Study Report SR426 [2019]

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

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Preface

This is the second report of an ongoing longitudinal study on key sustainability-related aspects concerning new New Zealand detached housing consented in the 2016 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 predecessor BRANZ Study Report SR342 should be read prior to or concurrent with this first update for best comprehension.

Acknowledgements

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Thanks also to the project's advisory group – their input is greatly appreciated:

- Vicki Cowan (Beacon Pathway) representing researchers and facilitators for positive change in the residential building environment.
- Heidi Mardon (Toimata) representing environmental building designers and educators.
- Nikki Buckett (ex MBIE) representing central government and building technologists.
- Ian Mayes (ex Hamilton City Council) representing the Eco Design Advisor network.

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

- Nick Brunsdon (economic indexes)
- Dr David Dowdell (building material embodied carbon)
- Dr Casimir MacGregor (social-based indicators)
- Amber Garnett (collating industry-specific and local government-specific initiatives).

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

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BRANZ Study Report SR426

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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 second report (i.e. the first update) in the series focuses on the calendar year 2016, comparing those results with the calendar year 2012 findings. Although this study report is a stand-alone document, its predecessor BRANZ Study Report SR342 (Jaques, 2015) should be read prior to or concurrent with this first 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 but, based on the thermal AccuRate NZ thermal modelling carried out, excludes the garage, hallway and bathroom zones.
CSIRO	Commonwealth Scientific and Industrial Research Organisation, whose global climate model for climate change forecasting (CSIR09) 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	Describes when a building relies on only passive solar means 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 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 research 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 the previous (year 2012) BRANZ report 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 2016 (Y2016). Some 210 building consents were randomly selected from the Y2016, extracted from three councils – Auckland, Hamilton City and Christchurch City – to examine their new-home specification and performance 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 for a comparator for the bulk of the performance metrics used. Some key findings for the eight domains are summarised in Table 1 following.

Table 1. Key findings from the eight domains summarised.

Domain	Key findings
1. Energy and CO_2	Compared to the Beacon NOW Home®, the Y2016 homes (with very rare exceptions) have considerably higher space heating and cooling loads/CO_2 emissions. The potential for harnessing and benefiting from solar radiance in new sites remains extremely high for almost all new sections in the three sampled cities examined (Auckland, Hamilton and Christchurch).
2. Water	There was a limited dataset of residential-specific water consumption figures available, with only Hamilton of the three cities having data. Daily consumption increased in the city of Hamilton in Y2016 compared to Y2012. Historical consumption figures are available for many other cities.
3. Indoor environment	Compared to the NOW Home®, the Y2016 consented homes, with very rare exceptions, are considerably less comfortable via passive means (Christchurch result available only), having more extreme temperatures in the main living area.
4. Functional resilience	Auckland's walkability has improved, while Hamilton and Christchurch remained static. The annual number of Lifemark®-awarded homes featuring comprehensive universal design has doubled. Thermal discomfort due to predicted climate change remains the same for the years 2030 and 2080.
5. Affordability	Cost of new housing increased by ~22% while the relative cost of ownership increased by ~36% in Auckland, ~15% in Hamilton and nil in Christchurch compared to Y2012. The cost increase for better windows stayed constant at ~30%.
6. Consumer demand	There has been a statistically significant decrease in new homeowners wanting to build for sustainability reasons in Christchurch when comparing to Y2012 figures. For Auckland and Hamilton, there has been no significant change.
7. Industry capacity	There is a fourfold increase in practitioners providing impartial, tailored sustainability advice compared to Y2012. However, sustainability issues still have a very small industry impact overall.
8. Policy and regulation	Two critical central government-based agencies – the Ministry of Business, Innovation and Employment (MBIE) and Energy Efficiency and Conservation Authority (EECA) – have not increased their supportive sustainable initiatives that directly affect the stand-alone housing stock when comparing Y2012 with Y2016.

1. Introduction

In New Zealand, sustainability is one of four purposes of the Building Act 2004, 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:

- the efficient use of energy and energy conservation and the use of renewable sources of energy in buildings
- the efficient and sustainable use in buildings of material and material conservation
- the efficient use of water and water conservation
- the reduction in the generation of waste during the construction process.

The principle objective of this BRANZ 2016 study is to continue the sustainability-related examination of the newly built detached housing stock to assess its performance and impactors. To this end, this study also refines the Y2012 result to provide even better longitudinal information to the user, but for the most part, this report is a simple update. The founding report established and detailed the background, methodology and interpretation and implications of the study. Consequently, to avoid repetition, those details have been largely omitted from this document. To best understand this Y2016 update, the Y2012 report (Jaques, 2015) should be read prior or in parallel.

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. This BRANZ study also significantly extends these works both with in-house and externally developed metrics.

In terms of some basic new housing stock statistics,[1] at the end of the 2012 year, some 16,929 new dwellings had been consented. 13,733 of these were classified as houses (rather than townhouses, retirement villages, apartments or units). The population was 4,410,700. In the 2016 year, 29,970 new dwellings were consented with 21,310 classified as houses, and the population was 4,696,500.

[1] Source: http://archive.stats.govt.nz/infoshare

Table 2. Summary of indicators and metrics for stand-alone homes (for Y2016).

Domain	Core indicator(s)	Metric(s) used
1. Energy and CO_2	Energy use for space conditioning	kWh/m^2, 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 for house-lot of materials
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
	Inclusion of universal design features	# of Lifemark® Design Standard awards
	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 Cost of improving thermal, energy and water efficiencies
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

This section remains unchanged to that previously documented in the Y2012 report:

- **Scope** – limited to new New Zealand stand-alone dwellings and their immediate amenities.
- **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 Y2012 report. The most important overriding difference between this update and the original report is the better and wider understanding of the implications of the enormity of climate change in terms of the viability for the health of this planet.

Writing a 'backcasting' report means that, by its nature, it doesn't capture the most recent important initiatives and resources affecting the new residential building stock. Given its global threat, mention should be made of key building-related resources that address either New Zealand's residential building climate change mitigation or adaptation aspects occurring since 2016:

- The Zero Carbon Act – more formally, the Climate Change Response (Zero Carbon) Amendment Act 2019.
- Royal Society's *Transition to a low-carbon economy for New Zealand* (Sims et al., 2016).
- New Zealand Productivity Commission's *Low-emissions economy* (New Zealand Productivity Commission, 2018).
- BRANZ Study Report *The built environment and climate change: A review of research, challenges and the future* (MacGregor et al., 2018).

The following BRANZ projects are also relevant:

- Carbon budget (2018–2019) – provides an absolute greenhouse gas emission design targets and thresholds for both office and residential buildings to meet New Zealand's 2050 international obligations. The dynamic tool is able to be continuously updated to best reflect progress.
- How can New Zealand construction deliver low to zero impact buildings? IEA EBC Annex 72 (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 Low-Carbon Built Environment programme, examining climate change and its impact on New Zealand's buildings (started in 2019).

3. Methodology

3.1 Introduction

The methodological approach for this Y2016 report is very similar to that of the Y2012 report, recognising that most of the establishment has already been carried out and to ensure between-year consistency. For details on the development of New Zealand-specific indicators, previous international indicator resource and the Year Zero yardstick house, the Y2012 report should be consulted. As before, there are eight overriding domains separated into three overriding themes (see Figure 1):

THEME	Domain(s)	THEME	Domain(s)
Building performance	1. Energy and CO_2	**Market forces**	5. Affordability
	2. Water		6. Consumer demand
	3. Indoor environment		7. Industry capacity
	4. Functional resilience	**Governance**	8. Policy and regulation

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

Once again, a steering group (now renamed advisory group) was established in early 2017. The group was tasked to further refine the original indicators and metrics where necessary, given the benefit of several years of new data collection opportunities and knowledge. Other external experts also provided useful feedback on potential areas for embellishment and improvement. A key discussion point was whether the number of indicators was about right for the likely end users of the report and therefore whether there were too few/too many. A statement in the Y2012 report was kept in mind: "Although having an expansive suite of indicators may be appealing, this conflicts with the overall desire to simplify interpretation and therefore communication of the issues." (Jaques, 2015, p.8)

The advisory group thought that the Y2012 report indicators and associated metrics on new housing were sound and useful, providing a good insight that was not previously available in an amalgamated format. However, discussions at the first meeting in late 2017 uncovered some possible avenues for improvement and/or exploration. These are detailed in section 3.2.

3.2 Changes to core indicator metric set (from Y2012)

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, even though this wasn't reflected in consumer demand
- newly uncovered data sources that could be easily leveraged for this study
- external provider's data stream ending
- a better understanding of the potential audience interest areas
- opportunities for clarification or data augmentation in the form of case studies.

Table 3 highlights the indicator and metrics changes made. Only those indicators/metrics where a change occurs have been included, with additions in red, substitutions in blue and ~~deletions as strike-through~~. The details on why individual changes occurred are discussed within the relevant section.

Table 3. Indicators and main metric changes made.

Domain	Core indicator	Metric(s) used
Energy and CO_2	CO_2 emissions from space heating	CO_2 emissions/person/year
	Mini study on shading from neighbouring recession planes resulting from district plans	Discomfort (degree-hours).
	CO_2 emissions from house shell	Embodied CO_2 for house (shell only) materials
Water	Average daily (per capita) residential water consumption	L/person/day by city
Affordability	~~Initial financial cost of five key environmental features~~ Housing affordability and key enviro-features costs	Cost of improving thermal, energy and water efficiency Inclusion of new build index (national) and relative cost of ownership (three cities)
Consumer demand	Demand/sales of some key sustainable products and services	Products: specification of ~~photovoltaic panels,~~ solar thermal ~~and rainwater storage~~

Perhaps the most contentious change is the reconsideration of the three key sustainable products typically associated with environmentally conscious homes: household photovoltaics, solar thermal water heaters and rainwater collection tanks. Balancing the environmental, economic and social attributes of products is challenging, even for those with full life cycle studies assisting the process. It was felt that the Y2012 study's approach needed to be more nuanced to better reflect the most recent New Zealand findings, which calls into question popular understandings (see discussion in section 5.12).

Another request from the advisory group was that the other residential typologies – specifically townhouses and apartments – are considered alongside single stand-alone homes. This was not able to be delivered for two main reasons:

- In Y2016, stand-alone homes make up by far the bulk of homes being built in New Zealand, even acknowledging the rapid increase in numbers of townhouses.
- There would need to be a considerable revisioning of the metrics used within this report due to the considerably more complex nature of shared resources.

3.3 Extending social-based indicators

Although there are several indicators that examine the social aspects of sustainability (albeit mostly through indirect measures), the advisory group felt that it should be augmented if practical. The exploration to strengthen the social metrics was initiated in mid-2017, via consultation with BRANZ's social anthropologist. He was tasked with investigating the possible development of a new indicator that met (at least the bulk of) the key attributes listed in section 2.2 of the Y2012 report. After much discussion and an assessment of existing New Zealand-based research, it was found that it was not possible to leverage existing resources to provide further insights. Thus, the Y2012 social-based indicators were not advanced in this Y2016 report.

BRANZ recognises the importance of this issue and will revisit it when supporting resources become available.

3.4 Analysis of changes in homes' performance attributes

The thermal analysis undertaken of the randomly selected houses consented within a year is by far the most intensive and time-consuming part of this project. It was suspected that, within the last 4 years, there would be very little in the way of thermal performance changes of the new stock in any of the three locations of interest: Auckland, Hamilton and Christchurch.

These suspicions were based on (lack of new) internal and external drivers that influence the thermal characteristics of a house:

- The residential market is known to be slow moving in terms of uptake of new ideas, especially if they are not mandated. Anecdotally, it seems that higher thermal performance contributors are one of the first things to drop off when new-build budgets are exceeded.
- Examining the 210 selected Y2016 plans and specification documents, there was little in the way of information on the individual elements that contribute to whole-of-house thermal performance such as orientation of glazing etc.
- The specification of (usually) the critical marker for higher thermal whole-house performance – with double glazing – remained at (with very few exceptions) Code levels, reflecting no change from the Y2012 results
- Other possible influencing external features had remained either similar to or unchanged from the Y2012 study, such as NZBC clause H1 *Energy efficiency* requirements and district plan regulations.

As a result, an exploratory examination was conducted of the most likely city to embrace higher thermal performance. If this city demonstrated a statistically significant change in thermal performance (comparing Y2012 with Y2016), dynamic thermal models of the two remaining cities would be carried out.

Christchurch was chosen to be the exploratory location for these reasons:

- There is a history of initiatives by building research and advocacy organisations (most notably Beacon Pathway and the Superhome Movement) to improve the thermal performance characteristics in both rebuilds and new housing, which have been very active since 2012.
- It has the coldest climate of the three locations investigated and therefore, everything being equal, homeowners are more likely to invest in better thermal options than the minimums required to meet the NZBC.
- It has a history of investing in better thermal options in new housing, choosing double glazing well before this became (almost) mandatory in New Zealand – it was estimated that some 68% of new homes in Christchurch were installing double glazing on all windows (NFO New Zealand, 2002).

The first lot of some 70 Christchurch houses were assessed in terms of a key metric – space heating requirements to maintain comfort – and the results are shown in Table 4. As can be seen, the mean space heating energy for Y2016 falls within the Y2012 95% confidence level, meaning there is no discernible difference in thermal performance between Y2012 and Y2016.

Table 4. Christchurch space heating energy intensity metrics – Y2012 versus Y2016.

Location	Sample size		Mean space heating energy and 95% confidence interval	
	2012	2016	2012	2016
Christchurch	68	70	76.7±2.2	73.7±3.6

The resulting unchanged space heating requirements are unsurprising when the individual thermal characteristics are examined such as:

- house size/volumes
- thermal mass placement/usage
- window size and placement
- access to sunlight
- most importantly, the specified double glazing.

As a result of the exploratory study, it seems very likely that the Y2012 metrics for both Auckland and Hamilton reflect the Y2016 situation on:

- energy use for active space conditioning (i.e. both heating and cooling)
- comfortable temperatures in a key occupancy zone (i.e. between 18°C and 25°C)
- healthy indoor temperatures for a key occupancy zone (i.e. not below 12°C or above 25°C).

As a result of this exploratory study, only the Christchurch results for the above indicators have been determined using dynamic software for each of the 70 houses examined as part of the random selection.

4. Interpretation

4.1 Yardstick applied and analysis

As in the Y2012 report, some 210 randomly selected, stand-alone house building consents from the three cities of Auckland, Hamilton and Christchurch were examined for the indoor environment, energy and CO_2 domains. For this Y2016 follow-up, the new home consents examined were all processed in the 2016 calendar year. The same yardstick – Beacon Pathway's NOW Home® – was used to provide a gauge of where the Y2016 housing stock sits in terms of a wide variety of building performance and sustainability-related indicators.

The NOW Home® was chosen as a suitable yardstick, as it:

- used current (circa 2017) construction technologies, systems and methods, while having an everyday aesthetic
- is well known and understood, having been intensely monitored and analysed, both prior to and post occupancy
- has met a comprehensive variety of environmental, economic and social high-performance goals, thereby providing a robust example of what is practically achievable in New Zealand.

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 (see Figure 2).

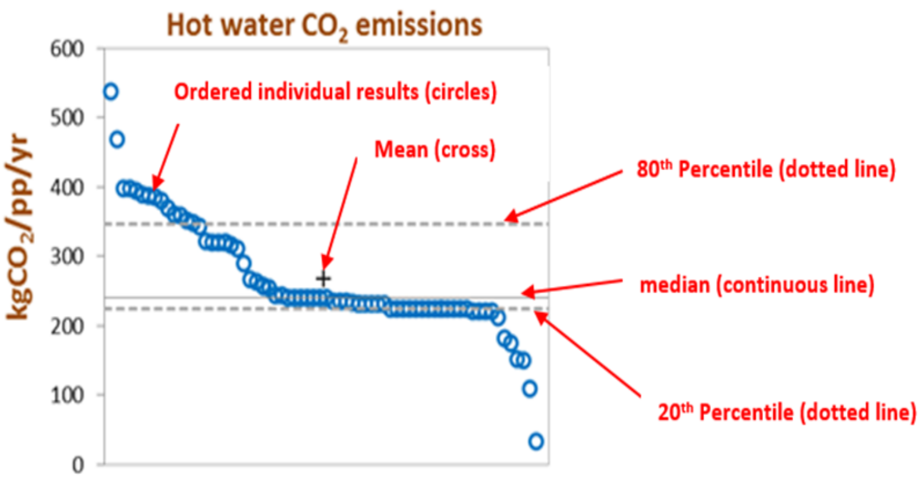

Figure 2. Annotated snake diagram to assist interpretation.

The approach used in the presentation of the tabular results was left largely unchanged for this Y2016 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.

5. Results

5.1 Energy use for active space conditioning

Background

The approach taken in this study report for this issue remains very similar to the Y2012 report.

The three metrics previously used to examine the randomly selected houses were repeated:

- Space heating energy required per unit floor area (kWh/m^2).
- Space heating energy required per household (kWh/household).
- Space heating and cooling energy required per occupant (kWh/person).

