Study Report SR483 [2023]

Measuring our sustainability progress: New Zealand's new detached residential housing stock (second update)

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Preface

This is the third report of an ongoing longitudinal study on key sustainability-related aspects concerning new New Zealand detached housing consented in the 2020 calendar year. It covers a range of core indicators grouped into eight domains: energy and CO_2, water, indoor environment, resilience, affordability, consumer demand, industry capacity and policy and regulation. It provides a breadth of information over three thematic areas: building performance, market forces and governance. Although a stand-alone document, its predecessors BRANZ Study Reports SR342 and SR426 should ideally be read prior to or concurrent with this second update for best contextualisation and comprehension.

Acknowledgements

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The following BRANZ experts provided targeted assistance in their specialist topics:

- Matthew Curtis – economic indexes and building material quantities.
- Dr David Dowdell – building material embodied carbon.

Thanks also to the three Victoria University postgraduate students Griffin Cherrill, Emily Howell and Simon Ellis who developed the energy models of all the 210+ houses from consent documentation.

We are grateful for supporting contributions from Nikki Buckett (Principal Advisor, Kāinga Ora), Dr Gareth Gretton (Senior Advisor, EECA) and Ben Liley (Atmospheric Scientist, NIWA).

This document relies on and in many cases builds on data and indicators suggested in 2008 by the research consortium Beacon Pathway on the need for a national housing indicator framework for New Zealand.

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Authors

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Reference

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Abstract

This report examines New Zealand's new-build residential (stock) sustainability aspects as part of an ongoing BRANZ longitudinal study. The long-term objective is to assess, benchmark and track trends of the performance and influencers on new detached housing. Three overarching themes – building performance, market forces and governance – are examined to provide a snapshot summary of impactors. Eight domains are covered under these themes: energy and CO_2, water, indoor environment, functional resilience, affordability, consumer demand, industry capacity and policy and regulation. Each domain has a set of individual indicators and metrics used to provide quantitative and qualitative information so that trends can easily be tracked.

This third report (i.e. the second update) in the series focuses on initiatives, measures and results from calendar year 2020 compared to calendar year 2012 and 2016 findings. Although this study report is a stand-alone document, its predecessor BRANZ Study Reports SR342 (Jaques, 2015) and SR426 (Jaques, 2019) should be read prior to or concurrent with this update for best comprehension.

Keywords

New Zealand housing stock, house metrics, sustainability indicators, detached houses, benchmarking, thermal performance.

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Glossary of terms

active space heating	Describes the use of artificial heating to provide the space heating necessary to achieve comfortable indoor temperatures (18–25°C) when solar and incidental gains are inadequate.
climate change	A statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period – typically at least several decades.
conditioned area	The volume of the home that is contained within (i.e. bounded by) the thermal envelope based on the thermal modelling using hourly climate files. Typically, this excludes the garage, hallway and bathroom zones.
CSIRO	Commonwealth Scientific and Industrial Research Organisation, whose global climate model for climate change forecasting is used in this report (Australian based).
degree-hours	A commonly used indoor thermal measure. For degree-hours too hot, it equates to the temperature difference between the overheated internal zone and the overheating threshold temperature (in this case 25°C) multiplied by the overheating length. This provides a better indication of the human response (i.e. physiological stress) to overheating, i.e. 1 hour at 26°C is not equivalent to the physiological stress of 1 hour at 29°C.
EDAs	Eco Design Advisors. A free independent council-based advisory service for industry, community groups and the public, applicable to both new and existing dwellings.
free-running mode	When a building relies on only design-related means (insulation, mass, shading and window placement) and incidental gains (from occupancy, space and water heating etc.) to provide comfortable indoor temperatures.
Hadley	The global climate model developed by the Hadley Centre for Climate Prediction Research by the UK Meteorological Office.
indicator	A quantitative, qualitative or descriptive measure representative of an aspect of building that impacts on the economy, environment or society, designed to communicate a situation at a point in time.
IPCC	Intergovernmental Panel on Climate Change. The leading international body for the assessment of the most recent scientific, technical and socio-economic information produced worldwide on climate change.
LCA	Life cycle assessment. A formal systems-based approach that examines the inputs and outputs of a product or service during its lifetime using standardised means.
MEPS	Minimum energy performance standard. These ensure that only efficient products that meet a minimum standard for energy efficiency are legally available for sale in New Zealand.
NIWA	National Institute of Water and Atmospheric Research (New Zealand based).
NZBC	New Zealand Building Code.
NZGBC	New Zealand Green Building Council.
passive (solar) design	Building design that takes advantage of the site, orientation, climate, form, layout and construction materials to minimise purchased energy needs for internal thermal comfort.
R-value	Physics measure of the resistance a material has to heat flow. The higher the value, the better the material is able to reduce heat flow from a warm zone to a colder zone (units = $m^2°C/W$).
thermal envelope	The imaginary barrier between the internally conditioned spaces within a building and the outside. Usually defined by the volumes bounded by external walls, ceiling/roof and floor. Typically excludes the garage.

Executive summary

The residential construction sector plays a vital role in terms of New Zealand's sustainable development, health and wellbeing. This report addresses the question of where New Zealand as a nation stands in terms of a whole suite of sustainability-related indicators associated with new, stand-alone residential construction. It builds upon previous reporting years (2012 and 2016) by providing updated results for a core set of 14 indicators – encompassing the areas of building performance, market forces and governance.

This report examines the new residential build-related activities and initiatives for the calendar year 2020 (Y2020). A major focus of the report is on the performance characteristics of some 210 randomly selected stand-alone houses consented by three councils (Auckland, Hamilton and Christchurch), examining their various aspects in detail. As before, due to the lack of publicly available comparative benchmarks, Beacon Pathway's NOW Home® – a proof-of-concept sustainable house designed and built in 2008 in Auckland – was employed as a comparator for a variety of indicators. Some key findings, separated into eight domains, are summarised in Table 1 following.

It should be noted that, as luck would have it, 2020 was – both nationally and internationally – a very unusual year due to the outbreak of the COVID-19 virus. By year's end, COVID-19 would infect an estimated 80 million people worldwide and kill more than 1.7 million people (New York Times, 2023). It is very difficult to quantify the direct (and indirect) effects COVID-19 disruptions to work and trade had on various aspects examined within this study, but it is likely to have some ramifications for the next edition of this BRANZ longitudinal study (Y2024).

Table 1. Key findings from the eight domains summarised.

1. Energy and CO_2	Compared to the Beacon NOW Home®, the Y2020 homes have considerably higher space heating and cooling loads/CO_2 emissions. While heating efficiency does not appear to have significantly changed since 2012 in Auckland and Christchurch, total space conditioning energy use does appear to have reduced in all regions, likely due to the reduction in average house size. The potential for harnessing solar in new sites remains extremely high in the three sampled cities examined.
2. Water	There was a limited dataset of residential-specific water consumption figures available. In terms of the estimated daily water consumption, Hamilton, Taupō and New Plymouth all reversed their 2016 increases, while Rotorua's increase appears to have continued. Conversely, Dunedin's 2016 decrease also appears to have been reversed.
3. Indoor environment	Compared to the NOW Home®, the Y2020 consented homes, with very rare exceptions, are considerably less comfortable via passive means, having more extreme temperatures in the main living area. In terms of daytime (7am–11pm) comfort, there has been no significant improvement in the randomly selected houses consented in Y2020 compared to those selected in previous years.
4. Functional resilience	The continuing low walkability in new developments in Christchurch and Hamilton is concerning. Unfortunately, the universal design metric has had to be put on hold due to the change in how Lifemark® measures their reach in terms of certification. Thermal discomfort due to predicted climate change remains the same for the years 2030 and 2080.
5. Affordability	In terms of New Zealand's housing affordability, the cost of new housing has grown 54.7% in the period 2012–2020, based on a single-storey reference house of 200 m^2 on a 500 m^2 section. The cost of homeownership (i.e. servicing a mortgage) has increased in Hamilton, while it has decreased in Auckland and Christchurch (~14% lower in Christchurch than in 2012).
6. Consumer demand	In terms of new homeowners wanting to build for sustainability reasons, only national rather than regional results were available this time (at 14%). Photovoltaic specification in new consents for the three regions still remained very low (at 1.4%).
7. Industry capacity	There is a 54% increase in practitioners providing impartial, tailored sustainability advice compared to Y2016. However, sustainability issues still have a very small industry impact overall.
8. Policy and regulation	Critical central government agencies – the Ministry of Business, Innovation and Employment (MBIE) and Energy Efficiency and Conservation Authority (EECA) – have provided some support to sustainable initiatives that directly affect the stand-alone housing stock when comparing to Y2016.

1. Introduction

In New Zealand, sustainability is one of four purposes of the Building Act 2004,[1] where "buildings are designed, constructed, and able to be used in ways that promote sustainable development".

The Act also requires certain principles to be taken into account, including the need to facilitate:

- efficient use of energy and the use of renewable sources of energy
- lower environmental impacting material choice and material conservation
- efficient use of water and water conservation
- reduction in the generation of waste during the construction process.

The principal objective of this BRANZ study is to continue the sustainability-related examination of the newly built detached housing stock to assess its performance and impactors. For the most part, this report is a simple update.[2] The exception to this is the transition to a considerably more powerful dynamic modelling energy tool called EnergyPlus.[3] Details of this transition process is provided in Appendix A.

In all, eight domains were utilised to describe key impactors on and of new residential houses in New Zealand. Although it is recognised that the groupings of the indicators and their respective metrics are an artificial construct, they help partition and rationalise a disparate range of issues into a digestible format. The relationship between the indicators and their associated metrics can be seen in Table 2.

As much as possible, the indicator set was derived from existing sources of information and knowledge, leveraging off various national-based agencies. Most notably, Beacon Pathway's indicator framework developed by Kettle (2008) and Trotman (2008), which examined the need for a national housing indicator framework for New Zealand, was drawn from. This BRANZ study also significantly extends these works both with in-house and externally developed metrics to provide a more rounded detached housing snapshot.

In terms of some basic new housing stock statistics, at the end of the 2020 year, some 39,420 new dwellings had been consented[4] – 22,212 of these were classified as houses (rather than townhouses, retirement villages, apartments or units). The total human population in New Zealand was 5,086,100 in 2020.

[1] www.legislation.govt.nz/act/public/2004/0072/latest/DLM306036.html
[2] To best understand this Y2020 update, the Y2012 and 2016 reports (Jaques, 2015, 2019) should be read prior or in parallel. These established and detailed the background, methodology, interpretation and implications of the study.
[3] https://energyplus.net
[4] www.stats.govt.nz/information-releases/building-consents-issued-december-2020

Table 2. Summary of indicators and metrics for stand-alone homes (applied Y2020).

Domain	Core indicator(s)	Metric(s) used
1. Energy and CO_2	Energy use for space conditioning	kWh/m², kWh/household and kWh/person
	CO_2 emissions for water and space heating	kg CO_2 emissions/person/year
	Potential of site for harnessing solar energy	Percentage availability of sun Degree-hour daytime discomfort
	Whole-house resource efficiency rating	Ratio of floor area to number of bedrooms + embodied carbon of constructions
2. Water	Uptake of household water-saving devices + average water consumption	L/person/day
3. Indoor environment	Comfortable indoor temperatures achieved passively	Daytime # of hours/year comfortable in main living area
	Healthy indoor temperatures in a key occupancy zone	Extreme heat (# of degree-hours/year above 25°C) and critically cold (# of days/year less than 12°C)
4. Functional resilience	Proximity to key amenities/public transit	Walk Score™ and Transit Score™ ratings
	Climate change implications on indoor thermal comfort achieved passively	Overheating (hours/day) and underheating (hours/day) projections for years 2030 and 2080
5. Affordability	Housing affordability and key enviro-feature costs	New-build index and cost of ownership index
6. Consumer demand	Demand/sales of some key sustainable products and services	Products: specification of eco-related products + whole-house demand Services: # of whole-house environmental awards
7. Industry capacity	Supply of some key sustainability-related services	# of supporting industry-related professionals # of banks providing green mortgages # of trade-specific capacity-building initiatives
8. Policy and regulation	Supportive government policy and regulation	# of existing and longer-term initiatives implemented

2. Background

In terms of this study's characteristics, the following provides some context on key issues:

- **Scope** – limited to new New Zealand stand-alone dwellings and their immediate amenities. The cities of Auckland, Hamilton and Christchurch were targeted to represent the nation for some indicators.
- **Requisite characteristics of indicators** – meaningful, specific to underlying phenomena, easily interpreted, consistent over time, linked to emerging issues and resonate with the intended audience.
- **Growing need for quantitative stock indicators** – economic contributions of our housing stock to our economy, changes facing New Zealand Inc. and the resulting threats and opportunities.
- **Audience and uses** – to provide a foundation on which to track changes in key aspects and to support strategic decision making and influencing policy, action and behaviour.

More detailed information on each of the preceding issues is provided in section 2 of the foundation (Y2012) report. The most important overriding difference between this update and the foundation report is the considerable shift in the scientific understanding and public appreciation of building-related climate change impacts (whether mitigation related or adaptation related) for all species' continued survival.

Writing a report that provides a snapshot of one particular year means that, by its nature, some important initiatives and resources affecting the new residential building stock are not captured. The following are some additional key initiatives that have occurred since the last BRANZ benchmarking report:

- The introduction of HOMEFIT[5] in 2018 – a practical, straightforward way to check how easily a home can be kept warm, dry and safe. Created by the New Zealand Green Building Council with the housing sector, it was updated in 2019 so that trained assessors can be used to show compliance with the healthy homes standards.[6]
- The Zero Carbon Act – more formally the Climate Change Response (Zero Carbon) Amendment Act 2019,[7] which provides a framework by which New Zealand can develop and implement clear and stable climate change policies that contribute to the global effort to limit the global average temperature increase to 1.5°C above pre-industrial levels and allow New Zealand to prepare for and adapt to the effects of climate change.
- The announcement by central government in 2020 that reducing the emissions from the built environment sector is key to delivering the climate change results that New Zealand needs and the development of an emissions reduction plan[8] that sets out the changes needed to allow New Zealand to meet its climate change goals.
- In August 2020, two frameworks to reduce emissions across the building and construction sector were released under the government's Building for Climate

[5] www.homefit.org.nz
[6] www.tenancy.govt.nz/healthy-homes/about-the-healthy-homes-standards
[7] www.legislation.govt.nz/act/public/2019/0061/latest/LMS183736.html
[8] www.environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/emissions-reduction-plan

Change programme (Ministry of Business, Innovation and Employment, 2020a, 2020b).

- The considerable upgrading of thermal performance requirements in Acceptable Solution H1/AS1 for clause H1 *Energy efficiency* for all housing in 2021.[9] These thermal upgrades are predicted to reduce the energy needs for comfort between 30–40% (Ministry of Business, Innovation and Employment, 2020a).
- The 2021 release of Superhome Movement's *The Healthy Home Design Guide.*[10]
- NZGBC's major update and release in August 2021 of its Homestar Technical Manual v5. A key change was the introduction of a formal method of carbon accounting, recognising the need to keep within the 2050 target and the fact that the average new house in New Zealand emits about five times too much carbon pollution (Chandrakumar et al., 2020). Both ongoing and embodied emissions are now accounted for. The quantification of the embodied emissions of building materials is achieved through the introduction of a BRANZ-developed calculator.
- The genesis of the Passive House Institute New Zealand (PHINZ) *High-Performance Construction Details Handbook* (Quinn, 2022) funded by the BRANZ Building Research Levy. It brings together selected high-performance construction details from residential projects successfully specified and built in New Zealand. A free to download resource, it provides build, thermal, carbon and costing data for around 100 roof, wall and floor details.
- The UN Climate Change Conference (COP26) in Glasgow had an entire day dedicated to the built environment (11 November 2021) named the Cities, Regions and Built Environment Day. Kāinga Ora's Ngā Kāinga Anamata development in Auckland was one of just 17 international projects selected to feature in the Build Better Now virtual exhibition.

The following BRANZ projects are also relevant:

- BRANZ/Massey University developed a method for calculating a carbon budget for New Zealand dwellings to meet New Zealand's 2050 international obligations. It takes a top-down approach that assigns a share of the global carbon budget for 2018–2050 to a country, then to its construction sector, then to each life cycle stage of a building (Chandrakumar et al., 2019, 2020). This resulted in two best paper awards at two distinguished international green building conferences.
- How can New Zealand construction deliver low to zero impact buildings? IEA EBC Annex 72[11] (2018–2021) establishes a common methodology and derives benchmarks to assess life cycle-based carbon emissions caused by buildings.
- The multi-year *Transition to a zero-carbon built environment* programme examines climate change and its impact on New Zealand's buildings (started in 2019).
- The release in 2021 of the CO_2RE tool,[12] which provides calculated carbon footprints per square metre for residential roof, wall and floor constructions obtained from the BRANZ *House insulation guide* (5th edition).
- Various climate-change-related BRANZ bulletins, including BU655 *Building blocks for new-build net-zero carbon houses* (BRANZ, 2020).
- The release of a suite of carbon calculators for the building industry. BRANZ developed the New Zealand whole-building whole-of-life framework to provide tools, data and information to support decision making for sustainable building

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[9] www.building.govt.nz/assets/Uploads/building-code-compliance/h1-energy-efficiency/asvm/h1-energy-efficiency-as1-5th-edition-amendment-1.pdf
[10] http://healthyhomedesignguide.co.nz/
[11] https://annex72.iea-ebc.org/
[12] https://www.branz.co.nz/shop/catalogue/co2re_1005/

design. The framework uses the techniques of carbon footprinting and life cycle assessment and includes LCAQuick, LCAPlay, CO_2NSTRUCT and CO_2MPARE.[13]
- The BRANZ Carbon Challenge seminars/webinars ran in early 2022. These presented optimisation strategies[14] derived from parametric simulation that considered both embodied and operational carbon.

Further key influencing initiatives are overviewed in sections 5.15 and 5.16.

[13] https://www.branz.co.nz/environment-zero-carbon-research/framework/
[14] https://www.branz.co.nz/low-carbon-resources/optimisation-strategies/

3. Methodology

The methodological approach for this Y2020 report is almost identical to that of the Y2016 report, recognising that most of the establishment has already been carried out and to ensure between-year consistency. Only minor avenues for indicator and metric improvement have been explored, reflecting the mature nature of this study now in its third iteration. There are a few exceptions to this rule discussed in section 4.3. For details on the development of New Zealand-specific indicators, previous international indicator resource and the Year Zero yardstick house, the Y2016 report should be consulted.

As before, there are eight overriding domains separated into three overriding themes (Figure 1):

Theme	Domains
Building performance	1. Energy and CO_2
	2. Water
	3. Indoor environment
	4. Functional resilience

Theme	Domains
Market forces	5. Affordability
	6. Consumer demand
	7. Industry capacity
Governance	8. Policy and regulation

Figure 1. Relationship between three thematic areas and their associated domains.

Reflecting its more mature nature, no steering or advisory groups were utilised for this iteration of the study.

4. Interpretation

4.1 Interpretation and yardstick applied

Some 210 randomly selected, stand-alone house building consents from the 2020 calendar year from the three cities of Auckland, Hamilton and Christchurch were examined in detail. Information from their drawings and specification notes provided the bulk of quantifying information concerning their indoor environment, energy and CO_2 domains.

For this study, the new home consents examined were processed by their respective councils in the 2020 calendar year. Beacon Pathway's NOW Home® was again used to provide a gauge of where the 2020 housing stock sits in terms of a wide variety of building performance and sustainability-related indicators due to its achievability, prominence in terms of validated exemplar buildings and comprehensive treatment of a wide variety of environmental, economic and social high-performance goals.

For much of the building performance-related studies, snake diagrams were utilised where individual homes' metrics are presented in an ascending/descending order. As before, for consistency in all the diagrams, the median is shown as a continuous grey line, and the 20th and 80th quintiles are shown as dotted grey lines (Figure 2).

