where larger houses are built to exceed New Zealand Building Code minimums. Large houses with just one or two people living in them are particularly bad from a carbon perspective.

3.0.2 In New Zealand, the average size of new homes (154 m^2 in 2021) is getting smaller after decades of getting bigger, partly because many more new homes today are multi-unit homes. Average size peaked at 200 m^2 in 2010. Our average house size is now larger than most developed countries other than the United States. There is international evidence that house occupants find good design more important than size, and there is a movement internationally to put greater value on quality of design rather than size. Having multi-purpose spaces and designing out hallways are two good options. Smaller but better-designed houses are more likely to have lower carbon footprints as well as being faster to clean, have lower maintenance requirements and so on. Encourage clients to choose quality over quantity.

4 PASSIVE DESIGN

4.0.1 The foundations of passive design are good building orientation for the sun, well-planned glazing and shading design, high levels of insulation and good ventilation. In practical terms, optimising all these features requires the use of computer modelling (see 10).

4.0.2 Understanding the specific micro-climate of the site is important – for example, for a house to benefit from cooling breezes in summer and shelter from cold winds in winter. For many parts of New Zealand, well-integrated passive design results in comfortable year-round internal temperatures of 18–25°C. There is a growing number of homes in New Zealand where the design is so effective that they require just a tiny fraction of the energy new homes typically require for space conditioning.

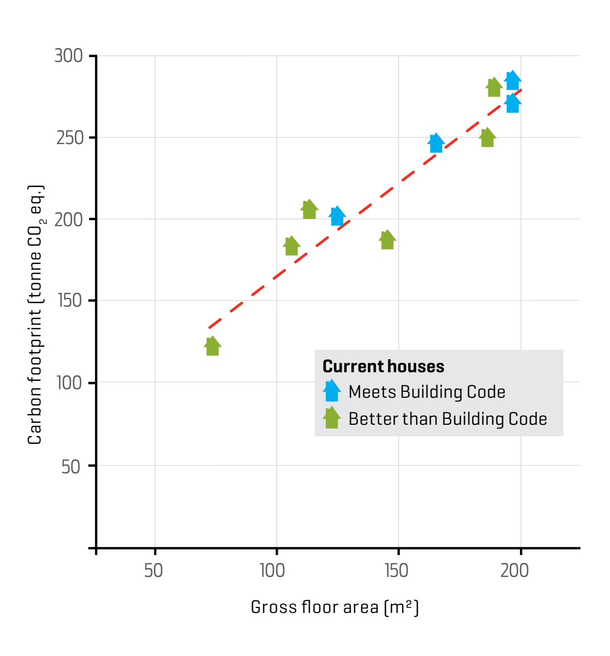

Figure 1. The carbon footprints of 10 New Zealand houses as calculated by BRANZ scientists.

4.0.3 Airtightness and well-designed ventilation can provide economical improvements to building performance. As the saying goes, "Build tight and ventilate right."

4.1 ORIENTATION, SHAPE AND ROOM LAYOUT

4.1.1 A compact rectangular floor plan running west-east is the best option for single-storey houses. Compact boxy-shaped forms are best for double-storey houses.

4.1.2 With good building orientation and solar access, thermal mass can improve indoor comfort by reducing temperature swings, especially in locations with large differences in day/night temperatures. For example, an insulated polished concrete floor exposed to the sun during cooler times of the year absorbs warmth during the day and releases it at night. Thermal mass must be inside the thermal envelope and must be considered along with window size and placement and insulation. Eaves or controllable shading devices can reduce the risk of thermal mass becoming warm in summer (thermal mass can actually help prevent overheating).

4.1.3 One complication with using concrete for thermal mass is that the concrete typically used in New Zealand house construction accounts for more greenhouse gas emissions than some other building materials. The concrete industry is working to identify ways of reducing this – for example, through the use of certain cementitious replacements.

4.1.4 Where ideal orientation or room layout are not possible, keep the area of windows smaller and design to optimise what sun is available – for example, by using clerestory windows. Specify glazing and framing R-values as high as the client can afford.