Once again, detailed thermal simulations were carried out on the randomly selected stand-alone building consents – this time for the 2016 calendar year but now only including Christchurch. AccuRate NZ, which relies on hourly climate files to provide an accurate assessment of heat flows, was used.

For comparative purposes on thermal performance, the Beacon Pathway Waitakere NOW Home® is used.

For more detailed information on the methodology, refer to section 5.1 of the Y2012 report.

Findings

NZBC climate zone 3: Christchurch

Figure 3 shows the annual space heating only and conditioning (i.e. accounting for both space heating and space cooling) energy load for the 70 randomly selected Christchurch stand-alone houses. Three key normalisers – by area, per household and per occupant – provide different perspectives on the homes' thermal performance.

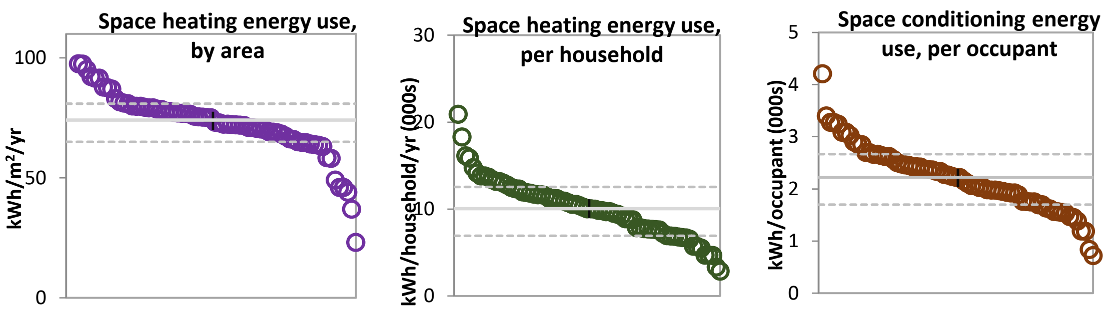

Figure 3. Space heating/cooling energy use by area, household and occupant.

Table 5 extracts some key statistics for the randomly selected Y2016 Christchurch houses and uses the Waitakere NOW Home® as a basis for comparison. MBIE's requested additional metric – examining conditioning energy use by area – is also now included.

Table 5. Key statistics examining household energy for Christchurch homes.

		Mean		50th percentile		80th percentile	
Christchurch	**NOW Home®**	**2012**	**2016**	**2012**	**2016**	**2012**	**2016**
Space heating energy use							
By area (kWh/m^2)	36	77	74	76	74	84	81
By household (kWh/household)	4,354	10,780	10,054	9,571	10,042	13,160	12,540
Space conditioning energy use							
By occupant (kWh/person)	1,146	2,256	2,210	2,040	2,220	2,632	2,664
By area (kWh/m^2)		78	76	77	76	85	84

Notable points

- As for Y2012, there is a considerable difference between the thermal performance of the worst and best house in terms of their active space heating requirements. The highest space heating use required per unit floor area is nearly quadruple the lowest figure.
- 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 considerable. This is true for whichever energy use metric (by area, by household or by occupant) is chosen.
- This gulf in thermal performance is even more startling when only a handful of selected homes designed for the Christchurch climate thermally outperform the Now Home®, which was designed for a considerably more clement climate.
- Otago University's Department of Public Health, who examined the impacts large houses are having, stated that "…despite insulation standards improving since the mid-seventies we are still using the same amount of energy to heat our houses as we did then".[2]

5.2 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. This extends the Y2012 report, where the appliance emissions focus was limited to just water heating, to have a more complete picture of the likely emissions profile of a typical new house.

Water heating

The methodology and reasons for choosing this indicator remains unchanged from the Y2012 report. The CO_2 emissions estimation is based on hot water algorithms from the WHAT HO! Tool, which was originally co-developed by EECA and BRANZ (Burgess & Cogan, 2008), which incorporates standardised user behaviour. For more details on the method, consult section 5.2 of the Y2012 report.

[2] Source: https://www.rnz.co.nz/national/programmes/nights/audio/201858580/new-zealand-s-ever-expanding-houses.

Once again, randomly selected building consent documents from stand-alone homes in Auckland, Hamilton and Christchurch were mined. For comparative purposes, the NOW Home® is used, which has an appropriately sized solar thermal collector combined with an efficient plumbing set-up.

Space heating

This indicator is new for Y2016. It was introduced due to the increasing need to account for this being a substantial residential carbon dioxide contributor. The Y2012 report discussed the reasons why a carbon metric for space heating was not applied. Although these reasons for space heater exclusion still apply (i.e. many building consents don't include details on heater type/efficiencies/zones serviced), given carbon's increasing importance, it was decided to explore other ways to sensibly fill in the data gaps.

After some discussion with both in-house and external experts, an approach was agreed on to determine a reasonably robust indicator that can be easily replicated year on year. The new emissions metric agreed upon is kg CO_2/yr/household. The approach has been 'backcasted' to include Y2012 data for completeness. The methodology is further detailed in Appendix C.

It is acknowledged that space heating will likely only be used during peak demand times – around breakfast time and dinner time. For space heating appliances that are electrically powered, relying on an average carbon intensity may mask the variability associated with the different combinations of generation types over different time scales (Khan et al., 2018). This requires moving beyond a yearly average carbon intensity to a more nuanced approach that considers time variability.

To explore this time variability further, half-hourly emission profiles from electricity generation plant were derived by BRANZ for the 5 years from 2012–2016 using Electricity Authority[3] data. The peak periods (6–9am and 5–11pm) for the three winter months were compared to the off-peak period (12–5am) for the three summer months). Surprisingly, it was found that there was only a small difference in CO_2 intensities between the two extremes.

This is supported by another more comprehensive study, which found that "daily peak time carbon intensity in New Zealand from electricity generation does not differ significantly from the carbon intensity during off-peak periods" (Khan et al., 2018, p. 1098), attributing this to hydro providing the dominant response to daily peak demand, acting like a big. Importantly, Khan et al. (2018) found that New Zealand has a relatively high carbon intensity for base demand but relatively low carbon intensity for peak demand, which is the opposite of many other countries.

As a result of these findings, the standard carbon emissions figure for electricity was resorted to for space heating emissions for electricity-fuelled appliances (0.18 kg.CO_2e/kWh – as used in the Y2012 report).[4]

[3] Source: www.emi.ea.govt.nz/Wholesale/Datasets/Generation/Generation_MD. Accessed 12 February 2019.
[4] It is acknowledged that this figure is dynamic and has a forecasted reducing intensity trajectory. However, for comparative inter-year simplicity, this longitudinal study will keep the electricity emission intensity constant.

For comparative purposes, the NOW Home® is used, which was specifically designed to rely on very good passive solar supplemented occasionally using plug-in heaters for year-round comfort.

Findings

Table 6 shows the considerable gulf between a carbon-efficient water heating system and what is typically being installed. Comparing the mean figures, the Now Home® has approximately 3.5x, 3.4x and 2.7x less carbon-intensive water heating requirements for Auckland, Hamilton and Christchurch respectively for Y2016. These comparative results were similar for the Y2012 figures.

Table 6. Household water heating-related CO_2 emission statistics.

Hot water emissions (kg CO_2/person/yr)							
	Mean	Mean		50th percentile		80th percentile	
Location	NOW Home®	2012	2016	2012	2016	2012	2016
Auckland	73	251	246	264	258	294	319
Hamilton	86	274	271	296	289	316	335
Christchurch	101	268	276	240	228	347	387

Table 7 shows the space heating-related CO_2 emissions for the three cities of Auckland, Hamilton and Christchurch, based on approximately 210 randomly selected stand-alone dwellings for Y2012 and Y2016. Only Christchurch CO_2 emissions could be calculated from the thermal models built of the Y2016 dwellings. There seems to be a decline in the amount of yearly CO_2 per household for the Christchurch houses, but this is not statistically significant.

Once again, the NOW Home® clearly displays the implications of a thermally well designed envelope.

Table 7. Household space heating-related CO_2 emission statistics.

Space heating emissions (kg CO_2/household/yr)							
	Mean	Mean		50th percentile		80th percentile	
Location	NOW Home®	2012	2016	2012	2016	2012	2016
Auckland	75	552	Not calc	463	Not calc	732	Not calc
Hamilton	151	728	Not calc	645	Not calc	873	Not calc
Christchurch	345	1,455	1,308	1,128	1,020	2,296	1,992

Notable points

Water heating

- There is a large CO_2 pollutant range for both Y2012 and Y2016.
- Y2016 consented Christchurch homes have considerably larger CO_2 emissions footprints than those consented in Y2012 on average. This is likely due to the shift towards the use of instantaneous gas for water heating.
- The change in average emissions intensity does not reflect the progressively colder climate of the more southern locations.
- The NOW Home® provides a good example of the potential of a well designed hot water system with emissions intensities per person well below that of the others or all three locations.

Space heating

- This is difficult to interpret for Auckland as in Y2012. 74% of the randomly selected houses were classified as having "unknown" space heating appliances, while in Y2016, only 30% were. The range of space heating-related emissions is considerable.

5.3 Potential of site for harnessing solar energy

Background

The reasons for choosing this indicator remain unchanged from the Y2012 report. A well solarised site has positive implications for the comfort and health of the dwelling's occupants, renewable energy generation and food production (Ghosh, Vale & Vale, 2008). Once again, the focus is on the site's potential for harnessing of energy and conversely the likely shading influences. The Y2016 scope has extended, however, to examine shading aspects more thoroughly.

Shading (and its implications for harnessing solar energy, health and comfort) is influenced by three factors:

- Topography – likely minimal in most new New Zealand developments.
- Nearby buildings – explored in this report and becoming more likely.[5]
- Nearby foliage – unknown, but unlikely to be considerable in new suburbs.

NIWA's online SolarView tool[6] quantifies the solar energy collection potential (in kWh/yr) of a given address, accounting for topographic influences. In the Y2012 report, it was found that the solar potential of all the randomly chosen sites for the three cities were close to 100% of what was available. Thus, the amount of shading from surrounding geographic features was close to nil. An assessment of the Y2016 house consents in all three cities revealed that this situation remains unchanged, which is unsurprising.

The potential influence of more local shading due to nearby buildings, based on what is allowable when adhering to local recession rules,[7] is explored here as a mini study. To quantify the influence of building-related shading in a suburban environment, the current district plan recession plane regulations for the three cities of interest were examined. A typical house was selected from the Y2016 Christchurch sample, chosen due to its passive thermal performance characteristics being very close to the mean. For the case study, an assumption was made that developers would likely design to the recession plane to maximise their coverage areas. Consequently, the shading on the adjacent property would also be maximised. Thermal simulations of the house were then conducted, with the living room's thermal comfort performance used as a whole-house comfort proxy.

To approximate the presence of an arbitrary object providing the maximum level of shade theoretically allowed within the simulations, shade was provided by artificial 'walls' constructed to touch the limits of the recession plane. These varied by district

[5] According to Peter Joyce, Principal Specialist Urban Design at Auckland Council, "… we are seeing homes getting closer and closer together and rules determining separation distances reducing all the time". Email correspondence with author, 3 May 2018.
[6] https://solarview.niwa.co.nz, where the cloudless figures in W/m^2 are used as the measure.
[7] Depending on the jurisdiction, also known as recession plane, daylight admission, height control envelope, building envelope, daylight controls, height in relation to boundary.

plan. Methodological details, including the thresholds of each of the three jurisdictions examined in this study (Auckland, Hamilton and Christchurch), are provided in Appendix F.

Finally, the remaining shading issue of possible concern – that from nearby foliage – is considerably more complex to both appraise and model. It is also likely to be more important in established rather than new suburbs. This shading issue may be explored as a future case study, with hilly Wellington being high on the list of likely trial locations.

Findings

Table 8 shows the local recession plane influence on living room thermal comfort (which is passively acquired) on the typical stand-alone house during the 7am–11pm period. The resulting thermal discomfort is measured using the degree-hours metric. This metric is simply the product of the temperature below a nominated set point (in this case, 18°C) and the annual time spent below this temperature (in hours). It is an easy way to comprehend the severity of the change in thermal comfort, as the more extreme the temperature is, the larger its effective weighting/value.

As can be seen in Table 8, the builder's/developer's influence is considerable in terms of winter-time comfort provision, based on a typical single-storey house.

Table 8. Annual daytime discomfort in a typical lounge during heating season.

Location	Daytime discomfort resulting from adjacent site (degree-hours)		
	No buildings and no shading	Built to local recession plane rules	Resulting increase in daytime discomfort
Auckland	1,226	2,795	128%
Hamilton	3,340	5,289	58%
Christchurch	10,794	14,190	31%
Unweighted mean of 3 regions			**72%**

The varying – and sometimes unclear – recession plane and set-back approaches between authorities is concerning and needs to be remedied.

For example, the terms 'daylight' and 'sunlight' are used interchangeably, when they are very different issues:

- Auckland Council Unitary Plan Appendix 10: "Its primary purpose has been to ensure that residential zoned properties … adjoining new building developments receive adequate minimum amounts of daylight."[8]
- Invercargill City Council District Plan: "The recession planes are calculated to reduce shading and to ensure a minimum allowance of sun and natural light for both you and your adjoining neighbours."[9]
- Gisborne District Council guidance: "These rules are designed to protect your neighbour's access to sunlight."[10]

From this BRANZ mini study, the efficiency of district plan rules must be called into question.

[8] https://unitaryplan.aucklandcouncil.govt.nz
[9] https://icc.govt.nz/wp-content/uploads/2017/03/Residential-1-and-1A-Zones-1.pdf
[10] https://www.gdc.govt.nz/guide-to-residential-development/

Notable points

- The randomly selected homes' excellent solar potential continues for Y2016 – at least when topographic features are concerned – remaining close to 100% of what an unobstructed horizon would provide.
- Each of the three cities' district plans have a considerable impact on passively derived daytime winter thermal comfort when adjacent homes are designed to allowable recession plane envelopes in the northern aspect. Building to these envelopes results in an average of 72% more discomfort (based on a typical' house) when measured in degree-hours with an 18°C comfort threshold.
- The vast difference in thermal impacts between the various regional recession planes needs to be explored further with councils and the Ministry for the Environment's current national planning standards initiative.[11] This seeks to rationalise the disparity of approaches by councils currently to make their plans and policy statements easier to prepare, understand, compare and comply with.
- It is likely that many laypeople's understanding of recession planes is to ensure good access to wintertime sunlight. Therefore, the varying – and often unclear – recession plane approaches between districts is concerning.
- A key question around shading from nearby buildings is: How is an 'adequate standard of daylight/sunlight' defined and by whom? This may be explored in the future with BRANZ scientists working with planners.

5.4 Whole-house resource efficiency

Background

This indicator acknowledges the importance of living modestly by responding consciously to our resource-constrained world. Providing a suitable indicator for whole-house resource use/efficiency that effectively simplifies, quantifies and communicates this is challenging – see the Y2012 report section 5.4 for more details. It was decided by the advisory group to extend the whole-house indicator to better account for embodied carbon, reflecting carbon's growing importance.

As a result, this section is now spilt into two parts, covering both the former metric examining whole-house resource efficiency via a spatial proxy and a new metric examining the embodied carbon in a house-lot of materials.

The whole-house resource efficiency indicator determination remains unchanged for Y2016. It is simply the ratio of the conditioned area of the house to the number of bedrooms. The lower the number, the more efficient the design is spatially and, by extension, the better use of resources house-wide.

As building lifetime CO_2 emissions decrease with the advent of new and more efficient technologies, the proportion of emissions from their component materials increases. Studies have shown that material-related CO_2 can make up a substantial portion of the lifetime carbon emissions (UKGBC, 2015; Giesekam et al., 2015, 2016; Ibn-Mohammed et al., 2013). The exact proportion is dependent on a number of characteristics including building use, location, material palette, service life and future energy supply (Ibn-Mohammed et al., 2013) as well as whether international trade is taken into consideration (Vickers et al., 2018).

[11] https://www.mfe.govt.nz/publications/rma/draft-national-planning-standards

This 'carbon spike' associated with the construction phase can dominate life cycle emissions in the time horizon relevant to adopted climate mitigation goals (Heinonen et al., 2011).

As a result, it has been argued that greater weighting should be attached to these material-related emissions over future emissions savings in economic analyses and policy making (Rhys, 2011; Vickers et al., 2018). This response aligns well with the advice provided by the most recent New Zealand Productivity Commission report, which recommends how New Zealand can best make the transition to a low-emissions economy (New Zealand Productivity Commission, 2018).

If New Zealand is to seriously examine building-related carbon contributions, those attributable to the construction phase (i.e. resulting from material selection) of new housing stock need tracking and reporting on.[12] This Y2016 report is New Zealand's first formal attempt to track embodied CO_2 emissions resulting from the construction of new detached dwellings over time. In future reports, the BRANZ LCAQuick – Residential tool[13] will be applied to provide considerably more comprehensive figures.