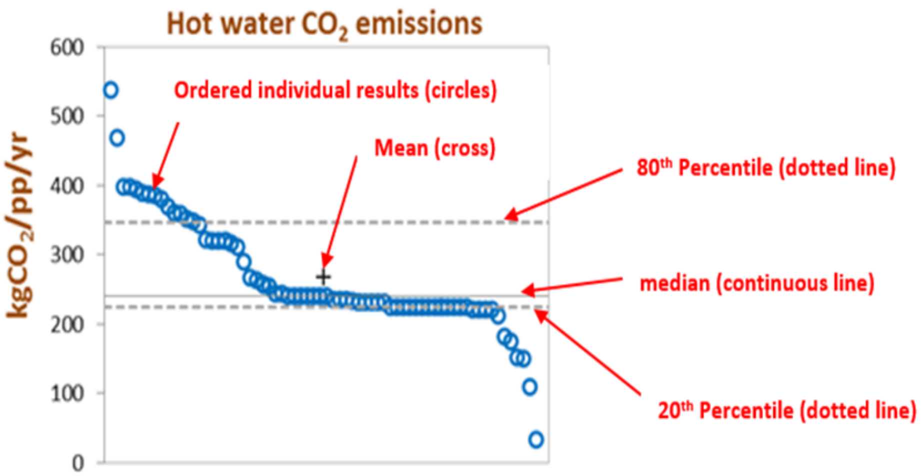


Figure 2. Annotated snake diagram to assist interpretation.

The approach used in the presentation of the tabular results was left largely unchanged for this Y2020 update. Only small refinements such as the inclusion of per capita and per consent statistics were added in to better contextualise the study-year results presented in tabular format.

4.2 Addressing previous reports' recommendations

In the recommendations section (6.2) of the Y2016 report, several suggestions were put forth responding to the realisation that the underperformance of new homes needs immediate attention. These are presented in shaded boxes in the remainder of this section followed by updates on progress.

Building performance

More leadership, education and actual demonstrations showing widely applicable cost-effective high-performing low-carbon options that consider the building's life cycle and its occupants and relationship with the wider community. It is essential that education aspect provides practical, demonstrable and cost-effective design solutions that industry can adopt with (ideally) minimal upskilling.

This is being addressed on multiple fronts:

- Cost effective low-carbon options: EECA and NZGBC are working on this project currently and hope to have some solutions at least for the residential retrofit market by the end of the 2022 calendar year (G. Gretton, Senior Advisor, EECA, personal communication, 3 May 2022).
- Education: BRANZ has run a series of webinars (March 2022) and seminars (April 2022) and provided ongoing *Build* articles, bulletins, advice and analysis for the Ministry of Education and provided tools for industry as well as regulator support (for MBIE) on carbon-efficient design solutions. BRANZ also provided demonstration input into the Kāinga Ora medium-density construction as well as the multi-year BRANZ NEXT Home project.

A clearer understanding of and therefore practical recommendations for low-carbon features for new homes that are life cycle based.

The BRANZ *Transition to a zero-carbon built environment* programme, BRANZ LCAQuick Residential tool (released late 2019) and the associated BRANZ carbon budget research, which establishes a carbon cap by dwelling type (Chandrakumar et al., 2019), and NZGBC's Homestar Embodied Carbon Calculator (HECC) tool all contribute towards providing robust technical direction for addressing embodied carbon.

BRANZ is currently analysing the performance of various types of (potentially) low-carbon residential water heating technologies over four seasons on a life cycle basis.

A further exploration of district plans' recession plane influence on adjacent properties' comfort, based on dynamic thermal simulation using both existing and predicted future climate files, for future policy development.

This has been put on hold due to associated thermal modelling requiring more resource that expected.

A multi-pronged strategy of incentivisation, regulation and demonstration for universal design.

- Regulation: Nothing mandatory yet.
- Demonstration: Lifemark® has many demonstration homes in 2020, including Kāinga Ora's new off-site manufactured bathroom and laundry pods.

An expansion of this BRANZ benchmarking study to performance measure other dwelling typologies (such as townhouses and/or apartments) in subsequent studies.

This was considered but not actioned. It was decided in this update that the focus on the transition to a more flexible whole-house thermal assessment tool was more important. It was felt that concentrating on the more urgent aspects (thermal performance/comfort/climate risk understanding at both the individual as well as stock level) would be more logical in progressing this space. Both issues – expanding the dwelling typologies and migrating thermal performance tools – are very resource intensive.

Market forces

Having show-homes or providing case studies to demonstrate the benefits of different options to consumers.

The Superhome Movement and to a less extent PHINZ have progressed this in the many open home day events (when possible due to COVID-19).

More research and funding into materials and testing of high-performance features.

The BRANZ *Transition to a zero-carbon built environment* programme is framed around this. By 2050, it aims to provide research support for an industry-led transition to deliver net-zero carbon buildings in an affordable way. This will be accomplished by:

- decarbonising across the whole building life cycle
- encouraging industry leadership and decision making to manage climate change mitigation.

In addition, BRANZ has provided two evaluation methods (Burgess & Jaques, 2021a, 2021b) to assist the window and glazing industry to verify the thermal and weathertightness performance of recessed joinery.

BRANZ to provide more knowledge and information around the importance of operational costs compared to initial costs to all those involved in the construction industry, including consumers.

EECA has a new tool (due late 2023) for examining residential water heating systems based on lifetime (financial and carbon) costs.

Governance

Mandating low-energy/carbon targets for residential builds in legislation, using an assessment system.

MBIE is addressing this under its Building for Climate Change programme.

Providing the construction industry with a range of alternative low-carbon responses:

- Design and specification in terms of materials, smaller-sized dwellings, etc.
- Procurement procedures – for example, shifting to the use of cement replacements and engineering timber for many structural steel applications.
- Product supply chain by reducing carbon in processes and products.

BRANZ ran a nationwide webinar series on low-carbon housing through March 2022. NZGBC now has more of a focus on recognising and rewarding low-carbon building (both embodied and operational) decisions within its Green Star and Homestar rating tools.

4.3 Changes to core indicator metric set (from Y2016)

In the previous study, some minor changes were made to the indicators examined and their associated metrics. The changes typically stemmed from:

- the growing importance/awareness of carbon's role in the construction industry
- newly uncovered data sources that could be easily leveraged for this study
- an external provider's data stream ending or changing significantly
- a better understanding of the potential audience interest areas
- opportunities for clarification or data augmentation in the form of case studies.

Changes were required for several metrics in this 2020 update:

- Building material-related embodied carbon: New data became available providing an opportunity to refine the previous metric (see Appendix B).
- Universal design: Disappointingly, determining certificated numbers of new detached homes has ceased due to a change in Lifemark® policy on data stream measurement. A suitable robust, meaningful, third-party certified, cost-effective and transparent replacement has not yet been identified. Further investigatory work for the next benchmarking update (Y2024) will be undertaken to see if this important metric can be reintroduced.
- Economic metrics, specifically the relative cost of ownership index: This has been refined and backcasted to the previous years examined to complete the dataset.

The authors have ensured that the same rigour and output usefulness have been achieved for the metrics and indicators concerned.

5. Results

5.1 Context

Before examining the benchmark indicators, it is beneficial to look at the relevant characteristics of the 2020-sampled houses in order to provide context as to why performance improvements may or may not be expected:

- Most houses continue to be insulated to no more than what is required by the Building Code. For those that do see increases, they are typically minor – for example, the use of R3.6 ceiling insulation instead of R3.2 in Auckland or the use of low-E glazing or thermally broken window frames but not both.
- Auckland may be expected to have seen some improvement in thermal performance due to a decline in the use of single glazing. In 2012, around a quarter of the houses in our sample used single glazing, while none do in the 2020 sample.
- Hamilton may see a small improvement due to a shift from being predominantly uninsulated slab to predominantly waffle slab, which has little thermal benefit, although it has insulated pods.
- Window to wall ratios in Christchurch houses appear to have reduced and are now consistent with the average level in the other regions – around 22%.
- Consistent with broader trends in New Zealand, house sizes have shrunk, particularly in Hamilton where the average house size in the sample has fallen from ~155 m^2 to ~120 m^2. This should reduce overall energy use. However, the apparent small floor areas of the Hamilton sample is concerning as Stats NZ data does not point to the average new Hamilton house being that much smaller than one in Christchurch. If garages and void areas are included in the calculated model floor areas, the Christchurch and Auckland averages line up reasonably well with the average floor area from Stats NZ but the Hamilton sample is still significantly lower (Table 3). Spot checks do not indicate any major discrepancies between the modelled areas and the consent data, which raises questions about the representativeness of the 2020 Hamilton sample.

Table 3. Average floor area of modelled houses, including garage and void spaces, compared to the average floor areas estimated from Stats NZ data.[15]

	Auckland	Hamilton	Christchurch
Modelled	195 m^2	150 m^2	179 m^2
Stats NZ	206 m^2	175 m^2	180 m^2

Figure 3 provides a comparison of key characteristics of the houses for the three periods sampled.

[15] Note that, as walls in the energy models have no thickness, we would expect the modelled floor areas to be slightly lower than that reported on consents.

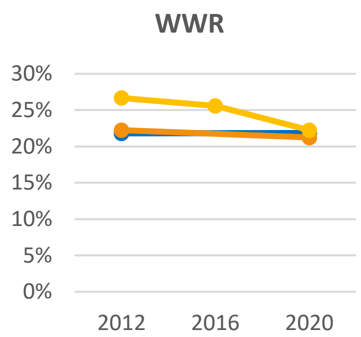
Proportion of Auckland houses with single glazing

2012	23%
2016	16%
2020	0%

Average floor area not including garage (mean/median)

	Auckland	Hamilton	Christchurch
2012	168/170	150/155	167/157
2016			168/166
2020	173/153	122/120	146/136

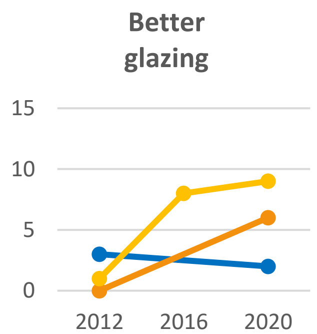
Average window/wall ratio



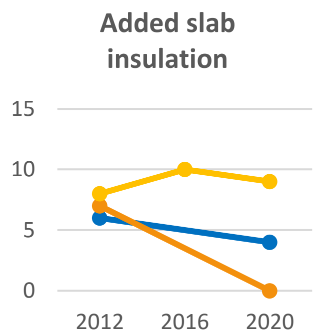
Proportion of houses with waffle slabs

	Auckland	Hamilton	Christchurch
2012	64%	11%	50%
2016			57%
2020	71%	90%	57%

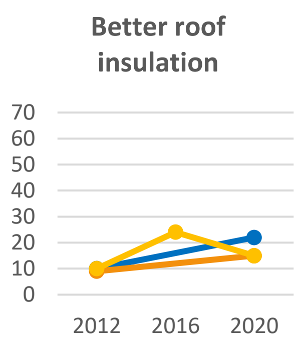
 # houses with improved windows (>R0.26) n=~210



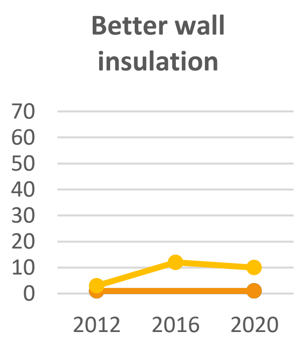
 # houses with additional slab insulation (edge or underslab; waffle pod systems not counted) n=~210



 # houses with above Code roof insulation (>R3.2 in Auckland/ Hamilton, R3.6 in Christchurch)



 # houses with improved wall insulation (>R2.1)



Key: **Auckland**, **Hamilton**, **Christchurch**.

Figure 3. Comparison of key characteristics of the houses sampled – Y2012, Y2016 and Y2020.

5.2 Energy use for active space conditioning

Background

The approach taken for this issue remains similar to the preceding reports. The three metrics previously used to examine the randomly selected houses were repeated:

- Space heating energy required per unit floor area (kWh/m²).
- Space heating energy required per household (kWh/household).
- Space heating and cooling energy required per occupant (kWh/person).

Detailed thermal simulations were again carried out on the randomly selected stand-alone building consents for the 2020 calendar year. EnergyPlus, a well-validated, continuously maintained open-source whole-building energy-simulation engine, was used rather than the former thermal simulation tool AccuRateNZ. The main reasons for this change are detailed in Appendix A and revolve around it providing more flexibility in simulation and analysis for future research purposes. This includes both at a micro level (individual house level) and macro level (. Regional or national housing stock level). Once again, for comparative purposes on thermal performance, the Beacon Pathway Waitakere NOW Home® is used. Note that the Y2016 energy use statistics for Auckland and Hamilton are missing as they were not calculated that year.

Findings

Figure 4–6 show the annual space heating efficiency and space heating conditioning and use for the 70 randomly selected 2020-consented, stand-alone houses in Auckland, Hamilton and Christchurch. The following Tables 4–6 extract key statistics of space conditioning and heating use using three different normalisers (area, household and occupant) to provide different perspectives on the homes' thermal performance.

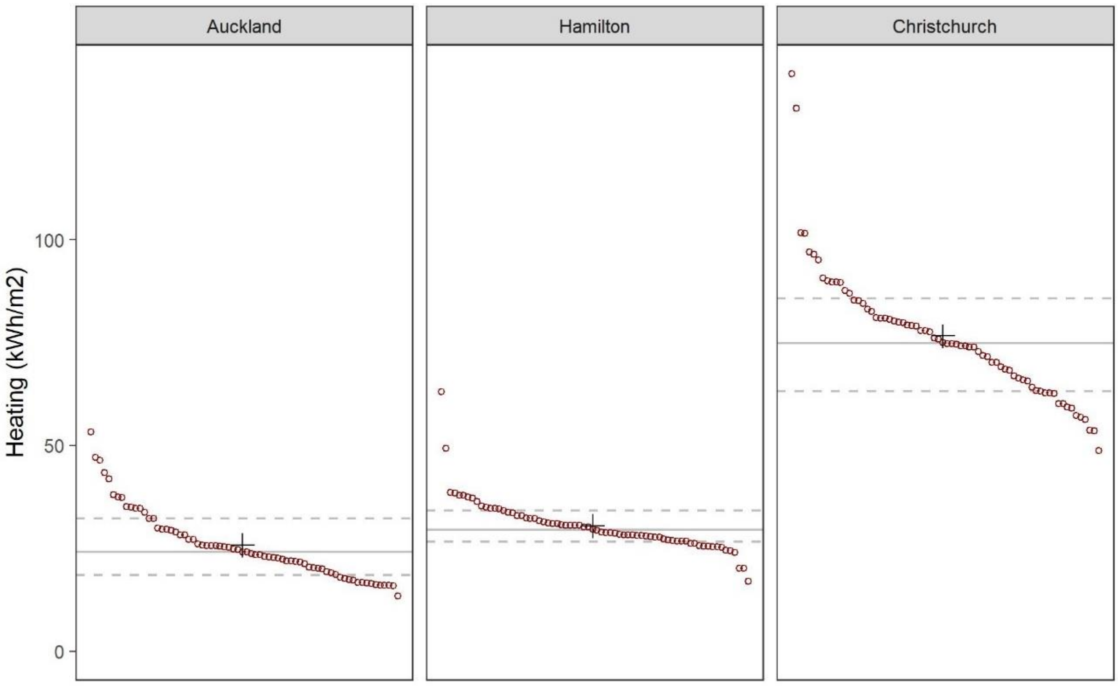


Figure 4. Modelled house space heating energy efficiency across the three regions.

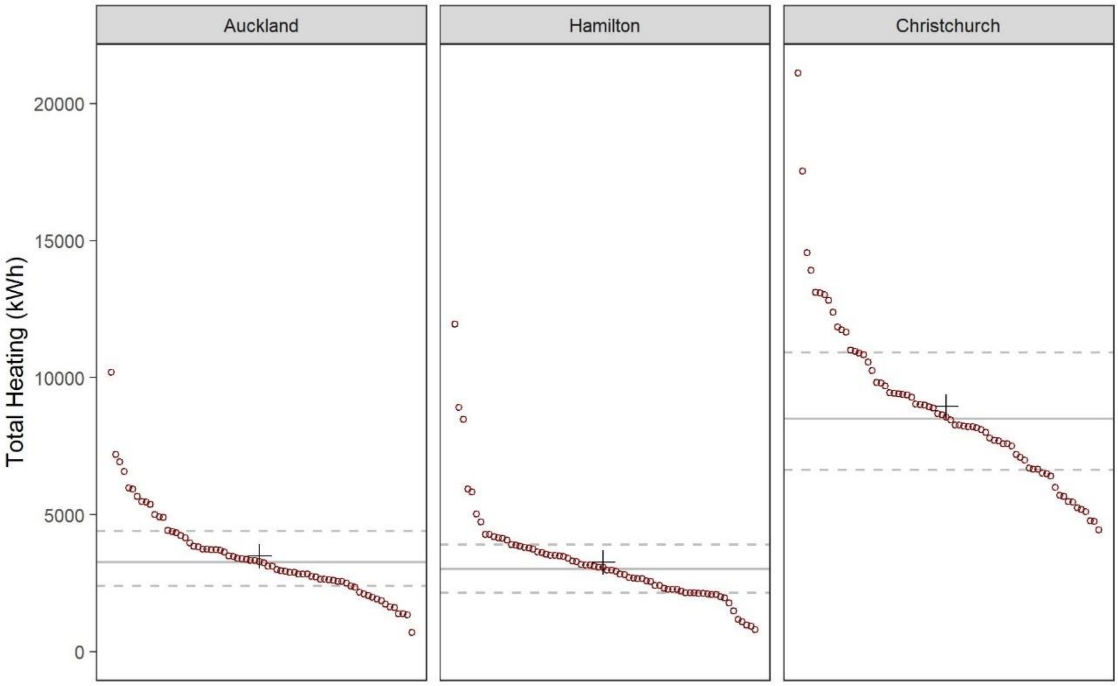


Figure 5. Modelled space heating use per household.

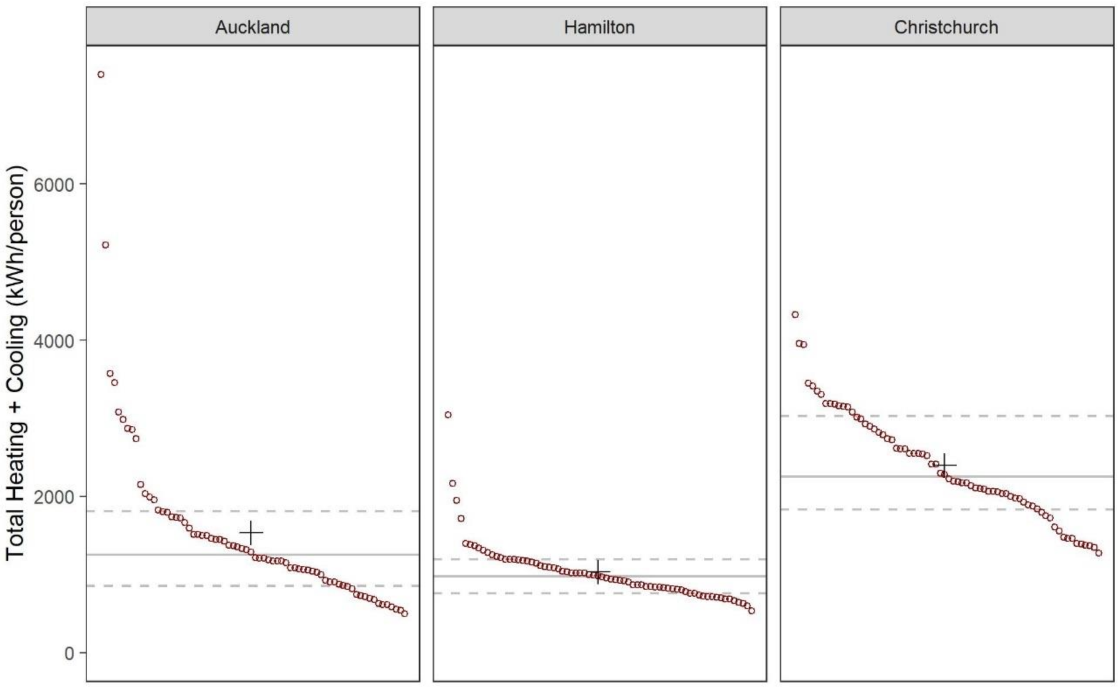


Figure 6. Modelled space conditioning use per occupant.

