Study Report

SR403 [2018]

The built environment and climate change: A review of research, challenges and the future

Casimir MacGregor, David Dowdell, Roman Jaques, Lee Bint and Brian Berg

Funded from the
Building Research Levy

1222 Moonshine Rd, RD1, Porirua 5381
Private Bag 50 908, Porirua 5240
New Zealand
branz.nz

ISSN: 1179-6197

Preface

This report is a break in a journey – to take stock, create a record of where and how climate change impacts the built environment in New Zealand (and vice versa), to survey the ground covered and the ground yet to cross. BRANZ has a history of actively examining climate change impact on the built environment. As the urgency for action to address rising carbon levels becomes critical, there will not be a quick fix or just one way to mitigate climate change. We all must find our own way to encourage action and transition to a low-carbon future. BRANZ cannot do this alone, so this report is about providing a platform for others – not just BRANZ – to help address the issue of climate and its impact on the built environment. Now more than ever, we need to encourage the building industry to play a key part in addressing climate change for the benefit of all New Zealanders.

Acknowledgements

We would like to acknowledge the generous funding from the Building Research Levy that helped make this possible. We also would like to thank a number of individuals who provided much needed advice in the making of this report: Richard Capie, Ian Short, Janine Smith, Paul Alexander, Celina Garcia, Sandi Sirikhanchai, Nick Brunsdon, Agneta Ghose, Nigel Isaacs, Julie MacArthur and Kevin Golding. We also wish to thank participants in a BRANZ climate change workshop held on 6 December 2017, which helped shape our thinking around climate action.

It should be borne in mind that there is nothing more difficult to handle,
more doubtful of success and more dangerous to carry through
than initiating changes.

Niccolò Machiavelli (1469–1527)

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Reference

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.

Abstract

Climate change presents one of the greatest challenges facing the world today. The built environment has a core part to play in how, as a society, we adapt and seek to mitigate the impacts of climate change. This research report examines the current scientific evidence and initiatives relating to the built environment and climate change and seeks to outline how New Zealand can plan a transition to a low-carbon economy. The report provides a brief overview of the global and New Zealand response to climate change. We also provide an assessment of New Zealand research related to residential housing and climate change, especially examining energy and thermal performance, materials in residential construction and tools available for evaluating carbon performance. Both mitigation and adaptation initiatives are examined. The report seeks to outline the challenges, barriers and drivers facing the building and construction industry to respond to climate change. The report considers some frameworks that underpin a transition to a low-carbon economy and outlines some strategic directions that enable the creation of a pathway for zero-carbon buildings and action to help the transition to a low-carbon economy. The report concludes by recommending future work.

Keywords

Climate change, low carbon, buildings, houses, offices, transitions.

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Executive summary

Climate change presents one of the greatest challenges facing the world today. The built environment has a core part to play in how, as a society, we adapt and seek to mitigate the impacts of climate change. This research report examines the current scientific evidence and initiatives relating to the built environment and climate change and seeks to outline how New Zealand can plan a transition to a low-carbon economy.

We have helped to highlight in this report that buildings primarily contribute to climate change impact in three key ways:

- The use of energy and where we obtain this energy, year on year, while the building is occupied.
- The materials used in and on buildings, which contribute to greenhouse gas emissions as a result of extraction, processing, transport and installation before the building is occupied, as well as periodic maintenance and the need for repair and replacement of materials during the building's service life.
- Urban and landscape design/planning.

Our research suggests that climate action needs to be directed at how carbon is understood within the social, regulatory and market context. Above all, we argue that the consideration of energy use (and the consequent carbon emitted) in buildings should not be divorced from the carbon burden of materials selected in building design. We suggest that the timing of carbon emissions is also potentially important in helping us plan our response to climate change. Large carbon emissions now to achieve carbon savings decades into the future may not be the best strategy. We highlight that, for New Zealand and our low-carbon intensity, grid electricity makes this particularly pertinent. Instead, we argue that any policy and market approach should not be entirely focused on carbon to the exclusion of all other potential impacts. Such an approach risks unforeseen consequences.

In order to help drive climate action in New Zealand, we need to acknowledge and focus on a number of social aspects, such as the barriers and challenges that are preventing the building and construction industry from creating a zero-carbon built environment. One of the key barriers identified has been a lack of economic incentives to prompt and encourage action. Further, the industry is experiencing gaps in skills and knowledge required to deliver zero-carbon buildings. At present, only a small number of companies could construct a zero-carbon building.

Industry and the market need a strong signal to invest in the construction of zero-carbon buildings. For example, prescribing zero or low carbon within the New Zealand Building Code would encourage industry to adopt the practice, as without regulation, it is unlikely the industry would adopt low-carbon practices.

In transitioning to a low-carbon economy, we outline a number of changes that are needed to human behaviours, attitudes, practices and policies that encourage information flows within the building system.

Our research report also highlights that carbon needs to be understood as a fluid concept rather than something fixed and ridged.

We conclude by acknowledging the need for all New Zealanders to have a shared carbon responsibility, which needs to be focused into direct climate action. Finally, we

outline three recommendations for climate action that need to be addressed to enable the transition to a low-carbon built environment:

Strategy 1: Increased energy efficiency

Our research recommends that, for buildings (whether new or existing), there is a need to improve energy efficiency, decrease the energy supply carbon footprint and manage peak demand. These measures could be taken up by government and industry in a number of ways, such as:

- encouraging passive solar design in new builds (for all typologies)
- providing incentives to help accelerate and improve thermal performance in existing buildings
- reviewing the Building Code for clause H1 *Energy efficiency* alongside its broader implications for clauses E3 and G4
- encouraging low-carbon fuel options for space and water heating
- increasing renewables supplying grid electricity
- investigating the feasibility of incorporating carbon performance into the Building Code
- providing ongoing tracking of building carbon performance
- providing additional, practical education resources to help consumers and the building industry better understand the implications of design choices from a carbon perspective over the building's lifetime

Strategy 2: Reduce embodied carbon

The research also found that there is a need to reduce the embodied carbon in the materials we make our buildings with, which could be done through a number of measures, such as:

- greater application of environmental impacts tools, such as NABERSNZ, Greenstar, and BRANZ's *LCAQuick* tool
- increasing opportunities for reuse, recycling or recovery of construction waste
- incentivising use of materials in buildings that provide lower embodied and life cycle greenhouse gas impacts.

Strategy 3: Strategic leadership for climate action

We need to adopt a socio-technical approach in formulating climate action. Four key areas of climate action that should be the focus of the transition to a zero-carbon built environment are:

- coordinated climate change action
- climate change literacy
- actualising change
- changing beliefs and practice.

1. Introduction

We are living in the age of the Anthropocene – an epoch when human actions have started to impact Earth's geology and ecosystems, such as through climate change (Crutzen & Steffen, 2003). Climate change is as much a social and cultural issue as an ecological one. Contemporary societies are often underpinned by an 'extractive' capitalism whereby environmental degradation goes hand in hand with market liberalisation and economic development, best exemplified by the natural resource and mining sectors (Sassen, 2014). As an alternative to extractive capitalism, the transition to a low-carbon economy is often suggested, whereby climate change is mitigated through the adoption of sustainable development. A low-carbon economy conveys the sense that it is possible to combine capitalist economic rationalisation, especially growth, with climate change mitigation and adaptation (Andersen & Massa, 2000). It typically refers to climate mitigation taking place in the green sectors such as renewable energy, energy efficiency and clean technologies as well as more general economy-wide shifts (including products and services) along the supply chain to embrace a low-carbon approach (Lovell, 2015). The notion of a low-carbon economy is a central element of this report and a goal for climate action.

The challenge imposed by climate change is strongly influenced by the built environment, especially within New Zealand, where at least 86% of the population live in cities (Stats NZ, 2017b). Lucon et al. (2014) for the Intergovernmental Panel on Climate Change (IPCC) state that

> … in 2010 buildings accounted for 32% of total global final energy use, 19% of energy related GHG emissions (including electricity – related), and approximately one-third of black carbon emissions and an eighth to a third of F-gases.

There is not yet a New Zealand-specific figure of emissions buildings contribute. The built environment cannot alone be tasked with solving all the identified issues to do with climate change mitigation and adaptation. However, the way people inhabit the built environment does make a large contribution to the causes of climate change. The IPCC stated in 2007 that buildings offer opportunities for cost-effective greenhouse gas mitigation comparative to other sectors (Lucon et al., 2014). This will require significant change to current practices in how to build, construct and refurbish buildings if we are to achieve the carbon targets set by the Paris Accord.

Climate change will impact the built environment in a number of ways – see Table 1 (adapted from Pedersen Zari, 2012, pp. 17–18) for a summary. Hunt and Watkiss (2011) have promulgated these impacts within an international context as:

- sea level rises and storm surges
- extreme weather events, such as heat waves, flooding and high winds
- changes to water availability.

Camilleri et al. (2001) outline some of the impacts that New Zealand is likely to experience including:

- an increase in inland flooding
- increased temperatures resulting in an increased need for indoor cooling
- increased damage due to a possible rise in number and intensity of tropical cyclones.

Table 1. The impact of climate change on the built environment.

Potential direct climate change impacts	Consequences for the built environment	Possible scale of the negative impact	Source
Change in temperatures (likely to increase in most areas)	Increased overheating and air-conditioning load	High	1, 2, 3, 4, 5, 6
	Intensified urban heat island effect	High	
	Decreased winter space heating	Low	
	Decreased water heating energy	Low	
Increased intense weather events	Damage to buildings and infrastructure	High	1, 2, 3, 4, 5, 6
Changes in precipitation patterns	Increased inland flooding	High	1, 2, 3, 4, 6, 7, 8
	Increased erosion, landslides and rockfalls	High	
	Changes in aquifers and urban water supply and quality	High	
	Heavier snow or ice loads	Medium	
	Increased fire risk associated with more frequent droughts	Medium	
	Damage to foundations, underground pipes and cables	Medium	
	Increased subsidence (clay soils)	Medium	
	Increased pressure on urban drainage systems and run-off	Medium	
	Increased stormwater run-off and leaching of pollutants into waterways or aquifers	Low	
Thermal expansion of oceans and changes in the cryosphere (ice systems) such as retreating snow lines and ice packs, and melting glaciers	Increased coastal flooding	High	1, 2, 3, 4, 5, 6, 7, 8
	Increased erosion and loss of land	High	
	Relocation or displacement from coastal areas	High	
	Changes in water tables and possible increased salinity of aquifers and estuaries	High	
	Loss of intertidal areas acting as buffer zones	High	
	Impeded drainage	Medium	
Changes in wind patterns and intensities	Changes in wind loading on buildings	Medium	1, 2, 3, 5, 8
Increased air pollution	Impacts on interior air quality management	Medium	1, 5
	Damage to building façades	Low	
Impacts on biodiversity	Changes in cooling, shading and evapotranspiration benefits from urban biodiversity	Medium	6, 7
	Changes to stormwater management	Low	

Sources: 1. BRANZ, 2001. 2. Camilleri et al., 2001. 3. Gluckman & Boyle, 2003. 4. Honey & Buchanan, 1992. 5. Mullan et al., 2008. 6. O'Connell & Hargreaves, 2004. 7. Woodward et al., 1998. 8. New Zealand Climate Change Programme, 2001.

Auld et al. (2007) have highlighted a number of key challenges associated with climate change. These problems go beyond policy problems, as they are all encompassing. They point out that

- time is running out to implement especially effective mitigation actions, as the natural environment cannot be negotiated with
- centralised governance is lacking and coordination across various scales is required
- human actors aiming to end the problem are also its cause
- decision makers and the public disregard even clear evidence on harmful consequences and instead focus on short-term actions.

This report is an opportunity to examine how climate change impacts the built environment within the New Zealand context and how we could help to facilitate a transition to a low-carbon built environment.

1.1 Structure of the report

In the context of this report, the built environment refers to all residential and commercial buildings including their associated reticulated energy and water services, although this report primarily focuses on residential dwellings. Our definition of the built environment is inclusive of the manufacture and prefabrication of building materials and components, energy/water supply and wastewater systems but excludes things like road infrastructure and civil works.

The report is presented as follows:

- Section 2 provides a brief overview of the global response to climate change before examining what New Zealand has done to address climate change, such as the establishment of the Emissions Trading Scheme (ETS). This section also examines how climate change relates to some building-specific legislation.
- Section 3 provides an assessment of New Zealand research related to residential housing and climate change. The focus is on energy and thermal performance, materials in residential construction and tools available for evaluating carbon performance. This section also examines commercial and other non-residential buildings, especially energy use and materials, and examines market mechanisms for evaluating office building performance. Initiatives around adaptation to climate change are also discussed.
- Section 4 discusses the challenges facing New Zealand in creating zero-carbon buildings, citing various industry barriers. This section also outlines some drivers that could be utilised to create zero-carbon buildings in New Zealand before an analysis of the cycle of blame that prevents the industry from delivering zero-carbon buildings.
- Section 5 considers some frameworks that underpin a transition to a low-carbon economy and outlines some strategic directions that enable the creation of a pathway for zero-carbon buildings and climate action in order to help the transition to a low-carbon economy.
- Section 6 summarises the overall findings and outlines some recommendations for future work especially for research and policy.

2. A pathway for climate action?

This section provides an overview of both the global and New Zealand response to climate change. New Zealand's target to cut emissions by 50% by 2050 may not be ambitious enough, especially compared to the UK.

It provides some context on the global response to climate change, outlines the legislation relevant to the built environment and provides insight into how existing legislation could be amended to help improve our response to climate change.

When compared to other nations, such as the UK Climate Change Act and the Dutch Building Code, it suggests there is room for improvement in a legislative response to climate change. Legislation is one way to ensure targets are set and plans are put in place to help achieve them.

2.1 The global response to climate change

It was not until the 1970s that it became evident that the environmental impact from climate change required a global response. The World Meteorological Organization (WMO) began to express concern that human activity might lead to a warming of the lower atmosphere and a rise in carbon dioxide emissions (SOAS, 2017). With increasing concern about human impact on the environment, including the resultant extreme weather events, the United Nations Environment Programme (UNEP) established the International Panel on Climate Change (IPCC). It was set up to investigate and report on the scientific evidence on climate change and develop possible responses to the issue. The IPCC has been central to the global response and establishment of scientific evidence that has illustrated that a rise in carbon dioxide emissions has led to climate change.

The IPCC's first assessment report in 1990 fed into the drafting of the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC was signed by 166 nations at the Earth Summit in Rio de Janeiro, Brazil, in 1992, but did not come into force until 1994. It is important to note that the UNFCCC did not include specific national or international targets to reduce carbon/greenhouse gas emissions. However, the UNFCCC set out a number of principles that have been important to international climate change processes:

- An objective of stabilising the climate to prevent 'dangerous anthropogenic interference with the climate system' in a time-frame that would allow natural systems to adapt without major damage to food systems and economic development.
- The need for countries to monitor and limit their greenhouse gas emissions and for different national limits, taking account of countries' different responsibilities and capacities.
- A particular concern for developing countries – and especially those most vulnerable to damaging climate change impacts, such as small island states.
- The importance of precautionary measures to respond to the severity of climate change threats, despite real scientific uncertainties regarding climate change processes and impacts. (SOAS, 2017)

The annual meeting of the UNFCCC has become known at the Conference of Parties (COP), with the first held in Berlin in 1995. Since the Earth Summit and the preceding COPs, there was a growing tension internationally in the lack of specific targets. This changed in 1997 with COP3 in Kyoto, Japan, which saw the creation of the Kyoto Protocol. The Kyoto Protocol helped to establish emissions targets for industrialised and developing countries (although many were non-binding) for 2008–2012. This outlined three main mechanisms for cutting carbon emissions (SOAS, 2017):

- An emissions trading scheme (ETS), enabling international trade of emissions allowances.
- A clean development mechanism (CDM), allowing developed country signatories emissions credits for investing in emissions savings in developing countries. The only Kyoto Protocol mechanism that allows for investment in developing countries is the CDM.
- Joint implementation (JI), allowing emissions-saving investments in other industrial (Annex 1) countries, including emerging economy countries, to be credited to signatory developed countries. This promoted more cost-effective emissions saving than would otherwise be achieved.

The Kyoto Protocol created controversy amongst some nations, due to non-binding emissions targets for developing countries. Some countries such as the United States never ratified the Kyoto Protocol, while others such as Canada withdrew from the agreement in 2012.

Following the Kyoto Protocol, climate change continued to be a politically charged topic, especially with climate change denial in the face of scientific evidence. The IPCC's fourth assessment helped to outline clearly that the warming of the climate was unequivocal and that "most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations" (IPCC, 2007, p. 39).

Due to a lot of media attention, the COP15 in Copenhagen faced a great amount of global expectation about creating global action on climate change. Many media outlets reported that the COP was in a state of disarray. Instead of a substantive way forward, the Copenhagen Accord, mainly created by the USA, China, South Africa, India and Brazil, was adopted despite opposition from Bolivia, Venezuela, Sudan and Tuvalu. This was due to a lack of targets and the nature of how the accord came about. Despite the optimism for the COP15 to address climate change, the Copenhagen Accord was met with limited success due to several factors. These included that the accord was not legally binding, no decision was taken on whether to agree a legally binding successor or complement to the Kyoto Protocol and the accord set no real targets for achieving emissions reductions.

Following the disarray and lack of any concrete measures at COP15 in Copenhagen. COP16 in Cancun, Mexico, produced a more pleasing result. Cancun resulted in the Cancun Agreements, which paved the way for a number of important arrangements, such as the Green Climate Fund, the Technology Mechanism, the Cancun Adaptation Framework and forest management reference levels.

The next significant meeting was COP21 in Paris in late 2015, which resulted in the Paris Agreement. A partially legally binding agreement for internationally coordinated action on climate change, the Paris Agreement contains:

- an ambitious collective goal to hold global warming well below 2°C, with efforts to limit warming to 1.5°C
- an aim for greenhouse gas emissions to peak as soon as possible and to achieve net-zero emissions in the second half of this century

- a requirement for mitigation measures of individual countries to be expressed in nationally determined contributions (NDCs)
- a process that demands a revision of NDCs at least every 5 years, representing progression beyond the last NDCs
- a mechanism for countries to achieve NDCs jointly, sharing mitigation targets, and a mechanism for countries to cooperate in achieving NDCs – countries can meet their NDC targets by transferring mitigation outcomes internationally either in the context of emissions trading or to allow results-based payments
- a mechanism for private and public entities to support sustainable development projects that generate transferable emissions reductions
- a framework for enhanced transparency and an expert review of NDCs
- a global stocktake from 2023 and every 5 years thereafter to review progress
- encouragement for parties to implement existing frameworks for REDD+[1], including through the provision of results-based payments
- a global goal of enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change and commitment to providing enhanced support for adaptation
- a non-punitive compliance mechanism that is expert based and facilitative in nature (Climate Focus, 2015).

Together with the United Nations Sustainable Develop Goal 13: Climate action, the Kyoto Protocol and the Paris Agreement, there is an internationally coordinated approach to climate change and assistance to design national measures as countries attempt to implement these agreements.

2.2 New Zealand's response to climate change

In recent years, New Zealand has set a number of greenhouse gas emissions targets – the first in 1997 with a 2012 target at Kyoto COP, in 2009 with a 2020 target at Copenhagen COP, and in 2015 with a 2030 target at Paris COP21. The fourth was set by the New Zealand Government in 2011 under section 224 of the Climate Change Response Act 2002, which aims to reduce emissions to 50% below 1990 levels by 2050 (New Zealand Productivity Commission, 2017). Table 2 outlines the specific targets made by the government that expressed in terms of net emissions – gross emissions minus the carbon dioxide taken out of the atmosphere by trees each year (Wright, 2017).

Table 2. Emissions targets set by New Zealand Government.

	Target year		Net emissions (million tonnes CO_2eq per year)
Kyoto	2012	Net emissions equal to 1990 gross emissions	64.5
Copenhagen	2020	Net emissions 5% below 1990 gross emissions	61.3
Paris	2030	Net emissions 30% below 2005 gross emissions	57.7
New Zealand '50 by 2050'	2050	Net emissions 50% below 1990 gross emissions	32.3

[1] REDD+ = reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries.

The New Zealand Productivity Commission (2017) has stated that New Zealand's current policy approach to climate change is consistent with its global position as a small trade-reliant country with a unique emissions profile to other countries. The Ministry for the Environment (2015) has outlined that the highest proportion of New Zealand's emissions are related to biological and transport emissions, with further scope to reduce emissions within the energy sector. To date, New Zealand has relied heavily on the international trading of carbon credits to help deliver it, carbon emissions targets. The main tool and principal response to climate change within New Zealand has been the Emissions Trading Scheme (ETS).

The New Zealand ETS was established under the Climate Change Response Act 2002 and commenced in 2008 (New Zealand Productivity Commission, 2017). The current ETS requires the energy, fishing, forestry, industrial processes, liquid fossil fuels, synthetic gases and waste sectors to report on and purchase and/or surrender units to the government. At present, the agriculture sector, one of the largest sectors responsible for carbon emissions, is excluded. Under the ETS, one unit that can be traded represents 1 tonne of carbon. Participants must surrender one New Zealand unit per tonne of CO_2eq (equivalent carbon dioxide). At present, one New Zealand unit is priced at NZ$25. Internationally compared, the New Zealand ETS is different from other emissions trading schemes as there is no limit or cap on the number of carbon units that are tradeable. Also, New Zealand allows other countries to buy an unlimited number of carbon units (Wright, 2017). The present ETS is New Zealand's main response to climate change.

2.3 A Climate Change Act?

In 2017, Parliamentary Commissioner for the Environment Dr Jan Wright recommended that New Zealand implement a Climate Change Act, modelled along the same lines as the United Kingdom. The UK Climate Change Act contains four aspects that could be useful for New Zealand to follow:

- **Emissions targets in legislation:** For example, the UK has set their emissions target at 80% of 1990 levels by 2050 – a contrast to New Zealand's 50% by 2050. The rationale for imposing targets in legislation is to make sure the target can be achieved through cross-party support, not the ebbs and flows of the electoral cycle.
- **Carbon budgets as a stepping stone to targets:** The setting of carbon budgets provides a pathway to meet the 2050 target. A carbon budget is the total net amount of greenhouse gases that can be emitted over a 5-year period (Wright, 2017). By setting budgets, the rationale is to encourage government to plan and set specific targets that can be meet and planned for.
- **Policies set by government to ensure carbon budgets are met:** Within the UK Climate Change Act, there are no specific policies, but rather the Act requires government to develop proposals and policies that will ensure emissions are kept within the set-out carbon budget. The principle of this recommendation is that it is legally binding that the government must act and tackle climate change.
- **An expert body is created to provide objective analysis and advice:** The UK Climate Change Act helped to establish an expert committee made up of a chair and five to eight members with a deep understanding of buildings, transport, electricity, agriculture, forestry and other core sectors. The committee has two functions. It seeks to provide advice on carbon budgets, such as what level they should be set at, and must report annually on progress on meeting the carbon budgets (Wright, 2017).

In 2017, the Labour Party won the general election through a coalition arrangement with New Zealand First with support from the Green Party. The have stated that they would seek to create a Climate Change Act and establish a commission on climate change.

2.4 Local government response

Local government has an obligation to address climate change through section 10(1)(b) of the Local Government Act 2002, which charges them with the responsibility for meeting the current and future needs of communities for infrastructure, local public services and regulatory functions. Planned action on climate change and the role of local government have a long history. For example, United Nations Agenda 21, which focused on sustainable development, has been successfully integrated in much local government policy and regulation (Hughes, 2000).