The total volume of materials used in the construction of new detached dwellings across New Zealand can be estimated with market share information from the BRANZ new dwelling survey. BRANZ surveys the builder/designer of approximately 5,000 new residential buildings per year, collecting information on the materials used in their construction (Rosevear & Curtis, 2017).

Survey data is supplemented with national building consent data and transfer ratios. Transfer ratios are used to express the average ratio of building elements such as walls and framing to the building floor area and are based on typical residential construction industry floor plans. This captures commonly used materials very well but may overstate or understate the share of less-common materials.

Further methodological details, including boundaries and caveats, are discussed in Appendix A.

Findings

Whole-house resource efficiency

The resource efficiency 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. The lower the number, the more efficient the house is likely to be. The NOW Home® was designed specifically to address this issue and, as a result, forgo indoor transition spaces (hallways) as a way of moving people from one space to the next in addition to having compact bedroom spaces. Thus, a figure of 29 should be seen as a very good result for this metric and might be aspirational for many.

Once again, the randomly selected stand-alone homes in the locations of Auckland, Hamilton and Christchurch represented the nation's housing stock. Some key statistics are shown in tabular format in Table 9. As can be seen, there is very little movement in the resource efficiency numbers between years for all three locations, but also the scores for Hamilton indicate very good spatial efficiency.

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[12] Dr David Dowdell, BRANZ Principal Scientist, personal communication, February 2018.
[13] www.branz.co.nz/buildingLCA

Table 9. Key statistics for whole-house resource efficiency in three locations.

Whole-house resource efficiency (conditioned area in m^2/number of bedrooms)									
Location	NOW Home®		Mean		50th percentile		80th percentile	
	2012	2016	2012	2016	2012	2016	2012	2016
Auckland	29		33	31	31	30	37	35
Hamilton			30	30	30	30	34	35
Christchurch			34	34	32	33	41	40

Embodied carbon for house-lot of core building materials

Table 10 provides an estimate of the climate change impact (based on CO_2 eq.) arising from materials in new-build stand-alone construction in New Zealand for the 2016 calendar year. These are an underestimate because the following components are excluded:

- Material wastage generated at construction sites. These rates vary depending on the material[14] – for example, for a material with a 10% wastage rate, 1.1 kg of the material will need to be manufactured in order that 1 kg can be used in a building.
- Transport of materials from manufacturer to the construction site – materials may be imported and/or transported long distances by truck.
- Wall and ceiling linings, insulation, floors, paint, plumbing, electrical, fixtures and fittings. These items, which can be carbon intensive, have been omitted for simplicity and lack of easily sourced information but may be included in future studies. These items have been labelled as 'Other' in Table 10.

Table 10. Estimated elemental embodied carbon in new detached houses in 2016.

Element type	Embodied carbon (tonnes CO_2 eq.)
Total for framing	-173,791
Total for foundations	180,422
Total for roofing (excluding Other)	72,850
Total for wall claddings (excluding Other)	33,070
Grand total all houses	**112,551**
Embodied carbon per house	**5.28**

As the number of new detached house consents in the calendar year 2016 was 21,310,[15] the average embodied carbon attributable per house for its major elements is estimated to be 5.28 tonnes CO_2 eq.

This figure is in line with another report looking at the embodied carbon content of New Zealand homes (Drysdale & Nebel, 2009). They cite a figure of just under 11 tonnes of CO_2 but include all building components. The BRANZ figure of 5.28 tonnes of CO_2 eq. also reflects the more rudimentary online calculator by NZ Wood.[16]

[14] An estimate of wastage rates at construction sites is provided in the Module A5 datasheet available in the Data section at www.branz.co.nz/buildingLCA.
[15] Source: Statistics NZ.
[16] www.nzwood.co.nz/learning-centre/house-calculator (accessed February 2018)

Only the Y2016 estimated elemental embodied carbon for new homes has been provided for this report, as the dataset was incomplete for retrospective Y2012 determination.

Notable points

- The whole-house resource efficiency figures (i.e. the mean, median and 80th percentile) for Y2016 remains similar to that of the Y2012 figures.
- The embodied carbon in building materials will likely become a new metric for resource efficiency and was therefore introduced in this Y2016 report.
- It is likely that this indicator will broaden to include more building components, reflecting the growing amount of embodied carbon information available. A current BRANZ project is about to release a carbon accounting tool for residential buildings (LCAQuick – Residential). This will automate the calculation needed and provide a more comprehensive result. In addition, it will set benchmarks for the various dwelling typologies, to track progress over time and to see how well they align with the 2050 Carbon goals (using the BRANZ carbon budget figures).
- It is likely that this metric will become increasingly important as New Zealand tries to meet its carbon obligations (mainly through the recently passed Zero Carbon Bill) to keep the global average temperature below 2°C above pre-industrial levels. This will require radical changes to the way nations operate.[17]

5.5 Household water-saving devices and consumption

Background

Water management is a key area of concern for many territorial authorities. This is echoed in the National Performance Review of Water Utilities (NPR): "Water is an essential resource that should be managed in a way that optimises the benefits of its use while minimising its wastage" (Water New Zealand, 2013, p. 19).

Using rainwater tanks as a proxy for efficient water management practices (as was done in the Y2012 study) is a less than an ideal metric. In addition, it is uncertain whether having a rainwater tank is environmentally more beneficial than the more conventional town supply in terms of carbon (see section 5.12).

Consequently, a new metric has been introduced to better capture the use of household water saving devices and consumption: average daily (per capita) residential water consumption. This leverages the online NPR resource.[18] Details of this calculation method are described in Appendix D.

The NPR, annually conducted by Water New Zealand, provides a yardstick for all those interested in metrics around public drinking water, wastewater and stormwater services. The resultant data is included in the International Benchmarking Network for Water and Sanitation Utilities[19] database, which enables global comparisons of some performance indicators.

As such, the new metric is well aligned to the desirable sustainability indicator characteristics outlined in the Y2012 report (section 2.2).

[17] www.reuters.com/article/us-climatechange-germany/radical-change-urged-over-20-years-to-attain-climate-goals-institute-idUSKCN1G727L
[18] www.waternz.org.nz/NationalPerformanceReview
[19] https://www.ib-net.org/

Findings

Table 11 shows the daily water consumption of many major urban areas in New Zealand for Y2012 and Y2016. Unfortunately, due to the newness of the collection method, there are a limited number of councils included in the table.

Because of inconsistent reporting methods applied by the various jurisdictions during early data collection, only those regions with a greater than 20% difference in water usage have been noted as changed.

Table 11. Estimated daily residential water consumption, for New Zealand cities.[20]

Council	L/person/day Y2012	L/person/day Y2016	Change > 20%
Whangarei	174	172	Stable
Rotorua	225	296	**Increase**
Hamilton	198	246	**Increase**
Tauranga	197	178	Stable
Taupo	287	364	**Increase**
New Plymouth	281	337	**Increase**
Wellington	225	256	Stable
Dunedin	221	172	**Decrease**
Invercargill	236	193	Stable

Some caveats with this data are listed in Appendix D, the main one being that the NPR covers all dwellings rather than just those detached and new. Given that it is unknown whether there is a distinction in volumetric usage between existing and new housing stock, it is assumed (until disproved) that its water needs are no different.[21]

Notable point

- In terms of the estimated daily water consumption, Rotorua, Hamilton, Taupo and New Plymouth all increased their usage when comparing Y2012 with Y2016. Conversely, Dunedin decreased its daily water consumption during this time – the only city to do so. The degree to which demand management interventions such as residential behavioural and attitudinal changes influence this figure is unknown.

5.6 Comfortable indoor temperatures in a key occupancy zone

Background

The methodological approach and reasons for choosing this indicator remains unchanged from the Y2012 report. It is suspected that, even though obtaining comfortable indoor dwelling temperatures via passive solar means is relatively easy in New Zealand's comparatively clement weather, for most of the population, it is still extremely unusual.

The 70 randomly selected consents from Christchurch were initially computer simulated in free-running mode to better understand the level of occupant comfort achieved

[20] Lesley Smith, Water New Zealand, personal communication, 14 November 2017.
[21] This may be become more transparent with the BRANZ Levy project looking to disaggregate water end use for a large sample of homes in the 2017–2019 period.

through passive solar means only. The idea was to determine whether there were any performance changes from Y2012.

The proxy for whole-house thermal comfort used was the number of daytime hours that the main living room temperature 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 4 shows the amount of time living room temperatures are comfortable during 7am–11pm for the randomly selected 2016 stand-alone Christchurch new-builds.

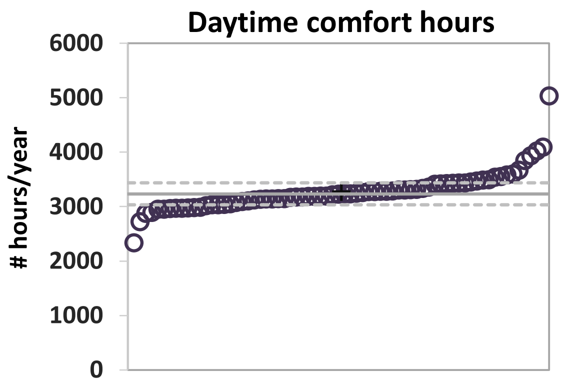

Figure 4. Comfortable living area daytime temperatures for Christchurch houses.

Table 12 extracts some key statistics alongside the NOW home® data and shows that Y2016 results are almost unchanged from the Y2012 results.

Table 12. Daytime living-area comfortable temperatures via passive solar means.

Location	NOW Home®		Random mean		50th percentile		80th percentile	
	hrs/yr	% of daytime	hrs/yr	% of daytime	hrs/yr	% of daytime	hrs/yr	% of daytime
Y2012 Christchurch	4419	76%	3248	56%	3296	56%	3422	59%
Y2016 Christchurch			3272	56%	3229	55%	3436	59%

Notable points

- Once again, there is a substantial difference between the best-performing and the worst-performing passive solar houses.
- In terms of daytime (7am–11pm) comfort, there has been no improvement in the randomly selected houses consented in Y2016 compared to those selected in Y2012.
- There is a vast difference between the thermal competence of the randomly selected stand-alone houses consented in Y2016 and the NOW Home®. This is true even through the NOW Home® was designed for a considerably more temperate climate for which the NZBC requires considerably lower thermal envelope insulation values.

5.7 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 5.6, which examines performance during active conditioning. It 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 the Y2012 report. Once again, the randomly selected dwellings were thermally simulated in AccuRate NZ where 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.

Findings

Figure 5 displays the amount of time the main living room temperatures are uncomfortably hot (temperatures greater than 25°C) for the 70 randomly selected 2016 consented Christchurch new-builds. It shows the extreme performance difference between houses that have been well designed and those that have not, with a factor 9 difference in the discomfort metric used.

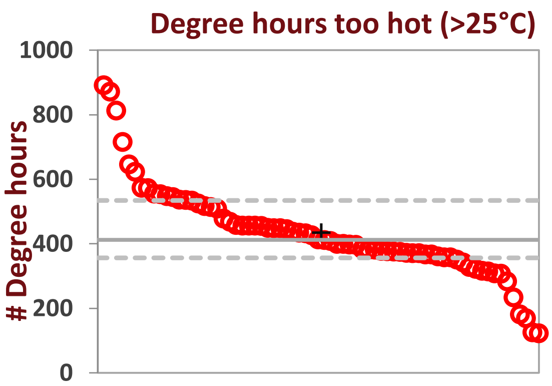

Figure 5. Overheating severity in main living room for the Christchurch houses.

Table 13 extracts a key comparative statistic from the NOW Home® to benchmark the randomly selected homes against. It shows that randomly selected homes overheating (defined as temperatures greater than 25°C) is almost unchanged for both the mean and median reference points.

Compared to the NOW Home®, the random homes have considerably more overheating in a key area – the lounge. This suggests that randomly selected designs didn't consider shading in a meaningful way.

Table 13. Key overheating statistics in Christchurch.

Overheating (degree-hours/yr)	NOW Home®	Mean	50th percentile	80th percentile
Christchurch (2012)	151	433	417	496
Christchurch (2016)		435	412	534

Figure 6 shows the amount of times (in number of days per year) the main living room temperatures are critically cold when not using artificial heating/cooling for the randomly selected Y2012 stand-alone new-builds. Only one house bests the NOW Home® in terms of providing fewer critically cold living room temperatures – in this case having zero days per year – against the research home's seventeen.

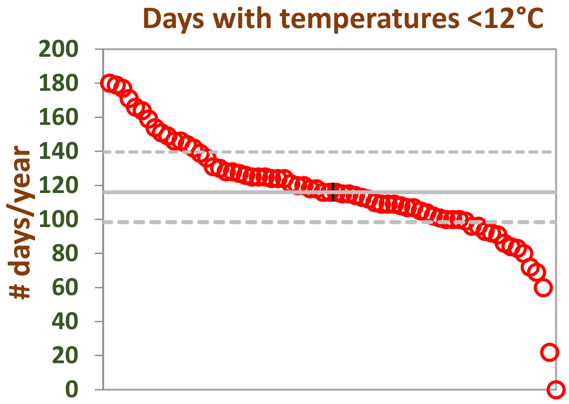

Figure 6. Critically cold living room daytime temperatures for Christchurch houses.

In Table 14, the NOW Home® displays its considerable thermal advantage, demonstrating how a well-designed home performs in terms of keeping its occupants thermally protected against unhealthily low temperatures.

Table 14. Daytime length living rooms are critically cold in Christchurch houses.

Location	# days outside temperature falls below 12°C (days/year)	NOW Home® # days mean indoor temperature <12°C (days/year)	# days mean indoor temperature <12°C	# days indoor temperature @ 50th percentile (days/year)	# days indoor temperature @ 80th percentile (days/year)
Christchurch (2012)	258	17	125	126	137
Christchurch (2016)			116	116	140

Notable point

- Once again, there is a large 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 both uncomfortably hot and unhealthily low temperatures when using the main living space as a proxy for the whole house.

5.8 Proximity to key amenities and public transportation

Background

The many benefits to having a home within proximity to amenities have remained unchanged since the Y2012 report (Auchincloss et al., 2013; Rogers et al., 2011). Web tools, utilising GIS-based mapping to assess how well a location is serviced by key nearby amenities and public transportation links, have also remained largely unchanged. The USA-developed web-based tool Walk Score® (www.walkscore.com) and its companion tool Transit Score® have been reapplied to this Y2016 report for quickly and accurately determining a location's nearby amenities. The tool applies a 1–100 scale where the higher the figure, the more walkable/public transport-friendly a location is.

As before, a Walk Score® of 50 or more translates to 'somewhat walkable' – where a reasonable number of errands can be accomplished on foot. Likewise, a Transit Score or 50 or more equates to 'good transit', where a reasonable public transportation service is available. The newly developed homes.co.nz, which collates property data into a user-friendly format, states that "anything with a score above 90 means you can accomplish all of your errands without a car or reliance on public transport".[22] More details on these two metrics can be found in the Y2012 report (section 5.8) or by visiting the Walk Score® site.

Findings

Table 15 extracts some key walkability statistics by location, targeting the 50th and 80th percentiles for the three cities. As can be seen, the largest shift is in the Hamilton median results, with a decrease of 9 Walk Score® points, and Christchurch in the 80th percentile, with an improvement of 14 Walk Score® points.

Table 15. Walkability statistics of Y2012/Y2016 homes in three locations.

Walk Score® rating	50th percentile		80th percentile	
	2012	2016	2012	2016
Auckland	54	57	66	69
Hamilton	22	13	38	32
Christchurch	27	26	36	50

The Hamilton results are concerning. Looking at individual consents shows that approximately 10% of all new homes rate a 0 in Walkscore®. This results in a very car-dependent living situation, which is undesirable for many reasons as noted in the Y2012 report section 5.8.1. Auckland still takes top spot in walkability of the randomly selected developments. Table 16 extracts some key transport statistics by location, targeting the 50th and 80th percentiles for the three cities, showing the Transit Score® trends. The public transport utility remains almost unchanged for Auckland. Transit Scores are still not available for the cities of Hamilton and Christchurch.

Table 16. Transit Score statistics of Y2012/Y2016 homes in three locations.

Transit Score® rating	50th percentile		80th percentile	
	2012	2016	2016	2016
Auckland	48	48	55	54
Hamilton	NA	NA	NA	NA
Christchurch	NA	NA	NA	NA

Notable points

- As for the Y2012 report, only Auckland city has a Walk Score® and Transit Score® that suggests it can be described as having reasonable public transport facilities when median values are assessed.

[22] https://blog.homes.co.nz/nzs-most-walkable-cities/. Accessed 2 February 2018.

- Hamilton city had the largest decline in its walkability rating – dropping 9 points on its median values. This may result from the urban sprawl currently happening.
- In terms of the three cities' proximity to public transportation, only Auckland collects this data. Its transportation amenity remains unchanged from Y2012.

5.9 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). The Y2012 report section 5.9 should be referred to, as little has changed in terms of the importance and approach taken for determining the uptake of UD features since. Lifemark® (www.lifemark.co.nz) has, however, reclassified its 1–3-star rating system to fit its new 3–5-star rating system. According to Lifemark®,[23] there has been no change in the rigour around the star levels. The change is more reflective of international best UD practice and the growing interest in medium-density design and construction.