4.2 INSULATION

4.2.1 High levels of thermal insulation keep a house warm in winter and cool in summer, reducing the amount of energy purchased for space conditioning and therefore the amount of greenhouse gas emissions produced.

4.2.2 Minimum construction R-values for roofs, walls, windows and floors of new housing are given in the schedule method in Building Code Acceptable Solution H1/AS1 5th edition amendment 1. (The figures for individual building elements can be varied if the calculation or modelling methods are used, but the performance of the building overall cannot be reduced.) While the thermal performance required of roofs, windows and floors increased in the current edition from the previous 4th edition, the requirements for walls – R2.0 – hardly changed (and did not change in some instances). Designers should ideally aim to achieve construction R-values in walls of R2.5–R4.6+, the lower figure only in warmer parts of the country.

4.2.3 Good installation is crucial to insulation performance, with no gaps, tucks, folds or compression or thermal bridges. For example, a 16 mm gap around the edge of ceiling insulation can cut its R-value by almost half. NZS 4246:2016 *Energy efficiency – Installing bulk thermal insulation in residential buildings* is a useful guide that can be downloaded at no cost.

4.3 WINDOWS AND GLAZING

4.3.1 In carbon footprint terms, the three important considerations for windows and glazing are:

- location and size of windows
- framing material
- thermal characteristics of both frame and glazing.

4.3.2 Window design will take account of views, climate, building orientation and other factors. In general terms, windows should be:

- larger on the north side of the building (ideally where the living spaces are)
- tightly controlled (or have movable shading devices) on the west side to reduce summer overheating
- as minimal as possible on the south side to avoid winter heat loss.

4.3.3 Considering materials, recent New Zealand research indicates that using timber frames gives the greatest potential for a reduced carbon footprint. For example, the research found that double-glazed timber windows consistently achieved greater reductions than triple-glazed aluminium windows. This is due to biogenic carbon – the fact that trees absorb and trap carbon dioxide from the environment as they grow.

4.3.4 Windows and glazing almost always account for more heat gain or loss than any other element in an insulated building envelope. Specifying the best-performing windows that the client can afford therefore has the potential to reduce the amount of purchased energy required for heating or cooling the house. Table E.1.1.1 in H1/AS1 indicates the construction R-values that can be achieved.

4.3.5 The Window Energy Efficiency Rating System (WEERS) is a voluntary New Zealand programme that compares the thermal performance of windows. It was developed by BRANZ in conjunction with the Window Association of New Zealand (now Window & Glass Association NZ). WEERS considers the frame and glazing and size of a window to calculate thermal performance. This gives extremely useful guidance around the performance offered by different framing and glazing options.

4.3.6 Skylights allow natural light into deep plan shapes but can allow high heat loss/gain, losing more than they gain overall. They should ideally be kept small. Double-glazed skylights with thermal breaks, low-E coatings and argon gas between the panes are readily available in New Zealand, as are triple-glazed skylights.

4.4 OVERHEATING

4.4.1 Overheating is a problem in many new houses and is likely to get significantly worse as a result of climate change. Some locations are forecast to see an extra month each year where temperatures are over 25°C. This has the potential to result in increased energy use for cooling.

4.4.2 In BRANZ research, a sample of 70 houses consented in Christchurch in 2016 had their thermal performance simulated. The living rooms of the houses showed an average of 435 hours per year when the temperature was over 25°C – uncomfortably hot. A simulation was also done for the Beacon Pathway NOW Home, an Auckland house carefully designed yet still built to a budget and constraints typical of ordinary New Zealand housing. The NOW Home is not a high-cost eco-home – it shows what is practically achievable. This simulation found overheating for around just one-third of the average time of the others – 151 hours. The results show that overheating can be considerably reduced with good design and energy modelling.

4.4.3 In practical terms, the best solution is to include external shading devices in house designs. Correctly sized eaves are an effective way to protect against excess solar gain on the northern aspect. The Level webpage on external shading (www.level.org.nz/passive-design/shading) provides simple guidance around calculating measurements for various locations. The west and east faces should also have dedicated shading systems, ideally movable with the seasons.