Table 4. Key household energy statistics on Auckland detached dwellings.

		Mean			50th percentile			80th percentile		
Auckland	**NOW Home®**	**2012**	**2016**	**2020**	**2012**	**2016**	**2020**	**2012**	**2016**	**2020**
Space heating energy use										
By area (kWh/m²)	**5**	26	-	26	25	-	24	31	-	32
By household (kWh/hh)	**537**	4,483	-	3,498	4,120	-	3,159	5,974	-	4,395
Space conditioning (heating and cooling) energy use										
By occupant (kWh/person)	**405**	908	-	1,538	847	-	1,250	1,120	-	1,809
By area (kWh/m²)	**15**	27	-	58	26	-	49	32	-	75

Table 5. Key household energy statistics on Hamilton detached dwellings.

		Mean			50th percentile			80th percentile		
Hamilton	**NOW Home®**	**2012**	**2016**	**2020**	**2012**	**2016**	**2020**	**2012**	**2016**	**2020**
Space heating energy use										
By area (kWh/m²)	**13**	42	-	31	41	-	30	45	-	34
By household (kWh/hh)	**1,409**	6,383	-	3,259	6,109	-	3,024	7,965	-	3,895
Space conditioning (heating and cooling) energy use										
By occupant (kWh/person)	**541**	1,298	-	1,033	1,270	-	978	1,580	-	1,195
By area (kWh/m²)	**20**	44	-	45	43	-	42	47	-	50

Table 6. Key household energy statistics on Christchurch detached dwellings.

		Mean			50th percentile			80th percentile		
Christchurch	**NOW Home®**	**2012**	**2016**	**2020**	**2012**	**2016**	**2020**	**2012**	**2016**	**2020**
Space heating energy use										
By area (kWh/m²)	**34**	77	74	77	76	74	75	84	81	86
By household (kWh/hh)	**3,716**	10,780	10,054	8,942	9,571	10,042	8,503	13,160	12,540	10,907
Space conditioning (heating and cooling) energy use										
By occupant (kWh/person)	**1,044**	2,256	2,210	2,396	2,040	2,220	2,253	2,632	2,664	3,030
By area (kWh/m²)	**38**	78	76	89	77	76	87	85	84	101

Note that, while the new EnergyPlus models were calibrated to align reasonably well with the previous AccuRateNZ models in terms of average heating energy use, the same is not true for cooling. The space conditioning values (which include both heating and cooling aspects) are thus not comparable with the Y2012 and 2016 studies.

While the Christchurch and Auckland results are much in line with previous years, the Hamilton results suggest a dramatic improvement in energy efficiency, using 25% less heating per square metre (31 kWh/m² compared to 42 kWh/m²). This is hard to explain given that, as noted, there has not been any significant improvement in insulation levels. The shift to waffle slabs would only increase the R-value of the slabs by a small amount, and we would only expect this to improve heating efficiency by a few percent. Similarly, we would not expect the reduction in house size (which has also occurred in the other regions even if not to the same extent) to significantly improve efficiency when we have already normalised the metric by floor area. The Hamilton houses simply appear to have much better performance than either the Auckland or Christchurch ones. If we move the Hamilton houses to the other regions, they outperform them. If we run the Christchurch houses in Hamilton, their heating use is much higher than the Hamilton houses and more in line with what we would have expected from Y2012 at 40 kWh/m².

Detailed and extensive checking of the models has failed to turn up any systematic errors or modelling differences that could explain such a large improvement in performance (see Appendix A: for further discussion). At the same time, it should also be noted that it is at least theoretically possible for design differences to produce improvements this large. Consequently, the Hamilton results presented here should be approached with caution. While no good reason has been found to say that the models are wrong (after extensive investigation), the results are unexpected as there remains a lack of a clear explanation for such good performance. The low average floor area of the sample is also notable and raises concerns about whether the randomly selected sample is representative as biases sometime occur even with random sampling.

Returning to the Auckland houses, it was noted that, in previous years, there had been a significant number with single glazing, which we would expect to have made heating efficiency worse with glazing being the most critical, thermally 'weak' building element. While the uncertainty from the change in thermal modelling tools can make clean comparisons difficult, we can produce a synthetic comparison by altering 23% of the 2020 houses to use single glazing as in 2012. The results suggest that, if single glazing was still being used to the same degree, the average heating energy use would be around 10% higher.

Notable points

- While space heating efficiency does not appear to have significantly changed since 2012 in Auckland and Christchurch, total space conditioning energy use does appear to have reduced in all regions, which may be explained by the reduction in average house size.
- If single glazing was still being used to the same degree as in 2016, the average space heating energy use in Auckland would be around 10% higher in 2020. Similarly, it would be reasonable to suggest that the Hamilton houses have likely improved by a few percent.
- Further investigation of the design of the Hamilton models could be fruitful. If their performance improvement is genuine, it would be valuable to understand how it occurred despite the houses' conventional general design and insulation characteristics. Indeed, there are a number of houses in all climates that show relatively strong performance without additional insulation so interrogating them could be revealing.
- The difference between what could easily be achieved through considered design (i.e. the Beacon Pathway NOW Home®) and what is currently being achieved (i.e. the randomly selected homes' median performer) in terms of active thermal performance is (still) considerable. This is true for whichever energy use metric (by

area, by household or by occupant) is chosen. This has been a constant through all of these BRANZ benchmarking studies.
- The new EnergyPlus models suggest significantly higher cooling energy use than the old AccuRateNZ models – particularly in Auckland. This is largely due to the differences in how AccuRateNZ operates ventilation and cooling. It ventilates very aggressively, bringing temperatures down below the setpoint of 23°C to ~21°C, while not turning cooling on until the temperature reaches more than 2.5°C higher than the 25°C cooling setpoint. The decisions around ventilation and cooling simulation assumptions and behaviour are complicated, and there is not necessarily any single "right" answer. However, using the standard Building Code H1 setpoint, our results suggest that cooling and overheating may be increasingly important to modern houses. There is a need to consider them more in design, regulation and modelling.

5.3 CO_2 emissions for water and space heating

Background

The two highest residential appliance-related energy end users (Isaacs et al., 2010) and therefore likely carbon dioxide emitters – water heating and space heating – are investigated in this subsection.

It should be noted that refrigerants in water heating and space conditioning appliances have lifetime climate change-related impacts – during manufacture, use, maintenance and disposal. These negative impacts counteract the efficiency benefits resulting from their use. A recent BRANZ investigation of the lifetime implications of both existing and new refrigerants commonly specified for residential space conditioning and water heating has shown these impacts to be marginal for a range of future scenarios (Jaques & Bullen, 2023). In the absence of more robust data, the global warning impacts from residential-based refrigerant use has been ignored for this study.

Water heating

The methodology and reasons for choosing this indicator remains unchanged. The water heating system CO_2 emissions are based on hot water algorithms from the BRANZ WHAT HO! Tool (Burgess & Cogan, 2008), which incorporates standardised user behaviour. For more details on the method, consult section 5.2 of the Y2012 report.

Space heating

The methodology and reasons for choosing this indicator remain unchanged. While consideration of the carbon produced by space heating is important, it continues to be a difficult metric to reliably estimate given that many consents do not specify the heating system, or where they do, they do not cover all conditioned zones in the house. For more details on the method, consult Appendix C of the Y2016 report.

Findings

Water heating emissions are still largely unchanged, with minor fluctuations over the years (Table 7). They continue to show the large gap between a carbon-efficient water heating system and what is typically installed, with the NOW Home® having roughly three times less carbon-intensive water heating requirements than the average new house.

Table 7. Household water heating-related CO_2 emissions statistics.

Water heating emissions (kg CO_2/household/yr)										
Location	Mean	Mean			50th percentile			80th percentile		
	NOW Home®	2012	2016	2020	2012	2016	2020	2012	2016	2020
Auckland	73	251	246	250	264	258	276	294	319	284
Hamilton	86	274	271	298	296	289	312	316	335	319
Christchurch	101	268	276	269	240	228	225	347	387	346

Table 8 shows the space heating-related CO_2 emissions for the sampled houses. With the previously noted decline in overall energy use as a result of reduced house size, emissions have likewise decreased. This is bolstered also by reductions in the average emissions factors of houses in the samples – particularly in Christchurch with a high uptake of heat pumps. This is particularly notable at the 80th percentile – in previous years, houses that combined high-emissions gas fireplaces with high energy use pushed heating emissions up significantly.

Table 8. Household space heating-related CO_2 emissions statistics.

Space heating emissions (kg CO_2/household/yr)										
Location	Mean	Mean			50th percentile			80th percentile		
	NOW Home®	2012	2016	2020	2012	2016	2020	2012	2016	2020
Auckland	43	552	-	436	463	-	358	732	-	565
Hamilton	112	728	-	358	645	-	332	873	-	455
Christchurch	295	1,455	1,308	872	1,128	1,020	774	2,296	1,992	1,033

Notable points

- Water heating efficiency and resulting CO_2 emissions have seen little change.
- The NOW Home® provides a good example of the potential of a well-designed hot water system with CO_2 emissions intensities per person well below that of the others at all three locations.
- Space heating CO_2 emissions have declined due to a combination of reduced house size and potentially less carbon-intensive heating systems.

5.4 Potential of site for harnessing solar energy

Background

Site shading on the 210+ new-build sites is again investigated. It has implications for harnessing solar energy, material durability, health and comfort and is influenced by topography/geography, nearby buildings and manmade structures and nearby foliage.

The previous methodology used to determine the topographic-influenced solar shading was refined following a discussion with the author of SolarView, NIWA's online tool (B. Liley, Atmospheric Scientist, NIWA, personal communication, 18 May, 2022). There was a concern that a misinterpretation of a dataset could have resulted in an underestimation in the amount of in situ topographic shading. In light of this, the potential impact of site shading on available solar energy was reanalysed for the 2020 sample to check if there were any issues.

NIWA's online SolarView tool[16] quantifies the solar energy intensity (in Wh/m²) collection potential of a given address, accounting only for topographic influences. Solar incidence on a vertical face representing a house wall (tilt = 90°; bearing = 0°) was determined for each address. The resulting cloudless (sky) energy for that site is calculated on an hourly basis for the year and compared to the topographically flat (i.e. featureless) horizon.

Note that recession planes were not investigated this year.

Findings

Batch analysis in SolarView, carried out with the generous assistance of Ben Liley (NIWA), indicated that the reduction in available solar energy (as measured by global horizontal irradiance) due to horizon shading from terrain is less than 1% for all the sites in the 2020 sample. The conclusions from previous years, that in these locations any site shading will be more a matter of local obstructions like trees or neighbouring houses rather than hills, are thus unchanged. Most of the sites here are relatively flat, and solar potential is thus generally good (within the constraints of the climate).

5.5 Whole-house resource efficiency

Background

This indicator attempts to quantify the how resource efficient the new-build is in a simplistic manner. Two aspects of whole-house resource efficiency are examined: its spatial effectiveness and its embodied carbon. The first metric is based on the Homestar Resource Adjustment Factor metric (NZGBC, 2017), calculated by simply dividing the conditioned area of a house by the number of bedrooms. (Note that studies and rumpus rooms are defined as bedrooms in Homestar.) The lower the number, the more 'efficient' the house is likely to be. The second metric is based on the embodied carbon intensity of consented stand-alone houses. This provides a measure of the climate change impact arising from materials in new-build stand-alone construction in New Zealand for the calendar year in question.

A new method for calculating embodied carbon intensities is utilised That refines the previous method and better reflects current thinking in a rapidly developing field. The details of the new method are provided in Appendix B.

Findings

The key statistics are shown in Table 9 for each of the three locations. As can be seen, there is very little movement in the resource efficiency numbers between years for all three locations. Hamilton continues to be around 10–20% more spatially efficient when examining just stand-alone houses than the other regions. That being said, the average household size in New Zealand is 2.7 people.[17] In that sense, using bedrooms as a proxy for occupancy is overly simplistic as the average new house has more bedrooms than the average number of occupants (Table 10). Bringing the average house size down to better align with actual occupancy could thus be a genuine improvement in resource efficiency, in terms of resources being used by people, but would not be reflected in this metric.

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[16] https://solarview.niwa.co.nz, where the cloudless figures in W/m² are used as the measure.
[17] https://www.stats.govt.nz/news/new-data-shows-1-in-9-children-under-the-age-of-five-lives-in-a-multi-family-household/

Table 9. Key statistics for whole-house resource efficiency (Lower is better).

Location	NOW Home®	Mean			80th percentile		
	All years	2012	2016	2020	2012	2012	2020
Auckland	29	33	31	33	37	35	39
Hamilton		30	30	30	34	35	35
Christchurch		34	34	36	41	40	41

Table 10. Average number of bedrooms in modelled houses.

Average # of bedrooms	2012	2016	2020
Auckland	4.2	-	4.4
Hamilton	4.0	-	3.4
Christchurch	3.8	3.6	3.4

Table 11 shows the calculated embodied carbon intensity of each of the external walls, roof, ground floor, mid-floor, interior walls and windows as well as the overall carbon intensity at the stand-alone house level for 2020.

Table 11. Estimated elemental carbon in new detached houses in 2020.

Element	Area total (m2)	Life cycle carbon total, exc. potential benefits (tonnes CO_2eq)	Potential benefits (biogenic CO_2 + module D (tonnes CO_2eq)	Carbon intensity (kg CO_2eq / m^2)	Potential benefits intensity (kg CO_2eq / m^2)
Wall cladding and framing	3,357,285	245,659	- 114,312	73	-34
Roof	2,563,685	184,977	- 79,862	72	-31
Ground floor	2,355,357	192,727	- 32,640	82	-14
Mid-floor	1,912,095	76,522	- 81,952	40	-43
Interior walls	4,249,727	140,664	- 93,914	33	-22
Windows	705,030	61,338	- 13,537	87	-19
Totals	**15,143,179**	**901,886**	**- 416,217**	**60**	**-27**

It is evident from Table 11 that, whilst interior walls and exterior walls comprise the largest calculated areas of consented houses in 2020, the windows and ground floor have the highest carbon intensity. This is because glass and aluminium commonly used in windows and concrete used in ground floor slabs are high embodied carbon materials. Exterior walls (wall cladding and framing) and roofs also have higher embodied carbon intensities. Mid-floors and interior walls are the least carbon intensive. When considering potential benefits, mid-floors and interior walls show significant values, reflecting the amount of sequestered carbon dioxide and the proportion of timber materials in these elements. Values could be improved across all elements with more diversion of waste materials away from landfill. Since this is a new method, Table 12 shows results based on 2016 consent data and the BRANZ New Dwellings Survey for 2016 for comparison.

Table 12. Estimated elemental carbon in new detached houses in 2016.

Element	Area total (m2)	Life cycle carbon total, exc. potential benefits (tonnes CO_2eq)	Potential benefits (biogenic CO_2 + module D (tonnes CO_2eq)	Carbon intensity (kg CO_2eq / m^2)	Potential benefits intensity (kg CO_2eq / m^2)
Wall cladding and framing	3,510,824	253,988	- 123,521	72	-35
Roof	2,537,134	182,864	- 78,865	72	-31
Ground floor	2,537,133	209,043	- 33,187	82	-13
Mid-floor	1,920,754	76,869	- 82,324	40	-43
Interior walls	4,444,081	147,097	- 98,208	33	-22
Windows	737,273	64,143	- 14,156	87	-19
Totals	**15,687,199**	**934,003**	**- 430,261**	**60**	**-27**

Comparison of Table 11 and Table 12 shows very similar trends between 2020 and 2016 with little difference in carbon intensity at the element level and also at the house level. Therefore, it is reasonable to conclude that there has been no discernible change in the embodied carbon of new stand-alone houses in these 2 years.

Notable points

- There have been no significant changes in resource efficiency since 2016.
- Houses in Auckland and Christchurch could improve resource efficiency by ~10–20% by matching Hamilton.
- House sizes could potentially be made smaller as the average house still has more bedrooms than the average number of occupants in a house.
- This is no discernible change in embodied carbon of stand-alone houses between 2016 and 2020 nor the elements of which they comprise.

5.6 Household water saving devices and consumption

Background

Water management is a key concern for many territorial authorities, with news articles raising concerns about shortages in major cities[18] and the increasing amount of water used by New Zealanders and lost from leaks.[19] The National Performance Review of Water Utilities (NPR)[20] was once again used to capture the use of household water saving devices and consumption via the average daily consumption residential water consumption (per capita). This survey enables global performance indicator comparisons of select data. For more background information, see section 5.5 and Appendix D of the Y2016 report.

Findings

Figure 7 shows daily water consumption of many major urban areas for Y2012–Y2020. The limited number of councils included in the table is due to the newness of the data collection. Note that Auckland and Christchurch councils didn't collect data in 2012.

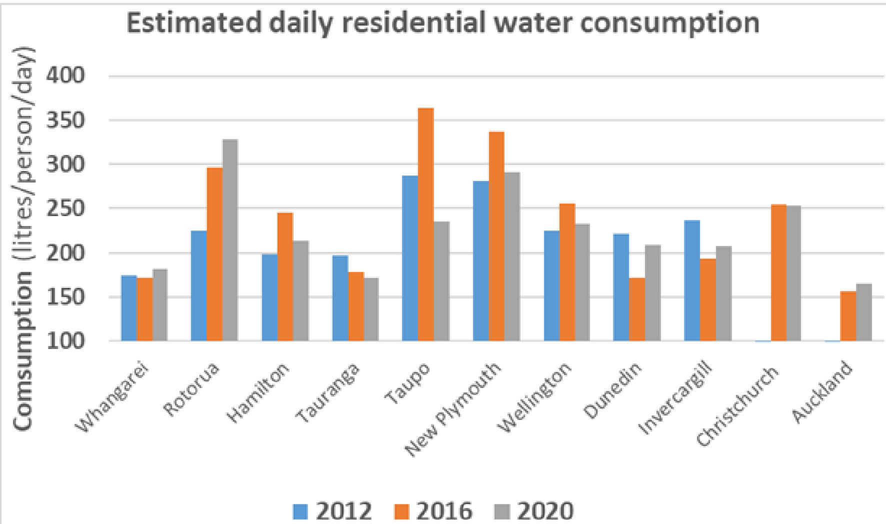

Figure 7. Estimated daily residential water consumption for New Zealand cities.

[18] https://www.wgtn.ac.nz/news/2021/01/policy-options-as-nz-faces-water-shortages
[19] https://www.newsroom.co.nz/hold-4-monday-our-water-problem-in-15-worrying-charts
[20] www.waternz.org.nz/NationalPerformanceReview

It should be noted that the NPR data includes all dwelling types rather than just those detached and new. It is assumed that (until counter evidence is provided) there is no distinction in volumetric water usage between existing and new housing stock.

BRANZ recently completed a study that collected new residential water use data from around the country. It commented on the shortcomings surrounding the use of averages when assessing residential water usage:

> This has sometimes been erroneously equated to 'typical' usage. The average is overinfluenced by high water users and gives a value that is higher than typical (median) usage. The median … will be less influenced by the high values. The median will more accurately represent typical values. The typical value of the winter daily water use per person … is roughly 25% lower than the average value. (Pollard, 2022, p. 17)

The study suggests that advice to homeowners should refer to the median water usage as a rule. Until more intensive national-based water studies are conducted where median figures are determined, this BRANZ study metric is limited to reporting averages.

Notable point

- In terms of the estimated daily water consumption, Hamilton, Taupō and New Plymouth all reversed their 2016 increases, while Rotorua's increase appears to have continued. Conversely, Dunedin's 2016 decrease also appears to have been reversed.

5.7 Comfortable indoor temperatures in a key occupancy zone

Background

The methodological approach and reasons for choosing this indicator remain unchanged from the Y2012 report. Some 70+ randomly selected building consents from Auckland, Hamilton and Christchurch were initially computer simulated in free-running mode to better understand the level of occupant comfort achieved through passive solar means only. The idea was to determine whether there were any performance changes from previous years.