Findings

For the calendar year ending 2016, a cumulative total of 3,243 (or a per capita of 1/1,450) new stand-alone houses were built to Lifemark® Design Standards in New Zealand. This includes 502 stand-alone homes certified in 2016. This compares to a cumulative total of only 706 certifications in 2012 (or 1/6,250), partially made up of 225–250 stand-alone homes. In terms of wider integration initiatives, Thames-Coromandel District Council incentivised the incorporation of UD standards into residential plans in 2016. This has resulted in over 10% of all new dwellings being built and independently verified to a Lifemark® 3-star rating (Penrose, 2019).

Although initially this may seem a very positive result (at approximately two times the yearly uptake since the Y2012 report) for such a beneficial new-house feature set, recent studies paint a more sombre state of affairs in terms of industry engagement. A 2016 report specifically looking at the lack of awareness of UD in the building industry (Saville-Smith et al., 2016, p. 15) states: "The core problem is the problem of mobilising public and private sectoral change … the take-up of universal design needs a multi-pronged strategy of incentivisation, regulation and demonstration."

The low engagement of the building industry in UD was demonstrated in the survey response, which was sent to 600 yet only 16 chose to participate. This was summarised in the report as:

> "Whether delivering housing or consuming housing, there remains a deep lack of awareness of universal design. What is even more problematic is the apparent inability to access accessible design from the building industry even when it is desired and explicitly sought by householders." (Saville-Smith et al., 2016, p. 14)

This stance reflects previous New Zealand-based findings (Saville-Smith & Saville, 2012). It also states that:

> - "Householders struggle to get accessibility embedded in design and builds even when they are knowledgeable and explicit about their requirements.

[23] Helen James, Lifemark®, personal communication, 25 October 2017.

- Householders who do achieve accessible design dwellings report considerable satisfaction across a number of functional and comfort dimensions." (Saville-Smith et al., 2016, pp. 14–15).

Notable points

- As in Y2012, there are likely to be few 2016 consented stand-alone houses that provide a comprehensive UD approach to the equivalent of Lifemark® certification that are not captured here. However, this assertion cannot be confirmed but is assumed for this report.
- The number of new houses featuring comprehensive UD features is still very small in absolute terms. However, as a proportion of New Zealand's population, there has been a marked increase in uptake – equivalent to over a quadrupling of house designs certified compared to Y2012.
- Overall, there is still a very low engagement in UD by those who deliver or consume housing. This needs a multi-pronged strategy of incentivisation, regulation and demonstration to rectify.

5.10 Climate change implications on indoor thermal comfort

Background

In the Y2012 report, the predicted climate change implications on indoor thermal comfort of a subgroup of detached houses in the cities of Auckland, Hamilton and Christchurch were examined. Thermal modelling and simulation were undertaken for the NIWA-predicted climates of 2030 and 2080 that had been applied to previous BRANZ climate change forecasting studies (Mullan et al., 2006; Bengtsson, Hargreaves & Page, 2007; Bengtsson et al., 2007).

Findings

As the NIWA climate change models applied in the Y2012 report remain relevant now[24] and the thermal aspects of the house designs have not changed noticeably in the intervening years, it was decided not to rerun the Y2012 thermal simulations.

Notable point

- The Y2012 report's corresponding section 5.10 findings remains valid (and therefore unchanged) for this Y2016 report.

5.11 Housing affordability and cost of key enviro-features

Background

The mean construction cost of an average house – rather than an apartment – has risen 28% over the past 5 years (Johnson et al., 2018). New Zealand's house prices were found to be among the most unaffordable in the world in 2016 by international research (Cox & Pavletich, 2017). The Demographia International Housing Affordability Survey rates housing affordability based on the median house price divided by median household income. Areas are classed as 'seriously unaffordable' between four and five times income and 'severely unaffordable' when the ratio is more than five times

[24] Brett Mullan, Principal Scientist – Climate, NIWA, personal communication, June 2017.

income. Overall, New Zealand housing in 2016 was rated as 'severely unaffordable', with a median multiple of 5.9. Auckland was rated as the fourth least affordable among the 92 major international housing markets (Cox & Pavletich, 2017).

Perhaps one the most interesting housing affordability studies carried out since the Y2012 study was Beacon Pathway's 'cost tower' report (Collins & Bealing, 2016). Although restricted to Auckland's social housing market, it examines the actual costs of real recently constructed homes. Costs were based on data derived from five builders/developers covering 69 affordable and social homes built in 2015. Costs were broken down into seven categories, where the focus was on the costs of housing as opposed to the final price that might be charged for a dwelling on a site. A summary by cost category is shown in Table 17.

Table 17. Cost categories for new social housing in Auckland.

Cost categories	Percentage
Land	25.8
Development	1.8
Professional fees	4.1
Construction	51.4
Council fees	4.0
Finance, valuation and real estate	3.8
GST	9.0

The most surprising finding for many would be that the land cost only makes up about a quarter of the overall build cost. Construction costs ranged from a lowest-quartile median of $1,617/m^2 to $2,569/m^2 in the top quartile – a considerable range. Land development costs also had large variances, with the lowest quartile being approximately a third of the top quartile over the 69 homes examined.

This report's advisory group felt it necessary to further explore financial-related issues in this Y2016 follow-up to better capture the state of play. As a result, there have been some changes to this subsection – including the title and the widened scope. Now it incorporates not only the initial cost of some key enviro-features typically associated with more sustainable houses but also an examination of whole-house affordability. It should be noted that the efforts to improve the environmental performance don't include zero or negative-cost features, which might be as effective in terms of impact. Examples of this include orienting the house better for solar access, a less-complex form for buildability/thermal integrity or even just less window area.

Housing affordability

The revised approach for Y2016 presents three discrete financial-related indices. In addition to the original cost examination of up-specifying of enviro-features, two housing affordability indicators were introduced – a new-build index and the relative cost of ownership index. The BRANZ Construction Industry Dashboard[25] was utilised to provide the new-build index, while the relative cost of ownership index was especially developed for this Y2016 report by BRANZ economists.

The new-build index, originally developed by BRANZ economists (Norman et al., 2014), captures movements in the purchase cost of new housing. It does this by tracking the

[25] https://sites.google.com/a/branz.co.nz/branz-construction-dashboard/

cost to deliver a standard 200 m^2 single-storey house on a 500 m^2 section, based on the average value of a new building consent (via Statistics NZ) and median land sale price (via REINZ). Specifically, it shows how housing costs change relative to overall prices. Prior to this, the only affordability indices covered the whole housing stock existing (Norman et al., 2014). The index base year is set to June 2012 = 1000. 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 Statistics NZ) and average floating mortgage interest rates (via the Reserve Bank of New Zealand). 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 is common practice.[26] The index base year is set to June 2012 = 1000.

Cost of enviro-improvements

Once again, the initial purchase cost of various building-related items was determined using a variety of methods, including:

- www.qvcostbuilder.co.nz for the insulation figures, which effectively replaces the (now defunct) Rawlinsons New Zealand Construction Handbook
- replicating Y2012 anonymous industry surveys
- online shopping for the sourcing of rainwater and LED costs, based on the average price of two large retailers.

Note that the thermal mass purchase cost figure (see the Y2012 report section 5.11) has been abandoned, as comparative Y2016 figures could not be sourced.

Findings

Housing affordability

Table 18 shows the period 2012–2016 featured strong growth in the housing market, with worsening affordability for new housing. The cost of new housing has grown 22.2% over these 4 years, as measured by the cost of new housing index.

Table 18. BRANZ new-build index.

Year	New-build index (as a nation)
2012	1000
2016	1222

Table 19 shows the cost of ownership has increased in all three cities over this period, driven by strong growth in the price of existing houses, which has exceeded growth in household incomes. Auckland has experienced the greatest increase in the relative cost of ownership, up by ~36%. This is followed by Hamilton with a ~15% increase, largely due to spill-over effects from the Auckland housing market. The relative cost of ownership in Christchurch has remained steady. This was initially driven by a shortage of housing during the earthquake recovery. However, strong growth in incomes in Christchurch has suppressed the growth in house prices. Interest rates over this period have remained relatively steady and have not influenced movements in the relative cost of ownership.

[26] Nick Brunsdon, BRANZ economist, personal communication, 2017.

Table 19. BRANZ relative cost of ownership index.

	Relative cost of ownership index (by city)		
	Auckland	Hamilton	Christchurch
2012	1000	1000	1000
2016	1362	1146	1002

Cost of enviro-improvement

Table 20 shows the cost increases for specifying a house-lot of 'better than typical' double glazing units and enhanced thermal wall and ceiling insulation.

Table 20. Purchase plus install cost increase of thermally improving typical house.

Item	Improvement	2012 (cost increase)	2016 (cost increase)
Double glazing	Standard aluminium double glazing upgraded to a thermally broken frame and low-E coating	33%	30%
Thermal insulation	Wall (R2.2 upgraded to R2.8) in zone 1, 2	44%	96%
	Wall (R2.6 upgraded to R2.8) in zone 3	23%	34%
	Ceiling (R3.2 upgraded to R4.6) in zone 1, 2	31%	40%
	Ceiling (R3.6 upgraded to R5.0) in zone 3	49%	47%

The increase in cost for up-specifying the double glazing was approximately 30% (or $7,370 for the house-lot) in 2016. The combined glazing-framing extra cost for 2012 is approximately $6,210, which equates to a 33% price increase over the standard specified double glazing.[27]

In 2016, the average (national) cost of a new-build house is estimated to be $467,000.[28] Assuming this cost reflects the typical house selected for this study, the up-specified double glazing add some 1.6% to this new-build cost. For some, this would seem to be excessive, being an upfront cost that they are not required to meet. For others who factor in its resulting lifetime thermal benefits, it is a worthwhile expense addressing the most critical component of the thermal envelope. Based on a recent BRANZ study (MacGregor & White, 2019), 48% of the building industry thought their clients would meet these costs (of up to $6,000), assuming it was accepted as a high-performance feature.

The methodology for up-specifying the wall and ceiling insulation levels was consistent with that used in 2012. In terms of the thermal insulation improvements, there is a considerable price jump if wanting to do better than the minimum allowable in the NZBC. The costs above include the purchase and installation costs. This has implications for what new homeowners will likely defer to when given the opportunity to choose between Code levels and enhanced levels of ceiling/wall insulation. Table 21 shows the costs of commonly specified LED lighting for houses has dropped considerably, reflecting a more mature product combined with the benefits of mass adoption. This product is now becoming a standard feature in new houses (Ade & Rehm, 2019) so will not be included in the follow-on study. Rainwater tanks have only

[27] It should be noted that the Y2012 report erroneously included the extra costs for just improved framing rather than the improved glazing-framing combination in its costings. This has been corrected.

[28] Matthew Curtis, BRANZ economist, personal communication, November 2017.

been included here for their resilience attribute, as they are not now considered to meet this study's new thresholds for significance of environmental impact and likelihood to consistently deliver its intended purpose (see section 5.12 for the reasoning behind this).

Table 21. Purchase-only cost of improving typical house specifications.

Item	Specifics	2012 price $	2016 price $	Units
Lighting	LED (5 W)	18.49	8.00	$/lamp
	LED (10 W)	29.97	11.50	$/lamp
Water collection	Rainwater tank (3,000 litre)	1,029	1,013	$/tank
	Rainwater tank (5,000 litre)	1,363	1,410	$/tank
	Rainwater tank (25,000 litre)	3,023	3,075	$/tank

These figures need to be contextualised in terms of the wider residential building materials costs in New Zealand. The first-quarter building material costs have risen by approximately 8%[29] in Y2016 compared to Y2012.

Notable points

For the period 2012–2016:

- In terms of New Zealand's housing affordability, the cost of new housing has grown 22.2%, 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 all three cities, with Auckland experiencing the greatest increase in the relative cost of ownership, up by approximately 36%.
- The upfront purchase cost of some environmental features, such as LED lighting, has dropped considerably. Rainwater tank costs have remained stable.
- The increase in purchase plus installation price for some enviro features, such as thermally broken aluminium window frames, has remained stable at around a 30% premium.
- The increase in purchase plus installation price for some enviro features such as better wall/ceiling insulation has remained similar for all but the R2.2 upgrade to R2.8 wall product, which has seen more than a doubling in price. It is unknown why this is the case.

5.12 Demand for key sustainability features and services

Background

This section overviews the Y2016 demand for key features and services that support new more sustainable (detached) houses. Once again, the shortlisted features and services are not comprehensive but aim to provide a current national snapshot.

In terms of features, the Y2012 report classified three as representing a sustainable purchase with respect to newly built houses: integrated photovoltaic (PV) panels, solar thermal for water heating and rainwater storage. It was stated that there is some uncertainty regarding the sustainable benefits of installing each of the three features into homes. However, on balance, it was assumed that the overall sustainability-related benefit is positive.

[29] Source: http://archive.stats.govt.nz/infoshare/, accessed 24 July 2018.

As before, all three facets of sustainability (social, economic and environmental) are considered. It is acknowledged that this is a complex balancing act that must account for a dynamic energy market both in terms of carbon content and price, public versus private good, local versus regional/global issues, short-term knowns and long-term unknowns and a paucity of robust life cycle information. However, the overriding emphasis is on environmental concerns for this report where CO_2 emissions are being used as a proxy for impact. This time, a re-examination of sustainability features considers new evidence and a more nuanced approach. Thus, more prominence is now on the feature's significance and likelihood to consistently deliver its intended purpose. It is hoped this will result in a more robust feature set.

Ideally, whole-of-life environmental, financial and social assessment should be carried out to provide more robust and transparent guidance, using an appropriate international standard such as EN 15804:2012 *Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products* or EN 15978:2011 *Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method*.

As an example, for the rainwater storage feature, the environmental functional unit for this life cycle assessment might be the amount of carbon (dioxide) required to deliver drinking-quality water to the household tap. The metric might be kg CO_2/m^3 of potable water, conducted over a 100-year timeframe. This would allow a fair comparison of the two delivery systems – municipal versus rainwater storage. Due to limitations in current data, this level of comprehensiveness is not possible yet in New Zealand.

Photovoltaic systems

More recently, there have been several New Zealand-specific studies examining the various sustainability aspects of residential technologies available today. The most comprehensive were produced by Wellington-based Concept Consulting Group, exploring the likely environmental, economic and social implications associated with widespread uptake of grid-connected PV and electric cars for New Zealand (Concept Consulting Group, 2016a, 2016b, 2017). These three reports, using various sensitivity studies and future scenarios, concluded that, for New Zealand, residential PVs – whether immediately supplying energy (on-site) or via delayed storage (battery-assisted) – are not particularly beneficial at reducing carbon. This is because of New Zealand's usual electricity generation mix that is powered mainly via highly efficient low-carbon renewables, chiefly hydro. They predict that the uptake of residential-installed grid-tied battery-less solar PV panels in New Zealand will likely result in fewer, considerably lower-emission hydro-power stations being built to meet demand. As stated in the report:

> *"These conclusions appear robust against a range of different scenarios relating to fuel prices, CO_2 prices and electricity demand growth." (Concept Consulting Group, 2016b, p. iii).*

This finding was supported by another New Zealand-centric report (Schwartfeger & Miller, 2015), which also mentions other potential environmental issues with PVs, such as the (typically) carbon-intensive manufacturing process, the use of carcinogenic materials and uncertainties in end-of-life disposal.

Solar PV systems can also be equipped with hot water diverters. These diverters energise the resistive element within pre-existing hot water cylinders after the other domestic electrical loads have been taken care of. Any further excess electricity is then exported to the grid. These add-on diverter units are new and not well known yet and have therefore been discounted for this BRANZ study. However, their lifetime carbon contribution – given the clever utilisation of a very effective energy store that can dynamically respond to varying grid carbon intensities – is an area for further investigation in future updates of this study.

As a result of this growing body of robust evidence, grid-connected residential-based PV will no longer be recognised as being a key sustainability feature for this study when specified on the micro-grid scale. This is even though PV is now an attractive economic investment for some types of New Zealand households with higher daytime loading (Miller et al., 2015). This stance may be revised further in a future update.

Solar thermal systems

Solar thermal (water heating using the sun directly) does have the advantage of time shifting energy needs – where the water tank essentially becomes a zero-cost battery that is recharged during the daytime sunny periods. This feature differentiates this technology from PV in that it can be used for replacing peak and non-peak electricity generation year round with a minimal additional embodied carbon investment. This is important as analysis found that, as hydro is the leading marginal fuel in New Zealand's electricity system, stored energy usable during the non-peak hours when the carbon intensity per unit of energy delivered is higher is more valuable environmentally (Khan et al., 2018).

In addition, solar thermal potentially also assists electricity providers during peak times as hot water cylinder stored energy replaces the much more expensively generated electricity during these times, thus providing a social benefit (Concept Consulting Group, 2017). However, it is conceded that, in terms of economics, residential-based solar thermal may not be worthwhile for the homeowner (PA Consulting Group, 2012). On balance, residential-based solar water heaters are still accepted as being a significant sustainability feature for new houses for this BRANZ study. This may change when further robust information is forthcoming.

