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Climate change adaptation of buildings in New Zealand – research prioritisation assessment

Nick Locke, Leoni McKelvey

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1222 Moonshine Rd, RD1, Porirua 5381

Private Bag 50 908, Porirua 5240
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Contact Details

Nick Locke
WSP
33 The Esplanade
Petone
Lower Hutt 5012
+64 4 587 0600
0273099602
nick.locke@wsp.com

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Prepared by

Nick Locke

Leoni McKelvey

Reviewed by

David Laversha

Approved for release by

Louise Malcolm

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Executive Summary

New Zealand's National Adaptation Plan (NAP) sets out high-level strategies, policies and proposals of the government for adapting New Zealand to the effects of climate change. Actions to adapt buildings to climate change are to reduce exposure to climate hazards, support businesses and communities to understand and respond to climate risks, and improve homes and buildings so they can withstand the expected range of temperatures, rainfall, wind and improve energy and water efficiency. Translating this high-level policy into action on-the-ground requires an understanding of the impacts and costs of the climate on buildings throughout New Zealand. The purpose of this review is to establish what knowledge gaps exist in our understanding of adapting buildings to climate change in New Zealand, with a focus on the adaptation needed to the building itself, i.e. changes to the building design, materials, structure and envelope that will allow buildings to continue to perform in the future climate.

Overall, the costs and specific adaptations to buildings that are needed for the changing climate in New Zealand are largely undefined. A few studies have been identified that quantify the impacts of climate change on the design and construction of New Zealand buildings at an aggregate level; and even fewer studies provide information that can be applied to specific buildings. MacGregor et al (2019) outline knowledge gaps in our response to sea level rise, rising temperatures, increased precipitation and flooding, and risk of fires. Other New Zealand studies have looked at the impacts of climate change on New Zealand housing; describing design strategies, guidance and costs at an aggregate or national level. Jalali et al (2023) note that the localised nature of many climate change impacts on buildings mean high resolution analyses are needed to correctly understand the impacts on buildings in different parts of the country.

International reviews of building adaptation to climate change have identified studies on a wide range of climate effects including changes in; average and extreme outdoor temperatures, heat cooling loads, overheating, solar radiation, humidity, moisture resistance, wind, hurricanes, storm surges and coastal and non-coastal flooding, sea level rise, wildfires and snow. Stagrum (2020) systematically reviewed literature on climate adaptation measures for buildings and found there is relatively little literature available, and the majority of the literature relates to warm climates, with potential for overheating being the major climate impact that is investigated. Kristl et al (2020) note that in relation to research interest and regulatory issues, "The review shows that climate resilience mainly deals with larger systems, whereas the field is still developing at the building level".

A selected group of New Zealand stakeholders were interviewed to assess the "current state" and future priorities for research against identified knowledge gaps, industry need, policy priorities and government strategies. Collectively stakeholders described that there is ample evidence, international learnings and examples of effective adaptations for climate issues. Whilst there are specific research gaps, stakeholders identified that the greatest challenge is in implementing adaptations as well as planning for the construction of future climate resilient buildings. An inductive analysis of stakeholder interviews revealed four key themes of; Implementation, Education and awareness, Responsibility, and Changes to future buildings.

Stakeholders believe the greatest challenge is in implementing adaptations as well as planning for the construction of future climate resilient buildings, which are interlinked and built within systems, such as infrastructure and communities.

Priorities for future research are:

- understanding why New Zealanders do not act to mitigate and adapt to climate change, and to understand the interventions that will motivate people to act.

- information that defines the climate that will affect New Zealand buildings, to allow the true impacts and costs of climate change on buildings to be quantified.
- estimating the impacts and costs of climate change on the design, construction and use of new buildings, and the impacts on the use and maintenance of existing buildings.
- reevaluate the performance and environment that buildings will need to deliver in our future climate.
- communicating knowledge to policy makers, the building industry and the general public to promoting action on adapting to climate change.

1 Introduction

The technological and political case for action to limit climate change is well established and widely documented (Cabeza 2022, Kristl 2020, Stagrum 2020). Mitigation of greenhouse gas emissions is relatively well understood and some action has started, to greater or lesser extent, depending on the politics and emission profiles of various countries and industry sectors. Whilst action to limit climate change is critical for our future prosperity, action to adapt to the climate changes that are already locked in are equally pressing. The impacts of the future changes in climate on buildings and the changes to buildings that will be needed are the focus of this report.

Within the building industry the knowledge and technologies needed to decarbonise are well advanced, with many current actions focused on transforming the sector to implement low carbon designs and technologies. Efforts to decarbonise both the construction of buildings as well as their operation are required to achieve the large reductions in greenhouse gas emissions that are sought. An increasing emphasis on life-cycle emissions, which includes the embodied emissions of materials and the construction process, will be needed in New Zealand to significantly decarbonise buildings as a large proportion of the electricity that is used to run buildings is already renewable. In New Zealand, most actions to mitigate climate change use pricing mechanisms and/or are voluntary in nature, with buildings being generally unregulated for climate change mitigation. The exceptions to this are energy efficiency provisions in the Building Code and the Minimum Energy Performance Standards for Products (for example, lightbulbs and heat pumps).

Regardless of how successful the global community is at reducing its greenhouse gas emissions, it is all but certain that our climate will change to some extent and that some adaptation to the new climate will be needed. Adaptation is also something of a hedge to inaction on climate change mitigation, as mitigation will require a concerted global effort to be effective, while adaptation can be effective for any country or person who takes action to adapt.