In recent years, a number of key documents have outlined the key role local government can play in directing climate action (LGNZ, 2017a, 2017b).

Local Government New Zealand (LGNZ, 2017b) details a plan for climate action, which is split into two sections – local government-led action on climate change what local government requires of central government.

Part one of the plan details what local government will do to implement climate action:

- Local government will collaborate.
- Local government will incorporate climate change implications into urban development and land-use decisions and take a long-term approach to waste management and energy us, including transport infrastructure.
- Local government will take an all-hazard approach to managing risks.
- Local government will factor in the impacts of climate change on water security.

Part two of the plan outlines four key areas of attention for central government:

- National campaign to raise awareness of climate change.
- Policy alignment and a clear mandate to address climate change.
- A decision on fiscal responsibility for adaptation
- Co-investment with central government to support low-carbon, climate-resilient infrastructure.

Local government in New Zealand is well positioned to play a key leadership role in order to implement climate action – directly as a provider of critical infrastructure and services and indirectly through its influence over activities responsible for emissions, such as waste management.

2.4.1 Local government leaders climate change declaration

Local government sees itself as a key actor so much so that, in 2017, a declaration was made by local governments across the country. A group of mayors and chairs representing local government from across New Zealand sought to demonstrate responsive leadership by developing a plan for climate action (LGNZ, 2017c). The declaration outlined goals that sought to:

- acknowledge the urgent need to address climate change for the benefit of all generations

- support the New Zealand Government to develop and implement a transition plan towards a low-carbon and resilient New Zealand
- encourage government to adopt ambitious climate change mitigation measures
- outline key commitments councils should take in responding to the challenges and risks posed by climate change
- recommend guiding principles to help support climate action.

Based upon these shared understandings and obligations, local government leaders made a commitment to:

- develop and implement actions plans to reduce greenhouse gas emissions and support resilience in their communities by:
    - promoting walking, cycling, public transport and other low-carbon transport options
    - working to improve the resource efficiency and health of homes, businesses and infrastructure in their districts
    - supporting the use of renewable energy and uptake of electric vehicles
- work with communities to understand, prepare and respond to the physical impacts of climate change
- work with central government to deliver on national emissions reduction targets and support resilience in New Zealand's communities.

The declaration set out guiding principles to help inform decision making about climate change as:

- precaution
- stewardship/Kaitiakitanga
- equity/justice
- anticipation (thinking and action long term)
- understanding
- cooperation
- resilience

This climate change declaration by local government leaders is a great step forward in helping to create climate action in New Zealand, but a more critical concern is to create a specific plan for each local government area that can set about reducing emissions.

2.4.2 Low Carbon Auckland

At local government level, few councils to date have their own emissions-reduction strategies. The Low Carbon Auckland plan (Auckland Council, 2017) was one of the first implemented by a local government. The plan was launched in 2014 and committed to reduce emissions by 40% by 2040. Between 2009 and 2015, emissions in Auckland increased (2.1% net emissions and 7.1% gross emissions). The city of Auckland is making progress towards climate action, such as signing up to the C40 Paris pledge for action, and with its unitary plan setting policy for quality compact urban form. The unitary plan also sets objectives to help mitigate natural hazards and create more climate resilience. Auckland's future climate action from 2018 is centred around transitioning to a low-carbon city.

2.5 Building legislation relevant to climate change

Within New Zealand, there a two main pieces of legislation that are relevant to buildings and climate change – the Building Act 2004 along with its amendments and the Resource Management Act 1991 along with its amendments.

2.5.1 Building Act 2004

The Building Act 2004 requires that "buildings are designed, constructed, and able to be used in ways that promote sustainable development". Consequently, the Building Code prescribes functional requirements and performance criteria for residential buildings.

The Building Code, launched in 1991, was originally designed with detached housing in mind. It is now expected that a third of new building consents across the country will be multi-unit dwellings, particularly apartments (BRANZ & Pacifecon, 2015). The Auckland region is leading the way for this, with considerable investment in medium-density and higher-density construction. As an indication of progress, the actual number of consented apartments in the Auckland region increased by 1,385% between February 2011 and February 2016 (Stats NZ, 2016).

The Building Code is a performance-based code, implemented through Verification Methods and/or Acceptable Solutions as a way of demonstrating compliance. Acceptable Solutions provide examples of materials, components and construction methods, while Verification Methods may be based on calculation or laboratory in situ testing. The New Zealand building control system regulates only those matters essential for ensuring that buildings perform in a way that safeguards people from injury, illness and loss of amenity, protects other property from damage and facilitates efficient use of energy. At this stage, climate change does not appear as an 'essential matter'.

Building Code clauses cover:

- A *General provisions*
- B *Stability*
- C *Protection from fire*
- D *Access*
- E *Moisture*
- F *Safety of users*
- G *Services and facilities*
- H *Energy efficiency*

Clause H1 of the Building Code "provides for the efficient use of energy and sets physical conditions for energy performance". This is predominantly through thermal insulation metrics for housing and small buildings.

The Building Code has the potential to be changed to one geared more towards climate change mitigation and adaptation. An example of international best practice is that of the Netherlands, which has a relatively advanced system for stimulating the building industry to use more sustainable, climate-conscious investments when compared internationally. The Netherlands Building Decree sets out technical requirements for existing and new construction, which includes an environmental examination of material impacts and assessment of the environmental performances of construction and civil engineering works (Scholten & Van Ewijk, 2013). The Dutch system for determining the environmental performance of buildings and construction works consists of an environmental calculation method and a third-party environmental product declaration (EPD) verified environmental profile. The environmental calculation method comprises a full cradle-to-grave analysis for the building materials being examined. Energy and water consumption during use are excluded. As part of this determination, mandatory global warming potentials are calculated. This system is said to provide transparency in the marketplace to provide lower-impacting building solutions.[2]

2.5.2 Resource Management Act 1991

Section 7 of the Resource Management Act 1991 (RMA) requires that particular regard shall be given to the:

- efficiency of the end use of energy
- effects of climate change
- benefits to be derived from the use and development of renewable energy.

In the context of the RMA, there are two ways in which the effects of climate change can impact regulation:

- As part of decision making – within the assessment of environmental effects in resource consent applications and notices, the effects of climate change should be outlined.
- In proactively assessing RMA policy statements and plans as they come up for review or other changes are proposed, with consideration of whether more explicit and/or up-to-date policies are needed to address the effects of climate change than are currently provided. For example:

> The effects of climate change can be integrated into local authorities' longer term planning under the Local Government Act, as part of their mandate to meet the current and future needs of communities for good quality local infrastructure, local public services, and performance of regulatory functions in a way that is most cost effective for households and businesses. (Greater Wellington Regional Council, 2017)

[2] www.milieudatabase.nl/imgcms/UKGBC_Webinar_dBase_11_July_2014_Schuurmans_2.pdf

3. State of knowledge: the built environment and climate change

Buildings are unique in comparison with many other products because of their bespoke nature (for example, due to differences in size, function(s), location, level of service) and long lifetime.[3] Many of the buildings in existence now will still be with us in 2030 and beyond, by which date we are seeking to establish a low-carbon economy under the Paris Accord.

Buildings primarily contribute to climate change impact in three key ways:

- The use of energy and where we obtain this energy, year on year, while the building is occupied.
- The materials used in and on buildings, which contribute to greenhouse gas emissions as a result of extraction, processing, transport and installation before the building is occupied, as well as periodic maintenance and the need for repair and replacement of materials during the building's service life.
- Urban and landscape design/planning.

Whilst overall residential energy demand continues to grow due to the increasing (absolute) size of the housing stock and population, individual dwelling energy use has been falling since 2000 (Royal Society of New Zealand, 2016). This is thought to be from improvements in technology and fuel switching (EnergyConsult, 2015). Conversely, total energy use in commercial buildings has been increasing – by 50% from 1990 to 2014 (Ministry of Business, Innovation and Employment, 2016).

During construction, the manufacture of materials, transport and installation into our buildings can contribute a significant amount of greenhouse gases in a short timeframe. Thus, buildings incur a carbon debt in construction that is added to as part of maintenance and renovation needs throughout the life of a typical building. As stated in the USA by environmental building organisation BuildingGreen (2011), "reductions in carbon emissions of materials have an immediate benefit, while the carbon reductions through operations accrue over a long period of time".

Also, material-embodied carbon is not dependent on behaviour, building energy source or quality of construction – making it more certain in some ways than operations-related carbon (BuildingGreen, 2011). Finding ways to reduce this initial debt and even repay it during the building lifetime provides another strategy for helping us achieve a low-carbon built environment.

On an individual-building level, a BRANZ study report (Jaques & Sheridan, 2006) is one of the earliest works on practically addressing climate change mitigation during the design process. It provides designers/specifiers a suite of options to significantly improve the climate change readiness of their proposed residential buildings at the concept/design stages. The main mitigation-related issues examined in the research related to thermal comfort, energy in use, embodied energy in building materials and proximity to amenities.

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[3] Research by Johnstone (1994) indicates a lifetime of 90 years and up to 130 years for dwellings in New Zealand. International research into commercial buildings indicates a service life of 50–60 years (Dowdell et al., 2016).

3.1 Households and dwellings

In 2013, there were 1.56 million occupied dwellings in New Zealand with a combined floor area of about 222 million m^2 (Statistics New Zealand, 2014). Of these, 1.19 million were detached houses, while 267,000 were other types of houses such as flats, units, townhouses or joined houses. Due to the non-uniform residential build characterisation processes employed by local authorities, further disaggregation is difficult. New Zealand's new-build detached housing stock is worth approximately $6 billion annually (Jaques, 2015). Further information about use of energy, materials and waste and their influence on climate change are examined further in this report.

3.1.1 Energy and thermal performance

With an estimated 1.19 million stand-alone dwellings in New Zealand, each consuming 11,410 kWh energy per year (Isaacs et al., 2010) at 1.77 tonnes CO_2eq per house,[4] means an annual contribution of more than 2 million tonnes[5] CO_2eq towards our climate change impact.

Together with this contribution, it is well recognised that New Zealand's housing stock is considered to perform suboptimally in terms of regulating its internal environment to provide comfortable and healthy living conditions (Jaques, 2015).

The most comprehensive longitudinal study conducted on New Zealand housing is the BRANZ Household Energy End-use Project (HEEP) (Isaacs et al., 2010). Its objective was to measure and model what, how, when, where and why energy is used in New Zealand households. The decade-long project commenced in 1995 with a pilot study and progressed to detailed data collection in 400 houses throughout New Zealand. The sample included households from Kaikohe to Invercargill, with each house monitored for approximately 11 months.

HEEP monitoring activities included a detailed occupant survey as well as a detailed energy examination. The monitoring covered all fuel types (electricity, natural gas, liquefied petroleum gas (LPG), solid fuel, solar water heaters) as well as temperatures in at least three locations for each house (such as bedrooms, living rooms and rumpus spaces).

Although now over 10 years old, the HEEP energy analysis is still the best information available currently for housing energy use. The average amount of energy used per house of 11,410 kWh per year is broken down by fuel type as shown in Figure 1.

The most common energy source was electricity, while the most common space heating fuel was solid fuel (mainly wood). Low temperature heat is the main use (at 63%) of household energy, providing space heating (34%) and water heating (29%). Electricity provides 75% of energy used for hot water, with gas (at 20%) and wetback (at 5%) providing almost all of the rest. Electric hot water cylinders were found in 77% of households, giving New Zealand the highest proportion of any country.

The study found that, in all cases, mandatory thermal insulation (required since 1978) was associated with less energy use.

[4] Calculated – compares to a figure of 2 tonnes calculated by Alcorn (2010).
[5] Excluding other types of dwellings that are not stand-alone such as flats, hostels and so on.

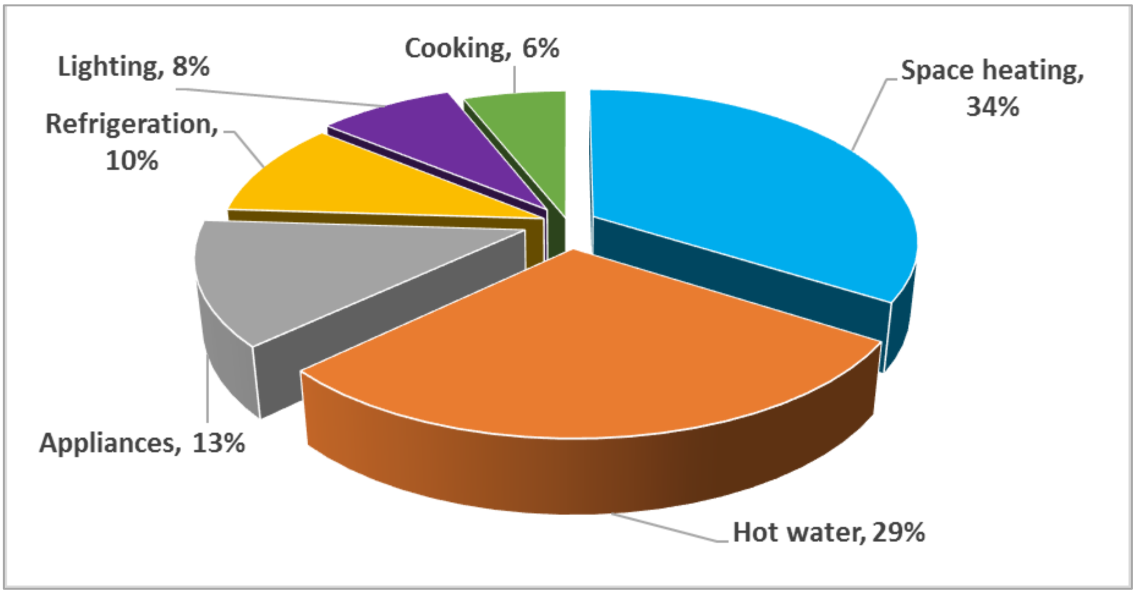

Figure 1. Average energy end use for residential building in New Zealand by category. (Source: Isaacs et al., 2010)

The HEEP data provided the first nationwide statistically representative study of standby and baseload electricity use for any country. The baseload is typically the lowest power consumption when everything that is usually turned off is off, while standby includes energy used by appliances while waiting to be used. On average, it was found that about 10% of the total average residential energy demand was standby and baseload.

Since the HEEP study, there have been several changes to the energy end-use make-up of New Zealand households. Most notably, there has been a significant increase in the number of heat pumps installed, especially in new homes, replacing other space heating appliances (such as oil column heaters and solid fuel burners). It is estimated that one in four households now have one or more heat pumps. The sale of heat pumps is forecast to continue to grow, particularly the smaller units used in homes. It is estimated that, by 2025, there will be over 1.2 million units installed, a 40% increase from 2012 (Ministry of Business, Innovation and Employment, 2013). Although the efficiency of heat pump units is better than other forms of heating, it is not known whether this translates into a reduced heating load or just a higher temperature setpoint/larger heated area in an average house.

3.1.1.1 Influence of renewables/micro-generation

The uptake of photovoltaics (PV) in residential buildings has been gaining pace in New Zealand, mainly due to its rapid decline in cost, making other renewables far less competitive/desirable. There were 9,533 solar connections in New Zealand at the end of March 2016, up on 5,760 at the same time in 2015 and 2,712 in 2014, according to the Electricity Authority (Fulton, 2016). Of the 2016 year’s solar connections, 9,022 were residential, 262 commercial and 249 industrial.

The drivers for household renewable energy generation include:

- isolation against rising energy prices
- the desire for independence and self-sufficiency
- reduced energy costs in retirement
- resilience against power cuts or natural disasters

- supporting energy-efficient and more sustainable homes (Ford et al., 2014).

A recent New Zealand-based report calls into question preconceived beneficial notions about the consumer benefits of investing in household solar PV – both with and without storage capability (Concept Consulting, 2016). The study looked at the financial, environmental and social implications of dwelling-installed PV. In terms of the environmental examination, the report looked at how solar panels will likely affect New Zealand's greenhouse gas emissions. They provided a detailed breakdown for various future scenarios as part of their sensitivity studies. It was found that, due to our unusual electricity generation mix (of around 80% renewables and growing), there are only modest environmental benefits (using CO_2 as a proxy) for domestic-scale PV installation in the near term due to the likelihood of it displacing generation from fossil-fuelled electricity supply.

In the longer term, the authors expect residential-scale PV uptake to displace new, large-scale, super-low-emission wind and geothermal that would otherwise have been built to meet a growth in demand or retirement of old existing stations. Thus, in this timeframe, residential-scale PV uptake will actually increase the need for fossil-fuel generation and therefore add to electricity sector emissions. This is because PV generates more energy in summer than winter, which is the opposite of what the New Zealand residential energy sector needs. This requires more power from controllable sources that operate sporadically, which will most likely be fossil-fuel based. Adding batteries/storage into the mix is not expected to fundamentally alter the results for PV by itself. This is because batteries are not well suited to shifting power across seasons.

Micro-wind is only suitable for very few urban areas in New Zealand. It requires very high average wind speeds and flat topography within an urban area so it does not really apply to most of New Zealand's population. Solar thermal is an option. The Parliamentary Commissioner for the Environment's (2012) report on the environmental benefits and cost-effectiveness of heating water from the sun found that, on a daily basis, solar water heaters are beneficial when it comes to reducing carbon dioxide emissions. On a yearly basis, because thermal power plants are run much more in winter than in summer when carbon dioxide emissions are greatest, the performance of solar water heaters is at its lowest. Thus, they do little to reduce the 'peakiness' of the annual demand for electricity and therefore do not reduce the pressure to build new peaking power plants and power lines.

3.1.1.2 Thermal performance

A BRANZ report (Jaques, 2015) examined the thermal performance of 210 randomly selected new detached houses from submitted consent documentation for the year 2012. The houses were from Auckland, Hamilton and Christchurch (~70 each). Detailed thermal modelling using sophisticated methods found the following:

- The average home built to the Building Code required twice to three times the amount of heating energy to maintain thermal comfort conditions as compared to a similarly specified and priced passive solar design[6] (Figure 2).
- There were long periods of critically cold indoor temperatures (below 12°C) under free-running (i.e. unheated) conditions during winter, even in Auckland's

[6] Passive solar design is where a building's orientation, insulation and glazing are specifically designed so that nature is able to provide an indoor thermal environment that is comfortable all year round.

comparatively mild climate. This was despite all the houses being placed on sections with good solar exposure and limited shading.

- The difference between what could easily be achieved in terms of year-round thermal comfort (using passive solar design) and what is currently being achieved is considerable. This is true for all three climate zones and whichever energy use metric (by area, by household or by occupant) is chosen.
- Just specifying higher-performance insulating glass units (mid-range double glazing), the most critical external thermal component, would have meant that the randomly selected homes' energy requirements would have reduced by between 16% (Christchurch) and 26% (Auckland). The cost of higher-specification glazing units in 2016 is approximately 1.5% higher than the Code-minimum units typically specified for the average priced house (R. Jaques, personal communication, March 2018).

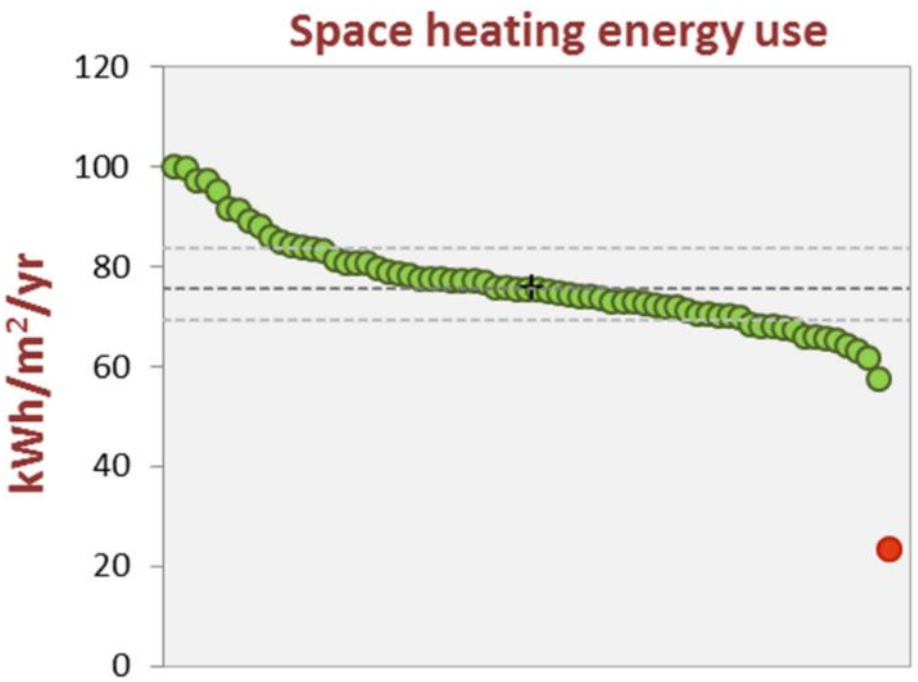

Figure 2. Space heating energy requirements for comfortable indoor temperatures, based on 70 randomly selected 2012 consented houses (green dots) compared to a well designed, modestly priced, passive house (red dot) in Christchurch. Dotted horizontal lines are the 20th, 50th and 80th percentiles. (Source: Jaques, 2015)

Examining these findings suggests that the Building Code is not delivering homes with a thermal performance that is anywhere near what a good home should be, let alone an ideal home. It also demonstrates that, as a function of both specification and design, even new homes require substantial applied heating to avoid sustained periods of temperatures below the 12°C health threshold (Braubach, Jacobs & Ormandy, 2011).

At the other end of the comfort envelope, overheating is becoming a growing problem in newer dwellings, mainly due to design trends for large windows without external shading (Jaques, 2010). This has implications for the use of air-cooling appliances. Research has shown that 58% of people with heat pumps in a 2010 study were using them to cool in summer (Burrough, Saville-Smith & Pollard, 2015). This is likely to increase as climate change is expected to lengthen the cooling season. Projected results are shown for the main cities by 2050 in Table 3.

Table 3. Impact of climate change on expected cooling days in New Zealand's three main centres – average days/year the maximum outdoor temperature exceeds 25°C.

Centre	2010	2020	2050
Auckland	20	25–37	31–81
Wellington	3	4–7	5–21
Christchurch	26	29–36	32–64

(Source: Jaques, 2010)

For the year 2030, the percentage increase in living area overheating is projected to be 61%, 32% and 15% for Auckland, Hamilton and Christchurch respectively. By 2080, the percentage increase in living area overheating compared to today is projected to be 254%, 160% and 61% respectively. Consequently, Auckland will shift from a heating-dominated climate to a cooling-dominated one towards the end of this century.

Given New Zealand's comparatively clement weather for most of the population, very little purchased/reticulated energy should be required to achieve comfortable indoor temperatures with careful residential design, specification, construction and operation. However, achieving comfortable indoor temperatures passively year round is still very rare in new house designs (Jaques & McNeil, 2012). As a consequence, approximately a third of New Zealand's household energy end use (with its associated CO_2 emissions) can be attributed to purchase of assisted thermal-conditioning fuels (Isaacs et al., 2010).

3.1.1.3 Dwelling size

The current New Zealand detached house size is just over 200 m^2 for around 2.2 persons, on average. This compares to a house size of 166 m^2 in 1990 and 140 m^2 in 1970, even as the occupancy rate has fallen (QV, 2011).