Rainwater storage

The most comprehensive study to date on the environmental costs and benefits of residential rainwater storage versus mains supply was carried out over a decade ago (Mithraratne & Vale, 2007). It compared the two main tank material types (concrete and polycarbonate) with the environmental impact of a more standard reticulated (mains) supply. Although the study was Auckland-centric rather than taking a national approach, it concluded that the selection of rainwater tank material is crucial in terms of the life cycle carbon, energy and cost. Mains supply with frugal demand management was found to have the lowest life cycle carbon emissions over a 100-year timeframe – but only slightly better than the concrete rainwater tank when good demand management was used. However, the environmental impacts from waste and stormwater management were outside the scope of this study.

The rainwater storage study's limitations are many – including household make-up, demand management, stormwater management and non-Auckland locations assessed (Mithraratne & Vale, 2007). Given these limitations coupled with the age of the study and the closeness of the two lowest carbon options, residential rainwater tanks have been rejected as a sustainability feature that meets this study's new thresholds for significance and likelihood to consistently deliver its intended purpose. This may change when further robust information is forthcoming.

Other more significant and certain opportunities

What other opportunities exist for new stand-alone homes that have more significant guaranteed outcomes for the environment? Changing a household's private mode of transport to a fully electric car is a guaranteed way to reduce New Zealand's carbon emissions (Concept Consulting Group, 2017) but is currently economically challenging in terms of the upfront cost. Choosing highly efficient heat pump technology for space and water heating (Carrington, 2011) is also environmentally beneficial but more financially acceptable. These and other options are explored further in section 5.2 as well as in a recent BRANZ research report (MacGregor et al., 2018).

Findings

Features specified and desired

Table 22 shows the results from assessment of the randomly selected building consents over the 2 years for the three cities in question. It shows a very low uptake of a feature that is often associated with sustainable houses – solar water systems. There may be an underestimation of actual units built in new houses where owners have installed them after building consent has been given or post-construction. However, this is likely to be the exception due to the extra consent fees incurred.

Table 22. Solar water heaters specified in building consent documentation.

Location	Solar thermal water heating systems specified	
	2012	2016
Auckland (n=~70)	1.6%	2.6%
Hamilton (n=~70)	0	0
Christchurch (n=~70)	1.5%	2.2%

In the Y2012 report (section 5.12), a combined New Zealand Green Building Council (NZGBC) and realestate.co.nz annual national survey was relied upon to provide details of sustainability-related individual features seen as desirable by the public. These two data sources were unavailable in 2016, as the NZGBC decided to discontinue the survey. No comparable replacement survey could be found for this BRANZ update, so this subsection has been refocused to examine new homeowners favouring environmental features via a BRANZ initiative (Curtis, 2017).

The survey was based on 270 responses from the three territorial authorities covering the cities of Auckland, Hamilton and Christchurch (Table 23). Although the survey's focus is on new homeowners' builder satisfaction, it also asks the interviewee other sustainability-related questions. It should be noted that the survey excludes spec-build type houses.

Table 23. Respondents favouring sustainability features in a new home.

Location	Wanted to build for sustainability reasons (%)	
	2012	2016
Auckland (n=90)	9.9	5.6
Hamilton (n=30)	0	3.3
Christchurch (n=150)	13.5	1.3

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'.

More specifically, sustainable buildings have often been considered as a healthy built environment, based on ecological principles and resource efficiency (Kibert, 2012).

Like any self-reporting, the results need to be viewed with caution and be seen as indicative.

According to the BRANZ survey, building for sustainable reasons has only changed for Christchurch significantly (at a 95% confidence) between 2012 and 2016.

Services – whole-house environmental awards

Table 24 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 Passive House Institute New Zealand (PHINZ)
- Living Building Challenge dwellings, certified by the International Living Future Institute
- Net Zero Energy Buildings, certified by the International Living Future Institute

The Y2016 figures in Table 24 were provided by their respective organisations.

Table 24. Whole-house certified numbers by various institutes.

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

Note that there were other environmental-related house awards available on a nationwide basis in New Zealand in 2012–2016. However, 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 three key sustainability features for new homes – PVs, solar thermal and rainwater tanks – previously used in the Y2012 study have all been reassessed for this Y2016 study. This is reflective of the growing and yet incomplete knowledge in this field and the complexity of weighing up the many (and sometimes uncertain) attributes of sustainability.
- A relook at the minimum threshold required for a key sustainability feature to be selected was carried out to increase the robustness of the process in light of recent research. As a result, two features – photovoltaics and rainwater tanks – were dropped. This is not to say that they do not provide some sustainability benefits over the medium to long term, but their likelihood to deliver considerable benefits (especially lower carbon) over other features/initiatives is questionable.
- In terms of demand for sustainable products, there has been a statistically significant decrease in people wanting to build for sustainability reasons nationally when comparing Y2016 with Y2012, but the reasons are unclear.

- In terms of demand for sustainable services, formal whole-house rating tools in New Zealand have increased considerably (i.e. over 7-fold) in the last 4 years. However, in terms of numbers of all new-builds constructed for New Zealand, the numbers are still negligible.

5.13 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 very similar to that used for the Y2012 report.

The nationwide service providers that are easily accessible to the public in 2016 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 Statistics NZ Infoshare online resource (mean year ended / total all ages).[30] The end of year figures are:

- Y2012 = 4,410,700
- Y2016 = 4,696,500.

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. Only two methods were available in 2016 for Homestar™, with the Homecoach option being folded:

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

The 2016 numbers[31] in each category are shown in Table 25.

Table 25. Homestar™ industry practitioners (2012 and 2016).

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

Passive House NZ provides a whole-of-house energy and thermal efficiency building performance standard and certification system and was established in 1996 in

30 http://archive.stats.govt.nz/infoshare/

31 Sam Archer, NZGBC, personal communication, 28 August 2017.

Germany as PassivHaus. The updated service-related statistics[32] are provided in Table 26.

Table 26. PHINZ-accredited practitioners (2012 and2016).

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

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 still numbered seven full-time equivalents (FTEs) in 2016. Previously, they were the only free, independent, nationwide (albeit only representing about 70% of the population) environmental-specific, multi-attribute practitioners operating. However, since late 2014, the Home Performance Advisors (HPAs) enterprise has been operational. An initiative of the Community Energy Network, Toimata (previously Enviroschools) and Beacon Pathway, it provides a complementary advisory service nationally. The number of certified HPAs (including HPA trainers) at the end of 2016 equalled 71.[33]

Table 27. Combined HPA accredited and EDA practitioners (2012 and 2016).

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

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®. Lifemark® Design Standards (www.Lifemark.co.nz), which formalises the assessment process, rates the comprehensiveness of the design into star bands/levels. The recent reclassification has meant that what was previously classified as levels 1–3 is now 3–5 stars. According to Lifemark®,[34] the rigour around the star levels remains unchanged. The reclassification is more reflective of international best UD practice and the growing interest in medium-density design and construction. 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 28.

Table 28. Lifemark® accredited practitioners (2012 and 2016).

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

[32] Guy Shaw, Energy Architecture, personal communication, 24 August 2017.
[33] Vicki Cowan, Beacon Pathway, personal communication, 14 December 2017.
[34] Helen James, Lifemark®, personal communication, 25 October 2017.

Once again, two of New Zealand's largest architectural/design professional organisations – the New Zealand Institute of Architects (NZIA) and Architectural Designers New Zealand (ADNZ) – were asked to provide information on their environmental-related education initiatives. A representative from the NZIA[35] stated that the organisation actively promotes education and advice to members on sustainability issues. This has included presentations by the Green Building Council, Passive House and individual designers and collaborative events with groups such as the IPENZ Sustainability Society. However, they do not provide any substantial, ongoing environmental-specific training as part of their continuing professional development in 2016 as in 2012. ADNZ held a total of 47 events (equating to 71 sessions in various locations) for their members that had significant environmental aspects to them during the year.[36]

The Real Estate Institute of New Zealand (REINZ) is also a very important building industry-related body, representing more than 14,000 real estate professionals nationwide. Bindi Norwall, CE at REINZ, was asked at the 2018 NZGBC Housing Summit whether real estate agents have training and understand environmental choice and benefits as opposed to a focus on larger houses, granite bench tops etc. Her response was that currently there is no environmental module as part of the Real Estate Authority's continuing professional development but this might be something they would consider in the future should an approach be made.

The New Zealand scene is reflective of the international property valuation industry's struggle with valuing sustainability and higher-performance homes. There seems to be a lack of data on the quantifiable effects on market value. Only one consistent formalised nationally recognised procedure to assist the environmental-specific valuation process for house valuers was found in the USA (Jaques, Norman & Page, 2015). The US Appraisal Institute has integrated sustainability considerations into property valuation since 1996 (Lorenz & Lutzkendorf, 2011) but more formally since the real estate industry initiated a suite of resources for Green Multiple Listing, starting in 2010 (National Association of Realtors, 2014). As part of this, guidance documents were developed for appraisers concerning the necessary background and core competencies needed to value green, high-performance or sustainable residential buildings (Baumgardner, 2013). Practical resources include consistent green building definitions and terminology, tailored data collection and appraisal tools and a wider appreciation of these homes for their lower risk and higher quality and comfort in the marketplace.

Just released research (BERL, 2019) supported this thesis of higher performance features not being accounted for more in the value equation by most New Zealand stakeholders but in the wider banking, valuation and insurance sectors. The BERL research found that valuations are holistic overviews largely based on market value and influenced by benchmarks against similar properties rather than features of individual homes. Further, the valuation sector has no mechanism for effectively recording building features that exceed minimum standards (BERL, 2019).

A new, albeit niche, initiative worthy of mention in the provision of sustainable services targeting residential construction is the Superhome Movement. According to its website (www.superhome.co.nz), its aim is to raise standards so that all new homes are healthier and more energy efficient. Its brief to assist in this is to facilitate education,

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[35] John Walsh, NZIA, personal communication, 28 August 2017.
[36] Kris Eriksen, ADNZ CPD Co-ordinator, personal communication, 30 April 2018.

lobbying for change and open-source sharing of new design ideas, technologies and building techniques by connecting designers, builders, researchers, education providers, government, stakeholders and leading experts in the industry to achieve collaboration toward higher building standards for all New Zealand homes. The Superhome Movement is notable because of its growing media presence, constructive cross-industry collaboration and regional-based case-study show homes that are publicly accessible in periodic open house tours. These initiatives combine to provide a strong platform reaching those who may not otherwise be 'in the loop'.

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 (www.ecanz.org.nz) and the Electricity Commission and was operating in 2016.[37] At the time of writing, 67 electrician businesses were registered as providing this service. No such initiative is offered by the New Zealand plumbers, gasfitters and drainlayers trades.

Green mortgages and sales

Kiwibank was still offering its Sustainable Energy Loan programme in 2016, which commenced in late 2012. It assists consumers to fund micro-renewables (solar power, wind energy, small-scale hydro or geothermal resources) 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, providing some provisos are met.

Following its introduction, Kiwibank saw strong interest in the loan in 2013. When comparing 2016 to 2013,[38] there was a 37% increase in the number of Sustainable Energy Loans drawn down. Kiwibank has contributed over $330,000 towards these systems since its inception.[39]

Trade Me Property, New Zealand's most visited online real estate website, still provides no statistics on Homestar™-certified homes in 2016 that are publicly accessible, unchanged from 2012. A spot check was carried out on 30 August 2017 as to the number of houses listed nationally that had the term 'Homestar' somewhere in their descriptions. It was found that there were 32 in total – but of those, only seven were built, with the remainder being potential design-builds.

Notable points

- There has been a groundswell of residential-building sustainability-related practitioners providing tailored advice (HPAs, EDAs, Homestar™, Passive House and Lifemark®). The total number of practitioners increased from 41 in 2012 to 584 in 2016. This is equivalent to one practitioner for every 8,040 New Zealanders in 2016, up from one for every 107,578 in 2012.
- Given that some 21,310 stand-alone houses were consented in 2016 in New Zealand, the supply of comprehensive sustainability-related services is still very small.

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[37] In the Y2012 report, it was incorrectly stated that they were defunct.
[38] 2013 is used as the base year here since the scheme only started part way through 2012.
[39] Ben Bracey, Kiwibank Associate Product Manager – Home Loans/Personal Loans, personal communication, 15 September 2017.

- Perhaps the most promising recent initiative has been the advent of the Superhome Movement. It has engendered considerable interest across diverse sectors as well as successfully facilitating open-source sharing between competitor industry groups.
- There is still no formal recognition of Homestar™ in New Zealand's largest property seller – Trade Me Property.

5.14 Supportive government policy and regulation

Background

Central and local government policies and regulation that facilitated more sustainable new homes for the 2016 calendar year were examined. As before, this could include initiatives such as environmental profiling guidelines, active water management programmes, building warrants of fitness and local body rate reductions for energy-efficient/renewable energy measures. Only operational (rather than just proposed) policies and initiatives relevant to new residential construction (rather than just rebuilds or retrofits) are accounted for here.

Findings

EECA

The resources EECA provided that are applicable to new homes in 2016 are very similar to those provided in 2012. The initiatives include the following:

- A new website specifically for assisting the design of an energy-efficient new home.
- Product standards and labelling (regulation of energy efficiency standards and labelling for products and appliances such as fridges, washing machines, dryers and computer equipment).
- ENERGYWISE™ information (website and other channels such as brochures, advertising and media releases to provide independent, reliable information about energy choices in and around the home), which included information on new homes (www.energywise.govt.nz/at-home/building/).
- The Energy Spot (a television segment that brings energy efficiency messages to a mainstream audience), which is more applicable to older houses.
- Minimum energy performance standards (MEPS) – thresholds for various household appliances.

MBIE

MBIE provided these initiatives that are applicable to new homes in the calendar year 2016

- An amendment to NZBC clause H1 *Energy efficiency*, with NZS 4218:2009 *Thermal insulation – Housing and small buildings* replacing NZS 4218:2004 *Energy efficiency – Small building envelope* in H1/AS1 and H1/VM1.[40] Overall, the requirements in H1/AS1 do not change, but foil insulation is no longer within the scope of H1/AS1.
- The updating of the Smarter Homes website (www.smarterhomes.org.nz) – a consumer-directed resource for more sustainable building/living – which was finally relaunched in May 2017.

[40] www.building.govt.nz/about-building-performance/news-and-updates/all-news-and-updates/bc-update-206/

Local authorities – water management

A separate survey assessed initiatives local authorities were carrying out to improve water management. Table 29 summarises the results.

Table 29. Local authority supporting better water management (2012/2016).

Council	Water meters required in new homes?	Volumetric-based charge?	Excess water use charge?	Any promotional campaign to better manage household water use?
Whangarei	Yes/Yes	Yes/Yes	No/Yes	Yes/Yes
Auckland	Yes/Yes	Yes/Yes	No/Metered, so charge volumetrically	Be Waterwise/Be Waterwise
Rotorua	No/No	_	_	Yes/Yes
Hamilton	No/No	–	–	Water alert levels 1–4/No
Tauranga	Yes/Yes	Yes/Yes	No/–	No/Yes
Gisborne	No – unless "extraordinary user"/No	Only "extraordinary user"/ Only "extraordinary user"	No response / Yes – over 300 m^3	The last educational campaign of note was done back in 2010/Yes
Napier and Hastings	Only in the Bay View Water Supply Area/No response	Yes – each property connected to the supply is charged a UAC for water (both Napier and Bay View)/No response	–	Water conservation advertising campaign, newspaper ads mainly/No response
New Plymouth	No – unless "extraordinary user"/Unchanged	Only "extraordinary user"/Unchanged	No response/ Yes – over 50,000 m^3	Newspaper ad in summer with water saving tips etc./No
Palmerston North	No/No	No response/Same	No response/ Same	No/Yes
Wellington	No – unless "extraordinary user"/No	Only "extraordinary user"	–	Sent out flyer in summer/Yes
Christchurch	Yes/Yes	Residential customers are only charged a targeted rate based on the capital value of the property/ Unchanged	No/Yes	No/Yes – annual residential campaign
Dunedin	No/No response	No response/No response	No response/ No response	No/No response
Invercargill	No/No	–	–/Yes	Yes/Yes

Local authorities – technologies to reduce electricity use

In November 2017, BRANZ updated the 2012 Parliamentary Commissioner for the Environment (PCE, 2012) survey to all New Zealand local authorities to determine their interest in technologies to reduce electricity use for households. The updated survey was for the 2016 calendar year.

The response from local authorities was less than ideal. Although repeated requests were made, 24 councils didn't provide any information for their operations. The following results were forthcoming from the remaining authorities.

Q1. What have you done to encourage solar photovoltaics, solar water heaters or any other technologies that can reduce electricity use for households?

	2012	2016
Councils having subsidy for building consent and/or inspection fees	15	9
Councils considering financing schemes	15	0
Councils with pilot schemes	4	0
Councils with demonstration installations	6	0

Q2. Approximately how many households did you intend to reach with these programmes?