4.4.4 Careful ventilation design, such as cross-ventilation, is another tool. For times when there is no driving external air pressure, consider passive stack methods. With passive stack ventilation, temperature differences lead to a natural, continuous movement of air. Warm air is naturally drawn up and expelled outside through a vent above the roofline, and cooler fresh air is drawn into the building lower down.

5 ENERGY AND ENERGY EFFICIENCY

5.0.1 Over a house's entire serviceable life, operational energy use accounts for the largest proportion of emissions (calculated from simulated energy use models), so energy decisions are key decisions. (Over coming years, as new house performance increases, the impact of embodied emissions from materials will become proportionally greater.)

5.0.2 Electrical appliances selected by a household are often outside the control of designers or builders, but where appliances are specified in a build, they should be energy-efficient models.

5.0.3 Smart homes and appliances are also likely to play a role in improving energy efficiency. Some hard-wired electric vehicle chargers can optimise charging away from peak times, for example. Appliances and systems such as these are not always incorporated at the design stage, however.

5.1 WATER HEATING

5.1.1 Water heating accounts for a significant amount of energy use in New Zealand houses and therefore a significant proportion of greenhouse gas emissions.

5.1.2 BRANZ modelled the emissions of the water heating systems for 210 consented new houses in Auckland, Hamilton and Christchurch in 2016 and again for the efficient NOW Home (Table 1). The average for the consented houses was over three times what is readily achievable, as the NOW Home showed.

5.1.3 These are the water heating systems with the lowest lifetime operation-related CO_2 emissions (not necessarily in order):

- Heat pumps with a CO_2 refrigerant and a coefficient of performance greater than 2.5. (Other types of refrigerant cause much greater damage when they leak into the environment.)
- Electric-assisted solar, but only where the system is designed and installed by people with significant experience.
- Wetbacks on log burners or pellet burners that use seasoned timber from sustainably managed forests (or seasoned waste timber). Wetbacks are only suitable for houses where a solid fuel burner is used regularly, however, and this is less likely to be the case in very well-insulated and glazed low-energy houses.

5.1.4 Another low-carbon option not yet widely available in New Zealand is the photovoltaic (PV) direct hot water system. PV panels on the roof supply DC energy through a controller to a heating element in a hot water cylinder. These systems are considerably easier to install, control and maintain compared to traditional solar thermal systems.

5.1.5 While traditional electric storage cylinders and gas instant hot water systems are very popular and convenient, they account for several times more greenhouse gas emissions than heat pump water heaters and the other options outlined above. Gas is also a finite resource.

5.1.6 Consider the resource (and cost) efficiencies that may be gained from combining space and water heating systems.

5.2 SPACE HEATING

5.2.1 For warmer parts of New Zealand, if a house has good passive design, it will have vastly reduced needs for added space heating. Inexpensive portable heaters may be sufficient for the short periods each year when active heating is required to bring the house up to the World Health Organization-recommended minimum temperatures for good health. Energy modelling can determine heat load and therefore the amount of heating likely to be required.

5.2.2 For cooler parts of the country and for sites where the ideal orientation is not possible, efficient heat pumps can be recommended because they produce more heat energy than the energy they consume. Domestic heat pumps for space heating that are charged with a CO_2 refrigerant are recommended because they minimise their global warming potential, but at the date of publication of this bulletin, they are not yet widely available in New Zealand.

5.2.3 Wood burners and pellet burners can also be considered providing they use seasoned wood from sustainably managed (replanted) forests or seasoned and untreated waste wood. Note that burners still produce non-CO_2 greenhouse gases, such as methane, nitrous oxide and hydrocarbons, but at about a tenth that of natural gas. However, combustion produces ultra-fine particles that are damaging to human health. Good ventilation is crucial.

5.2.4 BRANZ modelled the space heating systems for 70 consented new houses in Auckland and 70 in Hamilton in 2012 and for 70 consented in Christchurch in 2012 and 2016 (Table 2). In the worst case, space heating in the average new home accounted for over seven times more greenhouse gas emissions than the NOW Home.

5.3 LIGHTING

5.3.1 The most energy-efficient lighting with the lowest CO_2 emissions is daylighting. Building orientation, window size and placement and the use of clerestories and light tubes can allow good natural lighting in a house with minimum impact on thermal design.