The relationship between dwelling size and space-conditioning requirements should be kept in mind. A recent study undertaken by the University of Otago (Viggers et al., 2017) found that the increase in house size can cancel out the energy gains from increased insulation. This supports NZGBC's Homestar Technical Manual (v3), which states that "it is generally recognised that large homes consume more resources than small homes over their life cycle".

3.1.1.4 Indoor air quality

The airtightness of New Zealand's homes has increased over time with the introduction of sheet flooring and linings, tighter-sealing window and door joinery and the increased use of air-sealing methods in new buildings (Overton et al., 2013; McChesney, 2009). This has led to more airtight homes, which enables better control of air infiltration and thus benefits the energy efficiency parts of the Building Code (clause H1) through reduced heat losses from air leakage. The negative consequence of this is that this can have detrimental impacts on the indoor air quality if the house is not being adequately ventilated (through natural infiltration). The provision of secure passive ventilation or mechanical ventilation systems that source fresh outside air is uncommon in New Zealand. This places a heavy reliance on occupants to provide adequate ventilation through deliberate actions such as opening windows.

New Zealand research has found that "about two-thirds of all new homes are likely to need ventilation on top of the background infiltration to achieve acceptable levels of indoor air quality" (Overton et al, 2013). Around a third of the homes built after 1995 were found to be operating at ventilation rates below international guidelines for indoor air quality. This underventilation of homes has detrimental impacts for the quality of air (Building Code clause G4 *Ventilation*) and also means that indoor moisture may accumulate (Building Code clause E3 *Internal moisture*). In addition, it was found that nearly 20% of the homes in the sample were being overventilated. Of these, half had supply-only mechanical ventilation systems installed. While the overventilated houses are likely to achieve the objectives of clause G4, the overventilation contradicts the aims of clause H1 *Energy efficiency* in terms of space-conditioning energy being wasted through overventilation.

Thus, there is a ventilation 'sweet spot' for dwellings to achieve, which must meet both the health needs of the occupants and the (low) carbon needs of the climate. For this to happen, there needs to be considered design and integrated planning to balance out the competing needs between occupant health and low-carbon buildings. The approach will change depending on the house typology, construction practices and space-conditioning mechanism.

In contrast to New Zealand, many countries have specific mandatory airtightness and/or mechanical ventilation requirements or recommendations for new buildings. This includes Belgium, Canada, the Czech Republic, Denmark, Germany, France, Norway and many jurisdictions in the USA. The use of mechanical systems typically removes the reliance on occupants to actively vent the homes via windows.

3.1.2 Materials in residential construction

The total volume of materials used in the construction of new dwellings across New Zealand can be estimated with market share information from the BRANZ New Dwelling Survey. Around 5,000 new residential buildings are surveyed each 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 industry floor plans. This captures commonly used materials very well but may overstate or understate the share of less common materials.

The number of building consents in 2016 was 21,310 (Stats NZ, 2017a).

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.

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 of timber framing used in 2016, which is 98% of all framing by volume. 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 for foundations, typically in concrete floors, but also as part of timber pile foundations, with 1,229,000 m^3 foundation concrete used in 2016. Steel is occasionally used in new dwellings as light steel wall framing and heavy steel beams.

Table 4 and Table 5 provide an estimate of the climate change impact arising from materials in new-build stand-alone construction in New Zealand in 2016.

Table 4. Volume of materials used in structures of new stand-alone dwellings in 2016 with estimated embodied greenhouse gas emissions.

Material	Framing (m^3)	Embodied carbon (tonnes CO_2eq)	Foundations (m^3)	Embodied carbon (tonnes CO_2eq)
Concrete	5,000	1,289[7]	615,000	196,853[8]
Timber	358,700	-246,606[9]	23,900	-16,431
Steel	3,500	71,526[10]	0	-
	Total for framing	**-173,791**	**Total for foundations**	**180,422**
Total for framing and foundations (rounded)				**6,631**

Table 5. Area of roofing and wall claddings used in new stand-alone dwellings in 2016 with estimated embodied greenhouse gas emissions.

Material	Roof (m^2)	Total (tonnes CO_2eq)	Wall (m^2)	Total (tonnes CO_2eq)
Timber	0	-	933,000	-12,187[11]
Fibre cement	0	-	505,400	6,736[12]
Clay (brick, tile)	76,700	685	1,052,200	27,620
Concrete (brick, block, tile, panel)	266,700	1,739[13]	509,400	8,093[14]
Sheet metal	4,430,900	70,427[15]	176,700	2,809
Other	971,300	Not calc.	192,500	Not calc.
Estimate for roofing in 2016 (excl. other)	**Total for roofing (excl. other)**	**72,850**	**Total for wall claddings (excl. other)**	**33,070**
Total for roof and wall claddings (rounded)				**105,920**

These are an underestimate, due to the following exclusions:

- Dwellings other than stand-alone such as medium-density housing and apartments.
- Wastage at construction sites – wastage rates vary depending on the material.[16] For example, for a material with a 10% wastage rate, 1.1 kg of that material will need to be manufactured for 1 kg to 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.

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[7] Concrete block (20 series) with a 22 MPa grout infill, reinforced.
[8] Data for 20 MPa ready mix concrete with 25 kg steel reinforcing and mesh/m^3 (actual calculated figure is 27 kg/m^3 for a single-storey 200 m^2 house).
[9] Softwood timber, sawn and kiln-dried, sustainably sourced.
[10] Galvanised steel framing.
[11] 19 mm thick.
[12] 16 mm thick.
[13] Assumes a 25 MPa compressive strength.
[14] Autoclaved aerated concrete (AAC), 70 mm thick.
[15] 0.55 mm thick, zinc aluminium alloy.
[16] 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.

- Other materials required in these building elements such as fixings and coatings, which may be used in relatively small quantities but can have high embodied greenhouse gas emissions per unit.
- Other building materials, for example, wall and ceiling linings, insulation, floors, paint, plumbing and electrical, and fixtures and fittings.

Table 4 and Table 5 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. The common use of timber framing shown in Table 4 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 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 roofs clad in 2016, which is 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 one-third clad in clay bricks (1,052,200 m^2) and a further one-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 clad 15% of walls in brick, block and panel form.

From estimates provided in Table 4 and Table 5, the total embodied climate change impact associated with 2016 residential stand-alone consents amounts to 112,551 tonnes CO_2eq.

Applying an annual climate change impact of 1.77 tonnes CO_2eq (from section 3.1.1) associated with energy use in new dwellings once occupied, the total additional annual energy-related contribution to climate change rounds to 37,000 tonnes CO_2eq.

Based on these estimates, the embodied greenhouse gas emissions that arise in 1 year of construction are equivalent to the emissions that arise from more than 3 years of occupation due to energy use. The limitations of the figures used to derive this estimate set out in the bullet points above – this is likely to be a significant underestimate.

3.1.3 Tools for evaluating dwelling carbon performance

Market mechanisms currently available in New Zealand for evaluating dwelling performance include Homestar, Beacon's High Standard of Sustainability and the Passive House Standard. Information about these is provided in the following sections. None of these directly calculate the climate change impact of dwellings, instead focusing more on energy. BRANZ is currently rectifying this gap by developing a support tool called *LCAQuick – Residential*, which calculates greenhouse gas emissions associated with the building industry.

3.1.3.1 *LCAQuick – Residential* (BRANZ)

A new tool called *LCAQuick – Residential* is currently being developed by BRANZ, which will provide designers with the means to calculate the climate change impact of their house designs and compare this to a reference dwelling. The tool, which will be free to use, is anticipated for launch around August 2018 and builds on research completed in

2016 to develop the New Zealand whole-building whole-of-life framework (see section 3.2.3.2).

3.1.3.2 Homestar (New Zealand Green Building Council)

Homestar was developed from successful international rating tools and adapted for New Zealand-specific conditions. It can be used on any residential building, from stand-alone homes to multi-unit dwellings. Homestar is a comprehensive, independent national rating tool that measures the health, warmth and efficiency of New Zealand houses.

To rate a home's performance and environmental impact, Homestar awards points across seven categories: energy, health and comfort; water; waste; materials; site; home management; and an optional innovation category. Climate change is primarily addressed through recognition of renewable energy.

A home is rated on a scale from 6 to 10. A 6-Homestar rating or higher provides assurance that a house will be better quality – warmer, drier, healthier and cheaper to run – than a typical new house built to the Building Code minimum. A 10-Homestar rating equates to a world-leading house. Although, it has been in operation for approximately 10 years, Homestar's formal uptake has been minimal, with approximately 134 stand-alone homes certified as at the end of 2016 (S. Archer, personal communication, 25 August 2017). Anecdotally, this has been due to the high costs associated with the verification process required for certification, which is several thousand dollars.

3.1.3.3 High Standard of Sustainability (Beacon Pathway)

In 2007/08 New Zealand's Beacon Pathway developed a benchmark defining a high standard of sustainability for New Zealand houses, based on five key performance areas. The focus is on the homes of ordinary New Zealanders rather than any income or demographic group. Beacon's goals for consumers is that they can understand:

- the performance of their homes
- how their actions and habits affect how well their home performs – the gap between the home's design potential and its actual performance.

The five key performance areas are reticulated energy use, water use, indoor environmental quality, waste and materials (Table 6).

Table 6. Beacon Pathway's High Standard of Sustainability performance areas.

Issue	Measurement
Reticulated energy use	kWh/yr
Water	Litres/person/day
Indoor environmental quality	°C and % RH
Waste	kg/m^2
Materials	Third-party certification

The level of uptake of this benchmarking system, whether formal or informal, is not known as no tracking has been performed. However, it is likely to be minimal given its modest publicity.

3.1.3.4 Passive House Standard (Passive House Institute of New Zealand)

The global passive house movement provides a whole-of-house energy and thermal efficiency building performance standard and certification system. The Passivhaus building approach derives from Germany's Passivhaus-Institut, which was established in 1996.

For a building to be considered for Passive House certification, it must meet the following criteria:

- Space heating energy demand does not to exceed 15 kWh/m^2/yr of living space demand or 10 W/m^2 peak demand.
- Total energy used for all domestic applications (heating, hot water and domestic electricity) must not exceed 60 kWh/m^2/yr.
- Airtightness maximum of 0.6 air changes per hour (ach) at 50 pascals pressure, as verified with an on-site pressure test.
- Thermal comfort must be met for all living areas all year, with not more than 10% of the hours in each year over 25°C.

Although there has been considerable advocacy and interest in this performance-based movement, formal certifications are still low for New Zealand, at just over a dozen registered stand-alone homes by 2016. It is suspected that this is because of the extra resources needed for certification.

3.2 Commercial and other non-residential buildings

In 2014, the Building Energy End-use study (BEES) investigated the New Zealand commercial building stock. This included a nationally stratified snapshot of commercial buildings using a range of metrics:

- Number, age, size and height of buildings.
- Shape, form and material characteristics of buildings.
- Total electricity and gas use within buildings.
- Energy end uses by premises type.
- Total water use within buildings (Auckland only).
- Temperature, humidity and carbon dioxide monitoring.
- Post-occupancy evaluations.
- Thermal and energy optimisation modelling.
- Detailed interviews examining the energy and water efficiency take-up challenge.

It was estimated that there were more than 41,000 commercial (office, retail and mixed use) buildings in New Zealand with a total floor area of nearly 40 million m^2 (Amitrano et al., 2014) (

Table 7). The size distribution of these buildings is extremely skewed, with just 1% of buildings having a floor area of 9,000 m^2 or more and 67% with a floor area less than 650 m^2.

Table 7. Number and area of New Zealand commercial buildings.

Building size strata (m^2)	Commercial office		Commercial retail		Commercial mixed		Total	
	Number	Area (10^6 m^2)	Number	Area (10^6 m^2)	Number	Area (10^6 m^2)	Number	Area (10^6 m^2)
5–649	4,022	1.31	15,300	4.31	8,287	2.61	27,609	8.23
650–1,499	1,404	1.35	2,668	2.52	3,936	3.79	8,007	7.65
1,500–3,499	790	1.75	1,035	2.32	1,719	3.72	3,544	7.79
3,500–8,999	339	1.85	339	1.71	817	4.19	1,496	7.76
≥9,000	139	2.34	111	2.04	250	4.10	499	8.49
Total	**6,692**	**8.61**	**19,453**	**12.91**	**15,009**	**18.42**	**41,154**	**39.93**

(Source: Amitrano et al., 2014)

The potential climate change impact (and six other environmental impacts) has been calculated for a subset of 10 office buildings. Each office building was consented in the mid-2000s or later, located in Auckland, Wellington or Christchurch. The climate change impact for each building was calculated using consent documentation. From this, building information modelling (BIM) was carried out to obtain material types and quantities for the structure (including foundations) and enclosure. Energy simulation was used to model performance in each of the three climates.

The buildings represent a range of uses (commercial office and commercial mixed), sizes (from 1,500 m^2 gross floor area (GFA) up to over 9,000 m^2 GFA), structural systems and materials. They have been modelled using the BRANZ whole-building whole-of-life framework (section 3.2.3.2). Further information can be obtained in the Reference buildings section at www.branz.co.nz/buildingLCA.

Figure 3 summarises the climate change impact results expressed per square metre of GFA for the modelled buildings over a 60-year service life. The top chart shows results with operational energy use (module B6) whilst the bottom chart shows the same results, but with module B6 excluded.

Figure 4 from Berg et al.'s (2016) report shows the following (excluding potential benefits beyond the building life cycle):

- Operational energy use during the service life of office buildings (taken as 60 years) is the largest contributor to the buildings' potential climate change impacts (80%). The calculated mean value is 1,290 kg CO_2eq/m^2 GFA arising from energy use (including plug loads). The average energy use intensity (EUI) of 113 kWh/m^2 NLA/year for these buildings compares to typical New Zealand commercial building EUIs of 143–223 kWh/m^2/year (Isaacs et al., 2009). By contrast, a 'good' EUI for a net-zero-energy building is around 50 kWh/m^2/yr (Berg, 2014).
- The spread of energy use and resulting greenhouse gas emissions is large (from 866 kg CO_2eq/m^2 GFA to 2,086 kg CO_2eq/m^2 GFA) reflecting the diverse energy needs of different functions that may occur in office buildings, such as presence of retail, restaurants or cafés within the building.
- Manufacture of materials makes the next most significant contribution at 244 kg CO_2eq/m^2 GFA (15%) for the foundations, structure and enclosure only. These emissions occur in a relatively short period (for example, over 1 year) associated with the construction of the building.
- Other stages of the life cycle including transport and installation of materials, maintenance, replacement, operational water use and end of life collectively contribute another 5%.

Whole-building life cycle assessment of 30 commercial office reference buildings

Notes:

A1–A3: The product stages, e.g. raw material supply, transport and manufacturing.

A4–A5: The construction process stages, e.g. transport and construction/installation process.

B2: Maintenance – this is part of the Use stages B1–7.

B4: Replacement.

B6: Operational energy (OE) use.

B7: Operational water (OW) use.

C1–C4: End-of-life stages, e.g. de-construction/demolition, transport, waste processing and disposal.

D: The benefits and loads beyond the system boundary, e.g. reuse, recovery and recycling potential.

Refer to Berg et al., (2016) for details regarding the life cycle assessment calculation of these reference buildings.

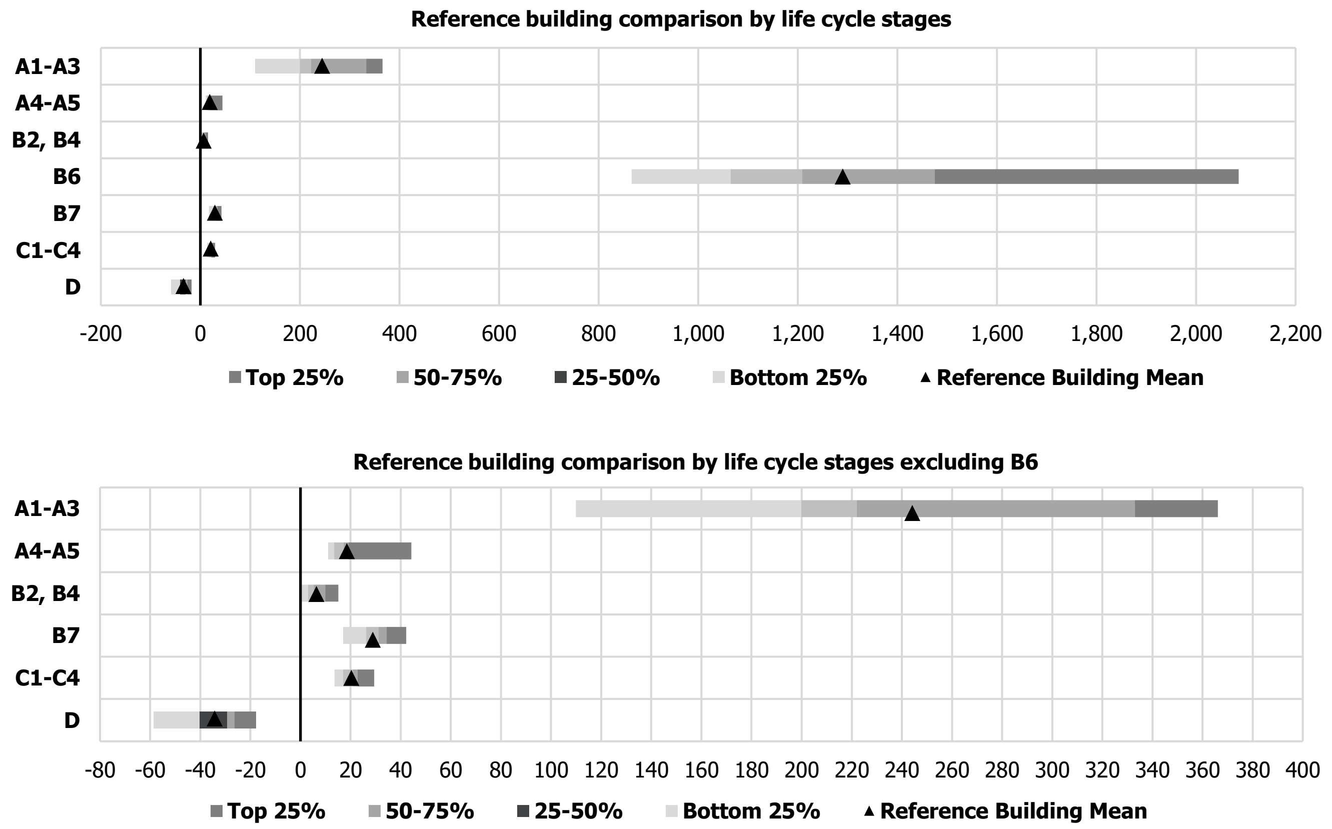

Figure 3. Mean and median climate change impact results for life cycle assessment (LCA) reference office buildings (Source: Berg, Dowdell & Curtis, 2016)

Applying a figure of 1,290 kg CO_2eq/m^2 GFA to the total non-residential floor area provides an annual estimate of greenhouse gas emissions of 860,000 tonnes CO_2eq.[17] This is less than the half the estimate provided in section 3.1.1 for dwellings.

This analysis shows that, while energy use in buildings makes the largest contribution to climate change, the contribution made by materials is also significant (Berg et al., 2016). Furthermore, as our buildings become more energy efficient and energy supply decarbonises, the proportionate contribution made by materials will increase further.

3.2.1 Energy use

The only information available on commercial building energy use at a national level, is from the Building Energy End-use Study (BEES). This was a 7-year programme of work with the objective of understanding how, where, when and why energy is used in commercial office, retail and mixed-use buildings.

A subset of buildings was investigated further, using intrusive monitoring for short periods of time within tenanted premises. Figure 4 details how energy was used within specific premises types.

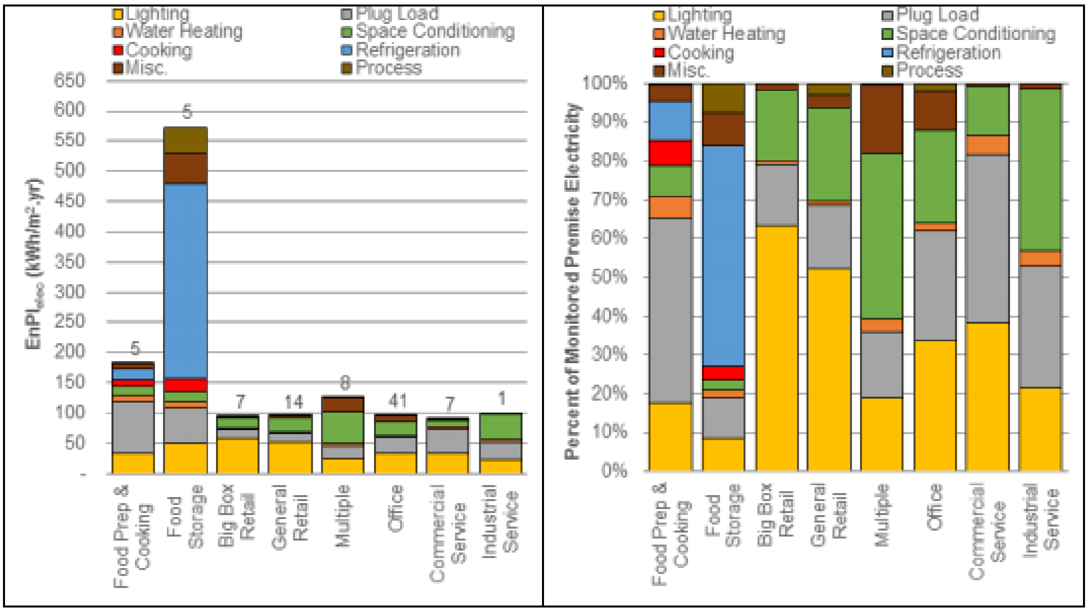

Figure 4. Building energy use distribution. (Source: Amitrano et al., 2014)

The biggest energy use identified was for refrigeration purposes. However, outside of refrigeration, an approximate rule of thumb from the 1980s (Baird & Newsam, 1986) is still maintained today: one-third lighting, one-third plug loads and one-third space conditioning and miscellaneous use.

The most common fuel source was electricity, with gas present in very few buildings (and even less solid fuel, diesel and other fuel types). This is consistent with the estimated energy supply breakdown nationwide. The estimated aggregate energy use for commercial buildings in New Zealand is 6,370 GWh/year of electricity and 1,130 GWh/year of gas (shown as the yellow segments in Figure 5).

[17] The limitation of this estimate is that it applies an office energy-use figure to all non-residential buildings.