Answers included:

- no set target
- no specific number
- 150 house assessments.

Q3. What is the motivation for any programmes you may have instituted?

Responses included:

- to support the council's sustainability policy
- community benefits
- uptake of technology.

Q4. Do you have any energy-reduction initiatives targeted at newly constructed households only?

Only one Hutt City Council provided a positive response:

> produced, in-house, a video called 'up-spec your build', which describes ways of bringing the thermal performance (and thus their heating requirements) to beyond the bare minimums of the building code.

Notable points

- Two critical central government-based agencies – MBIE and EECA – had not increased their supportive initiatives that directly facilitate more sustainable stand-alone housing when comparing Y2012 with Y2016.
- In terms of water management initiatives that local authorities have supported, there don't seem to be any notable changes from the Y2012 results.
- In terms of technologies that reduce electricity use initiatives that local authorities have supported, there were fewer initiatives to support sustainability-related house construction.

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 two datapoints (studies). Thus, for now, the results are taken at their base quantum with little exploration of statistical significance for this update.

Compared to the eco-consciously designed NOW Home®, the randomly selected Y2016 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 (all three cities)
- more energy-intensive space heating and cooling needs via active means (Christchurch only)
- less daytime thermal comfort in the main living area via passive means (Christchurch only)
- fewer extreme temperatures in the main living area (Christchurch only).

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

There is likely to be **considerable indoor thermal discomfort in the main living zone** in 2016-consented homes due to considerable solar shading from northern-aspect neighbouring houses due to allowable recession planes. This is true for each of the three key cities of Auckland, Hamilton and Christchurch. The average daytime discomfort (measured in degree-hours) resulting from neighbouring houses built to locally allowable recession planes for the three cities is 72%. Urban planners are recognising that new homes are being built closer together, with the rules determining separation distances reducing all the time. This issue needs to be explored further as it is likely that many people would have the perception that recession rules provide shading protection from adjacent buildings.

Compared to the Y2012 findings, the Y2016 figures show that:

- whole-house environmental certificates awarded have increased greatly 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 only decreased in the city of Dunedin but increased in Rotorua, Hamilton, Taupo and New Plymouth
- the number of territorial authorities encouraging better water management practices has remained largely unchanged
- the number of territorial authorities encouraging technologies to reduce electricity usage has reduced considerably
- walkability to nearby amenities is very similar for Auckland and Christchurch, at the 50th percentile, but Hamilton's walkability rating has dropped considerably
- there has been no change in the availability of public transport (Auckland only)

- the incorporation of a comprehensive amount of universal design features in new detached homes has improved, providing better safety, access and usability for all
- the delivery of a standard 200 m^2 single-storey house on a 500 m^2 section has grown 22% in cost since 2012 (nationally)
- mortgage servicing relative to household incomes has increased in all three cities – Auckland has experienced the greatest increase in the relative cost of ownership, up by ~36%
- the number of sustainable energy loans taken out by (in all likelihood) new stand-alone homeowners has increased
- solar water heater demand has remained very low at less than 3% (all three cities).

In terms of sustainability-related features and services supporting new stand-alone homes, there were some positive developments in Y2016 compared to Y2012. The stand outs are the numbers of whole-house environmental certificates awarded, industry practitioners providing environmental advice, sustainable energy loans provided by financial lending institutes and formally recognised comprehensive universal designs. However, the positive features and supporting services in Y2016 were outweighed by the many more negative ones.

There are **considerable extra costs** associated with higher-specified houses for the big-ticket items. For example, there is a premium for thermally broken double glazing and thermally better wall/ceiling insulation (with one exception). However, in terms of lighting, the price of the more thermally efficient and longer-lasting LED option (which has now become almost conventional) has decreased compared to its 2012 purchase price.

In terms of the **amount of carbon** associated with the building of new stand-alone dwellings and maintenance of the existing stock, it is too early to determine where New Zealand sits due to the carbon budget figures still being refined at the time of writing (Chandrakumar et al., 2019). It is likely, however, that all new houses will need to meet a carbon budget in the very near future, which is likely to have considerable implications on house size and choice of viable construction materials.

It is evident from these latest findings that developments in New Zealand's new-build housing in 2016 were not substantial enough to affect traditional outcomes in practice. These findings are reinforced by the building industry's misconceptions of new home performance. A recent BRANZ study (MacGregor & White, 2019) asked various industry professionals to describe the performance of the last house they worked on (see Figure 7). Three possible categories were provided to describe the home's performance:

- Meets the minimum Building Code standard.
- Incorporates substantial high-performance aspects such as renewable energy.
- Exemplifies best practice in world (e.g. 10 star rated Homestar®).

Overall, 6% of the respondents rated their last house as 'exemplifying best practice' on an international scale, demonstrating that many New Zealand building industry professionals have a wildly optimistic view of their new home performance attributes. Tellingly, none of the building control officers polled – who may be regarded as the most objective of the polled professionals – thought this was the case (MacGregor & White, 2019).

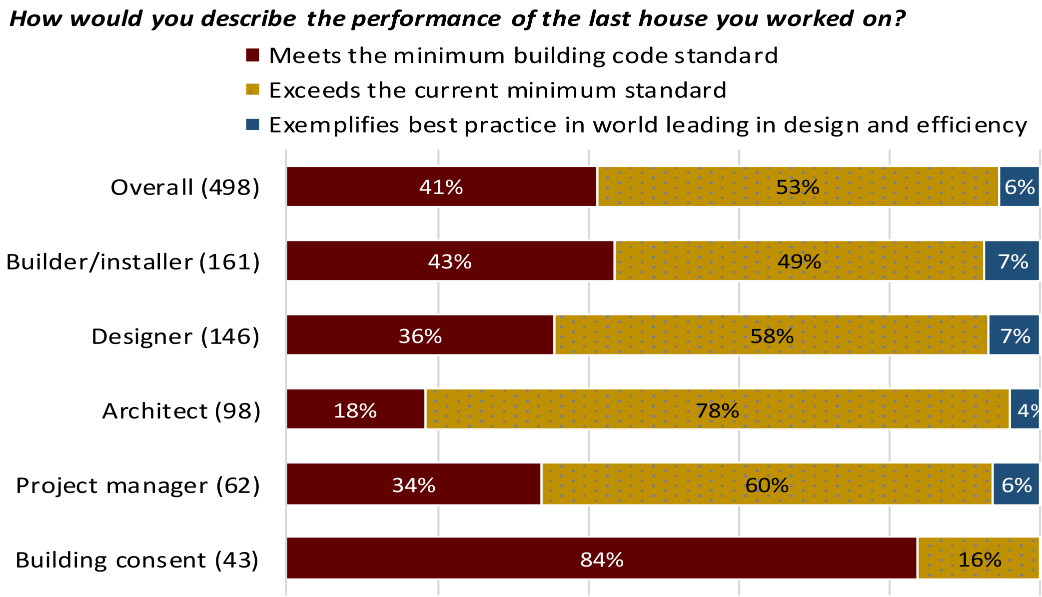

Figure 7. Respondents' perception of the last house they worked on.

6.2 Recommendations

The recommendations are divided into three thematic sections – building performance, market forces and governance. Although the recommendations concentrate on new detached dwellings, many could be applied to most building ages and typologies.

Building performance

As stated in a recent report, "Where properly planned and used, our homes can be low-carbon, more comfortable to live in, better for our health, and more affordable to run" (Committee on Climate Change, 2019). There is good evidence that newly built, detached New Zealand homes are far from well planned, based on those consented in 2016 in three key cities. This situation needs urgent remedying, especially if New Zealand wants significant progress in this area to meet its 2050 goals of being carbon neutral as well as generally improve new homes' comfort, health and affordability.

There needs to be opportunistic (co-benefit) integration between the related goals of year-round thermal comfort for human health, lifetime affordability and universal design. Added to this is the need to measure actual in situ performance[41] to best manage and refine implementation periodically.

The underperformance of new homes needs immediate attention. Subsequently, these actions need to be taken over the next 5 years:

- 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. To some degree, this is being actioned by the BRANZ Building Research Levy investment 'Exceeding the minimum' programme, which is developing end-to-end solutions.

[41] BRANZ started, in 2019, a 2-year project examining smart ways to measure in situ home performance as part of a wider Levy-funded programme.

- A clearer understanding of and therefore practical recommendations for low-carbon features for new homes that are life cycle based. The BRANZ LCAQuick Residential tool (released late 2019), the expanded BRANZ *House Insulation Guide,* which include carbon figures by construction element (due early 2020), and the associated BRANZ carbon budget research, which establishes a carbon cap by dwelling type (Chandrakumar et al., 2019), will all contribute towards providing robust technical direction for addressing embodied carbon.
- 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.
- A multi-pronged strategy of incentivisation, regulation and demonstration for universal design. Greater awareness could be provided by BRANZ, EDAs, HPAs and home ideas centres around the country.
- An expansion of this BRANZ benchmarking study to performance measure other dwelling typologies (such as townhouses and/or apartments) in subsequent studies.

There are several suitable tools that can assist industry to greatly improve new homes' performance:

- Design assistance tools such as LCAQuick and eTools can quantify lifetime emissions, provide benchmarks and streamline proposals in terms of meeting future carbon budgets. The upcoming extension to the BRANZ *House Insulation Guide* will include carbon intensities by wall/floor/roof element by area.
- Many dynamic thermal simulation programs are available to inform design decisions to provide year-round, passively derived thermal comfort.
- For universal design, there are many informal design guides (such as www.branz.co.nz/universal_design) and one award scheme that simplify the process.

Market forces

Initial build cost was the most commonly selected barrier for industry professionals exceeding the minimum building standard (MacGregor & White, 2019). Initiatives that could help professionals deliver high-performance houses include:

- having show-homes or providing case studies to demonstrate the benefits of different options to consumers
- more research and funding into materials and testing of high-performance features.

Housing affordability is a complex and considerable concern in New Zealand, especially when three of the largest cost contributors – land, materials and labour – are not forecast to reduce in the future.[42]

BRANZ recommends the following:

- Lifetime costs rather than upfront costs should be included in design decisions so that the maintenance and ongoing costs are factored in as part of the long-term finances. For minimising lifetime costs of cladding, BRANZ Study Report SR346 (Page, 2016) should be used as a guide.
- BRANZ to provide more knowledge and information around the importance of operational costs compared to initial costs to all those involved in the construction

[42] Matthew Curtis, BRANZ economist, personal communication, 12 February 2019.

industry, including consumers. This needs to be signalled both at the early concept stage of new buildings but also where major refurbishment takes place. Working with Consumer NZ and the Eco Design Advisors is one way BRANZ knowledge and information could reach a wider audience than that traditionally met.

Governance

At the time of writing, the government had just passed the Zero Carbon Bill.[43] Based on a proven UK concept that has been adopted in several other countries, the New Zealand Zero Carbon Act pursues three objectives:

- Getting New Zealand to zero carbon.
- Adapting to the changing climate.
- Supporting global climate action.

The Zero Carbon Act is likely to be very influential, having major ramifications for the new-build housing stock with new ambitious 2050 targets for reducing New Zealand's greenhouse gas emissions. It will, hopefully, drive meaningful climate change action, setting a legally binding pathway to this target without prescribing specific policies. How this legislation unfolds into resulting policy and guidance will determine the size and speed of change and whether NZ Inc. can meet its ambitious 2050 goal of limiting warming to below 2°C.

Without a considerable and sustained shift in governance support to facilitate more sustainable residential building in New Zealand, it is unlikely that substantial change will result soon. Given the immediate needs for reducing carbon, in particular, this is a great concern. The robust measurement of greenhouse gases in particular, both embodied (within the construction materials) and recurring (during operation), should be a very high priority (see section 5.4 for more details). A key finding from the recent Vickers et al. (2018) report is that the carbon footprint from the production stage of the built environment (5,021 kt CO_2e at the national level, unadjusted for international trade) is similar to the carbon footprint from the operational stage (4,814 kt CO_2e). As a starter for the residential building stock, determining where we currently are in terms of critical baselines for all residential typologies is required (the 'measuring to manage' concept).

As a first step, a good response to this would be to mandate low-energy and carbon targets for residential buildings in legislation, using an assessment system such as energy performance certificates. These certificates would be grounded by the national carbon budget and life cycle analysis work being currently developed by BRANZ and partners. This would ensure that a more comprehensive, meaningful and accurate pathway could be determined to increase the chances of meeting the 2050 targets. These targets should extend to existing buildings as well. As stated by Arcipowska et al. (2014), "Practical and high-quality [energy performance certificate] schemes are the prerequisite for any meaningful buildings policy".

Ideally, the embodied carbon of building material needs to be included in building codes and supported by market mechanisms. Only a few jurisdictions (such as Canada and Denmark) have started down a regulatory path for embodied carbon in construction, but it is expected more will follow (Castro et al., 2018). Castro et al. suggested policy options that increase in severity/effectiveness, starting from carbon reporting, then comparison through to carbon rating, carbon cap and finally to

[43] www.zerocarbonact.nz/zca-summary

decarbonisation. Given the urgency and benefits, New Zealand should only be investing in the last three options for rapid change. These options provide the construction industry with a range of alternative low-carbon responses:

- Design changes – change design and specifications to use lower-carbon materials and approaches, incentivise smaller dwellings, choose products and materials that have proven lower carbon.
- Procurement procedures – specify low-carbon product substitutes, such as the use of cement replacements and engineering timber for many structural steel applications.
- Product supply chain – respond to lower carbon requirements by reducing carbon in processes and products.

In terms of reducing operational carbon in new dwellings, this would be best responded to via policy change. The major policy instruments that could affect change are as follows:

- More stringent performance-based targets and requirements. Two critical areas to address are low-carbon heating appliances and better whole-house thermal design.
- Mandatory energy/carbon disclosure for all residential building types. Associated with this is the encouragement of low-carbon building
- The phasing out high-carbon fuels for space and water heating

There is a critical need to ensure that recommendations are only made for significantly environmentally (carbon) beneficial initiatives that include consideration of wider implications to minimise the likelihood of unexpected or perverse outcomes. Given the importance buildings have on climate change, there is a need for a well considered, multi-pronged response via governance (including the Climate Change Commission), regulatory, industry and consumer groups. The type of rapid and far-reaching change needed will require bold and brave concerted bipartisan support by successive governments that can think past the next election. However, unlike many other countries, New Zealand is well positioned to address climate change in relation to buildings, due to:

- having predominantly timber-based construction, allowing easy carbon sequestering
- a high proportion of New Zealand's electricity being generated from low-carbon means and as an energy source, its use can be increased further for building application
- many of the solutions in terms of support and technical fixes already being in the public domain.

The time for discussion is over.

References

Ade, R. & Rehm M. (2019). Buying limes but getting lemons: Cost-benefit analysis of residential green buildings – a New Zealand case study. *Energy and Buildings*, 186, 284–296.

Arcipowska, A., Anagnostopoulos, F., Mariottini, F. & Kunkel, S. (2014). *Energy performance certificates across the EU: A mapping of national approaches*. Brussels, Belgium: Buildings Performance Institute Europe.

Argos Analytics. (2017). *Guidelines for specifying WeatherShift™ future weather files*. Menlo Park, CA: Argos Analytics.

Auchincloss, A., Mujahid, M., Shen, M., Michos, E., Whitt-Glover, M. & Diez Roux, A. (2013). Neighborhood health-promoting resources and obesity risk. *Obesity*, *21* (3), 621–628.

Baumgardner, R. (2013). *Valuation of green buildings: Background and core competency*. Washington, DC: Appraisal Foundation.

Bengtsson, J., Bennett, J., McKernon, S., Mullan, B. & Page, I. (2007). *Climate change impacts in New Zealand: A cross-disciplinary assessment of the need to adapt buildings, with focus on housing*. Paper presented at SB07 NZ Conference Transforming our Built Environment, Auckland, New Zealand, 14–16 November.

Bengtsson, J., Hargreaves, R. & Page, I. (2007). *Assessment of the need to adapt buildings in New Zealand to the impact of climate change*. BRANZ Study Report SR179. Judgeford, New Zealand: BRANZ Ltd.

BERL. (2019). *Green mortgages: Financial incentives to design and build high-performance homes*. BRANZ External Research Report ER 43. Judgeford, New Zealand: BRANZ Ltd.

BRE. (2018). *Home Quality Mark One Technical Manual*. Watford, UK: Building Research Establishment.

Burgess, J. & Cogan, D. (2008). *A water heating rating tool for domestic construction in New Zealand and Australia*. BRANZ Ltd Report EC1475. Submitted to EECA (Energy Efficiency and Conservation Authority). Judgeford, New Zealand: BRANZ Ltd.

Burgess, J. (2012). *Product profile for windows in New Zealand housing*. BRANZ Study Report SR274. Judgeford, New Zealand: BRANZ Ltd.

Carrington, G. (2011). *Comparison of solar and heat pump water heaters in New Zealand*. New Zealand: Parliamentary Commissioner for the Environment.