The proxy for whole-house thermal comfort used was the number of daytime hours that the main living room zone achieves thermal comfort while operating passively, as before. The comfort temperature band equated to between 18°C and 25°C for the daytime hours of 7am–11pm year round.

Findings

Figure 8 shows the amount of time living room temperatures are comfortable between 7am–11pm for the randomly selected 2020 homes in the three regions. As we would expect, without heating, Christchurch homes are significantly colder and less comfortable than those in the other regions. As in previous years, we also observe significant variation between the different houses, highlighting the potential for good design to improve comfort.

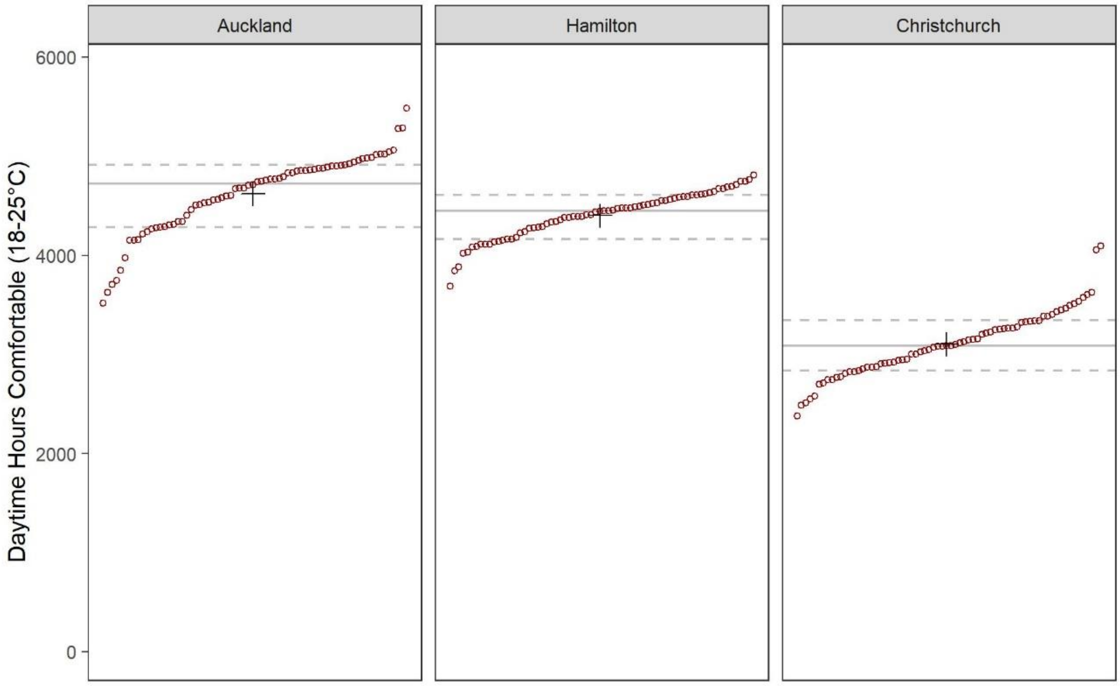

Figure 8. Daytime comfort hours in the living area for Auckland, Hamilton and Christchurch homes.

Tables 13–15 extract key statistics alongside the NOW Home® data and show that Y2020 results are almost unchanged from the previous years, accounting for additional uncertainty due to the change in dynamic modelling tools. Hamilton does see a small rise reflecting the models' apparent comfort performance improvement – however, this should be treated with caution. The average new house is still significantly less comfortable than the NOW Home®.

Note that, for Y2016, only the Christchurch region housing stock was sampled and assessed so there is no passive comfort data for the Auckland and Hamilton houses.

Table 13. Daytime living space comfort temperatures via passive solar means – Auckland.

Year	NOW Home®		mean		50th percentile		80th percentile	
	hrs/yr	% of daytime	hrs/yr	% of daytime	hrs/yr	% of daytime	hrs/yr	% of daytime
Y2012	5,652	97%	4,877	84%	4,921	84%	5,079	87%
Y2016	-	-	-	-	-	-	-	-
Y2020	5,449	93%	4,623	79%	4,726	81%	4,914	84%

Table 14. Daytime living space comfort temperatures via passive solar means – Hamilton.

Year	NOW Home®		mean		50th percentile		80th percentile	
	hrs/yr	% of daytime	hrs/yr	% of daytime	hrs/yr	% of daytime	hrs/yr	% of daytime
Y2012	5,299	91%	4,099	70%	4,142	71%	4,332	74%
Y2016	-	-	-	-	-	-	-	-
Y2020	5,204	89%	4,401	75%	4,447	76%	4,608	79%

Table 15. Daytime living space comfort temperatures via passive solar means – Christchurch.

Year	NOW Home®		mean		50th percentile		80th percentile	
	hrs/yr	% of daytime	hrs/yr	% of daytime	hrs/yr	% of daytime	hrs/yr	% of daytime
Y2012	4,419	76%	3,248	56%	3,296	56%	3,422	59%
Y2016	4,419	76%	3,272	56%	3,229	55%	3,436	59%
Y2020	4,248	73%	3,106	53%	3,088	53%	3,347	57%

Notable points

- Once again, there is a substantial difference between the best-performing and the worst-performing houses in free-running mode.
- In terms of daytime (7am–11pm) comfort, there has been no significant improvement in the randomly selected houses consented in Y2020 compared to those selected in previous years.
- There is a significant difference between the thermal competence of the randomly selected stand-alone houses consented in Y2020 and the NOW Home®. This is even true in Christchurch, despite the NOW Home® being designed for a considerably warmer climate.

5.8 Healthy indoor temperatures in a key occupancy zone

Background

This section's focus is on the indoor temperature extremes achieved while the dwelling is in free-running mode. It complements the analysis carried out in section 5.7, which examines performance during active conditioning. This section provides a good performance indicator of a dwelling's passive solar capability where indoor thermal comfort is dictated by its construction, internal zoning and orientation. In effect, it's a good indicator of a dwelling's overall thermal design competence.

The approach taken and assessment replicate those carried out in previous benchmarking reports except for the thermal simulation program used (now EnergyPlus). The living room was used as a proxy for the thermal performance of the rest of the house. As before, the NOW Home® is used as a comparative basis. More methodological detail can be found in section 5.7 of the Y2012 report and Appendix A of this report.

Findings

Figure 9 displays the degree to which the main living room temperatures are uncomfortably hot (temperatures greater than 25°C) for the 210 randomly selected 2020 consented new-builds. The scope for differences in performance here is particularly large, spanning over an order of magnitude. We may also observe that, even in Auckland, there are houses that manage to have minimal overheating. Climate is not an excuse.

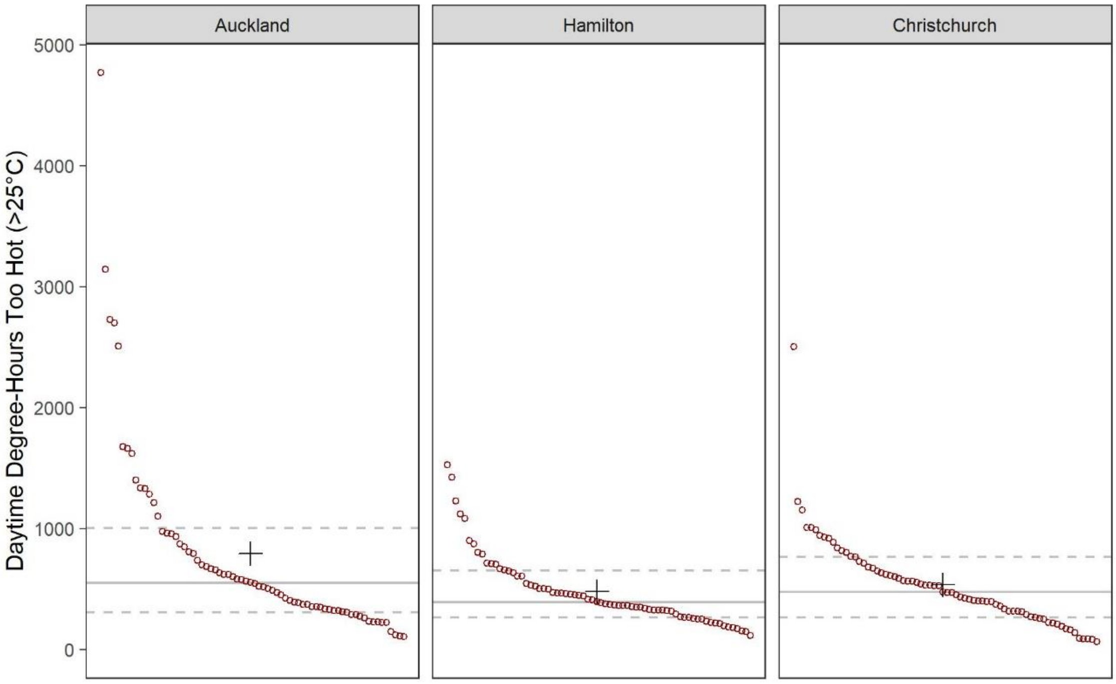

Figure 9. Overheating severity in main living room for the 2020 houses.

Tables 16–19 extract a key comparative statistic from the NOW Home® to benchmark the randomly selected homes against. Note that the current EnergyPlus derived models (demarcated in italics) tend to report more overheating than previously due to not operating ventilation as aggressively as AccuRateNZ does. This appears to have had a particularly noticeable effect on the results of the NOW Home®, and this should serve as a reminder of the inherent complexity of simulation.[21]

Table 16. Key overheating statistics (degree-hours/yr) – Auckland.

Year	NOW Home®	Mean	50th percentile	80th percentile
2012	32	161	122	250
2016	32	-	-	-
2020	*271*	*792*	*551*	*1,002*

Table 17. Key overheating statistics (degree-hours/yr) – Hamilton.

Year	NOW Home®	Mean	50th percentile	80th percentile
2012	105	236	212	316
2016	105	-	-	-
2020	*255*	*479*	*392*	*652*

Table 18. Key overheating statistics (degree-hours/yr) – Christchurch.

Year	NOW Home®	Mean	50th percentile	80th percentile
2012	151	433	417	496
2016	151	435	412	534
2020	*361*	*536*	*473*	*765*

[21] The estimates for the NOW Home® change as a result of the change in simulation tool.

Compared to the NOW Home®, the random homes have significantly higher levels of overheating, particularly in Auckland. This may be explained, in part at least, by the tendency towards two-storey houses there, which have less mass on the upper floors and so have a greater tendency towards overheating. However, it is also a reflection of the NOW Home's® good design.

Figure 10 shows the number of days per year the main living room temperatures fall below 12°C when not using artificial heating/cooling for the randomly selected Y2020 stand-alone new-builds.

As can be seen, this is relatively easy to achieve in Auckland, where the median house does manage to achieve it, but is considerably more problematic in Christchurch. There, only one house in the sample manages to come close to the NOW Home® at 34 days in the year.

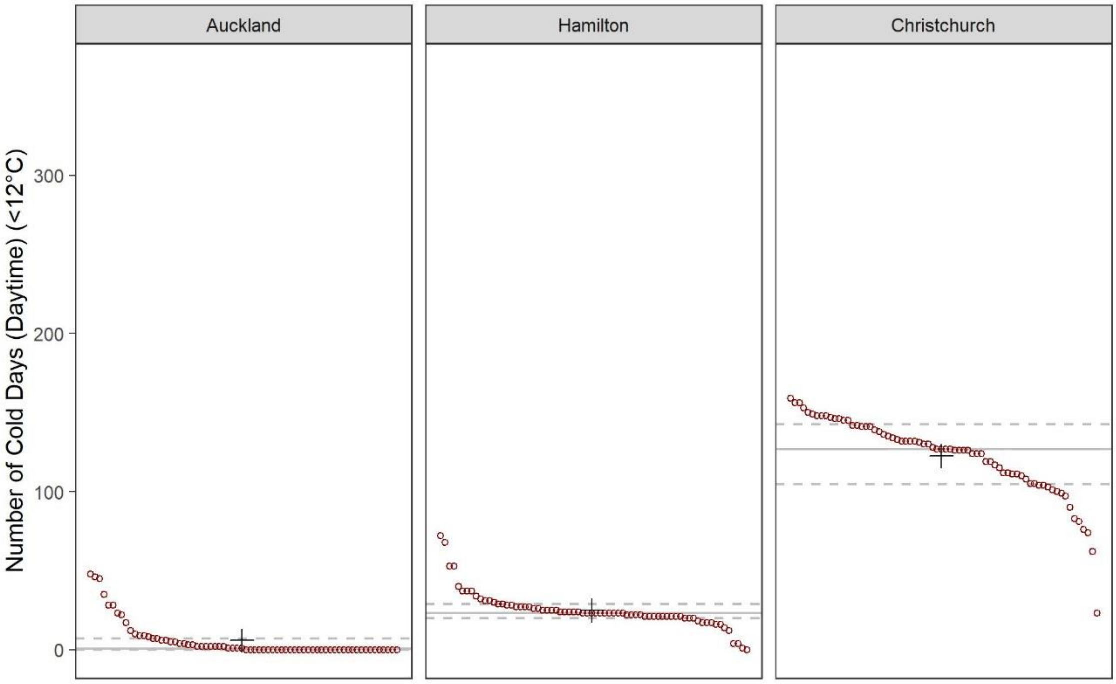

Figure 10. Days that temperatures in the main living space fall below 12°C.

Tables 19–21 extract a key comparative statistic from the NOW Home® to benchmark the randomly selected homes against.

Table 19. Daytime living space critically cold in Auckland houses.

Year	# days outside temperature < 12°C (days/year)	NOW Home® # days mean indoor temperature <12°C (days/year)	Randomly selected houses (n=~70)		
			# days mean indoor temperature <12°C (days/yr)	# days indoor temperature <12°C @ 50th and 80th percentile (days/year)	
2012	118	0	9	2	15
2016			-	-	-
2020			6	1	7

Table 20. Daytime living space critically cold in Hamilton houses.

Year	# days outside temperature falls below 12°C (days/year)	NOW Home® # days mean indoor temperature <12°C (days/year)	Randomly selected houses (n=~70)		
			# days mean indoor temperature <12°C (days/yr)	# days indoor temperature <12°C @ 50^{th} and 80^{th} percentile (days/year)	
2012			50	51	57
2016	215	0	-	-	-
2020			25	23	29

Table 21. Daytime living space critically cold in Christchurch houses.

Year	# days outside temperature falls below 12°C (days/year)	NOW Home® # days mean indoor temperature <12°C (days/year)	Randomly selected houses (n=~70)		
			# days mean indoor temperature <12°C (days/yr)	# days indoor temperature <12°C @ 50^{th} and 80^{th} percentile (days/year)	
2012		17*	125	126	137
2016	258		116	116	140
2020		28	123	127	143

* As estimated by the previous AccuRateNZ model.

Notable points

- There is a significant difference between the thermal competence of the randomly selected stand-alone houses and the NOW Home®. The thermal performance of the NOW Home® is considerably better in terms of limiting unhealthily low temperatures when using the main living space as a proxy for the whole house in colder regions and considerably better at managing overheating. This highlights the value of good design and the use of elements such as exposed thermal mass.
- That being said, avoiding unhealthily low temperatures in the main living space in the day is not particularly hard in Auckland given how clement the climate is, and most new houses appear to generally manage that well.
- There are a number of houses that stand out as having particularly high overheating risk. This highlights the need for overheating to be better handled in design and regulation in order to avoid houses falling below minimum acceptable standards.

5.9 Proximity to key amenities and public transportation

Background

This section remains unchanged from previous reports, but to summarise, the WalkScore®[22] is an internationally recognised metric to indicate the walkability to nearby amenities and services. It operates on a 1–100 scale, where the higher the figure, the more walkable a location is. A WalkScore® of 50 or more translates to 'somewhat walkable' – where a reasonable number of errands can be accomplished on foot. A house location that achieves lower than 50 translates as a car-dependent area

[22] www.walkscore.com

where errands require a car or reliance on public transport. Similarly, a Transit Score® of 50 or more equates to an area with a reasonable public transportation service.

Findings

Table 22 extracts some key walkability statistics by location, targeting the 50th and 80th percentiles for the three cities. As can be seen, statistics are largely unchanged from previous years, with the only significant shifts being the 80th percentile brackets for Hamilton and Christchurch. Walkability in these regions tends to be highly skewed, with most houses having very low walkability. Shifts in the upper percentiles then represent a subset of new houses being built in more walkable areas. Many of the houses with low walkability are in new developments. Ensuring that these new neighbourhoods have adequate local amenities as they are developed will be important if car dependency is to be avoided, and these scores may be taken as a warning.

Table 22. Walkability statistics of homes in three locations.

Walk Score® rating	Median – 50th percentile			80th percentile		
Year	**2012**	**2016**	**2020**	**2012**	**2016**	**2020**
Auckland	54	57	58	66	69	69
Hamilton	22	13	18	38	32	49
Christchurch	27	26	24	36	50	35

A Transit Score® was acquired for both Auckland and Hamilton houses in 2021. However, they are no longer available. In terms of what was observed, the public transport utility remains almost unchanged for Auckland (Table 23).

Table 23. Transit Score® statistics of homes in three locations.

Transit Score® rating	Median – 50th percentile			80th percentile		
YEARS	**2012**	**2016**	**2020**	**2012**	**2016**	**2020**
Auckland	48	48	46	55	54	52
Hamilton	NA	NA	41	NA	NA	63
Christchurch	NA	NA	NA	NA	NA	NA

Notable points

- The drop in median walkability rating noted in 2016 for Hamilton has rebounded slightly. There are a number of new houses that appear to be being built with much better walkability now, but the typical house's score is still low, which may reflect urban sprawl.
- Continuing low walkability in new developments in Christchurch and Hamilton is concerning.
- A Transit Score® is currently not available for any New Zealand city (as at October 2022), and this metric may have to be discontinued.

5.10 Inclusiveness of universal design features

Background

Universal design (UD) is the design approach that recognises that buildings should be accessible, safe and simply usable for as long as possible during their lifetime (Jaques, 2013). For more background information to this metric, the Y2012 report section 5.9 should be referred to.

Findings

Unfortunately, this metric/indicator has been put on hold, due the change in how Lifemark® measures its reach in terms of certification. A suitable replacement metric has not been found at the time of writing. Further investigatory work for the next update (the Y2024 update) will be made to reintroduce this important metric/indicator.

5.11 Climate change implications on indoor thermal comfort

Background

In previous reports, the predicted climate change implications based on NIWA-predicted climates of 2030 and 2080 (Mullan et al., 2006) were applied to a subgroup of the Auckland, Hamilton and Christchurch dwellings to assess the impact on indoor thermal comfort. The methodology has been detailed in the Y2012 report. It was decided this year to redo the study only if the passive thermal performance of the Y2020 randomly selected dwellings differed noticeably from previous years.

Findings

As the NIWA climate change models applied in the Y2012 report remain relevant now (B. Mullan, Principal Scientist – Climate, NIWA, personal communication, June 2017) and the thermal performance of the house designs have not changed noticeably in the intervening years, it was decided not to rerun the Y2012 thermal simulations.

Notable points

- The Y2012 report's corresponding section 5.10 findings remain valid and therefore unchanged for this Y2020 report.
- Work is under way between NIWA, Kāinga Ora, BRANZ and other interested groups to provide a considerably more nuanced set of climate change altered hourly weather files for public use. These will incorporate seasonal weather extremes, a wider range of future years to choose from (not just a choice of two), an updated and therefore more relevant 'current climate' and other variables. It is likely that these updated files will be available for the next update of this benchmarking study for Y2024.

5.12 Housing affordability and cost of key enviro-features

Background

The Demographia International Housing Affordability Survey rates housing affordability based on the median house price divided by median household income on a biannual basis. Areas are classed as 'severely unaffordable' when the ratio is more than five times the income. Overall, New Zealand housing in 2021[23] was rated as 'severely unaffordable', with a median multiple of 11.2. Auckland was rated as the seventh least affordable city among the 92 major international housing markets.[24]

The revised approach to housing economic metrics introduced in Y2016 was carried through to this report. Thus, the two housing affordability indicators are the new-build

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[23] No figures were available for 2020.
[24] http://demographia.com/dhi.pdf

index and the the relative cost of home ownership index. A BRANZ economist provided data for both the new-build index and the relative cost of ownership index, leveraging the Y2016 work.