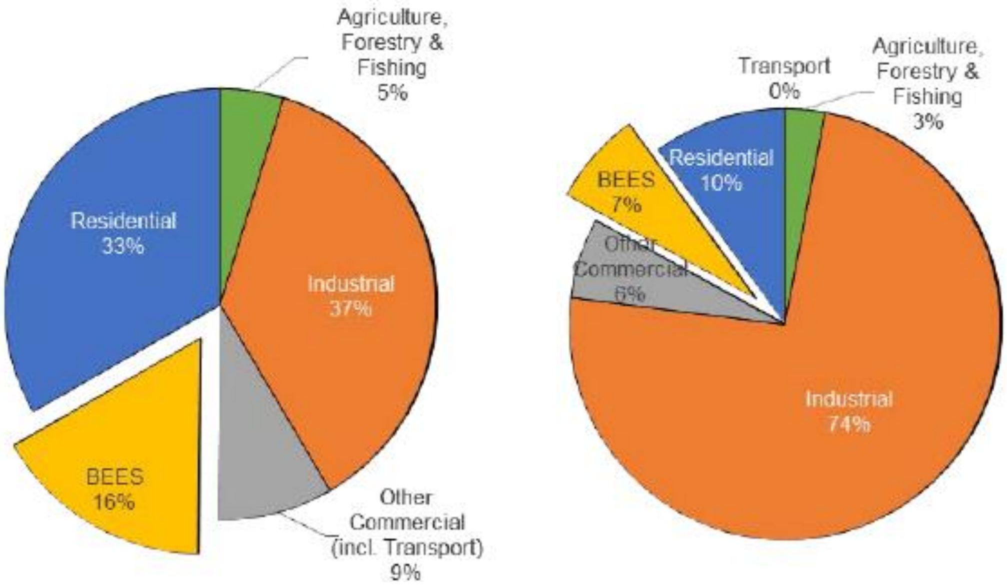

Figure 5. Estimated electricity use (left) and gas use (right) as a proportion of total New Zealand consumption. (Source: Amitrano et al., 2014).

Creswell-Wells (2014) examined the redevelopment of the Christchurch central business district and looked at how city planning can impact the spaces inside buildings and the pedestrian spaces between buildings. This was primarily through how the height and floor plate size impacted ability to naturally light and ventilate spaces. Hills (2014) developed a method of visualising energy and other resource-using intensities on buildings using a three-dimensional interface such as Google Maps.

Cory (2015) found that, "if we retrofit 1,200 of New Zealand's largest commercial buildings (sized over 3,500 m^2) to net zero energy, the savings would be equal to the annual electricity generated by all wind turbines in New Zealand". Net-zero-energy buildings use the greenhouse gas-free electricity grid or on-site generation, as well as reducing energy use. For these larger buildings, it was found the 45% of their primary energy[18] consumption is generated from greenhouse gas-producing energy sources. The types of retrofits included envelope modifications (insulation, glazing, solar heat gains, shading), natural ventilation, passive cooling, skylights and solar tubes, lighting and equipment energy efficiency, advanced lighting controls, heat pump efficiencies and photovoltaics where required.

Ghose (2018) focused on better understanding the environmental implications of deep energy refurbishments of New Zealand's office buildings, including strategies such as increased insulation, optimisation of the wall-to-window ratio, adoption of advanced glazing and solar shading, adoption of energy-efficient technical equipment for air-conditioning and lighting. Use of these strategies can potentially reduce over 60% of a building's annual energy consumption. However, the adoption of such measures is also associated with substantial construction processes, resource demand and waste generation.

[18] Primary energy takes into account the efficiency losses by converting the coal, gas and oil into electricity. For example, it takes approximately three times the amount of gas to generate one unit of electricity. Hence, when looking at primary energy, the gas portion of the electricity generation is roughly three times higher than the final energy.

For Ghose's (2018) work, the potential greenhouse gas emissions of upgrading and subsequent use of New Zealand's existing commercial office building stock was calculated using life cycle assessment with stock aggregation analysis. The results highlight that a refurbished building stock can potentially reduce current greenhouse gas emissions from energy consumption in the non-refurbished building stock by 40–65%. In addition to the energy-efficiency measures, increased share of renewable energy supply from grid electricity reduces the greenhouse gas emissions of buildings. If the adoption of energy-efficiency measures is combined with installation of on-site photovoltaics in refurbished office buildings, there is the potential to reduce greenhouse gas emissions from energy use in office buildings currently by up to 98%. However, use of on-site photovoltaics increases resource demand, which contributes to increase in other non-greenhouse gas emission-related impacts such as toxicity and resource depletion. The study results show that the refurbishment of the building stock – by adopting resource efficiency and waste management measures – can contribute to >65% reduction in greenhouse gas emissions without increasing pressures on other environmental impacts.

Another strategy to substantially reduce greenhouse gas emissions without increasing the embodied greenhouse gas impact associated with refurbishing the whole building stock could be prioritising refurbishment activities for buildings of a specific size or located in specific regions. Ghose's (2018) study results showed that, by focusing refurbishment on medium-large sized buildings (≥3,500 m^2), greenhouse gas emissions from energy use can be reduced by 40–45%. Moreover, refurbishing buildings located in Auckland, Wellington and Christchurch can reduce greenhouse gas emissions by 50–70%.

Overall, Ghose's research supports the need for energy efficiency refurbishments in the existing building stock to reduce greenhouse gas emissions.

3.2.2 Materials in commercial construction

Brunsdon and Magan (2018) carried out an assessment of the main materials used in commercial building,. The survey includes about 400 responses for new non-residential buildings each year.

Information on the main materials used in commercial buildings is drawn from an annual survey of builders and designers, which started in 1998. Survey data is supplemented with national building consent data and transfer ratios. Using this information, Table 8, Table 9 and Table 10 summarise total wall and roof cladding and structure materials in non-residential construction for the last 3 years, totalling a consented GFA of 9.13 million m^2. From these, the embodied greenhouse gas emissions are calculated. These are underestimated for similar reasons set out in section 3.1.2.

Based on this assessment, the embodied greenhouse gas impact of the structure and wall and roof claddings is estimated at 119.8 kg CO_2eq/m^2 GFA. With an average annual contribution from energy use of 21.5 kg CO_2eq/m^2 GFA, the buildings would need to operate for over 5 years in order that the cumulative greenhouse gas impact arising from energy use equals the impact arising from the manufacture of the materials of which the buildings comprise.

Table 8. Area of wall claddings for non-residential consents in New Zealand 2014–2016, with estimated embodied greenhouse gas emissions.

Material	Area (000 m^2)	Embodied carbon (tonnes CO_2eq)
Weatherboard 19 mm	176.5	-2,306
Ply 12 mm	18.2	-71
Fibre cement weatherboard 16 mm	66.9	892
Fibre cement other 6 mm	64.9	324
Fibre cement other 14 mm	0.1	1
Fibre cement other 9 mm	27.2	204
Clay brick 70 mm thick	127.8	3,355
Concrete wall block 200 mm thick	70.3	3,625
Concrete wall brick 70 mm thick	2.6	134
Concrete wall panel AAC 50 mm	114.9	1,304
Concrete wall solid 100 mm thick	1047.5	60,172
Curtain wall	125.1	6,340
Steel 0.55 mm	1638.4	26,041
Aluminium 0.7 mm	27.5	639
Total for wall claddings (per year)		**33,552**
Total kg $CO_2eq_{embodied}$/GFA		**11.0**

Table 9. Area of roof claddings for non-residential consents in New Zealand 2014–2016, with estimated embodied greenhouse gas emissions.

Material	Area (000 m^2)	Embodied carbon (tonnes CO_2eq)
Aluminium	0.7	16
Steel	5,766.6	83,324
Concrete roof tiles	120.2	784
Clay roof tiles	4.4	39
Bitumen	261.8	1,796
Total for roof claddings (per year)		**28,653**
Total kg $CO_2eq_{embodied}$/GFA		**9.4**

Table 10. Structural materials used in non-residential consents in New Zealand 2014–2016, with estimated embodied greenhouse gas emissions.

Material	Amount	Embodied carbon (tonnes CO_2eq)
Timber	205,200 m^3	-141,075
Steel (heavy gauge)	146,600 tonnes	417,810
Concrete	1,354,200 m^3	630,816
Total for structure (per year)		**302,517**
Total kg $CO_2eq_{embodied}$/GFA		**99.4**

New Zealand imports construction materials, particularly steel, timber, glass and whiteware, reflected in Figure 6 for 2011. Imported materials have greenhouse gas emissions from manufacture, which arises because of demand from New Zealand. These embodied overseas emissions are not captured in the New Zealand greenhouse gas accounting, as they do not occur within our geographical boundary. However, it is important to recognise that these emissions occur and to consider them when thinking about the shift to a low-carbon economy, as the radiative forcing effect of these emissions is the same whether they are emitted inside or outside New Zealand's geographical limits.

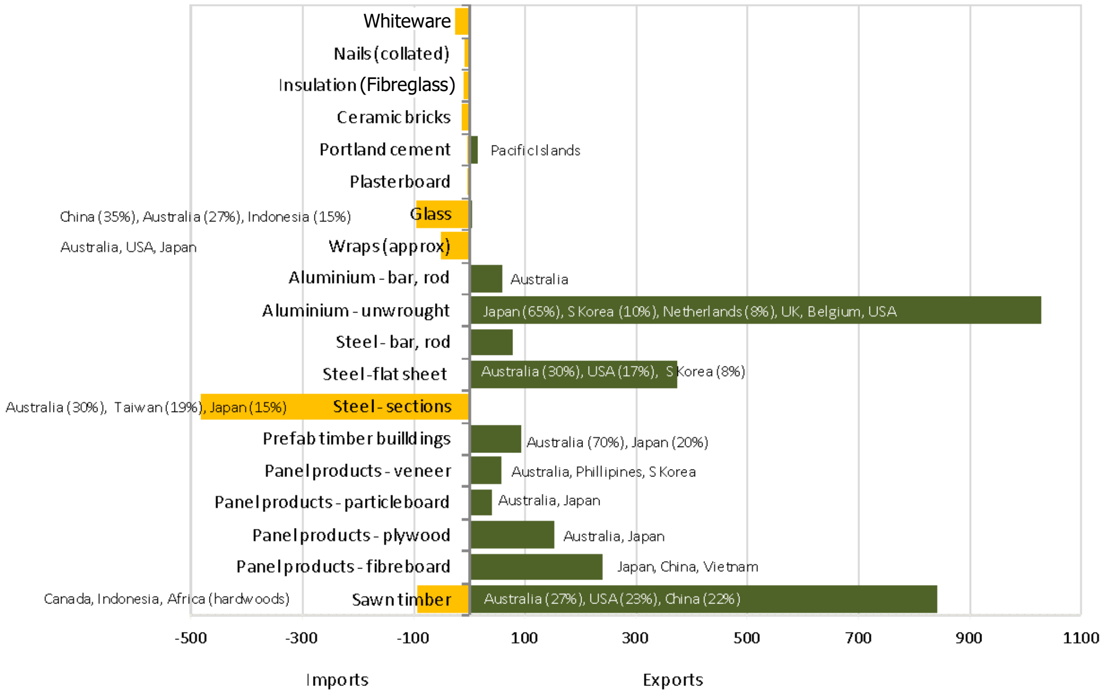

Figure 6. Export and import (NZ$ million) of selected building products in 2011. (Source: (Dowdell, 2013, p. 6))

For example, the closure of the Westport cement plant has removed a significant source of greenhouse gas emissions from New Zealand. However, since the cement that was manufactured at Westport is now imported from overseas, the greenhouse gas emissions associated with this manufacture have been 'exported' to another country[19] and would no longer be reflected in New Zealand's total emissions.

Thus, when considering materials, a supply chain approach should be used. This ensures a complete understanding of the totality of greenhouse gas emissions as a result of manufacture of products, taking into account where manufacture occurs, how energy is supplied and how materials are transported within the regions and countries where these activities occur.

3.2.3 Market mechanisms for evaluating office performance

The New Zealand Green Building Council (NZGBC) Green Star tool provides the main means for evaluating commercial building environmental performance in New Zealand.

[19] Taking a supply chain view of cement manufacture at Westport versus import of cement from overseas, there is a greenhouse gas benefit. This is because the Westport plant manufactured cement using a less-efficient wet process, which has been replaced with imported cement made with a more efficient dry process. Even considering the carbon emissions associated with transport to New Zealand, the overall result is a saving in greenhouse gas emissions.

There are isolated examples of other market mechanisms that have been used in New Zealand. For example, Tūhoe's Te Kura Whare[20] was designed and evaluated according to the Living Future Institute's Living Building Challenge, a building environmental rating tool from North America.

In 2016, BRANZ with project partners developed the New Zealand whole-building whole-of-life framework, which initially focused on offices. Information about this framework is provided in section 3.2.3.2.

Figure 7 summarises the elements for better transparency and mitigation of building climate change, which are described further below.

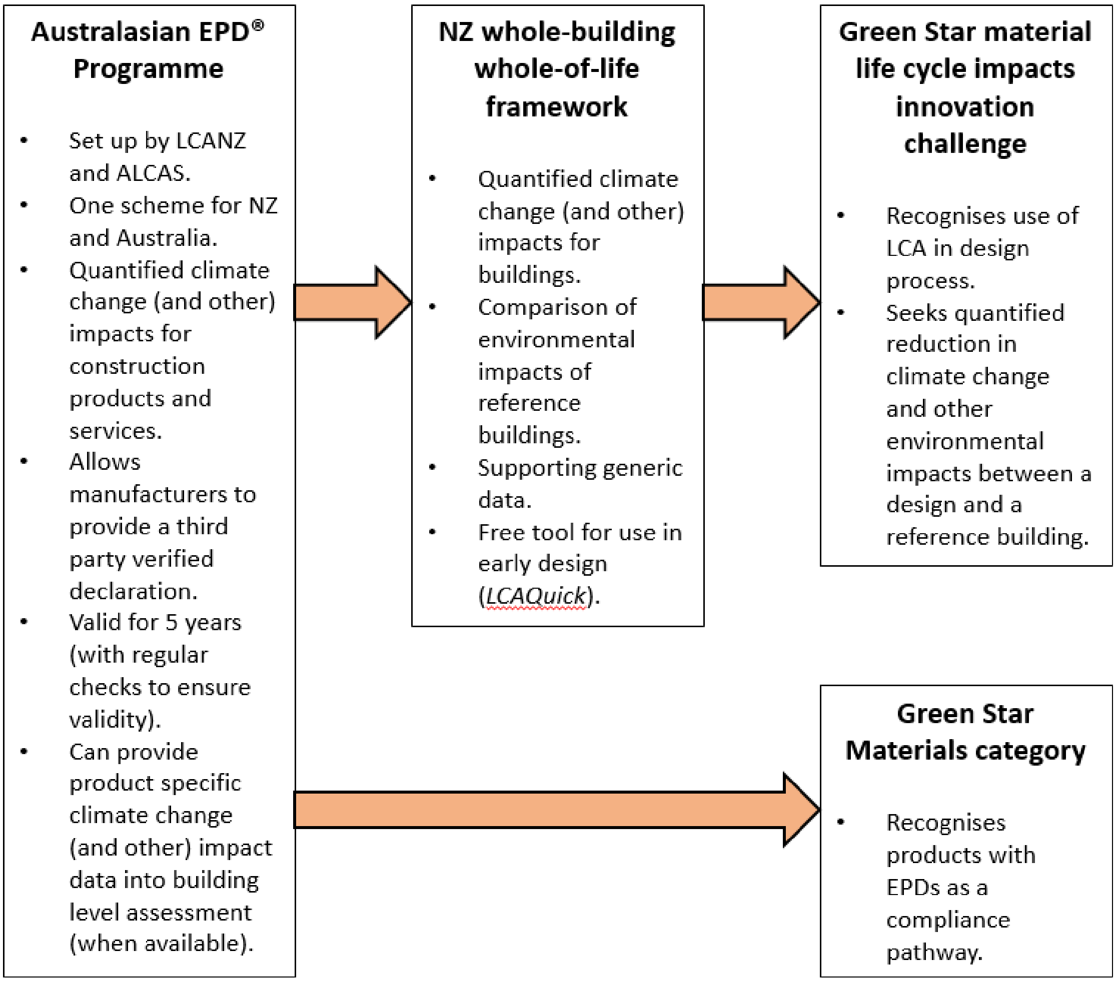

Figure 7. The three elements to better transparency and mitigation of building climate change (and other) environmental impacts.

3.2.3.1 Green Star New Zealand (NZGBC)

Green Star is an internationally recognised rating system for the design, construction and operation of base buildings, fit-out and communities. It rates the overall environmental impact of a building, fit-out or community development. Green Star rating tools award points across nine categories: energy, water, materials, indoor

[20] www.ngaituhoe.iwi.nz/sustainability-and-the-living-building-challenge

environmental quality (IEQ), transport, land use and ecology, management, emissions and innovation. Green Star directly considers climate change in the following ways:

- **Energy:** Approximately 16% of credits can be achieved through good design. It includes a calculation of carbon dioxide emissions because of energy demand and supply.
- **Innovation:** An innovation challenge called material life cycle impacts awards up to 6 unweighted points if a life cycle assessment (LCA) is carried out for a building design and the environmental impacts (including climate change) are compared to the environmental impacts of a suitable reference building. A means to demonstrate compliance with this innovation challenge is to use the New Zealand whole-building whole-of-life framework.

Based on a 6-Green Star system, equating to world leadership in terms of building performance, it has over 150 formal certifications throughout New Zealand. Launched in 2007, there have been several updates and changes to Green Star New Zealand to ensure it incorporates new thinking and practice and meets the needs of the market.

3.2.3.2 New Zealand whole-building whole-of-life framework

In 2013, following consultation with the New Zealand construction industry, BRANZ published a plan that set out how New Zealand could develop a quantitative approach to evaluation of environmental impacts (including climate change) of buildings based on LCA (Dowdell, 2013). This provides the means for building designers to reduce the environmental impacts of their buildings during the design process.

The plan set out the research required to develop a New Zealand whole-building whole-of-life framework, which is summarised below:

- A robust, science-based method that would allow construction product manufacturers to provide third-party verified declarations of the environmental performance of their products based on LCA. As a result, work went into establishing the Australasian EPD® Programme,[21] which conforms to international standard ISO 14025:2010 requirements for environmental product declaration (EPD) schemes and European standard EN 15804:2012+A1 for construction products. The EPD programme was set up by the Life Cycle Association of New Zealand (LCANZ) and the Australian Life Cycle Assessment Society (ALCAS) and operates as one programme across both countries. It is operated as a not-for-profit organisation with its own board and is linked with the International EPD® System.[22]
- Recognition of building LCA and use of EPDs in rating tools such as Green Star. The New Zealand Green Building Council (NZGBC) now recognises building LCA in its Material Life Cycle Impacts Innovation Challenge and use of products in the build with EPDs in its EPD Innovation Challenge.

The research focus was aimed at developing free resources that would facilitate use of building LCA to calculate climate change and other environmental impacts[23] in the design process.

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[21] www.epd-australasia.com
[22] www.environdec.com
[23] Other calculated environmental impacts (currently) are stratospheric ozone depletion, air acidification, photochemical oxidant formation, eutrophication, depletion of abiotic resources (minerals) and depletion of abiotic resources (fossil fuels). The method and basis for calculation is set out in BRANZ Study Report SR293 (Dowdell, 2014).

This led to development of the New Zealand whole-building whole-of-life framework, a set of resources aimed at helping designers to incorporate consideration of environmental impacts iteratively into early (concept/preliminary) design. Further information and access to the free resources of the framework can be found at www.branz.co.nz/buildingLCA.

Resources developed to date have been aimed at concept/preliminary design of office buildings and included the following:

- Overview of the framework – what it is, who can use it and how to engage with it (Dowdell & Berg, 2016).
- Methodology, including how to use BIM models to obtain accurate material quantities for building LCA (Berg et al., 2016).
- Data including generic data on wastage rates at construction sites, transport distances for construction materials, water use in office buildings and wastage at demolition (Dowdell et al., 2016).
- An LCA dataset for New Zealand grid electricity (low voltage), developed at Massey University with support from BRANZ (Sacayon Madrigal, 2016).
- A set of 10 reference office buildings for which environmental impacts have been calculated based on their location in Auckland, Wellington and Christchurch to provide a total of 30 possible comparators during design. The calculated climate change impacts for these reference office buildings are illustrated in Figure 3.
- A freely available, Microsoft Excel-based software tool called *LCAQuick – Office*, which calculates environmental impacts. This can be downloaded from www.branz.co.nz/buildingLCA. The tool includes a generic database of environmental impacts of common commercial building façade and structural materials, developed from EPDs (where available) and modelled in an LCA database called EcoInvent.
- Supporting YouTube training videos.
- A seminar series on building LCA held in Auckland, Wellington and Christchurch around November 2016. In total, over 400 registrations were received.

A residential version of *LCAQuick* is planned for release around August 2018.

3.3 Construction and demolition waste

Generation of construction and demolition waste makes a contribution to climate change in several ways:

- The embodied carbon in the manufacture and transport of materials that end up not being used for the purpose for which they were manufactured.
- Where a material is biodegradable, the contribution of greenhouse gas emissions resulting from material decay in landfill. An area of uncertainty concerns the extent that greenhouse gas emissions (primarily biogenic carbon dioxide and methane) are emitted from landfills because of disposal of timber and engineered wood products from construction. Overseas studies (for example, Ximenes et al., 2008, 2013; Wang et al., 2011) indicate that the proportion of carbon emitted from landfills within 100 years of disposal is low, meaning that landfills can act as carbon stores. Actual emissions of greenhouse gases from landfilled timber and engineered wood products is complicated by many factors including temperature, pH, moisture, size and type of substrate, timber treatment and presence of engineering measures to capture landfill gases and flare or use to generate energy. Further

work is needed to understand the extent of degradation in New Zealand landfills and opportunities to use landfills as carbon stores.

A significant factor in waste generation is thought to be the fragmented nature of the construction industry, given it is made up of a large number of small to medium-sized companies. In New Zealand, there were a total of 51,178 companies operating in the construction sector as of 2014 (Tran, 2017).

Much of construction and demolition waste has a high carbon content (see Table 11 for examples) or can easily be diverted from landfill. This is especially true for waste generated that comprises metals and polycarbonates. Evidence suggests that construction and demolition waste may represent up to 50% of all waste to landfill in New Zealand and the majority of waste entering cleanfill/landfill. That means that up to 1.7 million tonnes of construction and demolition waste is sent to landfill every year and similar amounts to cleanfill, depending on building activity.[24]

Table 11. Example embodied greenhouse gas impacts of materials manufacture

Material	Embodied greenhouse gas impact	Units	Source
25 MPa normal ready-mixed concrete	360	kg CO_2eq/m^3	Allied Concrete EPD (registration no.: S-P-00555)[25]
50 MPa normal ready-mixed concrete	608	kg CO_2eq/m^3	Allied Concrete EPD (registration no.: S-P-00555)
Float glass	1,230	kg CO_2eq/tonne	Glass for Europe (2011)
Steel welded beams and columns	2,850	kg CO_2eq/tonne	BlueScope Steel EPD (registration no.: S-P-00559)
Colorbond® steel	12.8/14.1[26]	kg CO_2eq/m^2	BlueScope Steel EPD (registration no.: S-P-00999)
Wall panel (KS1000 AWP and Evolution, 80 mm thick, R4.15	51.8	kg CO_2eq/m^2	Kingspan Insulated Panels EPD (registration no.: S-P-00847)

Although there are no recent representative quantitative figures for the amounts of waste generated by construction and demolition activity in New Zealand, a previous Auckland study has shown that construction waste composition by weight is timber (20%), plasterboard (13%), packaging (5%), metal (5%) and other (45%). It is estimated that about 50% (by weight) is able to be recycled on a construction site, according to BRANZ and Christchurch City Council studies.

There have been initiatives to address construction and demolition waste in New Zealand over the last decade. For example, the Auckland Resource Recovery facility was developed using funds from a government landfill tax and opened in 2015. It has the capacity to process up to 100,000 tonnes of material a year. The facility is capable

[24] See www.branz.co.nz/rebri.
[25] These values are taken from the current EPD, which reflects concrete made with cement from the Westport cement plant. It is expected that the values will reduce with imported cement used in 2016.
[26] First value reflects a base metal thickness of 0.42 mm, second value reflects 0.48 mm.

of reusing or converting about 70% of the waste materials, with timber making up nearly 40% of what was recovered (Anthony, 2015).