1.1 Adaptation of buildings

Adapting buildings to the future climate is less well understood than mitigating greenhouse gas emissions and has until recently received less attention. In part, this is due to uncertainty about exactly what changes will occur to the climate in future years, and therefore the level of adaptation that will be needed. The case for adaptation is nuanced and less simple than the case for mitigation where greater greenhouse gas reduction is always beneficial. Redesigning new buildings and upgrading existing buildings to adapt to climate change requires a clear understanding of future climate change impacts and the costs of intervention.

Adding to the complexity, building adaptation is driven by a range of issues, which extend beyond climate change impacts. Resilience to natural disasters as well as societies changing needs and increasing expectations of buildings also drives adaptation and performance improvements to buildings (Kinnane 2017). Insurance and commercial arrangements are also expected to affect building adaptation, as climate change make some settlements and buildings uninsurable or uneconomic to operate (Carlin et al 2023, Storey et al 2020 and Boston et al 2018).

1.2 Adaptation planning in New Zealand

New Zealand's first National Adaptation Plan (NAP) was published in August 2022, and sets out high-level strategies, policies and proposals of the government for adapting New Zealand to the effects of climate change (Ministry for the Environment, 2022). Objectives in the NAP that highlight the need for building adaptation to climate change include, HBP1 Homes and buildings are climate resilient, and meet social and cultural needs, and HBP2 New and existing places are planned and managed to minimize risks to communities from climate change. To achieve these objectives the NAP describes actions to reduce exposure to climate hazards, support businesses and communities to understand and respond to climate risks, and improve homes and buildings so they can withstand the expected range of temperatures, rainfall, wind and improve energy and water efficiency.

Responsibility for critical actions and future work plans within the NAP that relate to buildings sits with the Building Performance branch within the Ministry of Business Innovation and Employment (MBIE). Their programme, Building for Climate Change, describes the relevant NAP actions as follows:

Action 3.25: Design methodology for risk assessments of public buildings (2024-2026)

This action is to help owners of public buildings assess and understand climate risks and implement adaptation strategies.

Action 5.7: Reduce and manage the impacts of climate hazards on homes and buildings (2022-2026)

The research promoted by this action will inform regulatory and other changes needed to enable adaptation to climate hazards.

Action 7.4: Update regulatory requirements to ensure buildings are designed, and constructed to withstand more extreme climate hazards (2024-2028)

This action will improve the quality of buildings and make them more resilient to future climate impacts.

Action 7.6: Manage potential impacts of adaptation related to regulatory change (2026-2028)

This action will address negative impacts of regulatory changes for buildings and manage barriers to climate adaptation for the building sector.

The knowledge and understanding needed to implement the NAP actions is incomplete, with many of the detail about impacts and costs yet to be developed. Chapter 11 of the IPCC Working Group II report (Lawrence et al 2022) outlines the impacts, projected risks, vulnerability and adaptation to climate change for the Australasia region. In relation to cities settlements and infrastructure, Lawrence et al identifies the information gap as follows,

> *"Previous planning horizons for existing infrastructure are compromised by now having to accommodate ongoing sea level rise (SLR), warming and increasing frequency of extreme rainfall and storm events (Climate Institute, 2012; MfE, 2017a). There is almost no information on the costs and benefits of adapting vulnerable and exposed infrastructure in Australia or New Zealand. Given the value of that infrastructure and the rising damage costs, this represents a large knowledge gap that has led to an adaptation investment deficit."*

At a district level, a number of local communities have developed risk assessments and/or action plans for adapting to the impacts of climate change, for example Auckland Councils' Shoreline Adaptation Plans, Climate Adaptation Te Tai Tokerau and South Dunedin Future. These assessments and plans are generally concerned with impacts on existing communities and infrastructure. They are often concerned with communities and existing infrastructure that are already vulnerable to extreme weather, and where past weather events have severely impacted the community.

The suitability of land for new building development is considered within existing planning processes that are controlled by the Resource Management Act 1991 and administered by local councils via district plans. Standards and performance levels that new buildings must achieve are controlled by the Building Act and administered at a national level by MBIE and operationalised for individual buildings by local councils. Unsurprisingly, the coordination of planning decisions and controls on new building designs is difficult. Local councils have little control of new building standards, which do not prescribe specific site conditions and natural hazards. Specialist advice is often required to determine the site conditions and design impacts of natural hazards. Given the complexity of this land & building development regulatory process, it is unsurprising that climate change impacts do not feature in the approval process for most new buildings.

1.3 Purpose of this review

The effectiveness and affordability of adaptation relies on policy makers having a good understanding of the impacts that various interventions will have. The purpose of this review is to identify what research has been done on the specific adaptations to New Zealand buildings that will be needed and the implications these adaptations will have on existing buildings and new building designs. Knowledge gaps in our understanding of adapting buildings to climate change in New Zealand will be identified to inform future research.

This review focuses on the adaptation needed to the building itself, i.e. changes to the building design, materials, structure and envelope that will allow buildings to continue to perform in the future climate. While the distinction between building controls and environmental controls is easily made in legislation (i.e. the Building Act 2004 and the Resource Management Act 1991) the distinction of climate impacts in reality will not be as clear. We have not tried to draw a hard line between adaptation to buildings and adaptation of the built environment, such as planning, land-use and community adaptation, as these actions will overlap at times. For example, materials and designs to produce flood resistant buildings are only part of the adaptation to flooding that may also include planning restrictions for future building development, or managed retreat when existing buildings and communities are severely impacted. The balance between adapting buildings versus adapting the built environment will depend on the climate impacts and the affected communities, suggesting a local focus is needed to understand climate adaptations for buildings. Therefore, it is useful to note adaptation research on the built environment where it is likely to affect building structures.