5.3.2 With artificial lighting:

- specify LED lighting wherever possible – if displayed on the packaging, go for the highest lumens per watt rating (the ideal is more than 100 lumens per watt)
- avoid recessed downlights unless the fixtures are tightly fitted and allow thermal insulation to be placed over them
- don't overlight – where task lighting is required, design that rather than bright general lighting
- consider using daylight sensors or timers to ensure lights are turned off when not required.

6 WATER USE

6.0.1 Over a house's whole serviceable life, water consumption accounts for an estimated 9% of the house's greenhouse gas emissions (calculated with computer modelling). Reducing water use can therefore make a valuable contribution to reducing a house's carbon footprint.

6.0.2 Specifying water-efficient fixtures and fittings is relatively easy thanks to the Water Efficiency Labelling Scheme (WELS). Clothes washing machines, dishwashers, lavatories, showers and taps are required to have a star rating for their efficiency, up to a maximum of six stars (three for showerheads). Specifying products with more stars will reduce water use and therefore help a house achieve a lower carbon footprint. Because toilets can account for almost 20% of water used in a house, specifying a dual flush toilet of 4.5/3 litres is a good decision.

6.0.3 Reducing water use does not necessarily reduce occupant lifestyle. The NOW Home, for example, incorporated water-efficient fixtures and appliances and rainwater collection. The house occupants enjoyed long hot showers, yet overall water use in the house was still 40% less than the average for houses in that area of Auckland.

6.0.4 Rainwater collection tanks provide resilience benefits as an emergency water supply, but varied council pricing of reticulated water means that rainwater tanks have very long payback periods in some locations.

Table 1. Household water heating-related CO_2 emissions (kg CO_2/person/year).

	Mean	Mean		50th percentile		80th percentile	
Location	**NOW Home**	**2012**	**2016**	**2012**	**2016**	**2012**	**2016**
Auckland	73	251	246	264	258	294	319
Hamilton	86	274	271	296	289	316	335
Christchurch	101	268	276	240	228	347	387

Table 2. Household space heating-related CO_2 emissions (kg CO_2/household/year).

	Mean	Mean		50th percentile		80th percentile	
Location	**NOW Home**	**2012**	**2016**	**2012**	**2016**	**2012**	**2016**
Auckland	75	552	Not calc	463	Not calc	732	Not calc
Hamilton	151	728	Not calc	645	Not calc	873	Not calc
Christchurch	345	1,455	1,308	1,128	1,020	2,296	1,992

In the Waitakere NOW Home, rainwater collected in a 13,500 litre tank provided approximately half of the total water use in the home, saving the occupants over $500 per year because Auckland imposes direct charges for water use.

6.0.5 Greywater from baths, showers and handbasins can be used for garden irrigation and (with treatment) toilet flushing. Depending on the time of year, garden size and other factors, this can reduce the volume of reticulated water used in a household by 20–30%.

7 MATERIALS

7.0.1 Building materials have an impact on the environment across many decades, from their extraction/manufacture to their final disposal. This impact can be calculated through life cycle assessment or carbon footprinting – a process described on the BRANZ website and in publications (see 11).

7.0.2 The embodied carbon involved in construction materials needs to be carefully considered, bearing in mind that, for many materials, a significant proportion of their emissions have been released before construction begins. The BRANZ tools LCAQuick and CO_2NSTRUCT can help (see 10).

7.0.3 Of the materials used in significant volumes in New Zealand houses, steel and concrete have the largest carbon footprints. When steel roofing and concrete floor slabs are used in a house design, they are typically the highest contributors of carbon, by material type. To some extent, this can be addressed by substituting lower-carbon options, such as specifying an LVL portal rather than a steel portal.

7.0.4 By contrast, bio-based materials such as timber and engineered wood have benefits in net-zero carbon construction because they have captured and stored atmospheric carbon dioxide as the timber was growing. They can effectively have negative carbon footprints, so extensive use of them can actually make a building carbon-negative (see 9).