As part of the development of the New Zealand whole-building whole-of-life framework, default waste rates for materials were developed. These were based on literature, case studies (where these existed), overseas data and estimates. These are available as a downloadable spreadsheet by selecting a link called module A5 in the data section of www.branz.co.nz/buildingLCA. Similarly, waste rates for materials at building end of life are also available at the same location (by selecting the link module C1). Information on how these default datasets were developed is available in Dowdell et al. (2016).

Work is also currently under way at BRANZ to quantify the amount and flow of construction waste at a regional and project level, to enable regionally tailored sustainability initiatives to reduce construction materials going to landfill.

3.4 Strategies for reducing greenhouse gas emissions

Figure 8 illustrates how greenhouse gas can be reduced for new buildings. Strategy 1 focuses on emissions arising from energy demand and supply in buildings during the building's use phase.[27] Policies and market mechanisms that reduce the demand for energy and/or decarbonise the supply of energy will have the effect of reducing the gradient of the 'business as usual' line, thereby reducing the rate of increase in emissions from new buildings. If this can be reduced to the extent that buildings are zero carbon with respect to energy, the line becomes horizontal based on initial embodied emissions but with effectively zero emissions thereafter. Taken even further, buildings could potentially contribute to carbon reduction over time. In this extreme case, a building can effectively repay the carbon debt incurred through manufacturing of materials and construction of the building in year zero, thereby effectively becoming zero carbon with respect to energy and materials.

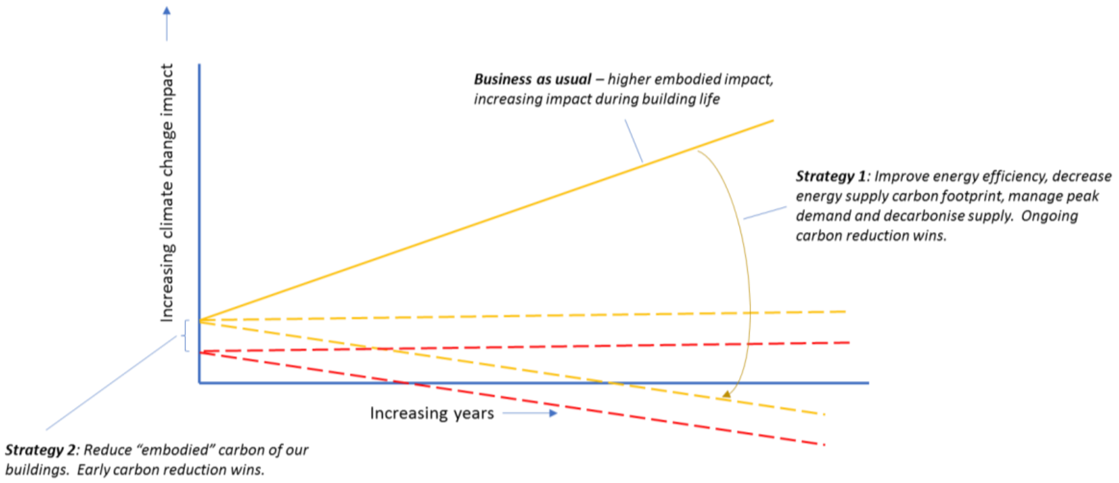

Figure 8. Building carbon reduction strategies.

[27] Other activities also contribute to greenhouse gas emissions during the use phase such as maintenance, repair and replacement of materials. In existing buildings, a significant building refurbishment may cause higher impacts during the year of refurbishment but deliver operational impacts that are better than pre-refurbishment impacts (provided climate change is a driver or consideration of the refurbishment activity).

Strategy 2 in Figure 8 focuses on reducing the initial carbon debt incurred by a building through aspects such as the building size, choice of materials and efforts to reduce waste. While still providing an initial carbon burden, this is less than it would otherwise have been. Given the magnitude of potential greenhouse gas emissions that occur in a relatively short period of time due to commissioning and construction of a new building, this is an important issue that has been identified in other research (Alcorn, 2010; Säynäjoki, Heinonen & Junnila, 2012).

Strategies 1 and 2 are not mutually exclusive and should be jointly implemented to maximise carbon-reduction opportunities. Strategy 1 is additionally relevant to existing buildings. Refurbishment of existing buildings so that they can be repurposed to meet needs in an energy-efficient way can be an attractive option to avoid or significantly reduce the embodied emissions that would be incurred through demolition and rebuild.

3.5 Māori responses to the built environment and climate change

There is a growing body of research being undertaken into the impact of climate change on Māori (King, Penny & Severne, 2010). More recent work has been undertaken as part of the Deep South National Science Challenge, such as the research project Climate Change & Coastal Māori Communities being led by Dr Huhana Smith.[28] To date, much of the literature about Māori climate action calls attention to the need to create resilient infrastructure and explores plans to move communities away from hazards impacted by climate change.

King et al. (2010) outline that it is important for future climate change planning that climate action is incorporated into:

> … iwi management plans and meaningful participation for Māori in the development of local and regional planning, such as hazard management, [which] are needed to prepare and reduce the exposure of Māori businesses, institutions and the community to climate variability and change. (p. 106)

They suggest that more research into the built environment and climate change especially within urban areas is needed to urgently understand the exposure, sensitivity and resilience of Māori groups to climate change. Research into urban areas is slowly gaining momentum with work being undertaken by Associate Professor Deirdre Brown, University of Auckland, as part of a QuakeCoRE project, which examines Māori built infrastructure in relation to the Earthquake Prone Buildings Amendment Act. This research brought up a number issues that seemed to open the door for a host of unanticipated discussions with others, such as GNS Science, in order to address the multidisciplinary challenge of climate change and Māori-built infrastructure.

3.6 Climate change adaptation

Internationally, BRANZ has completed some of the formative work on climate change impacts of and on buildings. However, some other organisations with building industry concerns have also published in this area to a lesser extent. Much of the (often very detailed) BRANZ studies were carried out in the mid-2000s, covering both adaptation and mitigation aspects – sometimes concurrently. The majority of studies have been

[28] http://www.deepsouthchallenge.co.nz/projects/climate-change-coastal-maori-communities

on designing and constructing buildings to make them fit for climate change impacts (i.e. adaptation.)

The studies can be considered at different scales – from individual building responses through to regional-based responses and progressing to the whole building stock. Note that some documents cited below occur both in the adaptation as well as mitigation subsections if they have an even split. Only key documents have been mentioned.

3.6.1 Key New Zealand adaptation-focused documents

- On an individual building level, a BRANZ study report (Jaques & Sheridan, 2006) is one of the earliest works on practically addressing the matter during the design process. It provides designers/specifiers a suite of options to significantly improve the climate change readiness of their proposed residential buildings at the concept/design stages via adaptation-related measures. The main emphasis is on the changes to and therefore implications of rainfall, flooding and wind.
- In another BRANZ study report, Bengtsson, Hargreaves and Page (2007) examined the vulnerability of the building stock with a focus on the areas of current build condition, risk of flooding in a 50-year return period, thermal comfort and societal impacts. The very detailed quantitative study considered both direct and indirect consequences of climate change. The estimated combined cost of adaptation of the existing housing stock to account for changes to rainfall, wind, hail, drought, bushfire, sea-level rises and temperature was estimated to be $2 billion. A key message in this report was that a strong, early and coordinated approach to climate change can potentially limit large societal, economic and cultural costs in New Zealand. Given the report's importance, its 12 key recommendations are detailed further below.
- Howden-Chapman et al. (2010) concentrated the focus mainly on the health impacts of climate change resulting from an increase in infectious diseases and flooding occurrence. The discussion then broadens out to consider adaptation at different scales, starting with the micro level and working up, through the community level, cities, the national level and lastly to global level adaptation issues.
- The NIWA et al. (2012) urban impacts toolbox is a resource to help planners, engineers, asset managers and hazard analysts in New Zealand urban councils understand and evaluate the potential impacts of climate change in their city. It provides guidance and decision tools that can be used by urban council staff and policy makers to reduce the potential adverse effects of climate change. There is an accompanying handbook that provides an overview of the toolbox structure and gives guidance on its use.

The Bengtsson et al. (2007) report stated that climate change adaptation should focus on residential, institutional and commercial buildings, as industrial-type buildings are usually fairly short-lived, and made 12 recommendations (p. x):

- **R1**: Implement a climate change adaptation plan for New Zealand: It is essential that the climate-change planning process start now, given the longevity of housing developments and infrastructure in increasingly at-risk communities. Local councils have an important role to play in reducing flood and fire vulnerability through development control and zoning.
- **R2**: Develop and retrofit with consideration of increasing climate exposure and vulnerability: Regions with high climate change exposure from increased risk of

flood, bushfire, temperature extremes and coastal hazards should be avoided or developed with due consideration of future climate change impacts.

- **R3:** Use recent natural events (e.g. storms/flooding/erosion/landslips) to raise awareness of climate change impacts on housing and our way of life: Housing adaptations can profitably be oriented to raising concern over storms/flooding/erosion/landslips as a threat to the New Zealand way of life, with particular impact for coastal communities/houses. Loss of iconic housing locations, lifestyles and landscapes is a powerful motivator for public concern.
- **R4:** Learn how to communicate about climate change and adaptation: Develop a communications strategy that makes it easy for the public to understand climate change, its impacts, and the need for housing adaptation specifically.
- **R5:** Develop behavioural change programmes: Develop behaviour change programmes that make behaviour change easy, attractive, stylish, and rewarding. Systemic programmes may need to span areas such as design, building, renovating, financing, and insuring as well as ownership/ dwelling.
- **R6:** Build the sector's proactivity**:** Develop a proactive approach that leverages research … towards a coherent and effective sectoral response to climate change. Synergies may be … achieved with initiatives that deal with health and other social issues.
- **R7:** Orient housing adaptation to social exclusion: As the broader strategic platform it is recommended that adaptations are oriented to the more vulnerable and socially excluded groups.
- **R8:** Integrate other sectors in future work: Coordinate building adaptation to climate change with other societal, institutional and technical drivers for change. Design of housing adaptations for climate change cannot be separated from design for other changes. Housing needs and vulnerabilities are concurrently shifting due to an ageing population, increasing obesity and so on.
- **R9:** Reduce sector's carbon footprint: Stimulate uptake of energy efficient techniques and practices and renewable energy generation. Indirect impacts from policy instruments to reduce greenhouse gas emissions, such as increased costs from carbon or GHG charges may … pose a risk to tenants and the building industry.
- **R10:** Improve confidence in projections of key climate change implications for New Zealand: Increased certainty is required for regional distribution-, direction- and magnitude of change of ex-tropical cyclones, wind, storm, hail and rainfall.
- **R11:** Continue working with scenarios for social impacts: A central, longer-term task is to develop a 'strategic discussion' about the role and activities of housing in managing the social impacts of climate change. A
- **R12:** Develop the CCSI [the BRANZ Climate Change Sustainability Index climate tool] and include bushfire and drought risk: It is recommended that the CCSI is expanded to include building vulnerability from increased fire and drought risk.

In November 2016, the government asked a cross-sector group of technical experts to provide advice to the Climate Change Minister on options for building New Zealand's resilience to climate change. A stocktake report was released (Climate Change Adaptation Technical Working Group, 2017), with the built environment as one of the sections. The scope was considerably larger, including all physical infrastructure and all building typologies.

3.7 International initiatives

Some of the more pertinent international initiatives pertaining to climate change and buildings are overviewed below.

3.7.1 World Green Building Council

Founded in 1999, the World Green Building Council (WGBC)[29] is a global network of over 70 green building councils that aim to transform the built environment for the better by championing local and global leadership and empowering communities to drive change. The WGBC recognises that buildings are major contributors to climate change and that buildings offer one of the most cost-effective solutions to climate change.

Green building councils are seeking to establish net-zero certification, which is particularly important given the impact existing that certification schemes have had around the world. To date, green building councils have registered 1.2 billion m^2 of green buildings – almost twice the size of Singapore – through certification schemes such as LEED, BREEAM, Green Star and DGNB.

The introduction of specific net-zero certification schemes is expected to drive the demand and supply of these highly efficient buildings and prove to regulators at all levels of government that the building sector is ready and willing to play its part towards achieving climate change goals. Green building councils have committed to establish these certification schemes by the end of 2017 or as soon as possible thereafter. They "aim to train over 300,000 green building professionals on net zero building by 2050 – those workers who will be absolutely vital to deliver the scale of change required" (Global Alliance for Buildings and Construction, 2016).

3.7.2 International Union of Architects

There have been some interesting adaptive and mitigative initiatives internationally in recognition of the impacts climate change is likely to have on buildings. One of the more universal is that of the International Union of Architects, with member organisations representing over 1.3 million architects in 124 countries worldwide. They have unanimously adopted the 2050 Imperative,[30] an Architecture 2030 declaration to eliminate CO_2 emissions in the built environment by 2050. The New Zealand Institute of Architects is a signatory to this.

This initiative requires the signatories to commit to the following:

- Plan and design cities, towns, urban developments and new buildings to be carbon neutral, meaning they use no more energy over the course of a year than they produce or import from renewable energy sources.
- Renovate and rehabilitate existing cities, towns, urban redevelopments and buildings to be carbon neutral whilst respecting cultural and heritage values.
- In those cases where reaching carbon neutral is not feasible or practical, plan and design cities, towns, urban developments, new buildings and renovations to be highly efficient with the capability to produce or import all their energy from renewable energy sources in the future.

[29] www.worldgbc.org/about-us
[30] www.architecture2030.org/downloads/uia_declaration_full.pdf

How influential and successful this bold 2050 Imperative initiative will be remains to be seen.

Another initiative, which has a wider remit than just climate change, deals with both adaptive and mitigative concepts. Passive survivability is the concept that buildings should maintain habitable conditions in terms of thermal comfort if they lose reticulated power for an extended period of time. It recognises that buildings are becoming increasingly vulnerable — whether from earthquakes, flooding or more intense storms with climate change. In the USA, the Resilient Design Institute was set up in 2012 to progress the thinking, research, knowledge and advocacy in this area.

The good news is that requirements for more resilient design in building codes would align well with the call for net-zero-energy buildings. "Buildings designed to achieve passive survivability will have highly insulated building envelopes, cooling-load-avoidance features, natural ventilation, and passive solar heating" (BuildingGreen, 2017) and thus able to easily achieve net-zero-energy performance.

3.7.3 International Energy Agency

The International Energy Agency (IEA) began in the mid-1970s with the aim of being a focal point for energy cooperation.

Collaborative research topics are investigated in annexes covering a range of energy-related topics, examples of which are provided below:

- Annex 21 Calculation of energy and environmental performance of buildings (1998) – focused on tools for calculating energy use.
- Annex 31 Energy-related environmental impact of buildings (2005) – recognised that, as the need to address environmental concerns becomes more pressing, energy and life cycle assessment tools will become increasingly important resources.
- Annex 53 Total energy use in buildings: Analysis and evaluation methods (2016) – focused on building performance and the discrepancy between designed and real total energy use (due primarily to human behaviour).
- Annex 70 Energy epidemiology: Analysis of real building energy use at scale.

Research focus on environment to date has been primarily on energy used as a proxy indicator of environmental impact. In countries with a high proportion of fossil fuels supplying grid electricity (for example) used in buildings, such a measure is not unreasonable due to the inherent linkages between energy, greenhouse gas emissions, sulphur dioxide emissions (contributing to air acidification) and fossil fuel depletion.

However, in countries such as New Zealand with a high proportion of renewables contributing to grid electricity supply (currently over 80% with a target to increase to 90% by 2025), energy as a proxy indicator of environmental impact has limitations.

In January 2018, a new IEA annex (Annex 72 Assessing life cycle related environmental impacts caused by buildings) commenced. The annex will look at building life cycle environmental impacts, not just energy. A scoping meeting for the annex in Copenhagen, Denmark, involved over 30 research organisations (including BRANZ) from over 20 countries. BRANZ has secured Levy funding for a related research project as the New Zealand contribution to Annex 72 – How can New Zealand construction deliver low to zero impact buildings? This work commenced in April 2018.

3.8 Country-specific initiatives

This section provides some examples of initiatives and research in other countries. Given the extent of work that is ongoing, this should not be considered as exhaustive.

3.8.1 United Kingdom

The UK Government set out its strategy for transitioning the UK economy to low carbon in its UK Low Carbon Transition Plan, published in 2009. Chapter 4 of the Plan concerns homes and communities. Unlike New Zealand, over 75% of energy used in homes for space heating and water is derived from gas-fired boilers. This accounts for 13% of UK greenhouse gas emissions and needs to be almost zero by 2050.

Key aspects of the plan to reduce emissions:

- Increase the obligation of energy suppliers to help households reduce emissions and save energy.
- Support households to take action by:
    - installing smart meters in every home before 2021, enabling people to understand energy use, maximise opportunities for energy saving and offer better services from energy companies
    - encouraging provision of smart displays for existing meters and launching a personal carbon challenge with rewards and incentives to save energy
    - developing more proactive services from the Energy Saving Trust.
- Help people meet the costs of transformation by:
    - piloting a move away from upfront payment to 'pay as you save' models of long-term finance for energy saving
    - introducing clean energy cash-back schemes.
- Coordinate support available by:
    - introducing a community-based approach for homes in low-income areas
    - considering delivery mechanisms that will best deliver significant whole-house energy saving treatments.
- Raise standards in every home by:
    - widening use of energy performance certificates (EPCs) for rented properties to be put on advertisements and extending access to EPC information.
    - requiring new-build homes to achieve zero-carbon homes from 2016.
- Helping communities through announcement of a green initiative challenge – for example, by developing online 'how to' guides).

3.8.2 Netherlands

The Dutch Building Decree, which came into force in April 2012, required that, by 1 January 2013, a calculation of the material environmental performance of dwellings and office buildings should be submitted as part of the consent process (Scholten & van Ewijk, 2013).

The aim of this requirement is to encourage consideration of the environmental implications of decisions during the design process. Life cycle assessment provides the basis for the assessment. To facilitate the process, a determination method and national environmental database were made available. Their development was blocked by the industry, due to concerns about complexity of the regulations and influence on the freedom of choice of materials.

No minimum performance levels are set in the regulations at this stage.

3.8.3 Finland

The abstract for a report by Säynäjoki, Heinonen and Junnila (2012) states:

> While buildings are often credited as accounting for some 40% of the global greenhouse gas emissions, the construction phase is typically assumed to account for only around one tenth of the overall emissions … [T]he significance of construction may actually be much higher when the temporal perspective of the emissions is taken into account. The construction phase carbon spike, i.e. high GHG emissions in a short time associated with the beginning of the building's life cycle, may be high enough to question whether new construction, no matter how energy efficient the buildings are, can contribute to reaching the greenhouse gas mitigation goals of the near future.

This issue is particularly pertinent in New Zealand, where materials may be produced based on fossil fuel-derived thermal energy and may be transported long distances (domestically by truck and/or imported). The building, once finished, is likely to subsequently derive a significant proportion of its energy from grid electricity, which comprises over 80% renewables.

These issues are important:

- Consideration of energy use in buildings and the carbon burden of the energy supplied should not be divorced from the carbon burden of materials selected in building design.
- The timing of carbon emissions is potentially important. Large carbon emissions now in order to achieve carbon savings decades into the future may not be the best strategy. The low-carbon intensity of New Zealand grid electricity makes this particularly pertinent.
- Focus should not be entirely on carbon to the exclusion of all other potential impacts. Such an approach risks unforeseen consequences.

4. Challenges for creating a zero-carbon built environment

New Zealand currently faces a number of barriers and challenges that are preventing us from creating zero-carbon buildings. It is important to make clear that zero-carbon buildings are different from net-zero-energy buildings, despite sharing similar features.

The key barriers identified are:

- a lack of economic incentives
- the skills and knowledge required to deliver zero-carbon buildings are currently confined to a small group of industry
- zero-carbon buildings need to be incorporated into legislation or else it is unlikely the industry would adopt low-carbon practices.

Some of the key challenges to promote climate action include a need to transform the building and construction industry to make it more responsive and able to nurture innovation. More research is needed in a number of areas. A key challenge is our lack of information, such as a need for a carbon budget.

Currently, a circle of blame exists that is stopping the creation of zero-carbon buildings at scale within New Zealand. System changes are needed to behaviours, attitudes, practices and policies especially around encouraging information flows within the building system to turn the circle of blame into a virtuous circle.

In order to help transition to nearly zero or zero-carbon buildings, more attention is required to acknowledge the challenges that exist within the building industry to address climate action. Section 3 highlighted the existing research about the built environment and climate change in New Zealand. The review of the research suggests that reducing the carbon impact from the built environment can be difficult, as greenhouse gas emissions within the built environment are often across sectors rather than within one specific sector. Making sure buildings have reduced carbon or a zero-carbon impact is important for New Zealand's transition to a low-carbon economy.

In 2007, the UK Government formally announced an intension to move towards a requirement for all new houses to be zero carbon from 2016. This policy was based on a directive from the European Union that "requires all new buildings to be nearly zero-energy by the end of 2020" (European Commission, 2018). Zero carbon was defined within the UK context as "over a year, the net carbon emissions from all energy use in the home would be zero" (Department of Communities and Local Government, 2007, p. 5). Based upon the UK experience of attempting to create a low to zero-carbon built environment, this section explores the convergences and differences between the UK experience and the path ahead for New Zealand.

One of the simplest ways of encouraging a low or zero-carbon built environment is to mandate it through legislation. This is what was planned in the UK but was later watered down to non-statutory means when this policy became unpopular, as it was perceived as a constraint on new house building and a drag on productivity (Osbourne, 2015). Recent BRANZ research suggests that, to encourage the building industry through non-statutory ways to build beyond the Building Code can be difficult (MacGregor & Donovan, 2018; MacGregor & White, 2018). MacGregor and Donovan (2018) suggest that current industry practices aim to meet, not exceed, current regulations. Where dwellings do go beyond the Building Code, it is often driven by informed consumers, builders and designers who are driven by the desire for quality, healthy occupants and energy efficiency. Within New Zealand, higher-performing buildings that seek to go beyond Code are not typical. The vast majority of New Zealand's existing housing stock needs to be brought up to a minimum standard, as many are cold and damp, to allow greater thermal comfort in order to help create healthier homes (White et al., 2017).

This section explores the barriers and challenges in delivering zero-carbon buildings and evaluates the drivers for zero-carbon buildings but first outlines some context concerning zero-carbon buildings.

4.1 What are zero-carbon buildings?

The term 'zero-carbon building' is often conflated with 'zero-energy buildings', despite the difference between these two concepts. Complicating the issue is that there is no standard definition for zero-energy buildings (Hernandez & Kenny, 2010).

The original definition of a zero-carbon house (and one we use for our report) is:

> Net carbon dioxide emissions from all energy used in the dwelling are zero or better … a 'zero carbon home' is also required to have a Heat Loss Parameter (covering walls, windows, air tightness and other building design issues) of $0.8W/m^2 K$ or less, as well as net zero carbon dioxide emissions from use of appliances in the homes (i.e. on average over a year). (McLeod, Hopfe & Rezgui, 2012, p. 26)

Aa net-zero-energy building has been defined as:

> A net zero energy building is low energy and offsets any energy that is generated from greenhouse gas emitting fuels with renewable energy generation such as hydro, solar and wind. (Cory, 2015).