2 Climate projections for New Zealand

Accurate climate projections are necessary for effective long term adaptation, because the optimum level of adaptation generally relates directly to the magnitude and the extent of the changes in the climate. Too much adaptation will be inefficient and costly, while too little adaptation will also be costly and disruptive, leaving buildings and communities vulnerable to extreme events.

The most recent projections for New Zealand's climate were reported in 2016 (Ministry for the Environment, 2016). The projections were derived from a number of climate models that were downscaled by NIWA to provide more detailed picture of the projected changes across New Zealand. These changes are summarised in Table 1 (reproduced from https://niwa.co.nz/our-science/climate/information-and-resources/clivar/scenarios).

Table 1. Climate change projections for New Zealand

Climate variable	Direction of change	Magnitude of change	Spatial and seasonal variation
Mean temperature	Progressive increase with greenhouse gas concentration. Only for RCP2.6 does warming trend peak and then decline.	By 2040, from +0.7°C [RCP2.6] to +1.0°C [RCP8.5]. By 2090, +0.7°C to +3.0°C.	Warming greatest at higher elevations. Warming greatest summer/autumn and least winter/spring.
Minimum and maximum temperatures	As mean temperature.	Maximum increases faster than minimum. Diurnal range increases by up to 2°C by 2090 (RCP8.5).	Higher elevation warming particularly marked for maximum temperature.
Daily temperature extremes: frosts	Decrease in cold nights (minimum temperature of 0°C or lower).	By 2040, a 30% [2.6] to 50% [8.5] decrease. By 2090, 30% [2.6] to 90% [8.5] decrease.	Percentage changes similar in different locations, but number of days of frost decrease (hot day increase) greatest in the coldest (hottest) regions.
Daily temperature extremes: hot days	Increase in hot days (maximum temperature of 25°C or higher).	By 2040, a 40% [2.6] to 100% [8.5] increase. By 2090, a 40% [2.6] to 300% [8.5] increase.	
Mean precipitation	Varies around the country and with season. Annual pattern of increases in west and south of New Zealand, and decreases in north and east.	Substantial variation around the country, increasing in magnitude with increasing emissions.	Winter decreases: Gisborne, Hawke's Bay and Canterbury. Winter increases: Nelson, West Coast, Otago and Southland. Spring decreases: Auckland, Northland and Bay of Plenty.
Daily precipitation extremes: dry days	More dry days throughout North Island, and in inland South Island.	By 2090 [8.5], up to 10 or more dry days per year (~5% increase).	Increased dry days most marked in north and east of North Island, in winter and spring.

Climate variable	Direction of change	Magnitude of change	Spatial and seasonal variation
Daily precipitation extremes: very wet days	Increased extreme daily rainfalls, especially where mean rainfall increases.	More than 20% increase in 99th percentile of daily rainfall by 2090 [8.5] in South West of South Island. A few percentage decrease in north and east of North Island.	Increase in western regions, and in south of South Island. No increase in 99th percentile in parts of north and east of North Island.
Snow	Decrease.	Snow days per year reduce by 30 days or more by 2090 under RCP8.5.	Large decreases confined to high altitude or southern regions of the South Island.
Drought	Increase in severity and frequency.	By 2090 [8.5], up to 50mm or more increase per year, on average, in July–June Potential Evapotranspiration Deficit.	Increases in PED most marked in already dry areas.
Circulation	Varies with season.	Generally, the changes are only a few hectopascals, but the spatial pattern matters.	More northeast airflow in summer. Strengthened westerlies in winter.
Extreme wind speeds	Increase.	Up to 10% or more in parts of the country.	Most robust increases occur in southern half of North Island, and throughout the South Island.
Storms	Likely poleward shift of mid-latitude cyclones and possibly also a small reduction in frequency.	More analysis needed.	See full report.
Solar radiation	Varies around the country and with season.	Seasonal changes generally lie between -5% and +5%.	By 2090 [8.5], West Coast shows the largest changes: summer increase (~5%) and winter decrease (5%).
Relative humidity	Decrease.	Up to 5% or more by 2090 [8.5], especially in the South Island.	Largest decreases in South Island in spring and summer.

The climate variables in Table 1 provide a useful reference for considering the potential impacts of climate change on building design in New Zealand. These climate variables do not describe all the impacts of climate change on buildings, such as sea-level rise, but they do give a complete picture of the changes in climate conditions that are likely to impact building design at a given site. Climate impacts that act over larger time periods and spatial scales, such as sea-level rise, flooding or overheating in urban heat islands cannot be mitigated by adapting building in isolation and require adaptations at community or national scale as well as to individual buildings.

Ongoing work at NIWA to reanalyse 30 years of historic weather data using the New Zealand Convective Scale Model (NZCSM) will significantly improve the spatial resolution of weather data, and associated extreme weather estimates that are currently used for building design across New Zealand. The improved design estimates that will result from this work will be further enhanced by incorporating the effects of climate change (Pirooz et al, 2023). The resulting design loads will reflect the current and future climate conditions that new buildings today will need to withstand over their lifetime, now and into the future.

As part of the MBIE programme Building for Climate Change, NIWA is updating the climate projections for New Zealand by downscaling the results of the latest regional climate models. This will underpin regulatory changes to incorporate the current and future climate impacts into planning and design of infrastructure and buildings across New Zealand. The updated climate data is scheduled for release in 2024 and 2025.

3 New Zealand Research

This section of the report outlines publications from New Zealand that relate closely to the climate change adaptation of buildings in New Zealand.