Castro, R., Terranova, E., Bruce-Hyrkäs, T. & Pasanen, P. (2018). *The embodied carbon review: Embodied carbon reduction in 100+ regulations and rating systems globally*. Helsinki, Finland: Bionova Ltd.

Chandrakumar, C. McLaren, S. J., Dowdell, D. & Jaques, R. (2019). A top-down approach for setting climate targets for buildings: the case of a New Zealand detached house. *IOP Conference Series: Earth and Environmental Science*, *323*, 012183.

Collins, N. & Bealing, M. (2015). Cost tower*: Residential construction costs for affordable and social housing in Auckland*. Report NEW2015/1. Auckland, New Zealand: Beacon Pathway.

Committee on Climate Change. (2019). *UK housing: Fit for the future?* London, UK: Committee on Climate Change.

Concept Consulting Group. (2016a). *Electric cars, solar panels and batteries – how will they affect New Zealand's greenhouse gas emissions?* Wellington, New Zealand: Concept Consulting Group Ltd.

Concept Consulting Group. (2016b). *Electric cars, solar panels, and batteries in New Zealand Vol 2: The benefits and costs to consumers and society*. Wellington, New Zealand: Concept Consulting Group Ltd.

Concept Consulting Group. (2017). *What is the case for electricity efficiency initiatives?* Wellington, New Zealand: Concept Consulting Group Ltd.

Cox, W. & Pavletich, H. (2017). *13th Annual Demographia International Housing Affordability Survey*. St Louis, IL: Demographia.

Curtis, M. (2017). *New House Owners' Satisfaction Survey*. BRANZ Study Report SR374. Judgeford, New Zealand, BRANZ Ltd.

Dowdell, D., Berg, B., Marston, N., Shaw, P., Burgess, J., Roberti, J. & White, B. (2016). *New Zealand whole-building whole-of-life framework: Development of datasheets to support building life cycle assessment*. BRANZ Study Report SR351. Judgeford, New Zealand: BRANZ Ltd.

Drysdale, D. & Nebel, B. (2009). *Life cycle assessment of the Waitakere NOW Home®*. Report SM3570/8. Auckland, New Zealand: Beacon Pathway Ltd.

Ghosh, S., Vale, R. & Vale, B. (2008). Local food production in home gardens: Measuring on-site sustainability potential of residential development. *International Journal of Environment and Sustainable Development*, *7*(4), 430–451.

Giesekam, J., Barrett, J. & Taylor P. (2015). Construction sector views on low carbon building materials., *Building Research & Information*, 44(4), 423–444.

Giesekam, J., Barrett, J., and Taylor, P. (2016). Scenario analysis of embodied greenhouse gas emissions in UK construction*. Proceedings of the Institute of Civil Engineers: Engineering Sustainability*, *171*(4).

Heinonen, J., Säynäjoki, A. & Junnila, S. (2011). A longitudinal study on the carbon emissions of a new residential development. *Sustainability*, 3, 1170–1189.

Ibn-Mohammed, T., Greenough, R., Taylor, S., Ozawa-Meida, L. & Acquaye, A. (2013). Operational vs. embodied emissions in buildings: A review of current trends. *Energy and Buildings*, *66*, 232–245.

Isaacs, N., Saville-Smith, K., Camilleri, M. & Burrough, L. (2010). Energy use in New Zealand households: Comfort, physics and consumption. *Building Research and Information*, *38*(5), 470–480.

Jaques, R, Norman, D. & Page, I. (2015). *Valuing sustainability and resilience features in housing*. BRANZ Study Report SR333. Judgeford, New Zealand: BRANZ Ltd.

Jaques, R. (2013). Rethinking universal design. *Build*, *138*, 79–80.

Jaques, R. (2015). *Measuring our sustainability progress: Benchmarking New Zealand's new detached residential housing stock*. BRANZ Study Report SR342. Judgeford, New Zealand: BRANZ Ltd.

Johnson, A., Howden-Chapman, P. & Eaqub, S. (2018). *A stocktake of New Zealand's housing*. Wellington, New Zealand: NZ Government.

Kettle, D. (2008). *Indicators Framework Working Paper. Final Revision A*. Report 6-2372. Auckland, New Zealand: Beacon Pathway Ltd.

Khan, I., Jack, M. & Stephenson, J. (2018). Analysis of greenhouse gas emissions in electricity systems using time-varying carbon intensity. *Journal of Cleaner Production*, *184*, 1091–1101.

Kibert, C. J. (2012). *Sustainable construction: Green building design and delivery*. Hoboken, NJ: John Wiley & Sons.

Lorenz, D. & Lutzkendorf, T. (2011). Sustainability and property valuation: Systematisation of existing approaches and recommendations for future action. *Journal of Property Investment and Finance*, *29*(6), 644–676.

MacGregor, C. & White, V. (2019). *Evaluating the benefits of exceeding the minimum'*. BRANZ Study Report (In draft). Judgeford, New Zealand: BRANZ Ltd.

MacGregor, C., Dowdell, D., Jaques, R., Bint, L. & Berg, B. (2018). *The built environment and climate change: A review of research, challenges and the future*. BRANZ Study Report SR403. Judgeford, New Zealand: BRANZ Ltd.

Miller, A., Hwang, M., Lemon, S., Read, G. & Wood, A. (2015) *Economics of photovoltaic solar power and uptake in New Zealand*. Paper presented at EEA Conference & Exhibition 2015, Wellington, New Zealand, 24–26 June.

Mithraratne, N. & Vale, R. (2007). *Rain tanks or reticulated water supply?* Paper presented at Rainwater and Urban Design, Sydney, Australia, 21–23 August.

Mullan, B., Burgess, S., McKenzie, R., Ramsay, D., Reid, S., Stephens, S. & Thompson, C. (2006). *Climate change scenarios for BRANZ study of built environment vulnerability*. Hamilton, New Zealand: NIWA.

National Association of Realtors. (2014). *Green MLS implementation guide* (v1.0). Chicago, IL: National Association of Realtors and NAR's Green Resource Council.

New Zealand Productivity Commission. (2018). *Low-emissions Economy: Final Report*. Wellington, New Zealand: New Zealand Productivity Commission.

NFO New Zealand. 2002. *New House Survey Report*. Prepared for EECA.

Norman, D., Curtis, M. & Page, I. (2014). *A construction dashboard of key industry measures*. BRANZ Study Report SR321. Judgeford, New Zealand: BRANZ Ltd.

NZGBC. (2017). *Homestar Technical Manual*. Version 3.2. Auckland, New Zealand: New Zealand Green Building Council.

PA Consulting Group. (2012). *Evaluation study of the EECA Water Heating Programme*. Wellington, New Zealand: Ministry of Economic Development

Page, I. (2016). *The value of sustainability – costs and benefits of sustainability and resilience features in houses.* Study Report SR346. Judgeford, New Zealand: BRANZ Ltd.

PCE. (2012). *Evaluating solar water heating: Sun, renewable energy and climate change.* Wellington, New Zealand: Parliamentary Commissioner for the Environment.

Penrose, G. (2019). It's universal design's time. *Build*, *172*, 6.

Rhys, J. (2011). *Cumulative carbon emissions and climate change: Has the economics of climate policies lost contact with the physics*. Oxford, UK: Oxford Institute for Energy Studies.

Rogers, S., Halstead, J., Gardner K. & Carlson, C. (2011). Examining walkability and social capital as indicators of quality of life at the municipal and neighborhood scales. *Journal of Applied Research in Quality of Life*, *6* (2), 201.

Rosevear, M. & Curtis, M. (2017). *Physical characteristics of new houses 2015*. BRANZ Study Report SR376. Judgeford, New Zealand, BRANZ Ltd.

Saville-Smith, K. & Saville, J. (2012). *Getting accessible housing: Practical approaches to encouraging industry take-up and meeting need*. Report prepared for the Office for Disability Issues and Building and Housing Group, Ministry of Business, Innovation and Employment. Wellington, New Zealand: Centre for Research, Evaluation and Social Assessment.

Saville-Smith, K., Fraser, R. & Saville-Smith, N. (2016). *Getting universal design into new builds and major renovations*. BRANZ External Research Report ER19. Judgeford, New Zealand, BRANZ Ltd.

Schwartfeger, L. & Miller, A. (2015). *Environmental aspects of photovoltaic solar power: The New Zealand context*. Paper presented at EEA Conference & Exhibition 2015, Wellington, New Zealand, 24–26 June.

Sims, R., Barton, B., Bennett, P., Isaacs, N., Kerr, S., Leaver, J. Reisinger, A. & Stephenson, J. (2016). *Transition to a Low-Carbon Economy for New Zealand*. Wellington, New Zealand: Royal Society of New Zealand.

Tonkin + Taylor. (2019). *Delivering low carbon buildings – Review of target setting and delivery mechanisms globally*. Wellington, New Zealand: Tonkin + Taylor.

Trotman, R. (2008). *Indicator Framework for Tracking the Sustainability of New Zealand's Residential Housing Stock*. Auckland, New Zealand: Beacon Pathway Ltd.

Troup, L. & Fannon, D. (2016). *Morphing climate data to simulate building energy consumption*. Paper presented at ASHRAE and IBPSA-USA SimBuild 2016 Building Performance Modeling Conference Salt Lake City, Utah, 8–12 August.

UKGBC. (2015). *Tackling embodied carbon in buildings*. London, UK: UK Green Building Council.

Vickers, J., Fisher, B. & Nebel, B. (2018). *The carbon footprint of New Zealand's built environment: Hotspot or not?* Wellington, New Zealand: thinkstep Australasia.

Water New Zealand. (2013). *2011/2012 National Performance Review of Water Utilities*. Wellington, New Zealand: Water New Zealand.

Appendix A: Embodied CO_2 in building materials

The inclusion of a core indicator measuring the embodied carbon associated with the building materials of the ~21,310 stand-alone homes built in 2016[44] is new. The metric used is the average building material embodied CO_2 (kg CO_2/house). Currently, this indicator only accounts for the embodied carbon associated with the framing + foundations + roof + wall claddings of the randomly selected houses. This is estimated to be around 50–60% of the total embodied in construction materials. Consequently, it can be recognised as a 'first-cut' indicator that will be refined in successive BRANZ reports but useful nevertheless in establishing a preliminary baseline.

While the design of residential buildings in New Zealand is characterised by great variety, the market shares of materials used in their construction portray homogeneity in construction methodology and material specification. While these shares do vary from year to year, they are relatively steady in the long run, reflecting a preference across owners, designers and builders for traditional, familiar products and methods (MacGregor et al., 2018).

The structure of new dwellings typically comprises concrete and timber. Timber is most commonly used for framing above the foundations, with 358,700 m^3 used in 2016 – 98% of all framing by volume (MacGregor et al., 2018). This is primarily made up of light natural timber framing but also includes solid wood wall panels and engineered wood framing. Concrete is most commonly used in foundations, typically in concrete floors but also as part of timber pile foundations, with 1,229,000 m^3 used in 2016 (MacGregor et al., 2018). Steel is occasionally used in new dwellings as light steel wall framing but more commonly as heavy steel portal frames around openings.

Table 30 and Table 31 show a negative figure for timber. This is due to uptake of carbon dioxide by trees during their growth cycle and includes processing required to produce timber products. It assumes that timber is sourced from sustainable sources.

Table 30. Structure-related CO_2eq. emissions of new stand-alone dwellings in 2016.

Material	Framing (m^3)	Embodied carbon (tonnes CO_2 eq.)	Foundations (m^3)	Embodied carbon (tonnes CO_2 eq.)
Concrete	5,000	1,289[45]	615,000	196,853[46]
Timber	358,700	-246,606[47]	23,900	-16,431
Steel	3,500	71,526[48]	0	-
	Total	**-173,791**	**Total**	**180,422**
Total CO_2eq. for framing and foundations – 6,631				

Table 30 provides the potential for a carbon sink, which can remain over the lifetime of a dwelling. The actual carbon sink provided through use of timber is dependent on factors such as service life in the building, end-of-life route(s) and, if landfilled, how

[44] Source: http://archive.stats.govt.nz/infoshare
[45] Modelled as hollow concrete blockwork (20 series) with a 22 MPa grout infill, reinforced.
[46] Modelled as 20 MPa normal ready-mix concrete with reinforcement (25 kg/m^3). Actual reinforcement content based on a 200 m^2 single-storey house with 2.27 kg/m^2 mesh over the horizontal surface plus foundation reinforcing of R10s at 600 mm centres that are 300 mm deep plus 2 x D12s top and bottom. This is calculated as 27 kg steel reinforcing and mesh/m^3.
[47] Modelled as softwood timber, sawn and kiln-dried, sustainably sourced.
[48] Modelled as galvanised steel framing.

much degradation occurs and to what extent landfills are engineered to capture and use landfill gas.

The roofs of new dwellings are typically clad in a sheet metal variant, with a total volume of 4,430,900 m^2 clad in 2016 – 82% of roofs by area. This includes corrugated steel or aluminium and pressed steel tiles. The remaining share is clad by concrete and clay tiles and other, which is primarily hydrocarbon-based shingles and membranes. Wall claddings of new dwellings are more diverse than roofs, with approximately a third clad in clay bricks (1,052,200 m^2) and a further third clad in timber (933,000 m^2), including weatherboard, solid wood and sheet form. Fibre-cement is also common, cladding 15% of walls by area in weatherboard and sheet form. Concrete also clads 15% of walls in brick, block and panel form.

Table 31. Cladding-related CO_2eq. emissions of new stand-alone dwellings in 2016.

Material	Roof (m^2)	Total (tonnes CO_2 eq.)	Wall (m^2)	Total (tonnes CO_2 eq.)
Timber	0	-	933,000	-12,187[49]
Fibre cement	0	-	505,400	6,736[50]
Clay (brick, tile)	76,700	685	1,052,200	27,620
Concrete (all types)	266,700	1,739[51]	509,400	8,093[52]
Sheet metal	4,430,900	70,427[53]	176,700	2,809
Other	971,300	Not calc.	192,500	Not calc.
Totals	**For roofing (exc. Other)**	**72,850**	**For wall claddings (exc. Other)**	**33,070**
Total CO_2eq for roof and wall claddings – 105,920				

The total figure for all the Y2016 consented stand-alone houses therefore equates to 112,551 tonnes of CO_2eq. for some 21,310 homes. This amounts to a CO_2 eq. loading of 5.28 tonnes/house. The house = framing + foundations + roof + wall claddings.

49 19 mm thick.
50 16 mm thick.
51 Assumes a 25 MPa compressive strength.
52 Autoclaved aerated concrete (AAC), 70 mm thick.
53 0.55 mm thick, zinc aluminium alloy.

Appendix B: Modelling climate change-influenced weather

The hottest summer and coldest winter weeks as projected for the year 2030 (i.e. in only 11 years' time) and the year 2080 weather files were used in the thermal simulation for power blackout analysis. As for the Y2012 report, the constructed 2030 and 2080 weather files is the average – essentially the mid-point of the most extreme of the Haley and CSIRO scenario models (see Y2012 report section 5.10 for specifics). In brief, this results in using the 25th percentile of the Haley model and the 75th percentile of the CSIRO model and averaging them.

Ideally, multiple projections from multiple weather files should be applied to these simulation models (Troup & Fannon, 2016). The approach – referred to as a 'multimode ensemble' – better explores the range of future possibilities (Argos Analytics, 2017). Specifically, it better reflects the complexity of what is being modelled and its intrinsic chaotic nature – what is commonly referred to as the 'butterfly effect'. The butterfly effect is where "very small differences in initial conditions can lead to large differences in future conditions. As a result of natural variability, there would be a substantial range in possible future climate conditions even if we knew precisely what future emissions would be and if we had a perfect model of the climate" (Argos Analytics, 2017).

Generally, the choice of the time period under investigation in this type of study should be based on the design life of the buildings in question. In terms of residential buildings in New Zealand, this is difficult to put a number on, especially for those that are built today whose inherent value is unknown. For this BRANZ study, the design life has been assumed to be slightly more than that required by the NZBC for materials that are difficult to access or replace, i.e. 60 years. Hence, the year of choice for climate change modelling was chosen to be 2080. This reflects other residential thermal rating tools such as the UK's Home Quality Mark One (BRE, 2018).

Appendix C: Space heater efficiencies and CO_2 emissions

This Y2016 report introduces a new indicator to trace the climate change implications of detached residential space heating via the examination of fuel-related CO_2 emissions. Previously, this issue was not addressed as a detailed consent check found that active space heating appliances were often left unspecified. This time, a further check was performed on some twenty-five 2016 Christchurch consents. It was found that only the lounge/dining/kitchen heating sources were (almost always) specified, with the bathroom occasionally and the rest of the house never. Thus, zone allocation for space heating is still challenging, and various defaults and assumptions were required to ensure that the Y2016 consented houses were examined consistently.

Given BRANZ's research experience in New Zealand residential space heating practices, the following convention was developed. It resulted from consultation with several space heating experts[54] combined with the now defunct EECA Home Energy Rating Scheme (launched in December 2007) approach. In addition, it has been spot tested on a subset of randomly selected consents. It is hoped that this approach will provide consistent results and useful findings longitudinally.