7.0.5 Timber must be sourced from sustainable forestry, with forests replanted after timber is harvested. One way of checking this is to look for certification provided by FSC (Forest Stewardship Council) or PEFC (Programme for the Endorsement of Forest Certification). New Zealand forestry is generally considered sustainable.

7.0.6 House design obviously has a significant impact on material use. For example, a steeply pitched roof uses more material than a low-slope roof.

7.0.7 Decisions around material use will involve balancing a range of factors from the volume of the material used to offsetting benefits it may have. For example, while adding more thermal insulation to a house is technically increasing the material used in construction, the extra carbon cost of this is extremely low and the benefits considerable.

8 WASTE REDUCTION

8.0.1 Construction and demolition waste makes up 40–50% of New Zealand's total waste going to landfill and cleanfill according to government and council documents. A considerable amount of greenhouse gases have been emitted in the manufacture and transport of this enormous volume of construction material. Reducing waste will reduce emissions.

8.0.2 Reducing waste begins at the design stage through:
- keeping the range of materials to a minimum and reducing design complexity
- knowing the sizes of materials and using modular sizes in design to reduce off-cuts
- arranging services to be compact with minimum runs
- selecting locally manufactured materials
- selecting prefabricated materials where possible
- identifying and sourcing suitable reused/recycled materials
- planning for end use and deconstruction, so materials can be reused or recycled rather than going to landfill
- requiring the building contractor to have a site-specific waste management plan.

8.0.3 Builders can help reduce waste by:
- taking care with ordering (the materials ordered, quantities ordered and delivery dates)
- careful storage and handling of materials on site
- not making changes to the design
- sorting waste for recycling or reuse – www.branz.co.nz/sustainable-building/reducing-building-waste REBRI has a great deal of practical guidance to assist

9 CARBON-NEGATIVE COULD BE POSSIBLE

9.0.1 A house using more sustainably sourced bio-based materials – such as considerable use of timber and wood-based materials from sustainable forests – has the potential to be net carbon-negative following construction. In Figure 2, House A is net carbon-negative following construction and can be lived in for 25 years before the cumulative emissions of a family of four reach the same level of emissions as House B when it is newly built.

10 TOOLS FOR DESIGNERS

10.0.1 Using a thermal modelling tool is the only way to ensure optimal energy efficiency in a house design – a crucial step towards net-zero carbon houses. Ideally, they should use hourly-based climate files from a nearby weather station.

10.0.2 Whole-building energy simulation calculates building performance areas influencing energy consumption such as indoor temperatures, thermal mass effects, construction R-values, natural or mechanical ventilation, heating and cooling loads and so on. The impacts that result from altering the building's orientation on site, physical layout, material properties (such as glazing or thermal insulation levels) and other aspects can then be easily explored. Modelling is about repetition and testing various options.