Overall, the costs and specific adaptations to buildings that are needed for the changing climate in New Zealand are largely undefined. A few studies have been identified that quantify the impacts of climate change on the design and construction of New Zealand buildings at an aggregate level; and even fewer studies provide information that could be applied to specific buildings.

A literature review of New Zealand's building regulatory system and built form as it relates to greenhouse gas emissions and climate change adaptation (MacGregor et al 2019) identifies a number of knowledge gaps that exist. The climate impacts and knowledge gaps from the review summary are reproduced below:

from Research and regulatory responses to the role of buildings in mitigating and adapting to climate change: Summary

Sea level rise

Impacts

- Increased risk of erosion, coastal flooding and saltwater intrusion leading to undermining or destruction of foundations and potential structural collapse of buildings.
- Disruption to critical infrastructure services, with flow-on effects for communities and businesses.
- Reduced coastal areas suitable for buildings or habitation.
- Increased cost of coastal protection works and of repairing or replacing built infrastructure affected by sea level rise.
- Coastal housing markets impacted by rising sea levels may respond to an insurance retreat if insurance becomes unavailable.

Evidence gaps to address sea level rise

- More research that defines building and design solutions for future climate risk due to flooding, such as examining guidance on minimum floor levels and adjusting building life expectancy within at-risk areas.
- Examine how climate change preparedness is impacted by longer-term planning, such as a 25-year plan at varying degrees of scale such as building level, district and city level.
- Examine the effectiveness of various community initiatives that could be used to help create awareness and solutions to rising sea levels, such as dune restoration initiatives.

Rising temperatures

Impacts

- Reduction of comfort levels in buildings, potentially leading to poor health in the more vulnerable and/or business disruption.
- Overheating in buildings due to temperature extremes but also due to higher levels of insulation.
- Increased demand for air-conditioning systems and electricity use over hotter summer months.
- Disruption to electricity supply, as lower river and lake levels inhibit the production potential of hydro-electricity and thermally generated electricity.
- Disruption to transport infrastructure (through buckled railway lines and damaged road surfaces) with associated repair costs.
- Increased risk of cracking or failure of building envelopes (including roofing, cladding, glazing systems) as well as sealants and finishes.

Evidence gaps to address overheating

- More research into the extent and severity of overheating in New Zealand buildings to enable the creation of an accepted New Zealand definition of overheating and internal temperature thresholds in buildings (other than early childhood centres and aged care facilities).
- More specific knowledge in terms of the need to establish best-practice design and construction principles that address overheating within New Zealand's buildings.
- Accepted best-practice operational principles that addresses overheating within New Zealand's buildings.

- Set performance-based indoor environment settings for different building typologies to reflect overheating risk. A key part of creating a performance-based measure is to enable a greater understanding of building occupants' behaviour and choices in relation to the indoor environment.
- Preparing for more overheating into the future – health promotion programmes are required to educate and inform building occupants, designers and builders about the dangers of overheating.

Increased precipitation and flooding

- Increased stormwater flooding in urban areas, with implications for roof damage, drainage pipes and sewer connections.
- Weathering (including corrosion of metals), which may lead to higher maintenance requirements.

Evidence gaps to address flooding

- Explore the viability of amphibious buildings in New Zealand in relation to need, design and cost.
- Information on the costs and benefits of flood-resistant building materials and their viability as a climate change prevention measure.
- Evaluate current flood mitigation schemes to see if they are fit for purpose and able to address future climate risk.
- Communicate future flood risk and the promotion of climate readiness for building projects in development or undergoing extensive refurbishment.
- Explore the use of natural and artificial ecosystems such as wetlands across New Zealand for use in flooding and storm surges.

Increased risk of fire

Impacts

- Increased frequency and magnitude of emergency fire events within the built environment, including bushfires.
- Pressure on building designs and materials to withstand fire events.
- Availability of water (particularly in times of drought) to fight fires.

Evidence gaps to address increased risk of bushfires

- Undertake research that investigates a cost-benefit analysis and practicality of constructing fireproof houses in New Zealand in areas identified as higher risk due to climate change to drive the market uptake of bushfire solutions or to help to create evidence for consideration for changes to building regulations.

Camilleri (2001) identifies strategies for adapting buildings in New Zealand to overheating, flooding (inland and costal) and tropical cyclones and storms, which are identified as the most significant impacts of climate change on buildings in New Zealand. The report provides a general outline of the information needed to assess if adaptation is required and options for adapting a building, but the reader is referred to other sources for specific information, such as construction details, or precise sun-angle calculations. The need for adaptation is established using an index called the Climate Change Sustainability Index (CCIS), while the impacts and strategies identified by Camilleri are summarised in the following box:

Overheating of houses:

- Reduce solar gain — reduce window sizes, shading by eaves or overhangs, shading by trees, shrubs or screens, reflective glazing, window orientation, internal reflective blind, double glazing, increase ventilation, increase insulation, use thermal mass, use air-conditioning.
- Ventilation — extractor fans, ceiling fans passive stack ventilation, passive vents in windows or walls, windows open on security latch.
- Insulation
- Thermal mass
- Air-conditioning

Overheating: office buildings

The causes of overheating in office buildings can be complex and specialist advice is suggested. Reduce lighting energy intensity is beneficial and may include:

- changing light bulbs or tubes to more efficient types, or reducing the number
- changing fluorescent light ballasts to high-frequency, high efficiency types
- changing light fixtures and reflectors
- changing lighting controls
- installing daylight dimmers.