In order to unpack what a zero-carbon building is, we need to take note of the complexity of the construction industry. The construction industry is a complex supply chain through which innovation takes place not in a linear fashion but rather as a heterogeneous network. Others have described zero-carbon housing as a "socio-technical system" (Goodchild & Walshaw, 2011) – an interconnected network of knowledge, material technologies, social practices and institutions.

To date, there is a complete lack of zero-carbon buildings in New Zealand. Based upon the UK experience, Goodchild and Walshaw (2011) and Lovell (2005) state that zero-carbon buildings have been discouraged by a number of factors within the system, many of which we would argue also apply to the New Zealand context. Lovell (2005) has argued that economic supply and demand theory is too simplistic to apply to complex housing issues, such as why there is a lack of zero-carbon buildings and suggests that the housing market has failed to deliver zero-carbon buildings because it has failed to respond to consumer demand for low-energy homes and the building and construction industry has attempted to stifle innovative building. The current market failure to produce zero-carbon buildings in New Zealand is in part due to the fact that building decision making and purchasing decisions are not just based on cost but on a number of factors that relate to neither supply or demand, such as personal preferences for location. While consumer perspectives are important, we must first understand the barriers and drivers facing the whole building and construction industry, as they are responsible for creating such buildings.

4.2 Industry barriers to zero-carbon buildings

Osmani and O'Reilly (2009) and Heffernan (2013) outline some of the key barriers identified by the building and construction industry within the UK in the delivery of zero-carbon buildings. It is likely many of these same barriers relate to the New Zealand context, given the lack of uptake of zero-carbon building here. The main barriers identified were economic, skills and knowledge, industry, legislative and cultural (Table 12).

Table 12. Summary of barriers and challenges for zero-carbon buildings.

Economic	Skills/knowledge	Industry	Legislative	Cultural
• Lack of market demand • Perceived market risk • Land values • Perceived cost • Capital cost • Financing	• Knowledge of clients/occupants • Knowledge of build team • Knowledge of design team • Skills availability • Public awareness • Team's knowledge maintenance • Knowledge of planners • Demonstration vs mainstream • Awareness of workforce	• Availability of products • Lack of collaboration working to address issue • Unproven/unknown technology • Failing to be locally specific • Hard to persuade people about the issue • Lack of drive from clients • Scale (group home builder vs SME) • Current business models • Resistance to change • Design process • Complexity of the issue • Every project is unique	• Regulatory uncertainty • Planning agenda • Current building regulation • Persuading government that a low-carbon economy won't stifle growth	• Culture of building industry • Innovation • Consumer values

4.2.1 Economic barriers

Economic barriers have been identified as the most significant barrier to the creation of zero-carbon buildings. Both Osmani and O'Reilly (2009) and Heffernan (2013) suggest that one of the strongest barriers to building zero-carbon homes is the capital cost of delivering them. Such sentiments are echoed within the New Zealand context, where first cost is seen as the main barrier to exceeding Building Code minimum performance standards (MacGregor & Donovan, 2018). More generally within New Zealand, there is a market scepticism about the value of sustainability features, with the exception of energy efficiency, which is often perceived as having a cost saving. For example, research by Christie (2010) helps shed light onto the market perception and value of houses with sustainability features. As part of her study, she compared print and online real estate advertising. Her results found that terms used for sustainability, such as energy efficiency, often dropped by 49% in advertisements when going from the online to print version. Such a finding suggests that the market perception of houses with sustainability, at least among real estate agents, is a lack of priority. Such a finding is like that experienced in the UK, where it was found that being 'environmentally friendly' ranked seventh out of 10 for overall priority (Green Building Press, 2007 cited in Christie, 2010). The mostly widely advertised sustainability features were 'solar water heating' (59% of advertisements) closely followed by 'double glazing' (48% of advertisements) and, thirdly, insulation at (10% of advertisements). Due to the high instance of the use of solar water heating, double glazing and insulation, it suggests these ideas are common and within homeowners' awareness and have a market presence.

To date, it is not known how much consumers are willing to pay to have a zero-carbon building, but at present, there appears to be a lack of market demand for them. Across the banking and financial sector in New Zealand, there appears to be widespread acknowledgement of climate change and its impacts, as most have policies in place that relate to aspects of climate change. However, for these institutions, climate action tends to be focused on mitigating the direct impact from the institution's own activities and are limited with respect to supporting customers rather than having a specific focus on creating a zero-carbon built environment. One bank is an exception. Kiwibank supports customers to install sustainable energy equipment in their homes with a grant and favourable borrowing terms (Kiwibank, 2018).

A lack of financial incentives should be seen as a major barrier to address climate change mitigation and adaptation within the built environment. Funding mechanisms are limited, but there are some New Zealand initiatives:

- Kiwibank offers a sustainable energy loan for its home loan customers. This entails a fee-free top-up to a new or existing loan, with a $2,000 contribution from the bank when borrowing over $5,000 for a sustainable energy installation.
- World Bank subsidiary International Finance Corporation offered green Kauri bonds in 2017. These bonds are denominated in New Zealand dollars and to be used exclusively for projects with positive environmental impacts.
- Previously, green loans for sustainable technology and environmentally housing were offered through Prometheus Ethical Finance and Westpac. However, Prometheus has since gone into receivership and Westpac has withdrawn its offering.

The insurance industry is just beginning to assess homes on an individual basis for climate change risk, which may incentivise adaptation efforts. Within the insurance sector in New Zealand, companies do not have specific mechanisms to deal with climate change. However, insurer IAG and the industry body Insurance Council of New Zealand have signalled an increase in premiums and/or excesses in areas with high exposure and/or frequent hazard (Cann, 2017). Ultimately, withdrawal of cover in some areas may eventuate if retreat or mitigation isn't implemented and hazard exposure becomes more of a certainty.

One strategy undertaken by some banks and investment funds has been divestment in fossil fuel companies. In Australia, Westpac aims to increase lending on projects that are climate solutions, which include things like renewable energy and energy efficiency, and rule out investing on projects that are can have adverse impacts on climate change (Hannam, 2017).

Osmani and O'Reilly (2009) have found a lack of financial incentives to be a major barrier in the uptake of zero-carbon buildings. As we can also observe, within the New Zealand banking sector, there is scope to help support the industry and consumer alike to develop zero-carbon buildings. This could mean financial packages that recognise that zero-carbon buildings have a number of benefits, such as less operational costs for consumers and a warmer, drier and healthier home. However, more research is needed to gain an understanding of how much consumers are willing to invest in a zero-carbon home, which impacts on the industry's ability to deliver such buildings. A review of the financial sector is required in order to see how it could better support climate change initiatives, such as the provision of more green loans to help support the creation of zero-carbon buildings.

In summary, the banking and finance sector needs to do more to support industry and consumers to help transition to a low-carbon economy. The sector should provide incentives to build low to zero-carbon buildings – for example, banks could offer different mortgage loan rates for building sustainably or other incentives if newly built homes provide greater costs saving due to increased energy efficiency.

4.2.2 Skills and knowledge barriers

Heffernan (2013) identified skills and knowledge to be an important barrier to the transition to low or zero-carbon buildings. The issue of the implementation of enhanced standards in new- build construction and for house building more generally is dependent on consumer demand and the industry being able to deliver what the client requests. However, as Lovell (2015) has highlighted, such conceptualisations of the housing market are too simplistic. Heffernan (2013) suggests that the level of awareness and the knowledge of end users and consumers/the public is a critical issue in the successful implementation of new building technologies. MacGregor and Donovan (2018) found there was a general lack of awareness amongst consumers around building standards and that the Building Code is a minimum. There is an identified need to educate the building and construction industry, consumers and policy makers on the importance of zero-carbon buildings and their role in addressing climate change.

Osmani and O'Reilly (2009) found a market dominance of group home builders who sell 'cookie cutter' homes and were reluctant to change practices and processes as low-carbon buildings were a risk that may endanger profits. Goodchild and Walshaw (2011) found there was a strong reluctance within the building industry to change design and production systems for new houses, as materials were often bulk-bought and designs standardised. Such views help to outline the inertia experienced within the building and construction industry to new technologies and processes. Such inertia may prohibit the benefits of zero-carbon buildings from being realised in the New Zealand housing market, not because they are not needed but because the industry is unwilling to act. For example, recent BRANZ research (Duncan, Kingi and Brunsdon, 2018) has outlined where industry capability is one of the biggest barriers to change in general and that small to medium enterprises are finding it hard to keep up with changes due to a lack of resources. Other issues to do with industry skill that may prevent the delivery of zero-carbon buildings may come from building consent authorities (BCAs), which may need upskilling due to a lack of knowledge about zero-carbon building and climate change mitigation and adaptation more generally. A lack of knowledge is a massive barrier that needs to be addressed, as anything beyond minimum or with a hint of innovation tends to get rejected. This primarily comes down to where the risk of failure falls as the BCAs are accountable (Duncan, Kingi and Brunsdon, 2018). The building and construction industry faces a number of skill and knowledge barriers in order to deliver zero-carbon buildings. Such a task is a big one but a crucial one if the built environment plays its part in helping to transition to a low-carbon economy.

In summary, the building and construction industry may not be able to deliver zero-carbon buildings, not because they do not have the will but because they may not possess the skills and knowledge to do so, especially as the industry currently has trouble delivering Code-minimum buildings let alone zero-carbon buildings. More needs to be done to support industry, such as educating industry and consumers about climate change and the need for zero-carbon buildings in order to make zero-carbon buildings possible in New Zealand. A coordinated strategic plan is needed to help turn current industry inaction into action.

4.2.3 Legislative barriers

At present, New Zealand has two major legislative barriers to creating zero-carbon buildings at scale. First, the Building Code possesses no requirement for zero-carbon buildings. The current Building Code is considered a barrier and challenge for the industry. As a performance-based Code, it is not prescriptive but sets out a minimum performance level. A majority of builders seek to construct houses that are of a minimum standard rather than going beyond Code to offer enhanced features that could improve the building's performance and improve health for occupants (MacGregor & Donovan, 2018). As the current Building Code does not set any specifications about buildings being zero or nearly zero carbon, this is a major disincentive to get the industry to act and tends to rely on clients asking for zero-carbon buildings rather than industry setting the benchmark.

The second major legislative barrier is the interaction between central and local government especially within the planning arena to adapt and mitigate the effects of climate change. At present, few local councils are creating legislation that is responsive to climate change. The few councils that have tried stopping development due to the risks of climate change have often experienced pushback from the public (LGNZ, 2017a).

UK experience with the creation of a zero-carbon housing policy helps to highlight the potential legislative barriers and challenges that exist for New Zealand. Within the UK context, builders were reluctant to build and prepare for a zero-carbon building future until legislation was in place (Heffernan, 2013). However, a major concern about a regulatory approach to zero-carbon buildings was the durability of the policy, as it was uncertain if successive governments would change the zero-carbon building regulations. Uncertainty about government approach to the regulation of zero-carbon buildings meant that building companies were reluctant to invest (Heffernan, 2013, Osmani and O'Reilly, 2009).

To overcome any legislative barriers for the creation of zero-carbon buildings, it is important that any legislation clearly defines 'zero carbon' and outlines acceptable solutions to achieve it. The legislation must also avoid uncertainty by having cross-party support to stop legislation changes within electoral cycles, such as the mandating of targets within a zero-carbon Act. However, having zero-carbon buildings the focus of regulation would give industry a sense of continuity. Any legislation must also have in-built mechanisms to review and revise the Building Code to allow for the integration of new research that could be beneficial to the construction of zero-carbon buildings.

In summary, the lack of legislation regarding zero-carbon buildings in the Building Code is a barrier for the industry, as is the lack of attention to climate change within planning laws. To regulate zero-carbon buildings, it is imperative that any legislation provides continuity to achieve cross-party support, as regulatory uncertainty disincentivises industry investment in zero-carbon building.

4.2.4 Cultural barriers

A number of barriers identified so far highlight that the current failure to create zero-carbon buildings in New Zealand is related to the overall culture of the building industry, which plays a major role in New Zealand's economy. Nevertheless, compared to other industries in New Zealand, the building and construction industry has long been criticised for its conservatism and lack of innovation. This, in turn, radically impedes its productivity in the construction process. Therefore, in order to overcome barriers associated with the implementation of zero-carbon building, it is important that innovation, risk and uncertainty within the industry is addressed.

An initiative undertaken as part of the Building Better, Homes, Towns and Cities National Science Challenge by the Transforming the Building Industry research team (Wilkinson et al., 2017) is examining the meaning of innovation within the building industry within New Zealand. One of their research participants, a facilities manager, summed up the meaning of innovation as:

> The subject is around improving upon what we currently do. How we improve our processes, the design and quality of products. The whole concept is sharing information in a shared learning environment that is problem-solving, risks involving, solutions are robust and value added to business. (Wilkinson et al., 2017, p. 21)

Blayse and Manley (2004) state that just understanding the meaning of innovation is insufficient – we need to also know why we should innovate as innovation involves people doing something new. Based upon focus groups with a range of members of the building industry, Wilkinson et al. (2017) suggest that a number of factors are involved as to why the industry in New Zealand is slow to innovate. One suggestion is the time involved in diffusing innovation as well as perceptions within industry that you shouldn't 'give away' innovations to your industrial competitors. They outline a number of methods of how to help improve the creation of greater innovation within the New Zealand building industry:

i. There is need to embed a culture of removing the fear of giving ideas away. There is therefore a need to create a culture in which all employees are actively encouraged to put ideas forward in order to help firms innovate. But how do you get the best from people and encourage them to be at their most creative is a good question?
ii. Innovation forums – This gathering could be government/industry-sponsored or a national, non-profit organization formed to recognize and encourage innovation that improves quality, efficiency and cost effectiveness in construction. Such a forum's interest in expanding innovation awareness may extend to the show casing of innovators, showing innovation in action, supporting innovation networking, promoting innovation, and finding innovative contractors. Arguably this is in place through the existence of such industry events as 'Buildex' here in New Zealand. However inevitably this type of event tends to recruit a limited subset of the industry and is regionally specific [as] such events tend to only be held in Auckland.
iii. Formation of innovation groups by the government or industry to drive innovation.
iv. Raising awareness of the measurable effects of innovation both within the building construction industry and more widely in society. There is an apparent need to create a culture of innovation throughout society if our industrial capabilities are to improve according[ly].
v. Showcasing innovations and innovators to the extent that the status of such individuals and organisations become cultural icons that [effect] change.

> This can be demonstrated in various ways e.g. advertising in social and professional media [as] has occurred in other industries such as with the creation of the image around, and impact of, 'Nano-girl' (Dr Michelle Dickinson) in the Biomedical Materials space. The very real question is 'Who is/are the ambassadors of construction innovation [especially zero-carbon champions] here in NZ?'
>
> vi. Funding innovation by the government and multinational companies most particularly through research and development goes a long way to help the building construction industry.
>
> vii. Development of a team ethos, rather than an individual focus, in organisations presents a significant opportunity to enhance the ability of companies to innovate. Internal collaboration among employees and team work or effort will help enhance the innovation process.
>
> viii. Inclusion of innovation as a critical aspect of the non-price attributes of construction companies in government procurement policy will go a long way to add value to projects and products that [are] created by leading innovators. The reality is that government has a huge amount of power to influence and shape behaviour in the construction sector. (Wilkinson et al., 2017, pp. 22–23)

If we are to transition to a low-carbon built environment, there is a great need for industry to overcome barriers, such as to nurture a culture of innovation and help mitigate risk and uncertainty. In terms of climate action, the creation of a culture of innovation is critical if we are to have a clearer understanding of how to embed new ideas and practices into the building industry, such as constructing zero-carbon buildings. But of course, such changes take time, which is unfortunately not in great abundance with the threat of climate change always present.

In summary, one of the biggest cultural barriers to deliver zero-carbon buildings is the current lack of innovation within the building industry. A number of changes are needed, especially system-level changes, in order to help facilitate a culture of innovation that would help the adoption and implantation of zero-carbon buildings within New Zealand.

4.3 Drivers for zero-carbon buildings

Drivers within the context of the report are existing resources that highlight particular strategies and leverage points that could address climate action on climate change within the built environment. Each of the drivers highlights a specific area of climate action that is required to enable the transition to a low-carbon economy. The listed drivers are not exhaustive but rather seek to highlight current work and what is happening within New Zealand. We then ask some key questions to help promote future thinking about leverage points that could use existing drivers in order to help create a response to climate change and implement a plan for creating zero-carbon buildings in New Zealand.

4.3.1 Legislative drivers

As we have previously outlined, the legislative measures relating to buildings and climate change are mainly focused on the Building Code and Resource Management Act. As noted, more work needs to be done to include carbon within the Building Code, and this should be periodically reviewed to keep abreast of research, policy and market changes. However, lessons can be learned from the UK's lack of success in creating a zero-carbon buildings law about the need for forward planning and not losing sight of zero carbon emissions (Lovell, 2015).

4.3.2 The adequacy of institutional frameworks for climate action

One of the best sources for understanding how governance impacts on climate change is the research undertaken by Lawrence (2015), which sought to examine if New Zealand decision-making frameworks were adequate to address the issue of climate change. The research found that the current decision-making framework enables long-term considerations and emphasises precaution and risk-based decision making. However, the research suggests that adaptive and transformational objectives are largely absent, coordination across multiple levels of government is constrained and timeframes are inconsistent across statutes. Lawrence argues that practitioners "rely heavily upon static, time-bound treatments of risk, which reinforce unrealistic community expectations of ongoing protections, even as the climate continues to change, and makes it difficult to introduce transformational measures" (Lawrence, 2015, p. ii). Some experimentation by local government was found, but improvements to both the institutional framework and to practices that could enable flexible and robust adaptation to climate change were found to be required. This research helps to outlines the governance gaps that need to be attended to in order to address climate change.

In terms of drivers within the built environment to help address climate change, a number of local governments have undertaken studies that outline how climate change will affect their local area, namely through a number of natural hazards such as sea level rise. Very few have focused on the role of the built environment in terms of mitigation and adaptation measures. One of the few exceptions is the NIWA et al. (2012) urban impacts toolbox – the culmination of a 4-year research programme that sought to create an online resource to help planners, engineers, asset managers and hazard analysts working in councils in New Zealand to understand and evaluate the potential impacts of climate change in their cities. This resource is mostly concerned with policy rather than a plan for direct climate action.

4.3.3 Economic drivers

A number of economic drivers were identified in order to help the transition to a low-carbon built environment. The core drivers were the need for an awareness of a carbon price and a current over-reliance on the Emissions Trading Scheme to help meet our mitigation obligations. There is also a need to address how household carbon emissions are linked to the expenditure, such as wealthier households tending to have a higher emissions profile. Also, within the wider economic system, the insurance industry needs to be more resilient to the effects of climate change.

Daigneault (2015) suggests that a carbon price and the buying and selling of carbon credits will be one of the ways for New Zealand to meets is carbon-reduction targets. For example, the report outlines that:

> New Zealand is unlikely to achieve emission reduction targets below 1990 levels of emissions through domestic GHG emissions abatement alone without an unrealistically large carbon price [such as $300/tCO_2eq] (and/or not pricing agriculture and forestry emissions). This is due to the mix of New Zealand's economic and emissions profile. (Daigneault, 2015, p. 6).

The author argues that the purchasing of international carbon units will initially form an important mitigation response for New Zealand for the post-2020 climate change agreement. He suggests that it is not "until domestic GHG emissions can be reduced or the cost of domestic GHG emissions abatement becomes less than the price of international carbon units" (Daigneault, 2015, p. 7). However, there are economic risks associated with a dependency on international purchasing due to the potential fluctuation in the price of carbon units.

McKim (2016) identified two important documents in her systematic review with an explicit focus on the implications of climate change for the financial sector (including banking, investment and insurance).

The first is a report by the Insurance Council of New Zealand (2014), which outlines how New Zealand should be better protected from natural hazards and climate change and argues for a change in the country's approach to resilience. It also suggests that climate action within the financial sector needs to focus on strategy and legislation, information to make the right decisions, funding and insurance. The key finding from the report is that a key driver to attend to climate change is a commitment to long-term annual funding of incentives to resilience (where the risk and investment trade-off justifies it) and well as a commitment to fund measures to reduce the risk of climate change. The report also recommends the removal of levies from insurance premiums in order to make insurance affordable.

The second report (Middleton, 2016) was prepared for Local Government New Zealand. It attempted to help councils to better understand risk and the essential features of insurance and dealing with the insurance market for events related to climate change such as hazards and disasters. Within the context of the report, risk means the chance of financial loss.

Recent Motu research (Allan, Kerr & Will, 2015) examined the relationship between household characteristics and greenhouse gas emissions from consumption in New Zealand. The research found that 82% of household emissions relate to food, housing utilities and transport. In terms of housing utilities (20% of the 82% of household energy use), mostly relate to household energy such as electricity, gas, solid fuels. The Motu study found that the main factor in determining a household's emissions were its expenditure and the number of people in the household – for example, a 10% increase in household expenditure leads to a 7% increase in emissions. This is because, as people get wealthier, they tend to spend more money on services. Interestingly, emissions from household energy do not increase much with expenditure, "[but this] makes sense [as] richer people do not use a lot more electricity as there tends to be a baseload amount of energy used in cooking, bathing, heating, and lighting for all households" (Allen & Kerr, 2015). Based on this research, Motu developed a climate action tool[31] to help people gain an understanding of their household emissions and to educate people on ways to help reduce their emissions.

4.3.4 Individual and social responsibility drivers

Some key drivers for addressing climate action within the built environment relate to the public's awareness and belief in climate change. Recent research by Milfont, Wilson and Sibley (2017) demonstrated from the New Zealand Attitudes and Values Study that two key beliefs that climate change is real and climate change is caused by humans have steadily increased over the 2009–2015 period. This steady and constant rise in

[31] https://insights.nzherald.co.nz/article/climate-action-tool/

the belief in climate change this provides some indication that climate action would be supported by the public.

Motu research by Leining and White (2015) found that a strong majority of New Zealanders were concerned about climate change and were taking some household reduction actions, such as installing low-emission household products, water saving/recycling and reducing household energy use. However, the study found that less than half were convinced that their actions can make a different on climate change, and most people were less likely to take action if they felt powerless to reduce the effects of climate change. The study revealed that those aged below 55 and especially the 18–34 age group were more likely to engage in environmental citizenship such as speaking out about environmental concerns.

To date, few initiatives examining a social responsibility towards climate change and the built environment exist. However, some may touch on it, such as Generation Zero, but few explicitly focus on social responsibility, housing and climate change. One exception is the Climate Safe House project[32] currently being undertaken by the Blueskin Resilient Communities Trust and partners such as Otago Polytechnic. It seeks to create a housing solution to the impact of climate change through creating a prototype house that is sustainable, modular and movable.

4.4 Building and construction industry

A number of drivers exist for the industry to respond to climate change. As we outline later in this report, a number of building industry businesses and organisations within New Zealand have climate change commitments, but only a few building companies are turning this commitment into climate action. In terms of advocating research to help drive climate action in the built environment, much needs to be done. At present, the core resources are the New Zealand Green Building Council, BRANZ, the Eco Design Advisor service, the Superhome Movement and the Passive House Institute of New Zealand.