Space heating carbon calculator convention

- What is specified in the consent documents is what gets installed.
- Where no space heater has been specified, assume that a heat pump will be installed to the main living zones in all cases, with plug-in electric heaters making up the remainder of the heating needs in the other conditioned spaces.
- Where a single heat pump is specified in the lounge/living room, it always heats 43%[55] by area of the entire conditioned house's area.
- Where more than one space heater type is specified, assume that they contribute equally to the conditioned area.
- Use the same fuel-specific CO_2 emission as used for the water heating calculations (see Y2012 report Appendix E for details). Although it is recognised that New Zealand's grid electricity CO_2 emissions vary from year to year, it makes sense to use a fixed emission intensity figure for consistency reasons when conducting longitudinal studies.
- The space heating figure only accounts for the conditioned area of the home, as defined by AccuRate NZ. Therefore, it excludes hallways, bathrooms and garages.
- If the house is centrally heated, use the same appliance and distribution efficiency factors as detailed in the Homestar Technical Manual (NZGBC, 2017).

This convention has now been applied to both Y2012 and Y2016 data.

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[54] Andrew Pollard (BRANZ), Nikki Buckett (MBIE) and Christian Hoerning (EECA) circa December 2017.

[55] This figure is based on a spot check of 23 randomly selected Christchurch houses and was necessary to estimate the lounge/living proportion of the entire house's conditioned area.

Table 32. Space heating types, efficiencies and resulting CO_2 emission factors.

	HEATER TYPE	Emission kg CO_2 / kWh	Spatial Influence + Specifics on type	Distribution Efficiency
POINT SOURCE HEATING	Gas fire	0.215	*57% gas fire to 43% elec resistive*	100%
	Gas fire + heat pump	0.170	*equal share*	100%
	Gas fire + Undertile heating	0.223	*equal share*	100%
	Heat pump	0.079	*80% heat pump 20% elect. resistive*	100%
	Unknown	0.121	*43% heat pump 57% elect resistive*	100%
	Wood burner	0.103	*43% wood burner / 57% electric resistive*	100%
	Gas fire + wood burner + resistive	0.142	*equal share*	100%
CENTRAL HEATING	Central heat pump	0.071	*100% air-air ducted heat pump*	79%
	Central gas	0.212	*100% condensing combi gas boiler*	58%
	Central elec. underfloor tile	0.178	*100% electric resistive*	100%
	Central hydronic heat pump	0.068	*100% air to water heatpump*	83%
	Central hydronic gas	0.254	*100% natural gas*	75%

Appendix D: Water usage caveats

The following qualifiers are associated with the water usage issue discussed in section 5.5.

New metric caveats

- Water New Zealand's National Performance Review (NPR) covers all dwellings rather than just those detached and new. Given that it is unknown whether there is a distinction in volumetric usage between existing and new housing stock, it is assumed (until disproved) that their water needs are no different.[56]
- The assessment year used in the NPR doesn't exactly match the calendar year applied to this BRANZ study. However, for this type of longitudinal study, this issue is incidental.
- It is recognised that this new proxy doesn't allow for residential behavioural and attitudinal changes resulting from demand management interventions, which can contribute significantly to overall water usage.
- Unfortunately, Y2012 information for Auckland and Christchurch was not available so Year Zero comparisons cannot be made.
- The confidence in the quality of the data reported to Water New Zealand declines the earlier the data is sourced, partly because of initial inconsistent council reporting methods. Thus, this metric is perhaps best examined over the longer term.

The equation used to calculate residential water consumption is:

$$\boldsymbol{Average\ daily\ residential\ water\ consumption}$$

$$= \frac{1000 \times water\ Supplied - nonresidential\ consumption - estimated\ total\ network\ water\ loss}{365 \times total\ water\ serviced\ population}$$

[56] This will become more transparent with the BRANZ Levy project looking to disaggregate water end use for a large sample of homes in the 2017–2018 period.

Appendix E: Glazing calculation

Although the aim of this Y2016 report was to leverage off existing collected metrics and data (whether collected by BRANZ or external sources) as much as practical, sometimes this was not possible. An example of this is costing of the double glazing. The Y2012 report leveraged the information from a BRANZ 2012 study, which utilised a reference house for its pricing template. The reference house has 206 m² of floor area and 20 glazed windows/doors with a total area of 45 m², closely reflecting common practice in 2012.[57]

Quotes were initially requested from 10 companies in two cities that supply windows for housing for aluminium and thermally broken aluminium (4/12/4 clear glazing with a mid-priced low-E coating). Glazing specifics were standardised to include the same function and inclusions, being for the supply of the reference house-lot of Code-compliant windows for a high wind area, complete with reveal liners, toughened glass etc. More details on the representative house can be found in BRANZ Study Report SR274 (Burgess, 2012, pp. 51–52).

These Y2012 figures were updated exclusively for this report using the same reference house and glazing-related variables for consistency. However, to provide a more nationally representative result and because the cities previously examined had widely varying results, the number of cities targeted was increased.

[57] Note that, in the Y2012 report, the glazing area mistakenly used was 40 m^2. This has been corrected for both years in this report. The percentage change in price (between non-thermally broken and broken) remains unaffected.

Appendix F: Recession plane mini study[58]

To quantify the actual thermal and comfort effects of shading from surrounding buildings allowable by local district plans, the three-city recession plane regulations were examined. For this mini study, a typical house was chosen from the Y2016 Christchurch sample, based on its passive thermal performance characteristics.

To examine variations in the district plans (all accessed via the internet in May 2018), the typical house was simulated in multiple recession plane scenarios. The basic assumption made was that developers would likely maximise the floor area (i.e. footprint) and therefore allowable coverage area (and thus next-door shading) for a particular section.

The key elements for determining possible shading were the recession planes that the neighbouring houses would have to meet (limiting the level of shade they could provide) and the distance of the house from its various boundary lines. To approximate the presence of an arbitrary object providing the maximum level of shade theoretically allowed, shade was provided by 'walls' constructed to touch the limits of the recession plane. These walls were placed 1 m back from the boundary, with a height equal to (in the case of Christchurch) 2.3 m + tan (recession angle).

The change to passively acquired thermal comfort is measured using the degree-hours metric. This metric is an easy way to comprehend the severity of the change in comfort. It is defined as the product of the temperature below nominated set point (in this case 18°C) and the annual time spent at this temperature (in hours). The three jurisdictions and rule name allocation alongside their respective threshold requirements are shown in Table 33.

Table 33. Three district plan basic rules on building envelope thresholds.

Council	Zone	District plan rule number and name	Threshold (boundary height + angle)
Auckland	Mixed Housing Suburban Zone	H4.6.5 Height in relation to boundary	2.5 m + 45°
Hamilton	Living Zone	21.45 Daylight admission	2.5 m + 37°
Christchurch	Residential Suburban Zone	14.2.3.6 Daylight recession planes	2.3 m + 26°

Auckland

Two scenarios were examined in Auckland, which are described in Rule Number H4.6.5. In scenario #1 for mixed housing zones, the NE boundary is set 6 m out from the living room based on the requirements for outlook in the district plan. This meets its requirements for 3 m under outlook as well. The NW boundary is set to 1m, meeting the minimum requirements for side yards and outlook of other spaces. Scenario #2 looks at the single house zone requirements. As neither outlook nor outdoor living space are required in this zone, the boundary distances are defined by the minimum yard dimensions, which is 1 m for back and side yards. In this case, due to the protrusion of the master bedroom, the actual distance from the living room is

[58] This section is authored by James Sullivan.

3.35 m. The recession angle for the surroundings is 35° and the shading walls 3.2 m high (at 1 m out from the boundary line).

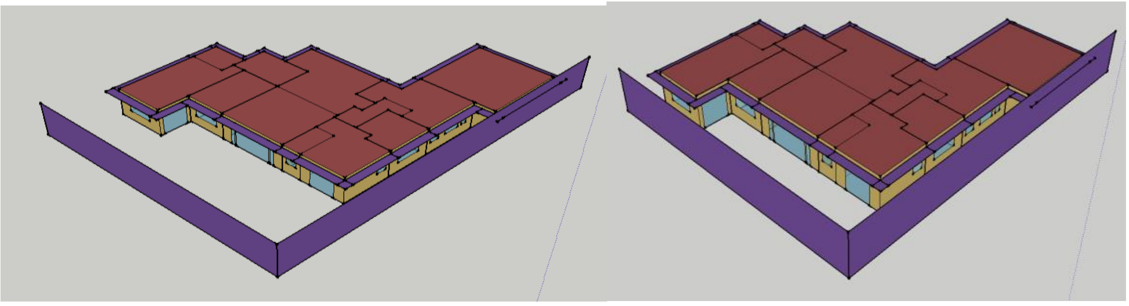

Figure 8. 3D layout and worst theoretical recession wall – Auckland.

Examining the temperatures of the main living space, the results demonstrate a considerable increase in daytime coldness when the house is run passively. This equates to an increase of discomfort of 83% (for scenario #1) and 128% (for scenario #2) in terms of degree-hours during the day.

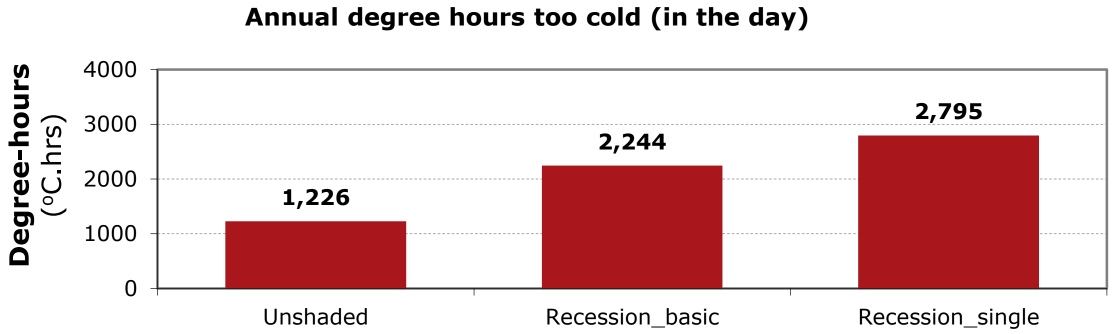

Figure 9. Uncomfortably cold in Auckland.

Hamilton

Hamilton has only one scenario modelled, which is described in Section 21.45; Daylight Admission, of the District Plan. Here, the NE boundary is set to 6 m from the living room to allow the appropriate outdoor living space, while the NW boundary is set at 1.5 m following the minimum set-back requirements.

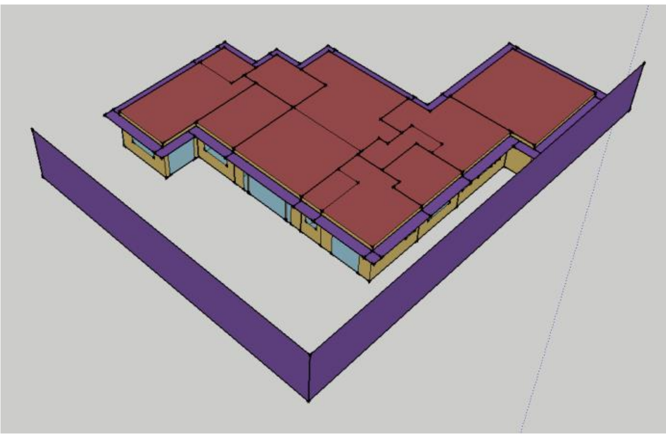

Figure 10. 3D layout and worst theoretical recession wall – Hamilton.

The recession angle for the surroundings is 28° and the shading walls 3.53 m high (at 1 m out from the boundary line). Again, significant effects on coldness and winter temperatures can be seen. This equates to an increase of discomfort of 58% in terms of degree-hours during the day.

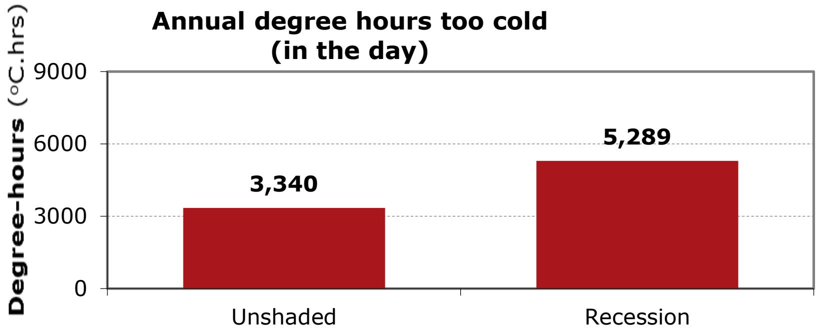

Figure 11. Uncomfortably cold in Hamilton.

Christchurch

Two scenarios were examined in Christchurch, which are described in their District Plan (Section 14.2.3.6; Daylight Recession Planes). Scenario #1 meets the basic requirements of the Residential Suburban Zone. The NE boundary is set 6 m out from the living room to meet the requirements of outdoor living Space. The NW boundary is set 1 m out from the garage, placing it 2.5 m out from the bedroom/bathroom. Scenario #2 is based on the denser Residential Suburban Density Transition Zone requirements. The NE boundary is brought in to 4 m to match the minimum allowed dimensions of outdoor living space, and the NW boundary is brought in to be 1 m from the bathroom/bedroom walls, as per the minimum required set-back. The recession angle for the surroundings is 32° and the shading walls 2.92 m high (at 1 m out from the boundary line).

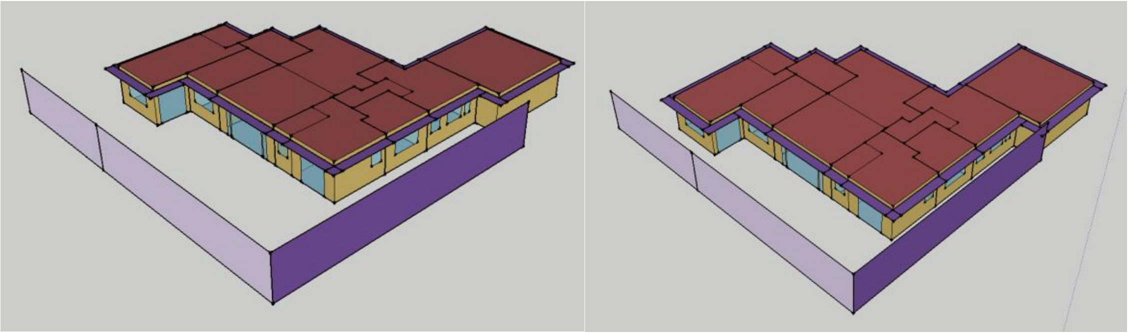

Figure 12. 3D layout and worst theoretical recession wall – Christchurch.

Examining the temperatures of the main living space, the results demonstrate a non-trivial increase in daytime coldness when the house is run passively. This equates to an increase of discomfort of 18% (for scenario #1) and 31% (for scenario #2) in terms of degree-hours during the day.

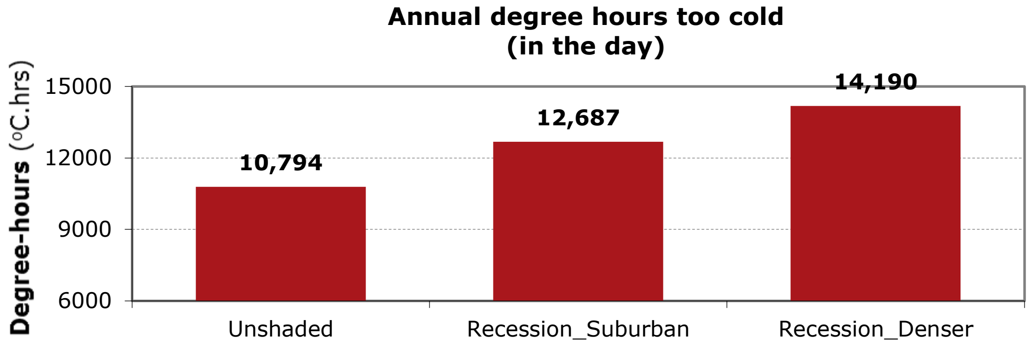

Figure 13. Uncomfortably cold in Christchurch.

Appendix G: Thermal modelling calculation

The thermal modelling in AccuRate NZ defaulted to using the 'Infiltration'; Building Description: 'Post 1960, Simple Design…" for all infiltration data input. This was done to ensure consistency between buildings which otherwise had no indication of actual infiltration rates.

In all the thermal modelling work carried out, there has been only one exception to this, which is the Christchurch PassivHaus house assessed in Y2016. For this build, there needed to be recognition of the considerably tighter building envelope (which had been formally pressure tested) and the integrated heat recovery system built into the mechanical ventilation system. As a result, the ventilation rate was adjusted down to 0.1 ach (rather than the typical 0.5 ach).

For other thermal defaults and approaches used, please consult the Y2012 report Appendix C: Thermal simulation methodology.