Flooding of houses:

- Reduce risk of flooding — raising or moving the house, flood-proofing or building a small levee or flood-wall immediately around the house, exceeding the minimum floor level clearance requirements for the area, ensure foundations are strong, and can resist being undermined by erosion or scouring by flood waters.
- Reduce damage potential of flooding to building and contents — choose water-resistant materials, flood-proofing key building services, make building services water resistant (e.g. install vulnerable equipment, such as wiring, hot water cylinders, meter boards etc, above possible flood levels or as high as practical)
- Improve ability to recover from flooding
- Flood preparedness

New houses:

- o don't build on a flood-prone site
- o be prepared for flooding
- o exceed minimum floor levels
- o consider multi-storey construction
- o use water-resistant materials
- o install essential, vulnerable equipment as high as possible.

Existing houses:

- o raise or move house
- o build a second storey and use first storey as non-living space
- o replace cladding, flooring, and linings with water resistant materials
- o move services (hot water, meter board) above flood levels
- o build levee or floodwall around the house
- o raise flood awareness and preparedness

Tropical cyclones: houses

- flooding adaptation strategies as above
- Existing houses: upgrade the roof structure (roofing fasteners, batten to rafter connection, and rafter to wall connection), and sub-floor fasteners. At the minimum, inspect condition of roof fasteners
- New houses: increase the structural strength by going up to the next higher NZBC wind zone
- Good attention to waterproofing and drainage detailing of all building elements, especially flashings, vents, and penetrations as building likely to leak during cyclones

Jaques and Sheridan (2006) provide a general design guidance for low-carbon dwellings in relation to heating, cooling, hot water heating, lighting, cooking, materials and transport. General design guidance is also provided for climate-adapted housing in relation to projected changes in rainfall, extreme winds and flooding. The design recommendations are detailed enough to be applied to individual buildings designs. However, a method is not provided to determine when particular design features or recommendations should be used on a specific site.

Jaques and Sheridan adaptation guidance is similar to that of Camilleri (2001) having come from the same programme of work at BRANZ. Their summary of housing adaptation is given below, noting that the adaptation approaches will not be applicable for every situation or building.

To mitigate the effects of more **intense rainfall**:

Design principles should be employed to achieve good moisture management i.e. deflection, drainage, drying and durability. The building elements that need to be considered are roof edges, open decks, walls and joinery, retaining walls, floors, balconies, wall/roof junctions and roofs.

The impacts of driving rain can be reduced by improving the building weathertightness:

- using continuous unbroken areas of roofing with a simple line
- avoiding internal box and valley gutters
- installing generous overflow areas and rainwater heads at downpipes if internal gutters need to be installed
- using steeper pitched roofs
- designing low wind profile buildings
- having generous eaves and overhangs
- using monolithic or sheet claddings
- using rainwater heads to feed water into downpipes
- leaving externally located downpipes unsealed at drain entry points
- limiting the number of roof penetrations to reduce the risk of leaks occurring
- installing head caps and head flashings on all openings
- install drainage cavities behind claddings.

To mitigate the effects of more **intense winds** (only for the Auckland/Northland areas):

It is suggested to increase the structural strength to the next higher NZBC wind zone to limit any potential damage. Roof areas are the most likely part of the house to succumb under attack from high winds, therefore:

- construct pitched roofs above 17°, built at right angles to the prevailing wind, so that uplift pressures are only experienced on down-wind sides
- install extra fixings at roof edges to minimise uplift pressures
- install extra hold-down straps on purlins over external wall lines
- construct mansard roofs.

To mitigate the effects of more **flooding**:

- do not build in a vulnerable site
- exceed the minimum floor levels
- consider multi-storey construction
- use water-resistant construction materials
- install essential, vulnerable equipment as high as possible.

Bengtsson et al. (2007) investigated adaption options for a house in New Zealand. Significant changes in the maximum and minimum temperatures, sea level, drought and fire risk, and UV radiation were identified, while changes in wind, storms, hail and solar radiation were either uncertain or likely to be within the range of interannual variability at most sites. The following impacts from these climate changes were discussed and adaptation options outlined in general terms:

Significant impacts: increased coastal flooding, erosion and rising water tables
increased inland flooding
structural considerations of rainfall changes
increased overheating risk
increased fire risk

Uncertain or minor impacts: ex-tropical cyclones
increased wind load
structural considerations of temperature changes
pest / infestation problems
degradation of polymers

The condition of the housing stock in New Zealand was reviewed by Bengtsson et al. (2007) to infer vulnerabilities to the climate impacts and thermal modelling was undertaken to assess indoor overheating and energy demand as outdoor temperatures increase. An economic analysis of adaptation options to limit overheating was described that derived optimum design features for housing in different regions of New Zealand. The economic cost of other climate impacts were estimated at the national level, making it difficult to apply the costs to specific regions or buildings.

Locke et al (2022) investigated the impact of increased wind speeds on the design and construction costs of light timber framed buildings in New Zealand. Three increases in wind speed (5%, 10% and 15%) were analysed in the absence of definitive climate change projections of extreme wind speeds in New Zealand. The changes in design and construction costs that corresponded to the changes in wind speeds were found to be small. The investigation was done as pilot study to test the analysis methodology given an absence of information on the cost impacts of climate change on buildings design and construction in New Zealand. Therefore, its conclusions cannot be generalized as the study only looked at low-rise light timber-framed buildings and did not consider all the common construction materials or types of buildings in New Zealand.