The BRANZ new-build index captures movements in the purchase cost of new housing. It does this by tracking the cost to deliver a standard 200 m², single-storey house on a 500 m² section based on the average value of a new building consent (via Stats NZ) and median land sale price (via REINZ). Specifically, it shows how housing costs change relative to overall prices. The index base year is set to June 2012 = 1,000.

Table 24 shows the period 2012–2020 featured strong growth in the housing market, with worsening affordability for new housing. The cost of new housing has grown 54.7% over these 8 years, as measured by the cost of new-build index.

Table 24. BRANZ new-build index.

Year	New-build index (as a nation)
2012	1,000
2016	1,222
2020	1,547

The relative cost of ownership index expresses mortgage servicing costs relative to household incomes. This is based on the median sale price for existing housing (via CoreLogic), median household income (via Stats NZ) and average floating mortgage interest rates (via RBNZ). It is assumed that buyers purchase with a 20% deposit (i.e. an 80% loan-to-value ratio) and borrow over a 25-year term as was common practice and has been kept for consistency. The index base year is set to June 2012 = 1,000. Regarding Table 25, the most significant issue dictating the relative cost of ownership in the last period was the role of low interest rates – even with growing house prices.

Table 25. BRANZ whole-house relative cost of ownership index,

Year	Relative cost of ownership index (by city)		
	Auckland	Hamilton	Christchurch
2012	1,000	1,000	1,000
2016	1,319	1,122	978
2020	1,137	1,182	857

Notable points

- For the period 2012–2020, in terms of New Zealand's housing affordability, the cost of new housing has grown 54.7% based on a single-storey reference house of 200 m² on a 500 m² section.
- The cost of homeownership (servicing a mortgage) has increased in Hamilton, while it has decreased in Auckland and Christchurch (~14% lower in Christchurch than in 2012).

5.13 Demand for key sustainability features and services

Background

This section overviews the Y2020 demand for key features and services that support new, more sustainable (detached) houses. The term 'sustainable' is used here in the context of 'lower environmentally impacting'.

The list of what features are deemed 'good representatives of a key sustainable purchases' with respect to newly built houses is under review. It still remains difficult without comprehensive New Zealand-specific LCA-based data and tools to robustly appraise the environmental impacts and repercussions of various key features/services associated with new housing.

A good example of this is the well-established micro-renewable technology of grid-tied photovoltaics. Gaining recent, robust carbon emissions data associated with their production process is challenging. Given their highly durable nature, with a warranty typically of 25 years,[25] assumptions need to be made of what the grid-emissions carbon would be substituting over that period. Then there is the consideration of what the likely implications would be on micro-grid en masse, potentially impeding the development of even lower-carbon, large-scale PV farms, as has been discussed (Concept Consulting Group, 2016a, 2016b, 2017; Schwertfeger & Miller, 2015). These are just some of the difficulties of ensuring that a feature does have an enduring lower-carbon benefit to society and the built environment. That being said, it may be acknowledged that the incidence of such devices may still serve as an indicator of interest in sustainability features and may be of interest to readers. Hence, they are still reported here.

It was decided in the Y2016 report that residential-based solar (thermal) water heaters were a reasonable example of a key sustainable purchase in new housing.

It is also recognised that the feature and services contained in this subsection are not comprehensive but more of a national snapshot in time. For more detail, reference should be made to section 5.12 of the Y2016 report.

Findings

Features specified and desired

Table 26 shows the results from assessment of the randomly selected building consents over the years for the three cities in question. It shows a very low uptake of a feature that is often associated with sustainable houses – solar hot water systems. While the number may appear to decline slightly in 2020, the difference in proportions between 2016 and 2020 is not statistically significant. The numbers of solar water heating systems in consents is simply very low (peaking in the samples here at two houses in the Christchurch sample in 2016). Given this, not finding any within a specific year's sample should not be surprising.

Table 26. Solar (thermal) water heaters specified in building consent documentation.

Location	Solar thermal water heating systems specified		
	2012	2016	2020
Auckland (n=~70)	1.6%	1.3%	0%
Hamilton (n=~70)	0%	0%	0%
Christchurch (n=~70)	1.5%	2.2%	0%

Photovoltaic (PV) systems similarly have continued to see very low uptake and this is unchanged, with only a single example in the regions' samples here (Table 27).

[25] Of 80% of their initial rated capacity (www.renewableenergyhub.co.uk).

Table 27. Solar electric (PV) panels specified in building consent documentation.

Location	Solar electric (PV) panels specified		
	2012	2016	2020
Auckland (n=~70)	0.0%	2.6%	1.4%
Hamilton (n=~70)	0.0%	0.0%	1.4%
Christchurch (n=~70)	0.0%	2.2%	1.4%

It should be noted that this data is derived purely from building consent documentation and so there may be an underestimation of actual units built in new houses where owners have installed them post-construction. BRANZ surveys of new house owners in 2016 found 5% of them reporting PV panels and 7% reporting solar hot water – significantly higher than observed in consent data (Curtis, 2017).

The number of new houses with rainwater tanks in Auckland has been steadily increasing over the decade (Table 28). Rainwater collection in Hamilton and Christchurch appear to be staying at relatively low levels.

Table 28. Percentage of rainwater tanks specified in new houses in three locations.

Location	Rainwater collection tanks specified		
	2012	2016	2020
Auckland (n=~70)	3%	23%	35%
Hamilton (n=~70)	0%	8%	3%
Christchurch (n=~70)	4%	3%	3%

Sustainability desires

This section investigates new homeowners favouring environmental features via a BRANZ initiative that explores new house owners' satisfaction (Curtis, 2017; Clarke & Lockyer, 2022). The survey excludes spec-build type houses.

In Table 29, note that for Y2020, only a national figure is provided due to the limited number of respondents overall in the three cities and in the three cities of interest. This national figure is based on only n=443, coupled with a bias towards regional centres/small towns. Thus, this figure is indicative. As stated in the Y2016 report:

> It is highly likely that most respondents will have interpreted 'sustainable' as equating to 'low environmentally impacting', rather than its other facets of 'social' and 'financial' … Like any self-reporting, the results need to be viewed with caution and be seen as indicative. (Jaques, 2019, pp. 35–36)

Table 29. Respondents' reasons for building a new house rather than buying.

Location	Wanted to build for sustainability reasons (%)		
	2012	2016	2020
Auckland	9.9	5.6	14%
Hamilton	0	3.3	
Christchurch	13.5	1.3	

It is also difficult to interpret because the question is specifically regarding the reasons why people choose to build a new house rather than buying one. It indicates that people going to build new houses are generally not doing so with sustainability goals high in their minds though this does not necessarily mean that they would not consider sustainability important if asked. We could potentially interpret this as indicating that clients are generally unlikely to be the main drivers for sustainable design though this is again not the same as saying they would not be receptive if designers encouraged it. The degree to which this implies barriers to the uptake of sustainable design is thus difficult to ascertain.

Services – whole-house environmental awards

Table 30 shows the cumulative total environmental-related awards to homes by various institutes in New Zealand, including:

- Homestar dwellings, certified by the NZGBC
- Passive House dwellings, certified by PHINZ
- Living Building Challenge dwellings, certified by the International Living Future Institute
- Net Zero Energy Buildings, certified by the International Living Future Institute.

The Y2020 figures in Table 30 were provided by the respective organisation's representative.

Table 30. Whole-house certified numbers by various institutes.

Award scheme	Totals for year end – for stand-alone dwellings only		
	2012	2016	2020
NZGBC Homestar™	18	134	188
PHINZ Passive House	1	13	37
Living Building Challenge	0	1	2
Net Zero Energy Building	0	1	1
Total (per capita)	19 (1/232,142)	148 (1/31,733)	228 (1/22,324)

Although there are other environmental-related house awards available on a nationwide basis, under scrutiny, it was felt that there were issues with an aspect of their independence, transparency, comprehensiveness and/or process control. Thus, they were not considered appropriate for this BRANZ study.

Notable points

- The uptake of solar photovoltaics (from building consent data) is consistently very low as a proportion of all new-builds, even though their price has dropped considerably since 2012. However, it is suspected that there is an under-reporting of this, as BRANZ surveys of new house owners have found the uptake much higher in previous years.
- The number of new houses with rainwater tanks in Auckland has been steadily increasing over the decade. Rainwater collection in Hamilton and Christchurch appears to be staying at relatively low levels.
- In terms of the number of homeowners favouring environmental features, it appears that people going to build new houses are generally not doing so with sustainability goals high in their minds. This indicative result excludes spec-build homes.
- In terms of demand for sustainable services, formal whole-house rating tools in New Zealand have continued to increase. However, in terms of numbers of all new-builds constructed for New Zealand, the numbers are still negligible.

5.14 Supply of some key sustainability-related services

Background

The supply of sustainability-related building service providers plays a critical role in assisting the development of higher-performing and cost-effective new homes. The approach used for this report is identical to that used for the Y2016 report.

The nationwide service providers that are easily accessible to the public are grouped into three subcategories:

- Environmental-based whole-of-home industry practitioners.
- Trade-specific environmental building support.
- 'Green mortgage' assistance offerings.

The per capita figures were based on the New Zealand estimated resident population from Stats NZ (mean year ended/total all ages). The end of year figures are:

- Y2012 = 4,410,700
- Y2016 = 4,696,500
- Y2020 = 5,089,800.

Findings

Industry practitioners

Homestar – New Zealand's environmental certification scheme for all housing typologies run by NZGBC – has several engagement methods to accredit industry practitioners. The two methods available in 2020 for Homestar are:

- Homestar Practitioners – who provide advice and recommendations
- Homestar Assessors – who are able to provide homeowners with full Certified Homestar ratings.

The new 2020 numbers in each category (Dani Wijekoon, NZGBC, personal communication, July 2021) are shown in Table 31.

Table 31. Homestar industry professionals.

NZGBC's Homestar	Number of industry practitioners		
	2012	2016	2020
Practitioners	3	246	215
Assessors	6	174	179
Total (per capita)	9 (1/490,078)	420 (1/11,182)	394 (1/12,918)

New for 2021 for NZGBC professionals is Homestar Designer™. They are trained to design and advise on the technical aspects of Homestar and the principles of sustainable design so that they can apply this knowledge when working on a Homestar project (NZGBC, 2023).

Passive House NZ provides a whole-of-house energy and thermal efficiency building performance standard and certification system and was established in 1996 in Germany as PassivHaus. The updated service-related statistics (Amy Tankard, PHINZ CEO, personal communication, 4 May 2021) are provided in Table 32.

Table 32. PHINZ-accredited practitioners.

PHINZ-accredited practitioners	Number of industry practitioners		
	2012	2016	2020
Designers/consultants	12	22	41
Tradespersons		24	51
Total (per capita)	12 (1/367,558)	46 (1/102,096)	92 (1/55,324)

Eco Design Advisors (EDAs) provide free, unbiased and independent advice on a wide range of environmental issues on residential buildings. They are all council-based, and numbered eight full-time equivalents (FTEs) in 2020. The EDAs are one of only two free, independent, advisor groups formally operating nationwide with an enviro-building focus. The other is the Home Performance Advisors (HPAs), an initiative of the Community Energy Network, Toimata (previously Enviroschools) and Beacon Pathway. They provide a complementary advisory service nationally. The number of certified HPAs (including HPA trainers) at the end of 2020 equalled 146 (Vicki Cowan, Beacon Pathway, personal communication, February 2021). Combined numbers are shown in Table 33.

Table 33. Combined HPA accredited and EDA practitioners.

HPAs and EDAs combined	Number of industry practitioners		
	2012	2016	2020
Total (per capita)	7 (1/630,100)	78 (1/60,200)	154 (1/33,051)

Universal design (UD) – the design philosophy that provides environments that are accessible to all people of all abilities at any stage of life – is championed in New Zealand by Lifemark®.[26] Lifemark® Design Standards formalise the assessment process and rate the comprehensiveness of the design into star bands/levels. Lifemark® runs an accredited partnership programme for building professionals, providing various supporting attributes such as training options and a plan review service. Accredited practitioner statistics for Lifemark® are shown in Table 34.

Table 34. Lifemark® accredited practitioners.

Lifemark®	Number of industry practitioners		
	2012	2016	2020
Builders	4	42	200
Designers	9	31	
Total (per capita)	13 (1/339,284)	53 (1/88,611)	200 (1/25,449)

Trade specific

EcoSmart Electricians (NZ), which started in 2009, promotes electricians who are upskilled in efficiency and has a mandate to leverage opportunities to save energy. It is an initiative of the Electrical Contractors Association of New Zealand and the Electricity Commission and was operating in 2016.[27] In late 2020, there were 58 electrician businesses registered providing this service. No such initiative is offered by the New Zealand plumbers, gasfitters and drainlayers trades.

[26] www.lifemark.co.nz
[27] In the Y2012 report, it was incorrectly stated that they were defunct.

Green mortgages and sales

Kiwibank was still offering its Sustainable Energy Loan programme in 2020, an initiative commenced in late 2012. It assists consumers to fund micro-renewables (solar power, wind energy, small-scale hydro or even geothermal-based) in their homes, providing certain criteria are met. The Kiwibank programme contributes up to $2,000 towards the cost of the system over 4 years.

Following its introduction, Kiwibank saw strong interest in the loan with a 37% increase in the number of Sustainable Energy Loans taken in the first 4 years.[28] However, the 2020 response from Kiwibank was more circumspect:

> We've had steady interest in our sustainable energy loans over the past few years, although there was a slight drop last year, which we believe was driven by the uncertain environment created by COVID. (Ben Bracey, Kiwibank Senior Product Manager – Home Loans/Personal Loans, personal communication, 6 July 2021)

In May 2021 **ASB** partnered with the New Zealand Green Building Council to encourage sustainable building practices. ASB is now giving customers who finance their new-build with a Back My Build variable rate home loan a cash contribution of $2,000[29] if they can evidence their intent to build a 6 Homestar rated home (or higher). To be eligible for the cash contribution, a minimum home loan of $250,000 is required.

Westpac started offering interest free loans in April 2020, but it was targeted to those already owning a home and landlords. Called the Westpac Warm Up loan, it is available to people living in their own homes and to landlords. It aids the purchase of any mix of insulation, heat pumps, double glazing, ventilation, wood burners and solar power systems.

Trade Me Property

New Zealand's most visited online real estate website still provided no explicit, publicly accessible search options for Homestar™-certified homes in 2020, unchanged from previous years. A spot check was carried out on 16 February 2022 as to the number of houses listed nationally that had the term 'Homestar' somewhere in their descriptions. There were 33 dwellings in total returned – but of those, eight were attached homes. Of the remaining homes, a third had actually achieved a Homestar 6 or better rating, while the rest were 'potentials', using vague language such as:

- "built to a high standard (HomeStar 6 equivalent)"
- "designed to meet 6 Homestar Standard (earthworks completed only)"
- "can provide HOMESTAR RATING"
- "built to NZ Green Building Council's Homestar standards"
- "with Homestar 6 rating if this is something you are interested in"
- "option to add Homestar 6 upgrade".

Notable points

- There has been a continuing growth in residential-building sustainability-related practitioners providing tailored advice (HPAs, EDAs, Homestar™, Passive House and

[28] Year 2013 is used as the base year since the scheme only started part way through 2012.
[29] This was increased later to $3,000.

Lifemark®). The number of practitioners has roughly doubled in most schemes since 2016, with the exception of Homestar™.
- There has also been growth in programmes from banks aiming at encouraging and supporting sustainable building practices though it is unclear how much impact they have had.
- Given that some 22,200 stand-alone houses were consented in 2020 in New Zealand, the supply of comprehensive sustainability-related services is still very small.

5.15 Supportive government policy and regulation

Some notable New Zealand Government initiatives occurred in the year 2020 that have important implications for new residential design, specification, construction or operation. This reflects a sea change in the number and significance of environmental-building-related initiatives.

Cabinet set the first three emissions budgets in May 2022. The first, from 2022 through to 2025, has been set at 290 Mt/CO_2e/yr or an average of 72.4 Mt CO_2e/yr. The second emissions budget, from 2026 to 2030, has been set at 305 Mt CO_2e/yr, an average of 61 Mt CO_2e/yr.[30] The third emissions budget, from 2031 to 2035, has been set at 240 Mt/CO_2e/yr. In May 2022, Climate Change Minister James Shaw stated:

> [The] reason it's taken Aotearoa so long to get started on serious climate action is because for decades we've thought about it as a sunk cost, rather than as an investment in our collective future.

In New Zealand's first emissions reduction plan (Ministry for the Environment, 2022), Chapter 12 Building and construction has two objectives:

> **Objective 1:** Reduce embodied carbon of buildings. We can reduce the emissions created during the extraction, manufacture, operation and disposal of resources used in buildings …
>
> **Objective 2:** Reduce operational emissions. Operational emissions can be reduced by improving building design so that maintaining a comfortable indoor environment uses less energy and by using energy from low-emissions sources.

Key actions in the plan include to:

- reduce the embodied carbon of construction materials by supporting innovation and regulating to promote the use of low-emissions building design and materials
- accelerate the shift to low-emissions buildings by promoting good examples, providing incentives and supporting the use of low-emissions practices
- improve building energy efficiency by amending the Building Code and measuring energy performance to ensure buildings are designed and retrofitted to use less energy for heating and cooling.

MBIE provided this list of initiatives for the calendar year 2020:

- MBIE commissioned a technical study to support the policy review of increasing residential insulation requirements of Building Code clause H1 *Energy efficiency* Acceptable Solution H1/AS1 for housing and small buildings. The background

[30] Source: www.greens.org.nz/building_a_low_carbon_future. Note that the last two periods are set 'in principle' and so are yet to be confirmed.

report (Jaques, et al., 2020) was released to the public in May 2021 as part of the the proposed changes to make homes and buildings warmer, drier and heathier with less impact on the environment.

- The Building for Climate Change (BfCC) programme was developed. It looks at system-level changes to the building sector to meet New Zealand's goal of net-zero carbon emissions by 2050 to reduce carbon emissions while improving buildings' resilience. MBIE consulted on proposals to transform the operational efficiency of buildings and to reduce the embodied carbon of buildings as part of this programme. Two BfCC mitigation frameworks were proposed: whole-of-life embodied carbon emissions reduction (Ministry of Business, Innovation and Employment, 2020b), which sets mandatory reporting and measurement requirements for whole-of-life carbon emissions as related to residential buildings, and transforming operational efficiency (Ministry of Business, Innovation and Employment, 2020a), which sets required levels of efficiency for energy use and water use and defines minimum indoor environmental quality measures for buildings.
- Weathertightness and thermal performance of windows – amendments to E2/AS1 and E2/VM1 including updating citation to NZS 4211 *Specification for performance of windows*.

Kāinga Ora has been delivering a significant number of important initiatives applicable to new homes. Note that some of these initiatives include townhouses as a typology:

- Adopted the 6 Homestar standard in June 2020 on all new-builds requiring an 80% waste diversion target and systematic recording of the actual construction waste produced on our new-builds.
- Provided responses to a number of proposed changes to New Zealand's building standards and regulatory environment such as clause H1 *Energy efficiency*, MBIE's Building for Climate Change programme and Homestar version 5.
- Piloted several projects aligned with a series of progressive low-carbon targets and explored a life cycle carbon portfolio model to assess pipeline carbon impacts. This allows Kāinga Ora to comparatively evaluate the performance of a range of different construction systems in terms of time, cost, quality, health and safety, and carbon.
- Delivered on broader social outcomes through refining and evolving Kāinga Ora's construction partnering agreement programme as well as working more closely to help grow regional Māori and Pasifika businesses and including apprentice development in projects.

EECA provided information on these initiatives that are applicable to new homes in the calendar year 2020:

- Equipment Energy Efficiency (E3) programme. This trans-Tasman programme regulates energy efficiency standards and labelling for products and appliances. It significantly improves the electricity efficiency of products and appliances available for sale in New Zealand. Minimum energy performance standards (MEPS) products must meet minimum energy efficiency standards to be sold in New Zealand. Mandatory energy performance labelling (MEPL) helps consumers compare energy efficiency and running costs of different products when deciding what to buy.
- Support for Gen Less, the home of inspiring ideas to reduce energy-related greenhouse gas emissions.