4.4.1 New Zealand Green Building Council

The New Zealand Green Building Council has issued a policy plan for the built environment (NZGBC, 2017), which outlines a number of policy propositions for government and the wider sector in order to help drive climate action:

- NZGBC calls on the government to work with the sector to establish a national roadmap for better homes and buildings.
- NZGBC will continue to challenge the property, construction and investment community to deliver a low-carbon quality future.
- NZGBC will provide useful tools and develop these with the sector, including tools that widen the market to existing buildings and other types of buildings.
- NZGBC calls on government to lead with their own portfolio of homes and buildings.
- NZGBC calls on local government to facilitate better buildings and homes through the levers they have, thereby facilitating improved quality at a time when density is increasing.

[32] http://climatesafehouse.nz/

All of the policy propositions call for the need for greater leadership, more research and a need for climate action, especially leading by example. These drivers are core actions needed, which we explore in greater detail in section 5.

4.4.2 BRANZ

BRANZ has been instrumental in examining how climate change will impact on our built environment. Four systemic issues BRANZ has identified recently (in addition to climate change) are:

- eliminating quality issues, including how to get greater BCA compliance
- exceeding the minimum
- warmer, drier, healthier homes
- medium-density housing.

Work is also currently under way at BRANZ to understand the barriers to change in the building and construction industry through the Industry Transformation Agenda and to examine the issues of climate change. BRANZ Principal Scientist Dr David Dowdell is also undertaking an International Energy Agency project on how to encourage the industry to deliver zero-carbon buildings.

4.4.3 BRANZ Level

Website: www.level.org.nz

The Level website is a resource devoted to sustainable building and its operated by BRANZ. Level is designed to provide information and guidance on sustainability features in the design and building of homes in order to create homes that have less impact on the environment and are healthier and more comfortable and have lower running costs. Level presents a lot of useful information that has potential to be adapted as a useful resource.

Level provides specific information on topics such as insulation or windows. The Level website also has a variety of free design guides. For example, the *Easy Guide to Eco-Building* has lots of ideas for building compatibly with the environment, such as positioning the house for solar energy and saving water. Other design guides cover photovoltaic design and passive solar design.

4.4.4 Eco Design Advisor

Website: www.ecodesignadvisor.org.nz

One key driver to help in the implementation of zero-carbon homes and enhancing of climate change literacy is the BRANZ-initiated Eco Design Advisor Service.

The Eco Design Advisor service provides free, independent, expert advice on new home design and renovation to home owners, house designers and industry professionals related to energy efficiency and how to better use water and materials on home improvement, building and renovation projects.

The Eco Design Advisor service is run through a number of councils within New Zealand including Auckland Council, Hamilton City Council, Palmerston North City Council, Kapiti Coast District Council, Nelson City Council, Christchurch City Council, and Dunedin City Council. Eco Design Advisors are available for face-to-face visits or at building sites or architects' offices or by phone or email.

The Eco Design Advisor Service is well placed to promote and provide much-needed information and advice on climate change to consumers and industry professionals. An evaluation of the Eco Design Advisor service (Jaques, 2013) found that consumers felt the main improvement that could be made to the service was building awareness through better promotion of the programme. This service is a much-needed resource and a critical element in any future developments in encouraging consumers to address climate change mitigation and adaption.

4.4.5 The Superhome Movement

Website: www.superhome.co.nz

The Superhome Movement is an industry-led non-profit group of builders and architects based throughout New Zealand but founded in Christchurch. Following the Christchurch earthquake, the city rebuild meant it has become a place of innovation with regard to sustainable architecture. It was launched in October 2015 to collaborate and share knowledge about high-performance homes and sustainable building.

The Superhome Movement was co-founded by Bob Burnett, an architectural designer who designed and built the first 10-star Homestar house (international best practice high-performance) in New Zealand, and Martin Reilly of Ecomaster, an organisation that provided the energy-efficient heating and ventilation systems for the 10-Homestar house.

The Superhome Movement seeks to revolutionise how New Zealanders perceive housing by helping people to build warm, dry, healthy, energy-efficient and environmentally sound homes. It has set a target to have 1,000 homes in New Zealand with at least a 6-Homestar rating by 2020.

The Superhome Movement website provides a resource for homeowners to learn more about innovative products and technologies and lists professionals and companies in different regions across New Zealand that can help with Superhome Movement projects. The Superhome Movement is a good example of how change can be inspired by those working within the building and construction industry. The organisation sets up education sessions around the country and is being influential in educating builders and designers about sustainability and the construction of high-performance homes. The builders in this organisation are the most likely to help push the creation of zero-carbon building in New Zealand.

4.4.6 Passive House Institute of New Zealand

Website: www.phinz.org.nz

The Passive House Institute of New Zealand is a charitable trust that seeks to educate the building and construction industry and the public about the improved energy efficiency and health benefits of a house designed to the Passive House standard, which focuses on increased energy efficiency so that little energy is needed for space heating or cooling. The Institute runs various seminars and conferences to help the industry gain knowledge about highly energy-efficient buildings. However, a potential barrier for greater uptake of the Passive House standard, irrespective of its benefits, is that houses must be certified by accredited Passive House professionals in addition to the usual building consent process.

4.4.7 National Science Challenges

The National Science Challenges are examining the impact of climate change on the built environment. The Resilience to Nature's Challenges National Science Challenge has a focus on the urban environment in the Urban – Resilient Cities programme being run by Professor Suzanne Wilkinson, University of Auckland. The Building Better Homes, Towns and Cities National Science Challenge also has potential to fund research into decarbonising the built environment but is yet to do so.

Despite a number of research programmes into climate change in New Zealand, such as the Climate Change Research Centre at Victoria University of Wellington and the Deep South National Science Challenge, few are actively and closely examining climate change and the built environment, which could provide the industry with the knowledge and ability to implement zero-carbon buildings. This is most clearly evidenced by the lack of examples of zero-carbon buildings in New Zealand.

4.5 The circle of blame?

The barriers and drivers for the implementation of zero-carbon buildings all share a common focus in that they all depend on the dynamic interaction of the socio-technical system. In the creation of pro-environmental behaviour, Shove (2010, p. 1275) suggests that:

> For all the effort invested in plotting the prevalence of positive and negative factors, the list of what is thought to be involved is surprisingly arbitrary... pretty much anything can qualify as a driver or a barrier, and it is in any case not always easy to tell which is which.

The distinction between driver and barrier is often fluid, but what is not fluid is that the challenge to implement zero-carbon buildings involves everyone – consumers, investors, developers, constructors – who pass on the responsibility to someone else. So far, this report has helped to outline that we have the knowledge and technologies needed to provide zero-carbon buildings. There are also a number of benefits, such as environmental, health and economic benefits from building zero-carbon buildings. From the New Zealand experience, we can observe a misalignment within the market of incentives between providers of buildings (the building industry), those who are going to invest in them (finance and banking sector) and those who will occupy the buildings (owners, end users and consumers). This misalignment of interests has been termed a vicious circle of blame (see Figure 9).

We are still seeing this circle of blame within the New Zealand building industry and only rarely are we seeing a break in this cycle. Pearce (2005) suggests that one reason why issues like climate change and sustainability are unable to gain traction within the building industry is because there is a shortage of sound guidance on just what the concepts mean for building and construction and what the industry would have to do to achieve it.

While the circle of blame can help to perpetuate a lack of action on climate change within the building industry, this vicious circle of blame could – theoretically at least – be turned around into a virtuous circle.

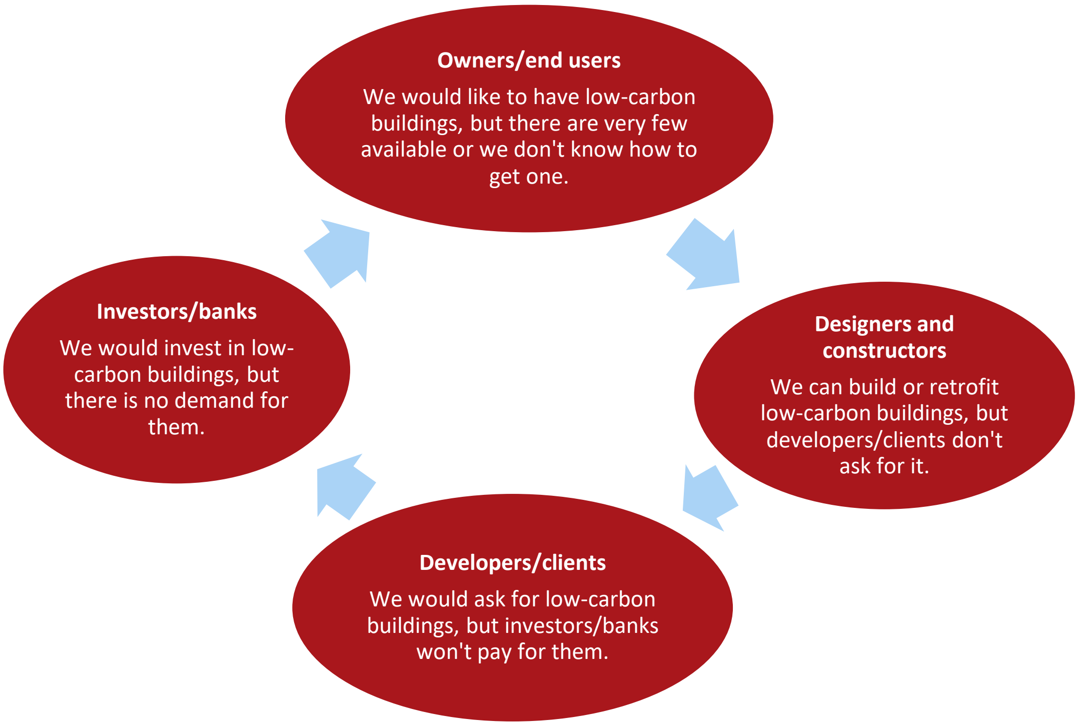

Figure 9. The vicious circle of blame (adapted from Cadman, 2000).

RICS (2008) argues that realigning incentives and creating appropriate feedback mechanisms are an important foundation for breaking the vicious circle of blame. It is therefore critical that action on climate change, especially the implementation of zero-carbon buildings, moves from one about rhetoric and talk about zero-carbon buildings to one of action of building and retrofitting buildings to reduce their carbon footprint. In attempting to break the circle of blame, it has been suggested that environmental and social aspects of building need to be balanced with the technical and physical aspects of construction, so there is potential for the alignment with building performance, financial performance and property value. It means that, within the building process, no part of the cycle should be prioritised over the other but through the interplay of all different actors (people, organisations and institutions) within the building and construction sector. What we are suggesting here is that a key element in turning the circle of blame into a virtuous circle is about enhancing information flows to be organised in such a way that the benefits of zero-carbon buildings are known and pervade all parts of the construction cycle including valuation, investment and risk analysis. The current problem facing the housing market and building industry is that the current information flows are not working or are not yet fully in place. Currently, the culture of the building industry and consumer expectations limits the rhetoric of climate change to turn it into climate action.

4.6 Key directions for the development of climate action

- Legislation is needed that addresses and encourages climate action, such as a Climate Change Act.
- Coordinated climate action between central and local government is imperative especially in developing complementary legislation.
- It is important that carbon and other measures to help in the delivery of climate change mitigation and adaption are brought into the New Zealand Building Code and periodically reviewed to keep abreast of research, policy and market changes.

- A carbon budget for the built environment, especially at the building/housing level, is required to help inform reduction strategies and initiatives to address climate action.
- It is important that banking, financial and insurance sectors provide information and plans that address climate change to help protect the interests of homeowners.
- More research is needed to find out how our economic decisions, such as household composition and expenditure, impact on climate change.
- Strategies need to be designed that outline what can be done to help reduce these emissions for households.
- More research needs to be done to examine individual decision making and social responsibility in relation to climate change and future built environment scenarios so plans and leadership can be developed for climate action.
- There is a need to recognise and tap into the growing public concern and awareness about climate change in order to invite positive climate action to facilitate transition to a low-carbon economy – for example, whether social marketing is required or public education campaigns such as a carbon credit card . The carbon credit card was first proposed by then UK Environment Secretary David Miliband in 2006 (Wintour, 2006). Under the scheme, every citizen would be issued with an individual carbon ration and every time they bought something, like petrol, electricity or a plane ticket, the carbon credit card would be swiped. The logic behind the scheme is to provide a way of pricing carbon emissions into individual behaviour in an effort to recognise carbon thrift as well as economic thrift in the transition to a low-carbon economy.
- The building and construction industry requires a roadmap that sets out how a transition to a low-carbon economy can take place and how their role is critical to help achieve this.
- More research is needed to understand why low or zero-carbon buildings are being built by the industry. For example, is more education or knowledge required?
- More research is needed to find out what support and/or incentives the industry requires to deliver low to zero-carbon buildings.
- Currently, a circle of blame exists that is stopping the creation of zero-carbon buildings at scale within New Zealand.
- Changes are needed to behaviours, attitudes, practices and policies especially about encouraging information flows within the building system if we are able to transition to a low-carbon built environment.
- In order to nurture information flows to help transition to the delivery of zero-carbon buildings, more attention is required to acknowledge the current working of the system and build in better feedback loops and integrate all actors into the communication cycle, such as the financial sector, researchers and educators and the property and real estate sector alongside the building and construction industry.

5. Transitioning to a low-carbon built environment

This section helps to frame how transition to a low-carbon economy can be conceptualised in order to create and plan/strategy for a low-carbon built environment. A number of key areas have been identified from our review that describe tension points within the built environment that could be used to support transition to a low-carbon economy. However, there a number of issues and areas of climate action that this section explores that need to be addressed to help to create a workable transition to a low-carbon economy:

- A transition to a low-carbon built environment must take into account the material-built environment and social practices – what people do rather than how people think they behave.
- Carbon needs to be understood as a fluid concept rather than something fixed and rigid.
- A shared carbon responsibility is needed as well as a strategic plan and leadership to help direct climate action.
- A transition to a low-carbon built environment needs to focus on establishing coordinated climate action, climate change literacy, actualising change and changing beliefs and practices.

5.1 Transitioning to a low-carbon economy

The term 'low-carbon economy' is not new with several UK reports helping to establish the meaning of the term (Department of Trade and Industry, 2003; Committee on Climate Change, 2008; Stern, 2006).

The 2003 UK Energy White Paper defined the low-carbon economy as one:

> … where higher resource productivity – producing more with fewer natural resources and less pollution – will contribute to higher living standards and a better quality of life … [where there is an] opportunity to develop, apply and export leading-edge technologies, creating new businesses and jobs. And the opportunity to lead the way, in Europe and internationally, in developing environmentally sustainable, reliable and competitive energy markets that will support economic growth in every part of the word (Department of Trade and Industry, 2003, p. 6).

Another definition put forward defines a low-carbon economy as:

> … one where all products and services, right through the supply chain, embrace a low carbon approach. 'Low carbon' is a way of thinking, behaving and operating that minimises carbon emissions while enabling sustainable use of natural resources, economic growth and quality of life improvements (Scottish Government, 2010, p. 4).

Both these definitions encompass a sense of how our economy – especially our economic logic and practices – needs to adapt to climate change. The creation of a low-carbon economy means that a society must transition away from a fossil fuel-based economy to a more low-carbon economy. The Stern (2006) review and the IPCC, amongst others, have stressed the need to transition to a low-carbon economy –

shifting our current dominant regimes and practices to more sustainable ones. As Rotmans, Kemp and Van Asselt (2001) put it, transitions are:

> … a set of connected changes, which reinforce each other but take place in several different areas, such as technology, the economy, institutions, behaviour, culture, ecology and belief systems. (p.16)

As transitions can have negative and/or positive outcomes, it is therefore important with the issue of climate change that transition to a low-carbon economy is a "long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption" (Markard, Raven & Truffer, 2012).

The linking of abstract theory with human action can be difficult, but the concepts outlined above help to highlight how transition to a low-carbon economy is possible through action. For example, transition theory sets out ways in which people, organisations and institutions can adjust, adapt and influence socio-governance systems to facilitate change. Kemp, Loorbach and Rotmans (2007) explain the core notion of transitions as:

> … experiments and cycles of learning and adaptation. Transition management helps societies to transform themselves in a gradual, reflexive way through guided processes of variation and selection, the outcomes of which are stepping stones for further change. It shows that societies can break free from existing practices and technologies, by engaging in co-evolutionary steering.

A key limitation of transition theory is that the overall goal of the framework is large-scale social transformation, but large-scale coordinated change is often quite rare and never neat and tidy. For example, as previously outlined, coordinated international on action on climate change has been slow to formalise, although an in-principle agreement was reached with the Paris Accord (see section 3). However, since the Paris Accord and Bonn COP 23 in 2017, the USA under the directive of President Donald Trump has withdrawn from the Paris Accord (Volcovici & Mason, 2017). This of course does not mean that the USA is shirking obligations, as evidenced by the thriving renewable energy sector in Texas (BBC, 2017). Such events help to highlight the challenges that full-scale transition to a low-carbon economy will face. Such examples help to illustrate that transitions need to incorporate all aspects of human society, such as culture, belief systems, behaviour and many others (Rotmans et al., 2001). Therefore, part of this report seeks to highlight where opportunities and actions could take place to help able cross-sector and transdisciplinary action on climate change and help create a low-carbon built environment.

5.2 From behaviour to practices: how to frame a transition to a low-carbon built environment

In recent years, there has been a move away from individualistic linear understandings in promoting greater environmental awareness to one that recognises the heterogeneous nature and complexity of transitioning to a low-carbon economy through the interactions between large-scale systems and the actions of individual actors (Lovell, 2015). However, rather than a bottom-up or top-down approach, increasingly approaches are highlighting the dynamics required to address critical issues such as climate change. Hargreaves (2008) suggests three dynamic things are needed in order to encourage greater pro-environmental behaviours:

- A new theoretical lens is needed by focusing on the social and collective organisations and the doing of practices rather than being concerned with individual behaviour.
- There is a need to consider the role of specific social contexts in the shaping and structuring of behaviour more than a mere variable within individual decision-making processes.
- Inherent individualism within many behaviour change models is often systematically blind to the crucial importance of social interactions in shaping how practices are performed, learned and changed.

Shove (2010) argues that the problem of climate change as a problem of human behaviour marginalises and excludes engagement with other possible analyses, especially those relating to social theories of practice and transition, suggesting that current climate change policy is centred around a rationality of social change as relating to an ABC framework – attitude, behaviour, choice.

The ABC framework is so popular that most current climate change policies relate that the responsibility for responding to climate change lies with the individual whose behavioural choices will make a difference. Such models of social change, such as transition to a low-carbon economy, are thought to depend upon values and attitudes (A), which are believed to drive the kinds of behaviour (B) that individuals choose (C) to adopt (Shove, 2010).

The underlying rationality of the ABC model for climate change policy is extremely influential in shaping government responses but does not allow us (as individuals or as a society) the ability to make "major changes in the way we meet our needs and aspirations" (Sustainable Consumption Round Table, 2006, p. 33).

As Uzzell (2008) suggests:

> Trying to persuade people [not] to consume and waste less through behaviour change programmes will address the larger and more significant problems concerning the ways under which people need or think they need to live and consume…an emphasis on individual behaviour change may not be the most effective way of tackling society's relationship with climate change.

In order to attempt to move the debate forward about how to transition to a low-carbon economy, we need to make clear distinctions between words like 'behaviour' and 'practices' that are often used interchangeably but are in fact quite different Hargreaves, 2008). Practices may be situated within social and institutional contexts, but such meanings of practice often do not recognise how practices are about the doing by actors and non-human actors and that practices evolve, form and fragment. In other words, practices are dynamic and fluid. It is important to understand this dynamism if we are to attempt social change. This is because social norms and practices of consumption often require constant reproduction. Further, the cultural conventions that underpin the context-based meanings of behaviour have no separate existence from systems of economy, governance, science and environment, as these practices themselves are sustained and changed through the ongoing reproduction of social practice. It is therefore imperative when considering transition to a low-carbon economy that an emphasis is placed on practice, as it illustrates endogenous and emergent dynamics rather than the rhetoric of behaviour that focuses on causal factors and external drives.

5.3 A pathway for zero-carbon building

So far, this report has highlighted the two domains of carbon governance that should be the focus of climate action. On the one hand, we have the material built environment, in which various forms of carbon policies, knowledge, standards and best practice have been utilised to reduce carbon emissions for buildings. On the other hand are the social practices and the rhetoric underpinning such practices that prompt action from individuals, organisations and institutions to do something about climate change, such as sustainability management plans, corporate social responsibility and so on. The domain of the material built environment and our carbon-based social practices are often positioned as distinct spheres of governance, but we would argue they are necessarily related and together create an urban carbon space that needs to be addressed from all sides.

Walker, Karvonen and Guy (2015) observe that, within policy discourse, zero carbon is often depicted as a fixed and absolute obligation but the zero in zero carbon is in fact a more fluid and negotiated regulatory object. Carbon fluidity then is crucial for a low-carbon built environment, but it is bound up with the material built environment and social practices. Thus, zero-carbon buildings are then in many ways just the right combination of materials and technologies that are situated relationally to social practices that create them – the buildings themselves become the embodiment of climate change. As we have previously mentioned, embodied carbon and operational carbon are important aspects in the implementation of zero-carbon buildings. For example, building standards specifying a zero-carbon building would be useful, but only relate to part of the picture in helping to transition to a low-carbon economy. If we only address the material built environment and not the social practices that help produce it, a transition is futile.

The transition to zero-carbon buildings is difficult, as Lovell (2005) has suggested buildings are an atypical consumer product as they are durable, expensive and of a fixed location. Lovell suggests one reason why there is presently a market failure concerning the implementation of zero-carbon buildings is because of a lack of familiarity with the concept, such as what a zero-carbon building looks and feels like. In a conservative industry, such as the building industry, it is unlikely that builders, many of whom are small to medium enterprises, would take business risks producing buildings where there is an uncertain market. Such market failures help to create a circle of blame (as we outlined in section 4) that helps to highlight the inertia within the building industry and the difficulty of transition.

Following Walker et al. (2015), we too argue that we must focus on the interdependencies between the built environment and social practice as the material built environment is often described by how people interact with each other. Therefore, the implementation of zero-carbon buildings may mean simultaneously creating a new normal of what the built environment may look like, but also new ways of living through social practices. By limiting the construction of zero-carbon buildings to merely a technological or an economic issue misses the importance of social practices in shaping a transition to a low-carbon built environment. It is therefore critical that a shared carbon responsibility emerges through interdependencies between the material built environment and social practice. Such dynamics create a means of embedding carbon conduct into climate action (Paterson & Stripple, 2010). The blending of the material built environment with social practices through a shared carbon responsibility creates zero carbon as a "specific ambition … attached to many other carbon units (communities, cities, businesses, products, journeys), each bringing their own interdependencies between the material and the social, and each raising questions about what is in and out of the process of becoming 'nothing' in carbon terms'" (Walker et al., 2015, p. 503).

5.4 A plan for the creation of a zero-carbon built environment transition pathway

In order to help develop a strategic plan to facilitate a transition pathway to a low-carbon built environment, it is important to highlight the internal tensions and outline areas of focus where climate action can take place. There are currently few initiatives that exist internationally that provide some hope for climate action within the built environment.