Jalali et al (2023) assess the impact of rising temperatures from climate change on the heat and cooling demands of stand-alone houses in New Zealand. From a review of previous studies of temperature impacts of climate change Jalali et al note, “for countries with similar climatic zones, noticeable differences have been reported. The findings of studies related to this topic are heavily influenced by several factors, including the projected climate change scenario, the type of building being studied, and the geographical location. This makes performing a regional and localised analysis necessary. The extent and nature of the impact of climate change on building energy consumption may vary significantly based on these factors, which highlights the importance of taking a localised and context-specific approach when developing strategies to mitigate the potential effects of climate change on building energy consumption.”. This highlights the localised nature of many climate change impacts on buildings, indicating high resolution analyses are needed to correctly understand the impacts on buildings in different parts of the country.

Detailed thermal modelling was used to estimate the decrease in heating energy that is expected, and the increase in cooling loads that are expected, for different climate change projections, in different locations across New Zealand. Overall, cooler locations in New Zealand are likely to still be heating dominated in future, but more temperate locations will switch from heat to colling dominated energy use. The impact on the design of housing adapted to the projected temperatures and the associated costs are not quantified.

4 International Research

Internationally, building adaptation is receiving increased attention as countries plan for the impacts of climate change. Extreme weather events, that are generally projected to increase in frequency and/or intensity with climate change, highlight the costs of more severe weather and are used to focus attention on climate change mitigation and adaptation.

Chapter 9 of the IPCC Working Group III report (Cabeza et al 2022) summarises a number of studies on building adaptation, and notes there can be interaction between climate change mitigation and adaptation. Adaptation efforts can adversely affect mitigation if measures to adapt increase energy and material consumption, leading to higher GHG emissions (Sharifi 2020, Kalvelage 2014). Conversely, the success of mitigation measures will affect the future climate and the degree of adaptation required. Cabeza et al (2022) outlines research relating to the following high-level climate impacts on buildings:

- Changes to heating and cooling loads that arise from changes in the average and extreme outdoor temperatures. These changes will affect energy consumption for maintaining comfortable indoor conditions, as well as more extreme events such as heat waves. There are a wide range of studies on heating and cooling impacts as the associated energy demand will be sensitive to the specific climate and the projected future temperatures.
- Changes to solar radiation that may affect renewable energy (e.g. photovoltaic panels on buildings)
- Performance, durability and safety of buildings, particularly historic buildings, that will be affected by changes in temperature, humidity, wind, and chloride and CO2 concentrations
- temperature and humidity changes affecting the building envelope durability and deterioration.
- Corrosion of steel reinforced concrete structures from chloride ingress and higher CO2 levels.
- Higher frequency and intensity of hurricanes, storm surges and coastal and non-coastal flooding
- Sea level rise
- More frequent wildfires

A number of recent reviews of building adaptation identify similar themes of adaptation and also highlight gaps in the knowledge.

Grynning (2017) reviewed research-based initiatives in Norway that relate to climate adaptation of building management, operation, maintenance and upgrading. Relatively few building adaptation projects were being done and most of these related to energy savings. Grynning reflects that the focus on energy research does not align with climate projections for Norway that show more intense rain and higher temperatures are expected, which will require research on the moisture resistance and damage of buildings. The majority of the research projects were also categorized as relating to legislation, planning and strategies, and not much research related to the implementation of systems, technical solutions and components categories. Grynning recommended work be done to develop plans that "identify systems, solutions and components that are critical to ensure climate adaptation of buildings with focus on building physical issues and challenges."

Kristl et al (2020) describe a systematic review of the three large scientific databases, Science Direct, WorldWideScience, and Emerald, for building adaptation related publications. The key challenges of climate change adaptation in the building sector are identified as:

- heat cooling loads (Andrić et al. 2017)
- moisture resistance – (Lisø et al. 2017)
- moisture resistance and existing buildings (Grynning et al. 2017)

- energy demand from retrofits (Pérez-Andreu et al. 2018)
- overheating (Bruno et al. 2017)
- solar exposure of envelope (Košir et al. 2014)
- effects of climate change (Bunten & Kahn 2017)
- damage from extreme weather (Champagne & Aktas 2016)

Kristl notes the in relation to the state of the art, research interest, and regulatory issues, "The review shows that climate resilience mainly deals with larger systems, whereas the field is still developing at the building level".

Stagrum (2020) systematically reviewed literature on climate adaptation measures for buildings and found there is relatively little literature available, and the majority of the literature relates to warm climates, with potential for overheating being the major climate impact. The literature was categorized into the following topic areas: Building envelope, Precipitation and wind impact, Design tools for integrating climate projections, Frameworks and guidelines, Overheating, Thermal comfort, Health impact, Sustainability, and Policy. Within these topic areas the following impacts and adaptation measures were discussed:

- Green roofs and facades to moderate hot climates and urban heat islands.
- Cool façade materials and phase-change materials to moderate overheating in hot climates
- Flood proof (to a depth of 750mm) housing
- Thermal mass of construction
- Solar shading
- Natural ventilation
- Durability of wood
- Wind driven rain
- Wind and snow loads

Kinnane et al (2017) describe the development of a climate adaptable energy efficient house in Ireland, that is termed a low-carbon dioxide adaptable home (LCAH). The LCAH design is a response to concerns that recent new housing in Ireland is airtight and prone to overheating. The majority of houses are naturally ventilated, which is problematic in warming climates where overheating is exacerbated by uncontrolled ingress of outside air. With temperatures projected to rise in the coming decades a more adaptable type of construction was investigated. The LCAH is constructed of light steel frame and prefabricated panels that can be easily removed and replaced, enabling the size of the dwelling to be increased relatively easily (if future occupancy increases) and for insulation in the exterior walls to up-rated. Other adaptation features include window lintels that are designed to enable solar shading devices to be attached, and prewiring for solar panels (not installed due to cost, but easily installed in the future if desired). Table 2 shows the features that are designed into the LCAH to allow it to adapt to the future climate.