5.16 Other notable initiatives

This section describes other important initiatives but is not comprehensive.

Industry roadmaps

The New Zealand Institute of Architects Declare initiative was launched in late 2019. It has since garnered 28 founding signatories including all 10 of the living NZIA Gold Medallists (as of July 2021). Officially called Aotearoa NZ Architects Declare Climate & Biodiversity Emergency, it was inspired by UK counterparts the Royal Institute of British Architects (RIBA). It responds to climate breakdown and biodiversity loss, with signees committing to strengthen their work practices to create architecture that has a more positive environmental impact.

NZIA Declare list of commitments as at mid-2021:[31]

- Raise awareness of the climate and biodiversity emergencies and the urgent need for action amongst our clients and supply chains.
- Advocate for faster change in our industry towards regenerative design practices and a higher Governmental funding priority to support this.
- Establish climate and biodiversity mitigation principles as the key measure of our industry's success: demonstrated through awards, prizes and listings.
- Share knowledge and research to that end on an open source basis.
- Evaluate all new projects against the aspiration to contribute positively to mitigating climate breakdown, and encourage our clients to adopt this approach.
- Upgrade existing buildings for extended use as a more carbon efficient alternative to demolition and new-build whenever there is a viable choice.
- Encourage life cycle costing, whole life carbon modelling and post occupancy evaluation as part of our basic scope of work, to reduce both embodied and operational resource use.
- Adopt more regenerative design principles in our studios, with the aim of designing architecture and urbanism that goes beyond the standard of net zero carbon in use.
- Collaborate with engineers, contractors and clients to further reduce construction waste.
- Accelerate the shift to low embodied carbon and non-toxic materials in all our work.
- Minimise wasteful use of resources in architecture and urban planning, both in quantum and in detail.

As New Zealand instigator Sian Taylor states in an online[32] thought piece about the RIBA initiative:

> These are lofty goals – but what actual change has it (or will it) drive(n) or inspire(d)? After all, it is voluntary and has no measurable goals, timeline or reporting requirement/verification attached – which makes it impossible to measure outcomes or progress? She then asks: "Similarly, Kiwis are also asking where we go from here. How do we move beyond declaring and into action?"

Taylor suggests four practical steps that New Zealand architects could enact today:

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[31] https://nz.architectsdeclare.com/
[32] https://architecturenow.co.nz/articles/beyond-declarations-sian-taylor

- Shifting to higher-performing windows.
- Using energy modelling to inform design decisions.
- Switching to non-toxic materials based on the Declare label.
- Utilising the BRANZ tool LCAQuick for assessing environmental impact.

Other commentators are equally critical of the Declare initiative, suggesting that it may be nothing more than virtue signalling. Fellow architect Chris Barton states:[33]

> "*Blame the journalist in me, but I can't help feeling a bit cynical about just how this fine rhetoric will translate into something a bit more … concrete. Which is, of course, the material that is now hugely problematic … building smaller, more efficient spaces is a desirable pathway for reducing the collective carbon footprint. But, for architects primarily serving wealthy clients wanting to realise their often obscenely large and unsustainable grand designs … it's easier said than done … [The NZGBC Zero Carbon Road Map] calls for other targets, including updates to the Building Code and the importance of getting the numbers right in disclosing buildings' energy bills. As a pathway to rapid decarbonisation of buildings and a way for Architects Declare pledges to become reality, proper measurement seems a pretty good place to start.*"

The recognition of the importance of quantitative measurement done well here is crucial and should be a key characteristic of all roadmaps concerned with buildings and the environment. The Construction Sector Accord's own initiative – the Construction Sector Environment Roadmap for Action[34] – fails on this account. This initiative is a joint government-industry commitment to create a high-performing construction sector. It sets out four construction sector priorities of:

- improving awareness
- scaling up the work
- demonstrating progress
- incentivising and aligning.

No targets or timelines are quantified, making the measurement of success (or failure) impossible.

Beacon Pathway

In 2021, Beacon finished its 2-year research into the issue of excessive framing in timber framed walls in New Zealand dwellings. It found that timber made up 34% of all areas, creating more thermal bridging than is usually assumed. Using that finding, the team investigated what regulations were driving the specification of so much timber, quantified the impact on the wall's thermal performance and explored possible wall solutions. Beacon's research reports and webinar are all available online for free.[35]

NZGBC

The NZGBC launched its latest revision of their environmental assessment tool Homestar (version 5) after extensive consultation in 2020. There are several key changes responding to the challenges of the impending climate emergency:

[33] https://architecturenow.co.nz/articles/editorial-chris-barton-on-declarations
[34] https://www.branz.co.nz/about/construction-sector-accord
[35] https://beaconpathway.co.nz/document-library/

- The incorporation of a user-friendly embodied carbon calculator to encourage and reward reduced carbon pollution in both operational and embodied emissions. Refrigerant impacts from heat pump technology are even included.
- A proprietary operational thermal/energy modelling calculator and overheating risk tool called ECCHO, which stands for Energy and Carbon Calculator for Homes, based on the Passive House PHPP tool.
- The expansion and reinforcement of mandatory minimums, which are key issues required for even the lowest (6 star) certification. Thus, all certified houses will require continuous extract ventilation, a maximum water consumption of 165 l/p/d and a maximum of 8 $kgCO_2/m^2$ for space and water heating and refrigerants and must not exceed 25°C for more than 7% of the year.

These are all marked (positive) shifts from previous Homestar versions, reflective of its growing confidence in the market.

Superhome Movement

A new guideline for new homes launched in November 2020 by the Superhome Movement, aims to banish cold, damp and mouldy homes by improving their design and construction. *The Healthy Home Design Guide*[36] was developed with the input of some 70 professionals around the country. It provides advice for multiple issues – everything from energy and water through to certifications and new technologies to achieve progressively higher-performing buildings. Importantly, each design aspect examined within the design guide has a stepped performance threshold, improving the design significantly from the Code Acceptable Solution or requirement. These are Base (Healthy Home), Better (Superhome) and Best (Superhome'. This separates this design guideline from a slew of others, as quantified limits provide certainty for the reader and clarity around targets. Available only as an online web resource, it is unknown what uptake it has had at the time of writing.

Notable points

- A number of the initiatives described above such as the emissions budge, were enacted post-2020. That being said, there has arguably been a sea change since 2016, with significant work aiming to push housing to be higher performance and lower carbon. Critically, this includes government legislation in the form of updates to the Building Code, work by Kāinga Ora to build large amounts of more sustainable housing and a government push to reduce carbon in buildings.
- Similarly, there has been a significant amount of work done by various organisations to provide better tools and guidance to support the design of better homes.
- A caution should be raised, however, that saying the right things about sustainability does not necessarily translate into action. Intentions need to be translated into buildings that can be demonstrated to be measurably more sustainable.

[36] http://healthyhomedesignguide.co.nz

6. Summary and recommendations

6.1 Summary and discussion

The following summarises the main results of the eight domains covering building performance, market forces and governance. It is recognised that it is too early for this longitudinal study to gather trends with only three data points (studies). Thus, for now, the results should be seen more as establishing a baseline from which to work from.

Compared to the eco-consciously designed NOW Home®, the randomly selected Y2020 consented homes, with very rare exceptions, (still) have:

- higher water heating-related CO_2 emissions (all three cities)
- considerably higher space heating and cooling-related CO_2 emissions (all three cities)
- lower whole-house resource efficiencies, by bedroom number, in Auckland and Christchurch
- more energy-intensive space heating and cooling needs via active means
- less daytime thermal comfort in the main living area provided via passive means
- more extreme temperatures in the main living area.

Thus, for each of the above environmental indicators, the randomly selected homes performance is (with very few exceptions) worse than the NOW Home®.

Compared to the previous findings, the Y2020 figures show that:

- performance has likely improved somewhat in Auckland due to the use of single glazing having declined.
- the vast majority of houses continue to be insulated to Building Code requirements, with few attempting to move significantly beyond.
- average house size has declined, which should reduce overall carbon emissions
- whole-house environmental certificates awarded have continued to increase on a per capita basis.
- industry practitioners involved in certification of Homestar and Passive House, Home Performance Advisors and Lifemark® practitioners have all increased, on a per capita basis.
- daily residential water consumption has tended to move back towards 2012 levels from increases and decreases in 2016 – consumption in Rotorua has continued to increase while Taupō has decreased.
- walkability has largely stayed consistent, with new developments in Hamilton and Christchurch continuing to have poor walkability.
- there has been no change in the availability of public transport in Auckland, and figures for public transport availability in Hamilton are now available.
- the delivery of a standard 200 m^2 single-storey house on a 500 m^2 section has continued to grow, increasing 55% in cost since 2012 (nationally).
- mortgage servicing relative to household incomes has varied by region – the relative cost of ownership is higher in Auckland and Hamilton and lower in Christchurch.
- programmes to provide loans for sustainable building practices have increased although it is unclear what their impact is.

- there has been substantial movement in government policy to build better houses, and reduce carbon emissions, and this is expected to continue in the coming years as the country works towards emissions budget goals.

6.2 Recommendations

Much of the recommendations made in the previous report regarding the importance of leadership, education and providing clear guidance, assistance tools and examples of how to produce low-carbon housing continue to be good suggestions and will not be repeated here. BRANZ is carrying out work that should contribute to these areas such as the low-carbon research programme.

Focusing on the question of housing performance, however, the clear message from these three reports is that almost all houses are built to the requirements of the Building Code and standard practice. Work from organisations and individuals to provide education and certification systems and tools to encourage sustainable design are laudable but ultimately do not appear to have a significant impact on general industry practice. If housing performance is to be significantly increased and carbon emissions reduced, the only solution appears to be government regulation. Work by MBIE to increase performance requirements should continue, as should attempts to extend compliance methods to account for carbon. As has been recommended before, new houses should be required to achieve high performance and meet low-carbon benchmarks in order to meet New Zealand's 2050 goals.

Other work should be geared towards supporting this. Providing design solutions for low-carbon housing that can be used as targets for the Building Code. Providing tools and education to assist the design of such houses. Devising the methods to assess performance and compliance and account for the many different factors of performance.

Factors such as urban design should not be forgotten as we build more houses – car-centric neighbourhoods with poor walkability will not support low-carbon living, regardless of how much we improve dwelling performance.

Overheating and interstitial moisture management will also be increasingly important as modern houses become more insulated. These are not currently well handled by the relevant NZBC clauses, so critical consequential changes will be necessary. These will be necessary despite their dependencies upon uncertain occupant behaviour, interior finishes and complicated interzonal ventilation.

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Appendix A: Transitional thermal modelling methodology

A. Introduction

This Y2020 study is distinctive due to shifting to a new, more powerful thermal simulation program (EnergyPlus), more commonly used by the international research community. The process undertaken and the comparative results with AccuRateNZ (the formerly used simulation tool based on CSIRO's Chenath engine) are outlined here.

The shift to EnergyPlus represents a change from the previous two BRANZ reports where AccuRateNZ was used. It was needed for several reasons:

- The lack of AccuRateNZ support and development, which risks creating problems in the future. For example, its material library cannot easily be changed, creating potential issues in the future if house constructions change.
- AccuRateNZ was never really designed for research purposes. It was designed to support New Zealand's (now defunct) Home Energy Rating Scheme, an EECA initiative from 2007. As such, it lacks flexibility in terms of inputs and parametric modelling capability that tools like EnergyPlus have. This limits the further utility and wider application of the growing BRANZ dataset of new houses being added to the longitudinal study periodically.

Changing the modelling tool in the middle of a longitudinal study can create obvious continuity issues and would normally not be recommended. However, in this case, the potential problems are minimised as most new stand-alone houses have been insulated to the minimum Building Code requirements since the start of this study. By and large, any differences in the simulation results should be due to differences in the simulation programs and not actual changes to house performance.

B. Method

Eight houses from 2012 were remodelled in EnergyPlus. This was done to test and refine the EnergyPlus modelling approach and to provide insights into how we might expect the results to vary between the two programs. Model assumptions were kept the same as in the previous Y2012 and Y2016 studies using AccuRateNZ as much as possible. The weather files used were the same typical meteorological year (TMY) files created by NIWA.[37] Material properties were set to be the same as in AccuRateNZ. Temperature setpoints for heating were 20°C for 7am–11pm for the living and bedroom zones. Active cooling starts at 25°C for all conditioned zones and continues 24 hours. Operative temperature (the average of air and surface temperature) was used for the setpoints to be consistent with AccuRateNZ. Like AccuRateNZ, heating and cooling were estimated using an ideal loads system rather than trying to model a real system. The ventilation setpoint was set at 22.5°C.[38]

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[37] https://energyplus.net/weather-region/southwest_pacific_wmo_region_5/NZL

[38] This was adjusted from 23°C to better align the results with those of AccuRateNZ and account for the differences in ventilation operation between the tools. See discussion in following section.

C. General modelling assumptions

A number of assumptions and simplifications were made with regards to what was modelled, reflecting previous modelling work:

- Trees and shading from the surrounding environment are not modelled.
- Carpet is assumed as the default floor lining when none is specified, while wet areas are assumed to be vinyl or tile.
- Bathrooms are combined into corridor and other miscellaneous zones where appropriate for simplicity as they are all assumed to be unconditioned and are not of particular interest to the overall house performance. En suites are treated as being part of their attached bedrooms.
- Roof geometry is simplified to save time as this only matters where it affects the shading of the house.
- External walls are assumed to have a framing ratio of 28% (Cox-Smith, 2001).
- Shading that doesn't affect windows may be ignored due to its insignificance.

D. Infiltration and ventilation

The baseline infiltration/ventilation rate in most zones was assumed to be 0.5 air changes per hour (ACH) as in AccuRateNZ. However, subfloors and roof spaces have their own models in AccuRate (Chen, 2013). The infiltration rate for the roof zones is estimated as $2 + v$, where v is the wind speed at the site.

The infiltration rate for the subfloor zone is estimated as: $A + Bv$

where $A = 0.00009612 * \frac{3500*Area}{Area*Height}$ and $B = 0.0003046 * (3500 * Area) * \frac{0.74}{Area*Height}$

Ventilation was set to activate at 22.5°C as long as the outdoor temperature was not higher than the indoor. Maximum ventilation rates were assumed to be 30 ACH in the main living spaces with good cross-ventilation potential and openable outside doors and 10 ACH in other rooms. These assumptions were based off estimates of ventilation rates that were readily reached in more complicated airflow network models when windows are opened. Hand calculations suggest they are reasonable: 30 ACH could be reached in a typical living room at ~2 m/s wind speed with two 2 m² doors for example. Smaller rooms are trickier. A small ~12 m² room could reach 10 ACH with 2.5 m/s of wind and two 0.1 m² window openings. While this seems reasonable, many such rooms only have one outside wall. Cross-ventilation is achieved by opening windows in different rooms and letting the wind flow through the house, which is difficult to calculate.

AccuRateNZ approaches ventilation distinctly differently from EnergyPlus. AccuRateNZ manages ventilation by setting window opening areas and calculating the resulting airflow through the house. This approach can be used in EnergyPlus as well via the AirflowNetwork model. However, past experience has found that the AirflowNetwork system has difficulty controlling the window operation in a reasonable way. It lacks any ability to estimate how much ventilation is actually needed, instead just opening all the windows in a zone at once.[39] Because of this, it has a tendency to overventilate and potentially create situations where ventilation and heating clash. This is especially true

[39] In theory, this can be controlled by adjusting how much the window is opened depending on the temperature difference. The problem with this is that a lot of individual fine-tuning would be required, which would not be practical for the hundreds of model houses examined.

in more highly insulated houses, wherein it would open all the windows in a zone (achieving around 70 ACH), drop the air temperature below the heating setpoint and engage the heating systems. In some situations, it could even produce the perverse result that adding insulation increased the heating energy use because of ventilation heat losses. The simple ventilation inputs do a much better job at adjusting the ventilation level to what is actually needed and may thus be better at approximating intelligent ventilation behaviour.

Additionally, unlike AccuRateNZ, which allows the baseline infiltration rate to be set separately from the ventilation calculations, EnergyPlus requires that the same method be used for both. Thus, if one uses an AirflowNetwork model, it must be used to calculate air leakage and infiltration as well as ventilation from window openings. Given that the focus of the benchmarking study has largely been on heating energy use, it was decided that it was more important to ensure that infiltration assumptions were kept consistent rather than trying to model ventilation in detail.

AccuRateNZ also applies the setpoint differently. The 23°C setpoint is when it opens the windows, but then rather than trying to hold the temperature at the setpoint, it only closes the windows once the temperature drops to 20°C. Moreover, it appears to apply the ventilation to the operative temperature while EnergyPlus applies it to the air temperature (which makes sense as air temperature is what ventilation changes). This means that AccuRateNZ's ventilation is effectively far more aggressive than EnergyPlus's. In the EnergyPlus model, the ventilation might stop the air temperature from getting above 23°C, but due to the sun heating up the surfaces, the operative temperature may rise significantly higher anyway. In contrast, in the AccuRate model, the ventilation drops the operative temperature down to 20°C. If, however, we were to use a setpoint of ~20°C in EnergyPlus to try to match this result, the heating energy use would be significantly increased. These differences not only mean the EnergyPlus models generally report the houses to be warmer but also contribute to the larger differences in heating estimates in warmer climates. To partially account for this difference, the ventilation setpoint in EnergyPlus was lowered from 23°C to 22.5°C to reduce these differences in heating energy use.

E. Interzonal air movement/heat transfer via openings

In AccuRateNZ, internal doors are assumed to be opened for ventilation when the ventilation setpoint is reached. AccuRateNZ may similarly model the airflow through permanent openings between zones. In EnergyPlus, this is more complicated. Permanent openings are modelled using an InfraredTransparent material with convection coefficients of 0.1 W/m² to allow radiative heat transfer through the opening. Heat transfer from air movement is approximated using ZoneCrossMixing objects to exchange air between the zones. For permanent openings, the baseline air exchange is assumed to be 0.1 m³/s of air for each m² of opening, assuming 0.1 m/s for still air as per Chartered Institution of Building Services Engineers (2006). When the ventilation setpoint is reached, internal doors are opened and an extra 0.3 m³/s of air for each m² of opening is added.

It should be noted that these values are highly approximate. In reality, the airflow between zones will be variable. Fortunately, however, the results are relatively insensitive to the exact value of the parameters used here as the temperature difference between adjacent zones tends to be relatively limited, especially if both zones are being conditioned. Doubling or halving the airflow through the openings may perhaps only adjust the heating load by ~1% even with a permanent opening between the main living space and an unconditioned hallway. This insensitivity is shown in Table 35 and Table 36, where three different opening scenarios are examined on an example house model.

Table 35. Sensitivity of heating energy estimates to interzonal airflow assumptions.

Opening scenario	0.5 x airflow	1 x airflow	2 x airflow
Doors only	4,625 kWh	4,605 kWh	4,568 kWh
Permanent opening between lounge and living	4,594 kWh	4,569 kWh	4,493 kWh
Permanent opening between living and hallway	4,813 kWh	4,848 kWh	4,493 kWh

Table 36. Sensitivity of cooling energy estimates to interzonal airflow assumptions.

Opening scenario	0.5 x airflow	1 x airflow	2 x airflow
Doors only	3,699 kWh	3,922 kWh	4,149 kWh
Permanent opening between lounge and living	3,745 kWh	3,913 kWh	4,203 kWh
Permanent opening between living and hallway	3,723 kWh	3,897 kWh	4,203 kWh

F. Ground modelling

The concrete slabs and ground were modelled using the GroundDomain model in EnergyPlus. Soil properties were assumed as shown in Table 37 below:

Table 37. Soil properties used.