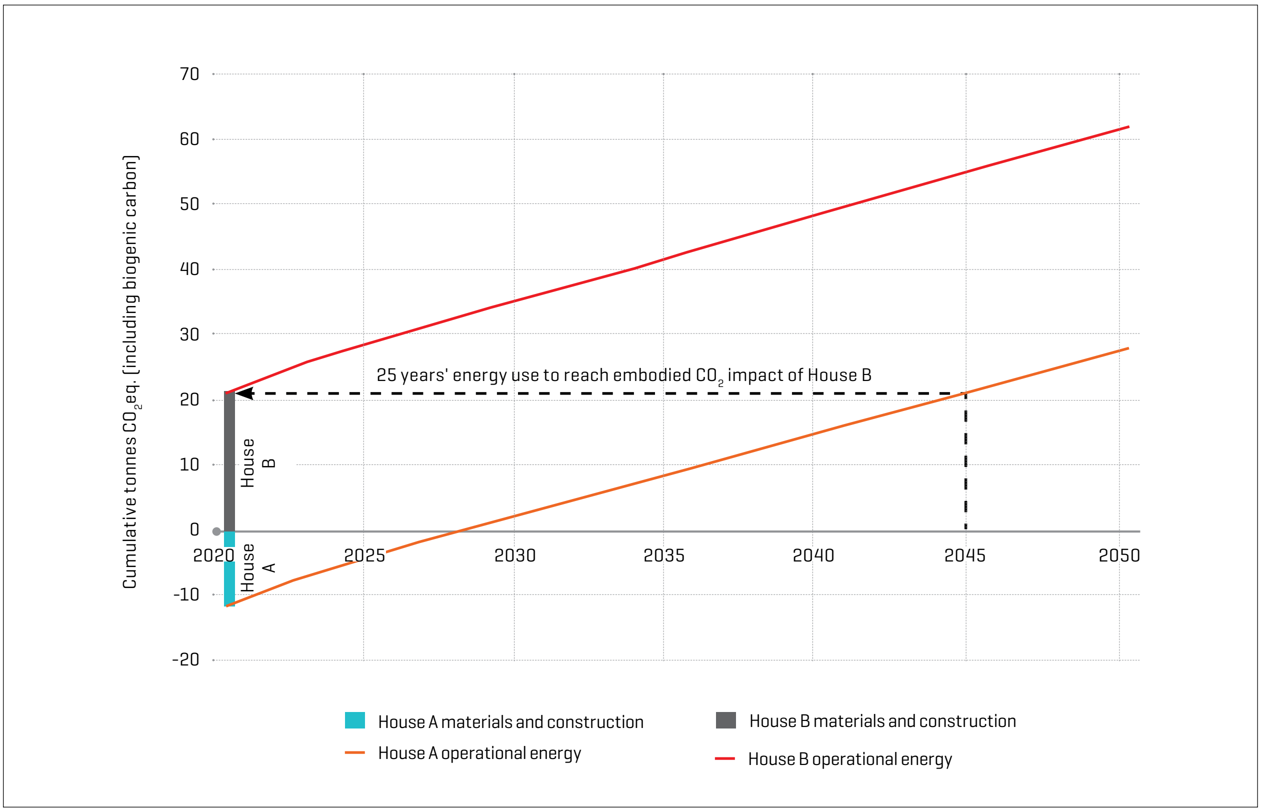

Figure 2. Illustration of the potential opportunity for net-carbon negative houses.

10.0.3 The earlier thermal modelling is integrated into the design process, the more likely positive, cost-effective performance changes can result. The largest opportunities for design alterations are found in the early design stages.

10.0.4 There are also a number of resources that New Zealand designers can use to help with materials selection. On the BRANZ website, the New Zealand whole-building whole-of-life framework has tools and data to help design low-carbon homes. These resources include:

- LCAQuick – evaluates the carbon footprint of a building design
- CO_2NSTRUCT – provides values for embodied carbon and energy values for construction materials including concrete, glass, timber and metals.

11 OTHER RESOURCES

BRANZ BULLETINS

- BU596 *An introduction to life cycle assessment*
- BU608 *Building life cycle assessment*
- BU651 *Climate change, net-zero carbon and the building industry*
- BU679 *Introduction to calculating whole-of-life carbon footprints of houses*

BRANZ STUDY REPORTS

- SR349 *New Zealand whole-building whole-of-life framework: An overview*
- SR351 *New Zealand whole-building whole-of-life framework: Development of datasheets to support building life cycle assessment*
- SR403 *The built environment and climate change: A review of research, challenges and the future*

BRANZ WEB RESOURCES

- www.branz.co.nz/environment-zero-carbon-research/framework
- www.branz.co.nz/environment-zero-carbon-research/framework/lcaquick
- www.branz.co.nz/environment-zero-carbon-research/framework/branz-co2nstruct
- www.branz.co.nz/REBRI – building and construction waste
- www.level.org.nz – sustainable construction. Some designers have found the Level Eco-hierarchy Tool a useful resource to discuss with clients – www.level.org.nz/material-use/life-cycle-assessment/eco-hierarchy-tool

OTHER PUBLICATIONS AND WEB RESOURCES

- Chandrakumar, C, McLaren, S. J., 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*, 106560. buildenv.2019.106560
- www.beaconpathway.co.nz/new-homes/article/the_waitakere_now_home
- www.nzgbc.org.nz – New Zealand Green Building Council, especially Homestar
- https://solarview.niwa.co.nz
- www.ecodesignadvisor.org.nz

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