The LCAH house was constructed in 2014 and post occupancy monitoring showed the house used more energy than a low-energy standard house, reflecting the occupant's preference for comfort by heating the house to between 23°-25°. Thermal modelling was used to predict the performance of the LCAH in future years where the climate is projected to warm – this modelling showed the LCAH is at risk of overheating in current climates but generally maintains comfortable indoor conditions. It showed that by 2050 overheating under business-as-usual climate projections significant overheating occurs. This suggests active cooling will be needed to manage internal temperatures for vulnerable and elderly occupants. The heating energy reduces, and cooling energy increases, as the climate warms, and by 2080 the cooling energy exceeds the heating energy. Solar shading is found to be the optimum future proofing strategy for adapting to rising temperatures.

Kinnane notes "Climate change scenario studies of residential homes are numerous, particularly for the evaluation of retrofit strategies into the future. However, there is a paucity of studies that have investigated new, lightweight, highly insulated constructions that are an increasingly popular contemporary home typology."

Table 2. Adaptation features of the low-carbon dioxide adaptable home (extract from Kinnane et al (2017)

Adaptation	Location	Options	Potential	Difficulty and expectation
+ Solar shading	Building facade	Add louvers, brise soleil, side fins to prepared structure	Reduction in direct solar incident on the facade and the solar transmittance through glazing	Likely; easy adaptation; Designed and prepared for
Δ Insulation	Building facade	Alter insulation thickness	Reduction in heat retention capacity but also heat exclusion capacity	Unlikely; disruptive adaptation; doable and prepared for
Δ Albedo	Building facade	Change cladding to white	Increase in proportion of solar radiation reflected from the surface	Unlikely; expected minimal impact due to facade design
Δ Glazing ratio	Building facade	Replacement by opaque wall	Reduction of solar gain transmittance resulting in the reduction of daylight and increase in lighting load	Unlikely; disruptive adaptation; doable but not designed for
+ Vegetation	Site	Add shading trees and vegetation	Shading of sun and wind impacts on building	Likely and implemented; waiting for mature growth
+ Renewables	Site/flat roof	Photovoltaic, wind turbine	Increased on-site electricity generation capacity	Likely, as electricity sources becomes more sustainable
+ Planting	Flat roof	Sedum, green roof	Reduction in heat absorption of roof layer and heat transmission through	Unlikely; possible minimal impact due to roof insulation
+ Reflective roofing	Flat roof	Reflecting or albedo slabs	Increase thermal reflectivity, reducing heat conduction through	Unlikely; possible minimal impact due to roof insulation
Δ Ventilation	Building interior	Change to natural or mechanical ventilation	Reduction in energy use if offsetting mechanical ventilation system	Likely; continuous mixed mode setting adjustment
Δ Space-conditioning system	Building interior	Cooling set point	Allows for cooling hence reduces hours of overheating	Likely; expected lifetime of ASHP: approximately 2|5 years; new system with cooling added.
+ Thermal mass	Building interior	Filling of service cavity (or addition of PCM plasterboard)	Absorption of internal heat gains Reduction in peak temperatures	Unlikely; possible disruptive adaptation; doable and considered
± Extension	Building plan	Addition of proposed pods or other extension	Low impact extension and contraction of building form as occupancy changes	Likely and implemented; designed for house extension and downsizing

+, addition of; Δ, change to; ±, elements can be added or removed; ASHP, air source heat pump; PCM, phase change materials

5 Stakeholder feedback

The purpose of this project was to perform a scoping exercise to identify critical gaps in our knowledge about the changes to New Zealand buildings that are needed to adapt to the changing climate. We engaged with a select group of stakeholders to assess the "current state" as well as scoping future priorities for research against identified knowledge gaps, industry need, policy priorities and government strategies.

5.1 Stakeholder engagement

The stakeholder engagement consisted of purposeful sampling of key stakeholders located in New Zealand. Initially stakeholders were identified through the literature review, existing contacts, and subject experts. Thereafter snowball sampling was used with interviewees to identify key people in New Zealand. Stakeholders included individuals from the Climate Change Commission, regional, district and city councils, Ministry of Business Innovation and Employment, Insurance Council NZ, LINZ (Land Information New Zealand), the Climate Adaption Platform and academics. Stakeholder engagement can be limited. Whilst efforts were made to ensure the relevant people and groups were included, with a small number of interviews, there are some gaps. Those gaps were community organisations and governmental organisations.

5.2 Data collection

Date collection occurred over a four-week period with a total of 35 individuals and organisations contacted to take part. 17 interviews took place. Interviewees were from diverse backgrounds with a mixture of ages and genders. Interviews were the primary method of data collection for stakeholder engagement, stakeholders also provided additional information through email. The project team used Microsoft Teams to conduct and record interviews which lasted between 45-70 minutes. Following each interview, interview notes were recorded and reviewed, noting down key points.

For the stakeholder engagement an internal ethical process was followed. A stakeholder protocol was developed within the research team. An information sheet and consent from was developed to provide details of the project, informed consent, confidentiality, the right to withdraw, and data storage and protection.

An interview guide was developed to guide conversational open-ended questions with stakeholders. The questions were developed to meet the project objectives and were informed by the literature review. The interview guide was developed through several iterations and reviewed with the research team. The interview guide provided consistency across interviews and allowed stakeholders to discuss their own perceptions and expertise, providing rich data. The interview focused on collecting stakeholders' perceptions of the climate issues New Zealand buildings need to respond too, including the likeliness and impact of identified issues. The interviews considered what further research should be prioritised and current gaps in knowledge. The interviews discussed the current state of adaptation to buildings in New Zealand, focusing on the adaptation needed to new buildings in the performance of their envelopes as well as considering what adaptation have already been implemented, future state and current state of adaptation to buildings in New Zealand.