Conductivity	1.2 W/m-K	BRANZ-recommended value for New Zealand (Trethowen, 2000)
Density	1,500 kg/m³	ANSI/ASHRAE Standard 140-2007 Addendum B Table B18-1, NZS 4214:2006 clay soil
Specific heat	800 J/kg-K	ANSI/ASHRAE Standard 140-2007 Addendum B Table B18-1

To model underslab insulation and account for the fact that the insulation does not go all the way to the edge of the slab (due to the slab thickenings at the foundations), the approximate R-value of the slab insulation was taken as:

$$R_{\text{approximate}} = R_{\text{slab with underslab insulation}} - R_{\text{uninsulated slab}}$$

where $R_{\text{slab with underslab insulation}}$ is taken from the BRANZ *House insulation guide* 5th edition.

Thus, it was modelled as providing an additional R-value of ~R0.5 rather than R1.2.

Groundwater depth and the depth of the boundary condition was estimated based on the elevation of the site as $d_{wt} = 0.1022 \cdot d_{elev}$ (Williams & Williamson, 1989).

G. Window modelling

Windows were modelled using the detailed window modelling methods in EnergyPlus rather than the simple glazing method that is commonly used. This is because the simple modelling method appeared to have problems with accounting for the conductivity of aluminium frames as well as underestimating the benefits of low-E coatings. This is illustrated in Figure 11 in a set of comparisons using a simple test cell in Christchurch.[40] EnergyPlus appears to significantly underestimate the heat loss of single-glazed windows, estimating their heating use to only be ~5% more than that of double glazing, as well as suggesting only minor differences between single-glazed windows with PVC/timber frames and windows with aluminium frames. Low-E coatings similarly appear to have reduced benefits, only saving ~2% heating energy as opposed to ~6%.

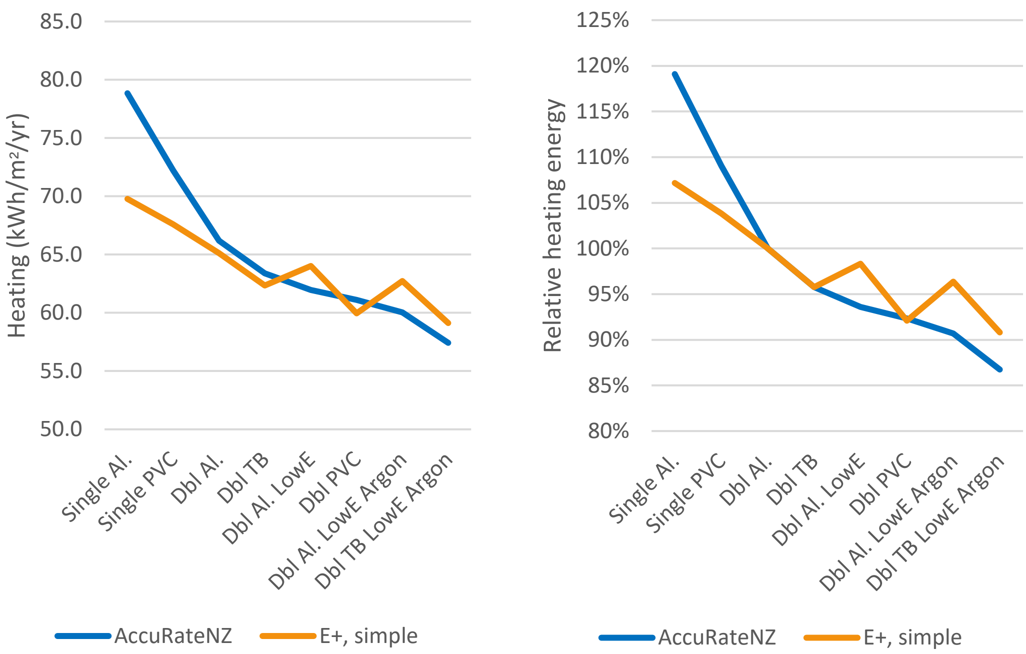

Figure 11. Comparison of the effect of different windows on heating energy use in AccuRateNZ and EnergyPlus (E+) – simple window modelling method.

Two factors appear to be responsible here. First, single glazing has difficulty being represented in EnergyPlus's simple glazing method as, due to surface-air resistance, the highest U-value that it can produce is ~U5.8, well below the U6.7 for aluminium single glazing. Secondly, low-E coatings appear to not be represented well because the simple glazing method simply translates a given set of U-value, visual transmittance and solar heat gain coefficient into conductivity, transmissivity and reflectances. It leaves the emissivity of the modelled glass unchanged, which is of course the main property low-E coatings affect.

To address this, the detailed window modelling method was used instead. LBNL WINDOW8.0 was used to put together combinations of glass, air gap, spacer and frame with the same properties as the windows in the AccuRateNZ construction library. These were then exported into the EnergyPlus idf format and modelled.

[40] The test cell was a simple single zone 10 x 10 x 2.7 m box, with 20% glazing on the north, east and west walls and 10% on the south. R-values were standard Building Code construction with a concrete slab, and infiltration was 0.5 ACH. Heating was to 20°C operative during daytime, and cooling was 25°C. Internal gains were set to those used in AccuRateNZ for a living space, and there was no ventilation as AccuRateNZ and EnergyPlus manage that very differently.

Testing this on the same test cell shows significantly better alignment, with results within ~5% in all three study climates (Figure 12).

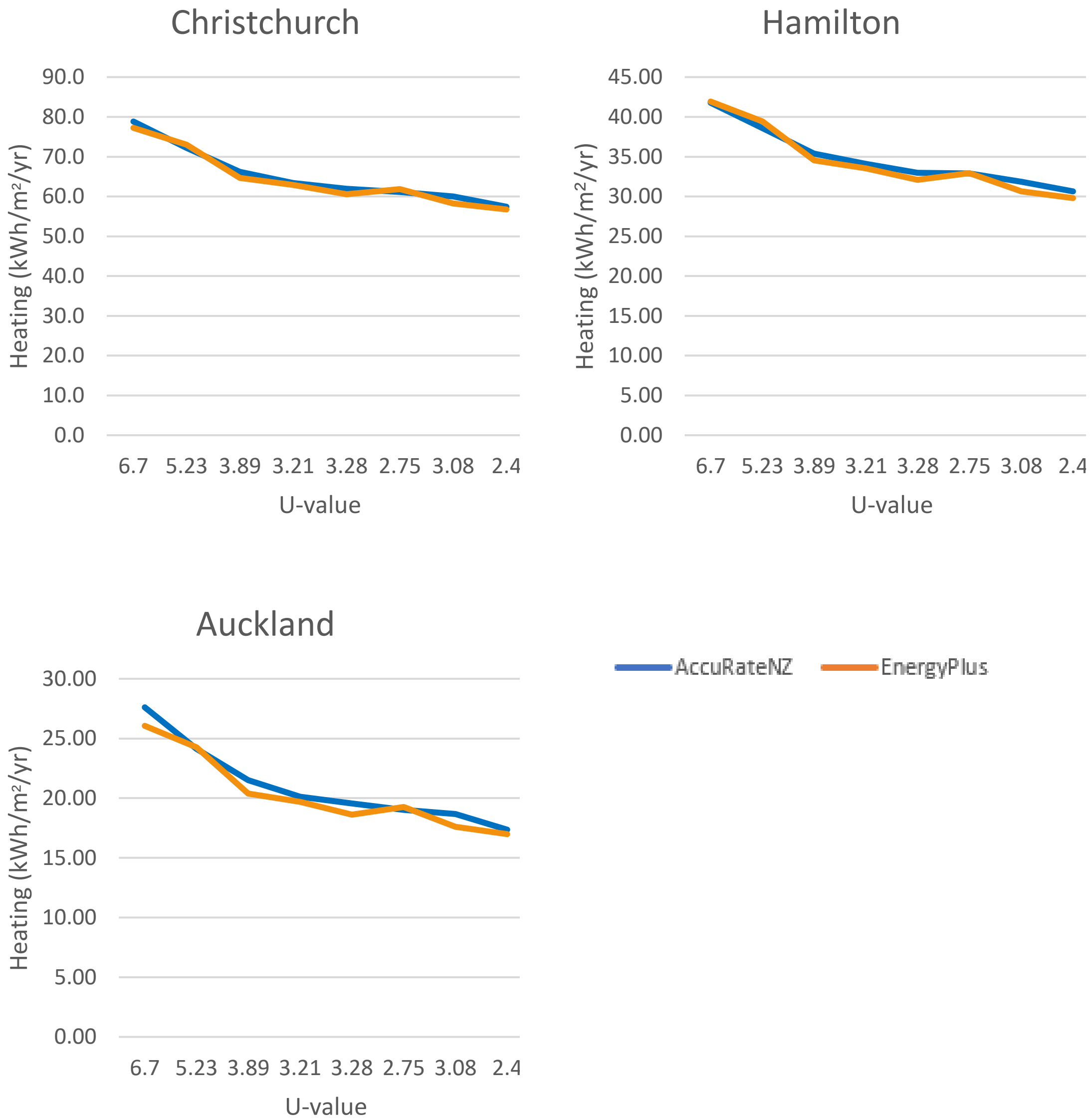

Figure 12. Comparison of the effect of different windows on heating energy use in AccuRateNZ and EnergyPlus – detailed window modelling method.

H. Internal gains schedules

The internal gains used in AccuRateNZ were derived from Burgess (2007), which informed the adaptation of the Australian version. The internal gains were derived from the BRANZ HEEP study,[41] which monitored New Zealand houses from 1995 to 2005 and were based off estimates of an average house.

In general, AccuRateNZ implements the gains by scaling the lighting loads by floor area and assigning the equipment loads as static values to a given zone – for instance, all living zones are assumed to have the same equipment load regardless of floor area.

[41] https://www.branz.co.nz/environment-zero-carbon-research/heep2/heep/

Occupancy appears to only be applied in the calculation of the bedroom loads. No hot water loads appear to be placed anywhere.

Zone types

- Living: the living load includes an equipment load and a lighting load in W/m².
- Kitchen: the kitchen load includes an equipment load, a cooking load equal to 80% of the load from HEEP (presumably reduced to account for losses to latent heat and extract fans) and a lighting load in W/m².
- Living/kitchen: combined living/kitchen zones have an equipment load equal to the sum of the living and kitchen zone loads, a cooking load as before and a lighting load in W/m².
- Bedrooms: bedrooms have a single occupant, an equipment load and the lighting load in W/m². Once the number of bedrooms reaches four, the occupant load is reduced by 25%.
- Bathroom: bathroom zones have a constant 21 W load representing the average heated towel rail load across HEEP houses (which is an average of houses both with and without heated towel rails) plus the lighting load in W/m².
- Other: the other zone type includes equipment loads and lighting loads in W/m². The other equipment loads are divided up amongst all the other zones in the model based on their area.

For typical zones, the sensible gains may be roughly as shown in Figure 13, although it will vary between houses.

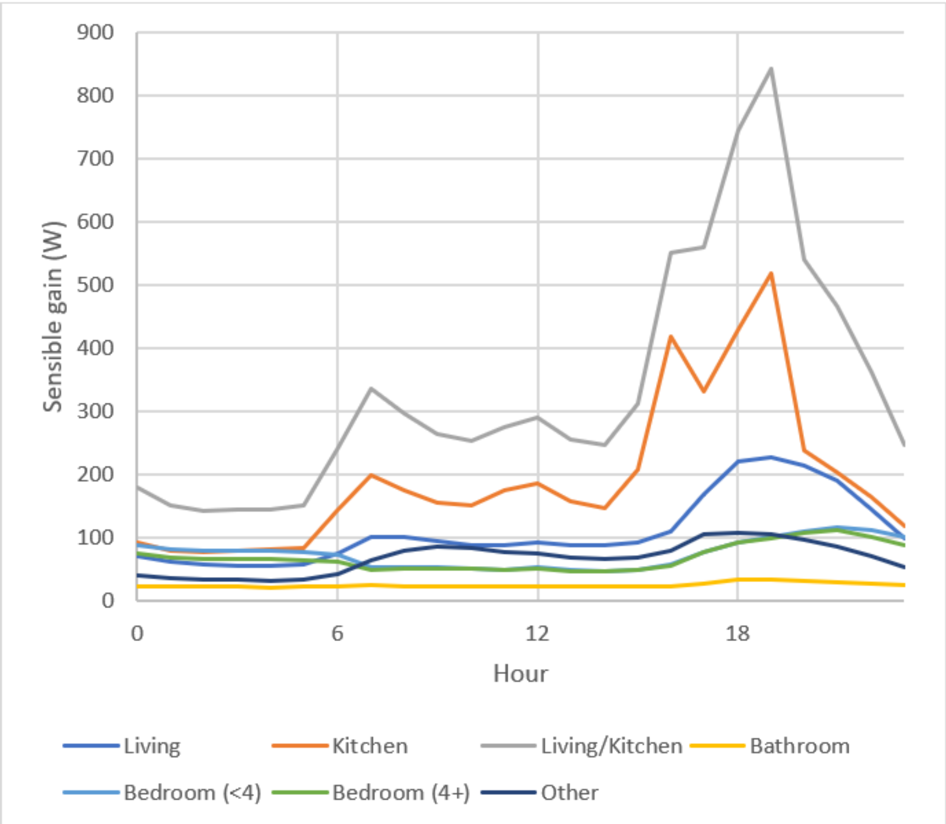

Figure 13. Typical internal heat gain schedules in different zone types.

I. Comparison between AccuRateNZ and EnergyPlus results

The change in thermal simulation tool should be expected to result in some changes in the observed results. Significant variation may be found even within the ANSI/ASHRAE 140 BESTEST (Judkoff & Neymark, 1995) validation procedure for thermal simulation tools. Indeed, if we compare the validation reports that were published for both AccuRate (Delsante, 2004) and EnergyPlus (Henninger & Witte, 2004; 2013), we find that estimates of the heating energy requirements were generally lower for EnergyPlus. Moreover, EnergyPlus's estimates have lowered over time. Differences between the tools are in the order of 15–30% for the low and high mass test cases, despite the simple nature of the test comparisons.

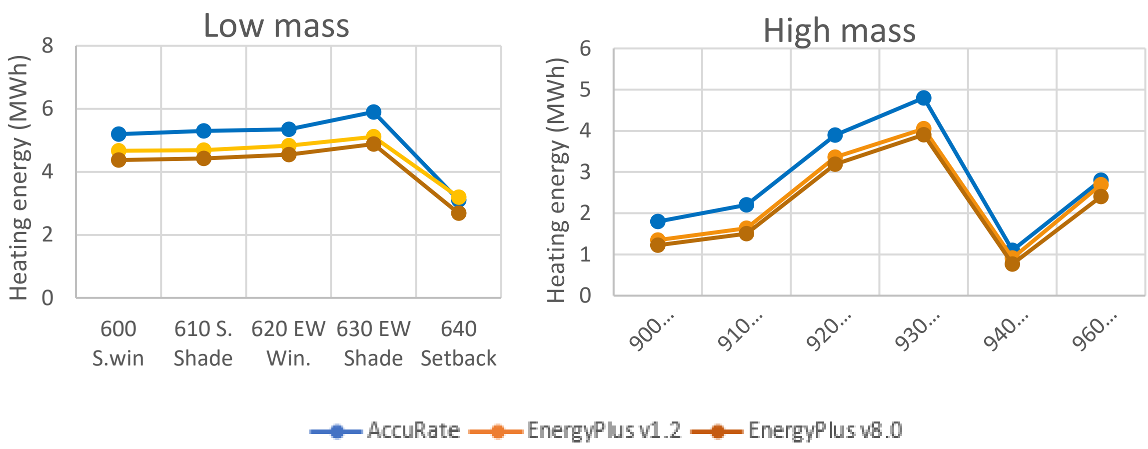

Figure 14. Comparison of heating energy results from the BESTEST validation reports for AccuRate and EnergyPlus.

Focusing on this study, there are a range of important differences between the tools that may cause discrepancies:

- AccuRateNZ's wing walls, used for side shading, are assumed to have infinite height. This may result in significant overshading of some zones in certain circumstances, and such zones may get more sun in the EnergyPlus model.
- The carpet + rubber underlay material in AccuRateNZ has an R-value of 0.68, which is rather high. Indeed, it is double the combined R-value of the individual carpet and rubber underlay materials, suggesting that it is the result of input error. This has been corrected in the current models, and we have used a more standard R-value of 0.34 for the carpet.
- Both AccuRateNZ and EnergyPlus use algorithms to calculate surface heat transfer from convection and radiation. This can have significant effects for highly conductive surfaces like windows. However, it is unclear how much.
- In terms of reported R-values, AccuRateNZ uses the NZS 4214 surface air resistances of R0.09 + R0.03, while EnergyPlus uses the traditional ASHRAE values of R0.12 + R0.03.
- The ground models for concrete slabs are different. The tools appear to agree closely when the slab is carpeted. However, they disagree on the effects of exposed slabs, with EnergyPlus seeing them as more beneficial. As exposed slabs are rare in our sample, this is not a significant issue but is worth noting.
- As previously discussed, ventilation is determined very differently between the programs. AccuRateNZ tends to predict far less overheating than EnergyPlus.

- Cooling operation differs between the tools. AccuRateNZ's estimates of cooling energy use can be lower than EnergyPlus results (notably for Auckland's climate). As the focus of the benchmarking study has been on heating, it was decided that trying to match these was not a priority.

In order to examine the alignment of the simulation tools as well as checking the modelling approach, a number of houses from the previous studies were remodelled in EnergyPlus in three climate zones. The houses, a mixture of single and two storey of varying complexity, are provided as wired frame representations in Figure 15.

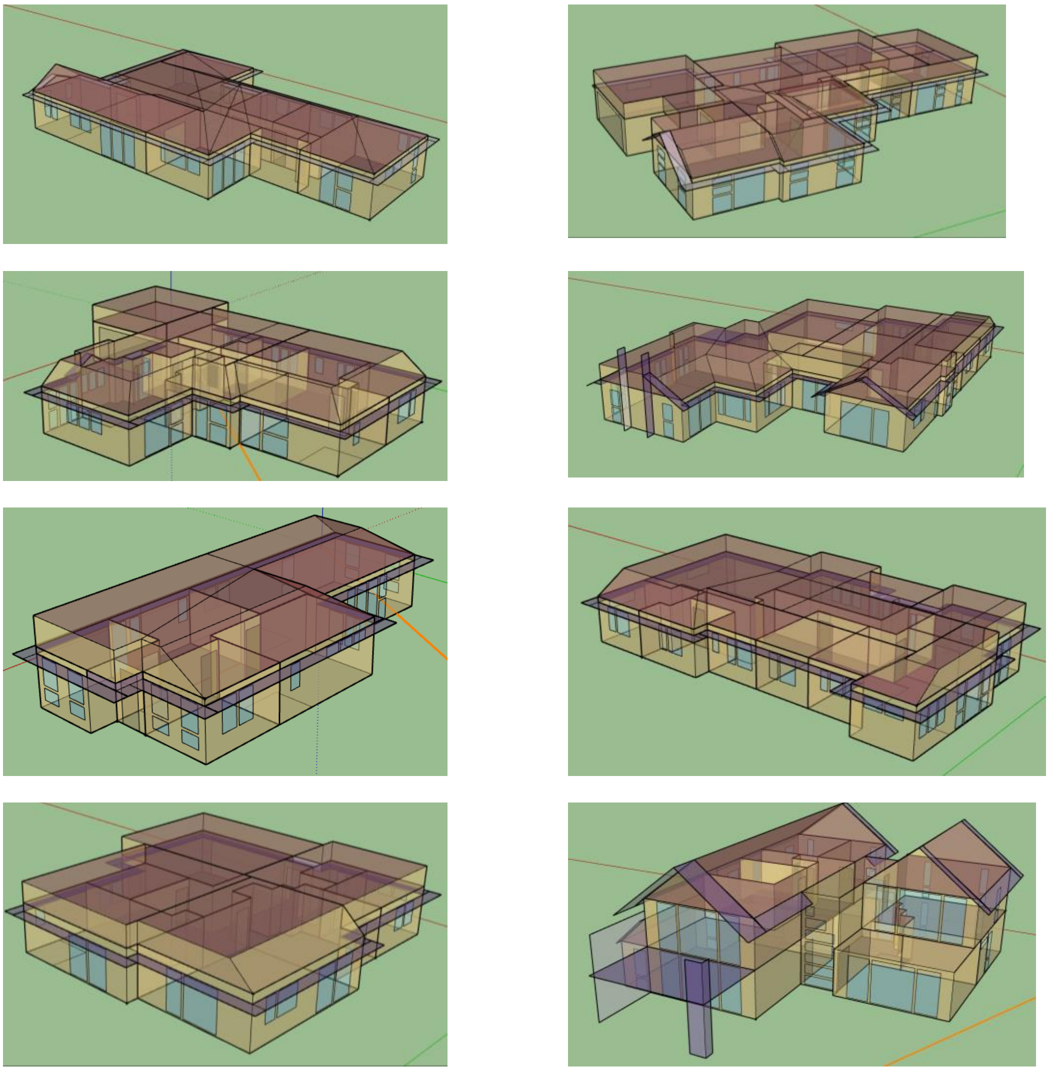

Figure 15. OpenStudio models of selected houses used to compare AccuRateNZ and EnergyPlus.