5.4.1 City of Vancouver zero-emissions building plan

The City of Vancouver zero-emissions building plan (City of Vancouver, 2016) is underpinned by four strategies that lay a foundation for climate action for the built environment:

- **Limits** – establishing greenhouse gas and thermal energy limits by building type and stepping these down over time to zero.
- **Leadership** – requiring central and local government building projects to demonstrate zero-emission building approaches where viable.
- **Catalyse** – develop tools to catalyse leading private builders and developers to demonstrate effective approaches to zero emissions.
- **Capacity building** – build industry capacity through information-sharing tools, climate change literacy to facilitate the removal of barriers, sharing of knowledge and development of skills required to successfully achieve this.

The City of Vancouver's 2050 target of zero-carbon buildings requires the uptake of renewable energy for the majority of buildings and all new buildings to achieve this target by 2030. Alongside the aggressive energy-efficiency and renewable energy targets, the transition to zero-carbon buildings requires a "restructuring of the City's policies and tools as well as leadership by the City and industry to demonstrate effective approaches for achieving this goal. It will also require a collaborative approach amongst many stakeholders to share knowledge, remove barriers, and ensure that the required skills are developed and widely available" (City of Vancouver, 2016, p. 44). The zero-emissions building plan is a collaborative effort to transform how new buildings are designed and built but will also encourage healthier and more climate-resilient buildings for the future.

5.4.2 Carbon*n* climate registry

The Carbon*n*® Climate Registry[33] is the leading global reporting platform for cities, towns and regions tackling climate change. It helps local and other subnational governments to track and report on their targets, actions and performance in relation to climate action. This platform allows for exchange, learning and benchmarking among its 950+ registered entities while providing data that feeds into global climate negotiations through the International Council for Local Environmental Initiatives (ICLEI), now more commonly known as Local Governments for Sustainability, as a focal point for the Local Governments and Municipal Authorities Constituency. One

[33] http://carbonn.org/

such initiative that the registry highlights is the Building Efficiency Accelerator[34] – a public-private collaboration that turns global expertise into action to accelerate local government implementation of building efficiency policies and programmes.

5.4.3 European union energy efficiency directive

The European Union's energy efficiency directive[35] provides a supra-country regulatory solution to help direct climate action. It establishes a set of binding measures to help the EU reach its 20% energy efficiency target by 2020. Under the directive, all EU countries are required to use energy more efficiently at all stages of the energy chain, from production to final consumption. In November 2016, the energy efficiency target was revised to 30% for 2030. Under the EU targets, member nations must ensure major energy savings for consumers and industry alike, for example:

- energy distributors or retail energy sales companies have to achieve 1.5% energy savings per year through the implementation of energy-efficiency measures
- EU countries can opt to achieve the same level of savings through other means, such as improving the efficiency of heating systems, installing double-glazed windows or insulating roofs
- the public sector in EU countries should purchase energy-efficient buildings, products and services
- every year, governments in EU countries must carry out energy-efficient renovations on at least 3% (by floor area) of the buildings they own and occupy
- energy consumers should be empowered to better manage consumption, which includes easy and free access to data on consumption through individual metering
- national incentives for small to medium enterprises to undergo energy audits
- large companies will make audits of their energy consumption to help them identify ways to reduce it
- monitoring efficiency levels in new energy-generation capacities.

The Informal Energy Council (2012) has suggested that the energy efficiency directive will help to reduce carbon emission and create a low-carbon economy through its implementation, as it will contribute to increased EU GDP of €34 billion and increased net employment of 400,000. It also suggests that other outcomes of the policy include:

- increased costs for investment in energy efficiency (house insulation, energy management, control systems and so on) of an average of €24 billion annually
- reduced costs for investment in energy generation and distribution of an average of €6 billion annually
- reduced fuel expenditure of an average of about €38 billion annually as a result of a lower need for energy.

A report by Grözinger and others (2014) examining the progress of the policy outlines that, compared to the 2013 progress report, the situation surrounding the creation of greater energy efficiency, especially from zero-energy buildings, has clearly improved, as there are have been more zero-energy buildings built across Europe. However, there is still space for improvement. The EU directive provides a good template for other countries to enact a climate action policy at scale – something that is needed if we are to address the issue of climate change quickly and in a coordinated manner.

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[34] http://buildingefficiencyaccelerator.org/
[35] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1399375464230&uri=CELEX:32012L0027

5.5 Towards a zero-carbon built environment

Building upon the strategy outlined by the City of Vancouver (2016), we outline four key areas identified during the process of our research that provide a strategy for climate action and help to institute a transition pathway for zero-carbon buildings in New Zealand. These ideas relate to the interconnection and complexity of the issue and are actions that depend on the interdependencies of the material built environment and social practices, which can cut across levels of scale from the actions of individual consumers to actions for central government. Essential to this, as we have highlighted in the report, is a collaborative approach that seeks climate action.

Within New Zealand, we currently have the knowledge, the materials and the will – all we need is leadership and action.

Action space 1: Coordinated climate change action

Coordinated action is imperative if we are to help create a zero-carbon built environment. An independent climate commission should be established that can set about creating awareness, be a source for information and provide a point of contact for the public in search of information and support. Another aspect of coordinated climate action is to just get on with building zero-carbon buildings. The act of doing so will help the industry to develop skills and knowledge to make zero-carbon buildings a reality in New Zealand and help to establish a market for zero-carbon buildings.

Action space 2: Climate change literacy

There is a great need for climate change literacy. By this, we are not meaning to imply a deficit model where the paternalistic state educates its masses. Rather, it is about the establishment of information flows that help to enable people and organisations to talk in the same language about the same issues and to create resources for guidance to help consumers and the industry and other sectors to play a part and see how their actions and practices are interlinked with the impact of climate change on the built environment. A core part of climate change literacy is about utilising existing infrastructure such as the Eco Design Advisor service to help inform industry and help consumers design houses that incorporate zero-carbon building and design features that may mitigate and adapt to the impact of climate change. Once we, as individuals and as a community, understand our role in the impact of climate change, we are more likely to act on it.

Action space 3: Actualising change

There is a great need to move beyond the rhetoric of climate action and start actualising change. The bank and financial sector needs to be more forward thinking to help support investment in zero-carbon buildings. Research needs to be undertaken to address the knowledge gaps for our transition to a low-carbon economy. Strategic forward planning will help promote building quality but also provide a more resilient housing infrastructure that will create a housing stock that will last longer, be more efficient and healthier. We need legislation that sets out zero-carbon requirements and also legislation that helps to respond to climate change by changing planning and consent procedures so that the houses we build today are resilient to climate change into the future.

Action space 4: Changing beliefs and practices to create vision

There is a great need to change individual, community and industry beliefs and practices about carbon in order to create a vision for climate action. For example, it is important to know the operational carbon or the timing of emissions as this may help us encourage or promote consumers, businesses and the industry to think about the timing of carbon emissions during the design phase of their builds. How can we incorporate the Paris Climate Accord at the building level? What is needed is the urgency about action on climate change. For example, the housing being built today will still exist in 2050 but will not be able to cope with the requirements of being carbon neutral, so it is urgent that action is taken now.

6. Conclusion and recommendations

This report has provided a review of research, challenges and the future facing the New Zealand built environment as a result of anthropogenic climate change. We have outlined the current global and New Zealand policies directed at climate action.

We have helped to highlight in this report that buildings primarily contribute to climate change impact in three key ways:

- The use of energy and where we obtain this energy, year on year, while the building is occupied.
- The materials used in and on buildings, which contribute to greenhouse gas emissions as a result of extraction, processing, transport and installation before the building is occupied, as well as periodic maintenance and the need for repair and replacement of materials during the building's service life.
- Urban and landscape design/planning.

Our research suggests that climate action needs to be directed at how carbon is understood within the social, regulatory and market context. Above all, we argue that the consideration of energy use in buildings and the carbon burden of the energy supplied should not be divorced from the carbon burden of materials selected in building design. We suggest that the timing of carbon emissions is also potentially important in helping us plan our response to climate change. Large carbon emissions now in order to achieve carbon savings decades into the future may not be the best strategy. We highlight that, for New Zealand and our low-carbon intensity, grid electricity makes this particularly pertinent. Instead, we argue that any policy and market approach should not be entirely focused on carbon to the exclusion of all other potential impacts. Such an approach risks unforeseen consequences.

A 2016 Royal Society of New Zealand report suggested that the best ways for reducing greenhouse gases in the building industry (including both commercial and residential) is to:

- tighten the minimum energy efficiency requirements within the Building Code
- specify more low-carbon materials in building construction
- provide policies to reduce the most inefficient appliances via the use of minimum energy performance standards
- promote more efficient buildings through green certification organisations and more efficient appliances through programmes such as EnergyStar[36]
- educate and train those involved in the building industry to provide more energy/resource-effective solutions such as passive building design and mechanical technology as required.

From our research, we would add to this Royal Society of New Zealand (2016) list on climate action by suggesting that we must not solely focus action at a building-specific level but rather across the building's whole life as we need to take into consideration how materials interact with design and other materials in different ways, for example.

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[36] EECA is withdrawing the EnergyStar label at the end of December 2017, but the Energy Rating Label is still in force.

We also need to acknowledge and focus climate action on a number of social aspects, such as the barriers and challenges that are preventing New Zealand from creating a zero-carbon built environment. Key barriers identified include:

- a lack of economic incentives to prompt and encourage action
- gaps in industry skills and knowledge required to deliver zero-carbon buildings – at present, only a small group of industry could construct a zero-carbon building
- industry and the market need a strong signal to invest in the construction of zero-carbon buildings – for example, prescribing zero or low carbon within the Building Code would encourage industry to adopt the practice as, without regulation, it is unlikely the industry would adopt low-carbon practices.

One of the key long-term challenges to promoting climate action includes a need to transform the building and construction industry to make it more responsive to and able to nurture innovation that supports climate action, such as carbon budgeting for buildings and life cycle assessment.

In transitioning to a low-carbon economy, we have outlined that a number of systemic changes are needed to behaviours, attitudes, practices and policies, especially about encouraging information flows within the building system, if we are able to turn the circle of blame into a virtuous circle. Currently, a circle of blame exists that is stopping the creation of zero-carbon buildings at scale within New Zealand. Therefore, a transition to a low-carbon built environment must take into account the material built environment and social practices – what people do rather than how people think they behave.

Our research report highlights that carbon needs to be understood as a fluid concept rather than something fixed and rigid. We also need to acknowledge that we all have a shared carbon responsibility that needs to be focused to create a strategic plan and leadership to help direct climate action.

While this report has explored the impact of climate change on the built environment, our recommendations relate specifically to climate action for the built environment. However, we recognise that a set of non-built environment recommendations could also be made, such as those concerned with policy, tools and urban planning considerations, which have not been covered here but have been done so by others:

- A Parliamentary Commissioner for the Environment report (Wright, 2017) sets out a case for adopting legislation and processes akin to those used in the UK as a means to achieve our carbon reduction target.[37]
- Tools are already available to help inform users on how to adopt lower-carbon lifestyles that go beyond buildings and include aspects such as food and transport. An example is the household climate action tool[38] developed by Motu

[37] Further information about a Zero Carbon Act for New Zealand is available at http://zerocarbonact.nz/zca-summary/.
[38] https://motu.nz/our-work/environment-and-resources/emission-mitigation/shaping-new-zealands-low-emissions-future/household-climate-action-tool-2/

- There are also approaches that go beyond the buildings themselves.[39] The Hobsonville – urban design master plan[40] and development is an example of this.

The three recommendations outlined below are provided to help drive future climate action within the built environment. The strategies themselves are not mutually exclusive, and there is merit in pursuing all three. Whilst strategies have been divided in this way, there would be much overlapping in their implementation.

6.1 Strategy 1: Improve energy efficiency

When a building is occupied, energy demand (and how it is supplied) makes the largest ongoing contribution to the climate change impact of our buildings. Virtually every building we have constructed, are currently constructing and plan to construct adds to the size of the climate change problem – whether it is an office, shop, house, restaurant, school, sports centre or other building.

We need to reduce the demand for energy from our existing and new building stock and decarbonise the source(s) of that energy in the following ways:

- **Encourage passive solar design in new builds** (all building typologies), which will require a balance of improved thermal zoning, advanced envelope design and natural ventilation and solar shading approaches.
- Continue to i**ncentivise and accelerate activities that provide improved thermal performance in existing dwellings** (i.e. via insulation and draught-proofing), which will help ensure that New Zealanders can condition their houses effectively and more affordably.
- **Review the Building Code** for clause H1 *Energy efficiency* alongside its broader implications for clauses E3 *Internal moisture* and G4 *Ventilation*. These three clauses need to be examined together, as changing one affects the others, and will help bring New Zealand more in line with international best practice.
- **Encourage low-carbon fuel options** for space conditioning and water heating for both new and existing dwellings. For space heating, encourage use of high-efficiency wood pellet burners or high-efficiency ground or air-source heat pumps. For water heating, encourage use of simple time-managed control if available, wood or pellet-fired hot water boiler heating and air or ground-source heat pump technology.
- **Increase renewables supplying grid electricity** as close as practical to 100%. Grid electricity is the largest source of energy in dwellings and commercial buildings. Use of grid electricity based on near-100% renewables would dramatically reduce year-on-year climate change impacts. It would also reduce the

[39] Another function that may be considered on the fringes of the scope of this report is linkages/transportation based on location of a development. There are a number of tools/calculators that can be used to determine the carbon intensity of various new development options. In the public domain, two of the best are Walkscore/Transit Score and the USA's Housing and Transportation Affordability Index, both of which leverage the internet's mapping capability. The index has a more sophisticated way of determining the carbon cost of transportation as part of the choice of home location to estimate auto ownership, auto use and transit use. The beauty of both is they provide metrics very quickly (only an address needs to be known) for users to determine the implications of their site-location decisions. The limitation of both, however, is that they can only display current conditions.

[40] https://www.nzta.govt.nz/resources/urban-design/hobsonville/hobsonville.html

climate change impacts of other parts of the New Zealand economy including manufactured goods and services as well as emissions associated with electric transport (cars, buses and trains).

- **Investigate the feasibility of incorporating building carbon performance into the Building Code**, based on functional requirements and performance criteria. This should take into account energy and materials and therefore would most likely have its own clause. Carry out any feasibility studies on the moderate climate change projections at the end of the building's anticipated lifetime, and if feasible, require that the climate change impacts of buildings are a part of the design, consenting and the building process to ensure that buildings meet performance criteria and the needs of a low-carbon economy.
- **Provide additional, practical education resources** to help consumers and the building industry better understand the implications of design choices from a carbon perspective over the building's lifetime. This might include professional development around comprehensive life cycle (carbon) assessment tools or thermal and energy-efficient design rating tools. These could be championed by BRANZ scientists/educators, NZGBC technologists/educators and Eco Design Advisors and Home Performance Advisors through roadshows, seminars and even in-house demonstrations.
- **Provide ongoing tracking of building carbon performance** that meets as many of the Stats NZ good indicator characteristics[41] as possible. Track national progress (on space and water heating, construction-related embodied carbon and so on) to understand trends/progress periodically. Leverage and extend the BRANZ benchmarking study reports (currently focused on new, detached dwellings) for useful indicators and metrics. This could be added to the existing scope of the BRANZ Construction Dashboard,[42] which focuses on economic issues..

6.2 Strategy 2: Reduce embodied carbon

We need to reduce the embodied carbon impact of our buildings. Recommendations to achieve this aim may include the following:

- Provide incentives so that clients/customers and designers determine and understand the life-time carbon implications of their designs and material choices and any associated trade-offs incurred. This should derive from greater application of **environmental impact tools** having a dedicated carbon estimator – for example, BRANZ's *LCAQuick* tool.[43]
- **Increase opportunities for reuse, recycling or recovery of construction wastes** – the carbon implications of diverting material from landfill should be assessed to ensure they deliver a benefit, as has previously been undertaken overseas,[44] complete with sensitivity studies to ensure choice robustness, for the main centres in New Zealand.

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[41] Such as valid and meaningful, sensitive and specific to the underlying phenomenon, statistically sound, consistent over time, linked to policy or emerging issues.
[42] https://sites.google.com/a/branz.co.nz/branz-construction-dashboard/home
[43] http://www.branz.co.nz/buildingLCA
[44] In the late 1990s, an environmental calculator named WISARD was adapted by the Ministry for the Environment from the UK to better quantify the implications of different collection systems. WISARD calculated the environmental effects from transport, infrastructure development and operation, recycling processes, landfilling and incineration, energy recovery and avoided burdens (where applicable). It is unknown if it is in use today by any authority.

- **Incentivise manufacturers to be more transparent about the carbon and other environmental impacts of their products.** With public reporting comes an increased incentive to demonstrate reduced environmental impacts over time. Currently in New Zealand, the Australasian EPD® Programme exists to provide such a platform, but the number of New Zealand construction product manufacturers that have participated is low (in comparison with Australian product manufacturers).

6.3 Strategy 3: Strategic leadership for climate action

We need to adopt a socio-technical approach in formulating climate action. Carbon needs to be understood as a fluid concept rather than something fixed and rigid. We also need to acknowledge that a shared carbon responsibility is needed as well as a strategic plan and leadership to help direct climate action.

Four key areas were identified that should be the focus of the transitioning to a zero-carbon built environment:

- **Coordinated climate change action:** Coordinated action is imperative if we are to help outline how to create a zero-carbon built environment. An independent climate commission is to be established that can set about creating awareness, be a source for information and provide a point of contact for the public in search of information and support. Another aspect of coordinated climate action is the need for a building and construction industry climate action roadmap to help drive coordinated action for industry and the public.
- **Climate change literacy:** There is a great need for climate change literacy to make sure we are all talking the same language, such as what a zero-carbon building is. We need climate change champions such as the Eco Design Advisor service to help inform industry and help consumers design houses that incorporate zero-carbon building and design features that can mitigate and adapt to the impact of climate change. Once we, as individuals and as a community, understand our role in the impact of climate change, we are more likely to act on it.
- **Actualising change:** There is a great need to move beyond the rhetoric of climate action and start actualising change. Climate change needs action now. As most of the buildings being built today will still be around post 2050, our actions today will have a big impact on our response to climate change in the years to come.
- **Changing beliefs and practices**: Transitioning to a low-carbon society means that there is a great need to change individual, community and industry beliefs and practices about carbon. We need to change our relationship with the climate as our current approach is not working. By creating a low-carbon world, we need human action that will create a new world that is more sustainable for everyone.

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Appendix A: Summary of climate action for the built environment

Climate change action initiatives	New Zealand initiatives (current and past)	Comparative initiatives	Driver of adoption in New Zealand market context	Barrier to adoption in New Zealand market context
Increased energy efficiency (energy supplier, consumer).	**Mandatory**[45] • Electricity Authority code.	• Danish Energy Regulatory Authority –energy-efficiency obligations and transitioning into a low-carbon economy. Danish energy consumers have the right to have individual meters installed to measure consumption. • Various energy policies globally.	• Competition between electricity retailers and suppliers (business perspective). • Marketing/social component of retaining consumers (business perspective). • What are the drivers/barriers for suppliers and retailers to start charging for carbon and not electricity?	
	Voluntary[46] • Energy retailers implementing smart meters. • Apps for consumers can better keep track of energy.	• Grants from energy companies (Denmark –see SparEnergi.dk).		
Help people meet the cost of transition to a low-carbon economy (consumer and producer of buildings and government).			• Increase corporate social responsibility (business perspective). • Reduce hospitalisation costs (government perspective). • Lower cost to homeowner (homeowner perspective).	• What are the barriers to financial incentives? Costs to the government, can't allocate money elsewhere (government perspective).
	• Warm Up New Zealand. • Other insulation incentives. • Some initiatives from banks exist as means of financial support.	• Many schemes globally. • LiveSmart BC: efficiency incentive programme. • See DSIRE for programmes across the US. • Tax deductions and labour benefits (Denmark).		

[45] Actions that must be undertaken by the consumer (homeowner, builder, developer).
[46] Initiatives that are/were available to consumers but not required to be undertaken.

Climate change action initiatives	New Zealand initiatives (current and past)	Comparative initiatives	Driver of adoption in New Zealand market context	Barrier to adoption in New Zealand market context
		• Various subsidies and funds for building in European countries.		
Coordinated climate action (everyone).		• UK requires large projects to use BIM.	• Could say smoother and well designed buildings (but this could be argued) but currently there is no real drive to coordinate (business perspective).	• No coordinated strategic plan in the building and construction industry (producer perspective). • Poor interaction between central and local government (government perspective).
	• Transition hub. • Integrated whole-building design guidelines. • Generation Zero.	• International green building tools award points for team coordination. • Community action on energy efficiency programme in British Columbia.		
Raise building and construction standards for low or zero-carbon buildings – new builds and rentals.	• Minimum performance level • Clause H1 • Building Act.	• LCA for consent (Netherlands). • Wales requires the code for sustainable homes to be met for social housing to be funded.	• Healthier buildings (homeowner perspective). • Lower running costs (homeowner perspective). • Fewer hospital visits (government perspective). • Achieve reduction in environmental impact goals (government perspective). • Greater productivity in office buildings (business perspective).	• Reluctance from homebuilders to change practices and processes (producer perspective). • Lack of knowledge from BCAs (producer perspective). • Lack of innovation from building industry (unfamiliarity of technologies, few precedents). • Lack of knowledge from consumers about building standards (homeowner perspective). • KiwiBuild timeframe (government perspective).
	• Homestar. • Review of Building Code. • NABERSNZ. • Integrated whole building design guidelines. • LCA. • Eco Design Advisor. • Insulation incentives for rentals. • PrefabNZ.	• Integrated environmental design in British Columbia.		
Nearly net-zero energy building requirement.	• No policy specific to building announced in New Zealand.	• UK. • USA federal buildings must be designed to be net-zero energy after 2020. Federal government emissions must	• Achieve net-zero 2050 goals (government perspective). • Better-quality homes (homeowner perspective).	• Building to meet Building Code culture (building provider perspective).

Climate change action initiatives	New Zealand initiatives (current and past)	Comparative initiatives	Driver of adoption in New Zealand market context	Barrier to adoption in New Zealand market context
		be reduced by 40% over the next decade (from 2008). Federal building energy use must decrease by 2.5% per year between 2015 and 2025.		• Few precedents (designer and homeowner/buyer perspective).
	• GreenstarNZ. • NABERSNZ. • Homestar.	• Net-zero energy commercial building initiative – aim to achieve marketable NZEB by 2025		
Helping communities with sustainability goals – 'how to' guides			• Commitment from local government to promote low-carbon transport, resource efficiency and renewable energy (local government perspective).	
	• BRANZ Level. • Community Energy Network and related websites. • EECA Energywise. • Climate Safe House project.	• Carbon Trust (UK).		
Mandatory green ratings.		• Australian federal buildings must be NABERS rated. • Abu Dhabi federal buildings must be green rated.	• What are the drivers for government to green their buildings? • Set an example to the country (government perspective). • Lower energy bills – reallocate budget (government perspective).	• What are the barriers for government to green their buildings?
	• Greenstar. • NABERSNZ.	• Thailand aims for green federal buildings.		
Strategic leadership.	• Emissions Trading Scheme. • Climate Change Response Act 2002.	• City of Vancouver and British Columbia climate action plan 2007. • Climate Change Act 2008 (UK)		

Climate change action initiatives	New Zealand initiatives (current and past)	Comparative initiatives	Driver of adoption in New Zealand market context	Barrier to adoption in New Zealand market context
		• Polish national strategy for adaption to climate change.		

We need to know about how building works in New Zealand to understand whether international examples of initiatives could work here. We could also identify why they wouldn't and the barriers to transitioning. We need to say why the example is a good example for New Zealand. We need to relate to facts about the context.