With the initial 23°C ventilation setpoint, EnergyPlus estimated the heating energy use to be around -5% to -15% lower than AccuRateNZ depending on the climate, with the largest differences in Auckland. These differences were reduced by adjusting the ventilation setpoint in EnergyPlus to 22.5°C as discussed. With this, the average difference in heating energy use between the tools ranged from -2% in Christchurch to -6% in Auckland. Passive thermal performance in the main living spaces (in terms of degree hours <18°C) showed greater variability, and while the average difference was 5% for Christchurch and Hamilton, the Auckland results were noticeably warmer (Tables 38–40). Given the characteristics of the tools, such differences were not unexpected. It was decided to prioritise consistency in the primary metric of heating energy use.

Table 38. Active and passive living-space heating: AccuRateNZ vs EnergyPlus – Auckland.

Auckland	Heating (kWh/m²/yr)			Too cold (degree.hours)		
	AccuRateNZ	EnergyPlus		AccuRateNZ	EnergyPlus	
House 1	11.8	10.1	*86%*	256	147	*57%*
House 2	28	29.6	*106%*	1389	1,365	*98%*
House 3	26.4	23.2	*88%*	1254	1,052	*84%*
House 4	25.9	25.4	*98%*	1097	1,015	*93%*
House 5	26.2	24.6	*94%*	1550	1,128	*73%*
House 6	22	18.0	*82%*	430	322	*75%*
House 7	17.9	18.3	*102%*	653	608	*93%*
House 8	23.2	21.8	*94%*	999	557	*56%*
		Avg.	*94%*		Avg.	79%

Table 39. Active and passive living-space heating: AccuRateNZ vs EnergyPlus – Hamilton.

Hamilton	Heating (kWh/m²/yr)			Too cold (degree.hours)		
	AccuRateNZ	EnergyPlus		AccuRateNZ	EnergyPlus	
House 1	21.6	20.5	95%	1008	978	97%
House 2	44	45.5	103%	3851	4,027	105%
House 3	41.6	36.9	89%	3480	3,283	94%
House 4	41.5	40.9	99%	3324	3,537	106%
House 5	43.5	40.8	94%	4441	3,674	83%
House 6	36.4	32.2	88%	1953	1,799	92%
House 7	30.9	31.4	102%	2441	2,515	103%
House 8	36.9	36.2	98%	3645	2,769	76%
		Avg.	96%		Avg.	95%

Table 40. Active and passive living-space heating: AccuRateNZ vs EnergyPlus – Christchurch.

Christchurch	Heating (kWh/m²/yr)			Too cold (degree.hours)		
	AccuRateNZ	EnergyPlus		AccuRateNZ	EnergyPlus	
House 1	45.8	45.3	99%	4,331	5,053	117%
House 2	79.2	82.1	104%	9,900	10,740	108%
House 3	75.7	72.3	96%	9,293	9,712	105%
House 4	76.9	75.1	98%	9,306	10,281	110%
House 5	80	78.7	98%	10,729	10,412	97%
House 6	71.2	64.6	91%	6,537	6,693	102%
House 7	62	63.1	102%	7,563	8,466	112%
House 8	66.3	63.0	95%	9,729	8,514	88%
		Avg.	98%		Avg.	105%

J. The strangely high performance of the Hamilton houses

In the results for the 2020 houses, the heating energy efficiency (in kWh/m²) lined up well with the previous years' estimates for Auckland and Christchurch, indicating that the calibration of the model assumptions documented above had been successful.

In Hamilton, however, the houses appear to be significantly more energy efficient than previously, needing ~25% less heating at 31 kWh/m² compared to 42 kWh/m². This stood out as anomalous because, according to the fundamentals, there was no obvious reason for the Hamilton houses to see significant performance improvement. The Hamilton houses continued to have much the same Code-level insulation and construction as previously, and while they have shrunk, this would not be expected to significantly affect the energy efficiency when it has already been normalised per m². Further, as the Christchurch and Auckland houses do have much the same heating use as before, simple differences between simulation tools does not seem a reasonable explanation. Indeed, if we put all the houses in the same climate zones, we find that the Hamilton houses are the best performing. The Christchurch houses for example, when run in Hamilton, have an average heating use of ~40 kWh/m², which is much more in line with what would have been expected based on the Hamilton houses in 2012. We would expect the Christchurch houses to be the best performing on average because they tend to have slightly higher insulation levels, yet here the Hamilton houses perform significantly better.

It is also not a result of a few outliers distorting the average. A look at the plot of heating energy use shows that the Hamilton houses are very consistently performing at that high level (Figure 16).

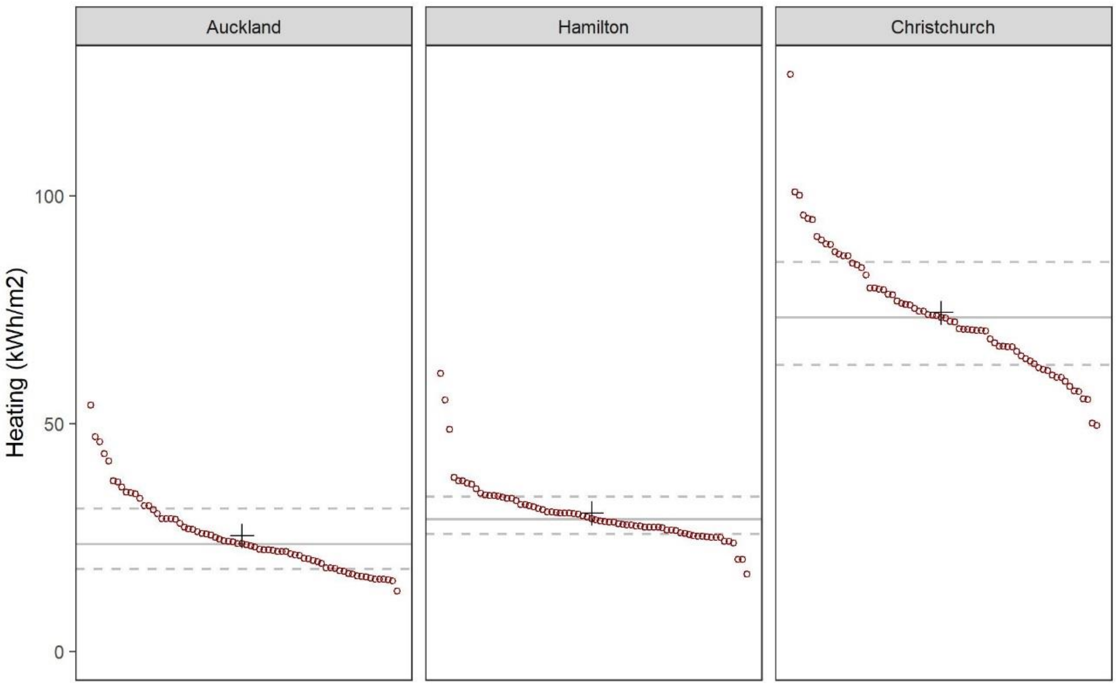

Figure 16. House space heating energy efficiency across the three regions.

An obvious question then is whether it could be due to some kind of modeller effect – a systematic error or just the way a certain modeller modelled the houses. Indeed, the Hamilton houses were largely modelled by one of the three modellers. Every house was modelled using the same template and construction library. The modellers then had to zone the house and model the geometry in OpenStudio before the model was processed via an R script that assigned all the key assumptions such as internal loads, heating, infiltration and ventilation according to predetermined rules. The key assumptions should thus be consistent across all models, limiting the potential for input error to distort the results.

Nevertheless, the models were checked extensively for potential errors or possible reasons for their low heating use. This was done via a combination of spot examination of individual models and scripts to read and check for possible errors in all the models. This included checking:

- that assumptions were all being assigned correctly
- that the processing of the results was being done correctly and no mathematical errors were creeping in
- that constructions and R-values were correct
- for a range of possible errors – houses had ventilation, window frames had been assigned, non-ground floor surfaces weren't incorrectly linked to the ground, garage ceilings generally didn't have insulation, zones were all named correctly and recorded floor areas were correct.

While a variety of errors were found in all three climate zones and fixed, nothing significantly shifted the average heating use of the Hamilton houses. Errors such as the garage ceiling being insulated instead of uninsulated could only change energy use by a few percent, and many of the errors were equally likely to be increasing the heating use as decreasing it. The Hamilton models appear to be working correctly.

To check for modeller differences, three average houses were remodelled by a different person to check for consistency as well as being modelled in AccuRateNZ to compare (Table 41). This cross-comparison identified some minor errors, which were fixed, and did suggest a small modeller effect with the original Hamilton models tending to have lower heating use. The main observed difference was a greater willingness by the first modeller to simplify internal zone geometry, which would not be expected to have a large or systematic effect. The effect was still far smaller than the gap we are concerned with here – only a few percent instead of 20–25%. Modelling the houses in AccuRateNZ found significantly higher results that were much closer to the level we would have expected from the 2012 report. This could indicate that the Hamilton houses are inclined towards producing larger differences between AccuRateNZ and EnergyPlus, but with such a small sample, this could also just be chance. As was apparent during the calibration exercise, the level of agreement between the tools can vary significantly between houses, and these could just happen to be ones with large disagreements.

Table 41. Comparison of the estimated heating use (kWh/m²) of three Hamilton houses that were remodelled.

	Original	Remake	AccuRateNZ
House 1	27.5	27.9	35.2
House 2	33.1	34.4	39.9
House 3	32.2	34.4	39.2

Their insulation levels are as expected and do not stand out as high. Most houses have R2.2 wall batts, R3.2 ceiling batts and standard aluminium double glazing. All are single storey as is normal for Hamilton, and nearly all are concrete slabs (not exposed).

They did not inadvertently all have edge insulation applied to them – and even if they had, the reduction in heating would be too large. Their average groundwater depth is slightly deeper than Christchurch's (~4.4 m rather than ~3.4 m), which could slightly reduce the heat losses through concrete slabs but shouldn't produce a difference anywhere near as large as this (a test on a single model suggested this could explain perhaps a 2.5% difference). This also isn't something that can really be applied to the comparisons with the 2012 data, as ground depth isn't an available input in AccuRate's slab model. They do have a tendency towards having less ventilation potential than the other regions, but again trying to increase this only shifts heating use by a few percent. Average window/wall ratios are also slightly lower in Hamilton at 21% instead of 22%, but again we wouldn't expect this to lead to a 20% reduction in heating.[42]

One interesting change is that the level of waffle slab penetration has increased dramatically in Hamilton over the past decade – in the 2012, sample only 8/70 of the houses had waffle slabs. In the current sample it is 63/70, placing Hamilton's penetration higher than Christchurch's (40/70). While the insulation value provided by waffle slabs is small, it could nevertheless reduce the heating load by a few percent.[43] This is somewhat mitigated by the lack of any houses with slab insulation, but there weren't many of them in 2012. This also wouldn't explain much of the difference between the Hamilton and Christchurch houses, which are also majority waffle slab. While Hamilton has more, the difference caused by this could probably only be 1–2%. Combining these factors – difference in groundwater depth, slab insulation levels, higher ventilation levels in Christchurch and possible modeller effects – we could potentially explain around 40% of the difference between the Christchurch and Hamilton houses, although that is ignoring the fact that the Christchurch houses generally have higher insulation levels.[44]

Overall, the results are hard to explain. Based off the shift from uninsulated slabs to waffle slabs as standard, we might expect heating energy use to have declined by a few percent since 2012. A 25% improvement in heating efficiency points to either a significant modelling error or a major improvement in design, yet neither of these are apparent. The Hamilton house models perform much better than those in other regions, and while these differences might partially be explained by an accumulation of various small effects such as groundwater depth, ventilation, slightly higher slab insulation and a small modeller effect, these would only explain part of the difference.

Remodelling some houses in AccuRateNZ suggests that, if it were still being used, the results could be much more in line with previous work, but it is not clear why the Hamilton houses would see a greater discrepancy than the those of the other regions, which are quite consistent with previous work.

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[42] A spot test of increasing the window/wall ratio from 20% to 22% on a house found that it mostly increased the cooling load, with no meaningful effect on heating use (29.13 vs 29.15 kWh/m²). Such a small effect could potentially just be characteristic of that particular house, but it does suggest this is unlikely to be a major driver.

[43] A test on a single house suggested a 5% difference.

[44] As an approximate exploration of these difference, the Hamilton houses were synthetically adjusted to be mostly uninsulated slab as in 2012, have more generous ventilation and have 1 m more ground depth. Together, these raised the average heating use by ~6% to 32 kWh/m². If we then add another 5% in assumed modeller effect, this could increase it to ~33.7 kWh/m² – still significantly below the 2012 value (42 kWh/m²) or what running the Christchurch houses produces (40 kWh/m²).

These results highlight the difficulties and uncertainties involved in energy modelling. For the moment, the Hamilton results should be treated with caution. Even if we discount ~5% of the difference as a modeller effect[45] and another few percent as variation due to differences in ventilation, we would still be left with a ~15–20% decline – far more than could be explained by the small increase in slab insulation from waffle slabs. Without a good explanation for such a large decline, drawing strong conclusions would be premature. Trying to determine what, exactly, has caused such an apparent improvement in heating efficiency, however, could potentially be a fruitful avenue for further research.

[45] This would be worth exploring if it has somehow led to noticeable efficiency improvements. If the way an individual modeller draws and zones the house can improve energy use like this, this could indicate ways to improve design.

Appendix B: Embodied carbon methodology

Introduction

An improved methodology was developed for calculating an embodied carbon intensity metric for stand-alone houses, reflecting the maturation of this specialist field. This metric:

- provides carbon intensity metrics at the building element level (walls, ground and mid-floors, roofs, windows and interior walls) and at the house level
- is based on house consent data for the year together with data from the BRANZ New Dwellings survey – some assumptions and simplifications have needed to be used, which are set out below
- utilises data for residential constructions embedded in BRANZ's CO_2RE tool[46] released in 2021
- sets building service life at 90 years, being the default settings in the CO_2RE tool (version 1). This was developed and released prior to publication of the MBIE embodied carbon technical methodology (Ministry of Business, Innovation and Employment, 2022), which sets the service life at 50 years. Results are calculated excluding potential benefits, which are presented separately (see below), in line with MBIE (2022).

This method is an improvement on the method used in previous reports, which only considered specific parts of buildings (framing, foundations, roofs and walls).

Method

1. Using stand-alone housing consent data for the year, the total floor area is obtained. This is divided into an estimate of the ground floor and mid-floor areas, using the split obtained from the BRANZ New Dwellings Survey.
2. From this, estimates of the areas of external and internal walls, mid-floors, roofs and windows were obtained as summarised below:
    a. **External walls:** Calculated using a ratio to the floor area. For small single-storey houses (up to 150 m² in total floor area), we assume a transfer ratio of 0.79, where 1 m² of floor area = 0.79 m² of external wall area. For a medium single-storey house (150–200 m²), we assume a transfer ratio of 0.78. For a large house, we assume a transfer ratio of 0.74.
    b. **Internal walls:** Calculated by deriving a multiplication factor where 1 m² of internal walls = 1 m² of external walls – window to wall ratio (WWR). The WWR was derived from this study and produced a multiplication factor of 1.27 applied to the external wall area to obtain the internal wall area.
    c. **Roofs:** Based on average house size (obtained from this study) and assuming the house is square, the square root was taken to obtain the length of the external walls on each side of the house. Assuming eaves of 600 mm on all sides of the house, the area needing to be spanned by the roof was calculated. In percentage terms (with rounding), this meant that the area needing to be covered by the roof is 9% higher than the area of the floor. Therefore, to calculate the area to be spanned by the roof, we take the ground floor area and multiply by a factor of 1.09. Note, that since most consented houses are not square, the area of the roof will be greater than calculated using this method.
    d. **Windows:** External wall area multiplied by the WWR (from this study).

[46] https://www.branz.co.nz/shop/catalogue/co2re_1005/

3. The areas derived for each construction were further divided into areas by construction types using weightings derived from the BRANZ New Dwellings Survey. This survey does not provide all the detail needed in some cases, so simplifying assumptions have been made. For example, data is not collected on the dimensions of the wall studs. Therefore, the insulation type and R-value were used to estimate the dimensions. We also assume there is some regional variation in the types of materials used and therefore weight our responses by construction activity in each territorial authority surveyed.
4. Each construction type was then matched to its nearest construction in CO_2RE, with the following assumptions needed in order to help make matches:
    a. A framing ratio of 22% for timber-framed walls.
    b. All timber framed walls are 90 mm unless otherwise stated.
    c. Timber cladding is painted (rather than stained or oiled).
    d. Interior plasterboard linings (on external and internal walls, as well as ceilings) are painted.
    e. Constructions with steel claddings use 0.55 mm BMT (base metal thickness) Endura steel cladding in exposure zone C.
    f. All walls are cavity drained unless stated otherwise.
    g. Where brick veneer is used, bricks have a 90 mm thickness. In practice, the brick specification depends on the finish that the designer wants on the house, with no general preference between 70 mm or 90 mm thick bricks.
    h. Roofs with a roof space have a 15° slope, with battens at 600 mm centres. In reality, roof design and batten spacing can be house dependent.
    i. 200 mm rafters for all skillion and low-slope roofs.
    j. Membrane roofs represented by 1.5 mm butyl rubber membrane with rafters at 1,200 mm centres.
    k. For suspended timber floors, joist thickness of 140 mm, a closed perimeter with an area/perimeter ratio of 2.5 and no lining.
    l. For suspended timber floors with plywood, joists at 600 mm centres.
    m. For concrete floor slabs, no thermal break and connecting with 90 mm wall framing. A/P ratio of 2.5.
    n. For mid-floors, 140 mm joists at 600 mm centres.
    o. For interior walls, 10 mm plasterboard on both sides and no insulation.
    p. For windows, non-thermally broken aluminium, double glazing with a ratio of frame to glazing of 23%.
    q. Junctions between elements (such as external wall to floor, window to external wall, mid-floor to external wall, including flashings) not considered.

Where elements are included in the assessment, they include an estimate of all materials in the element, including fixings. Exclusions from the assessment are plumbing, electrical, mechanical ventilation, fixed forms of heating (such as heat pumps), kitchen units and appliances, bathroom units and appliances, and floor coverings (such as carpets).

Any potential carbonation of concrete during or post-building service life is excluded, given the range of factors that can affect this.

The carbon footprint calculation includes modules A1–A3, A4–A5, B2, B4 and C1–C4 (as defined in EN 15978). The base calculation excludes potential benefits, which are provided separately:

- Biogenic carbon – the atmospheric carbon dioxide that is absorbed and stored by a growing tree, prior to harvest when it is manufactured into a building product. This sequestered carbon continues to be stored in the timber material in houses and may be accounted for if the source of timber is from (for example) a responsible forestry management scheme.

- Recycling, reuse and/or recovery of waste materials (module D) – diversion of waste from landfill whether construction waste (module A5), waste derived from replacing materials during the building service life (module B4) or waste at the building end of life (modules C1 – C4) may provide carbon benefits (or burdens) in other life cycles that utilise these wastes as secondary materials rather than using primary materials.

Calculations are based on embodied carbon values for constructions provided in CO_2RE, which are themselves derived from modelling using LCAQuick v3.5.