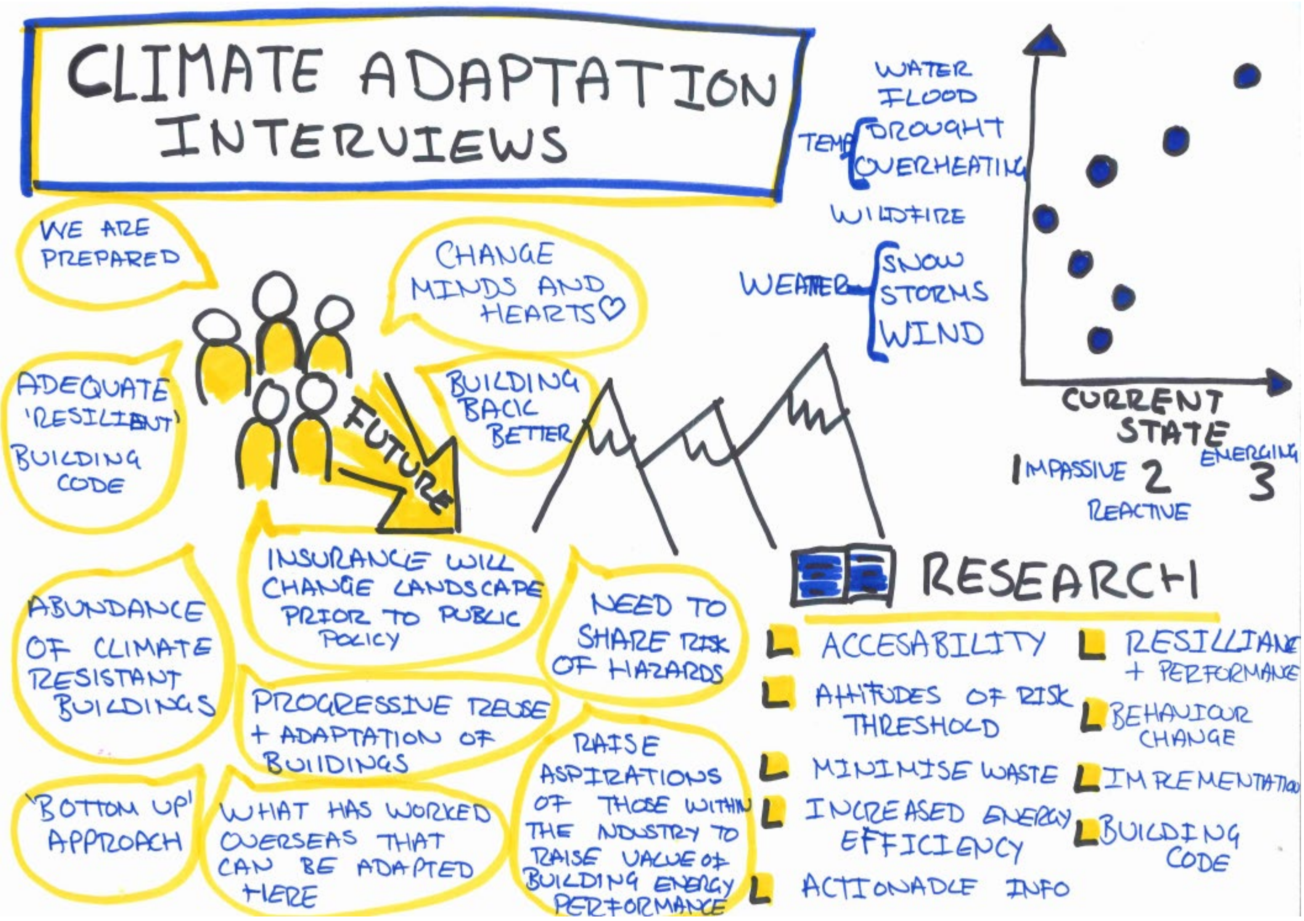
All stakeholders were emailed an Information Sheet with details about the project, and consent form. These documents were reviewed internally to ensure clarity and for quality assurance purposes. Written and verbal consent was obtained for all interviews (see Appendix I). Several stakeholders gave consent to be named in this report, where quotes have been used, these were member checked by the interviewee to ensure quality assurance and that their words were interpretated correctly. Those who choose to remain anonymous are presented as 'stakeholder'.

During the data collection period, inductive thematic analysis was applied to analyse data gathered from the individual interviews. Inductive thematic analysis makes sense of data through identifying patterns, themes and categories by organising the data into increasingly more abstract units of information (Bryman, 2008; Creswell, 2007). As Bryman (2008) points out by analysing and organising research data in this way the findings of the study are data-oriented which means that rather than confirming a hypothesis and/or theoretical assumptions, the identified priorities and barriers to adaptations to New Zealand buildings in response to climate change are the results of the iteration of the research team with the data and what was revealed from it. Data analysis started in parallel with data collection, which supported consequent interviews.

5.3 Key findings

This section describes the key findings from the stakeholder engagement. Initially this section will provide a descriptive overview of the current state, current adaptations, shared themes and unique climate adaptation responses. Examples of climate adaptations will be given, alongside a discussion on critical knowledge gaps and research priorities identified by stakeholders. A graphic recording was created of the interviews depicting some of the key ideas and conversations and is shown in Figure 5-1 Graphic recording of stakeholder interviews below.

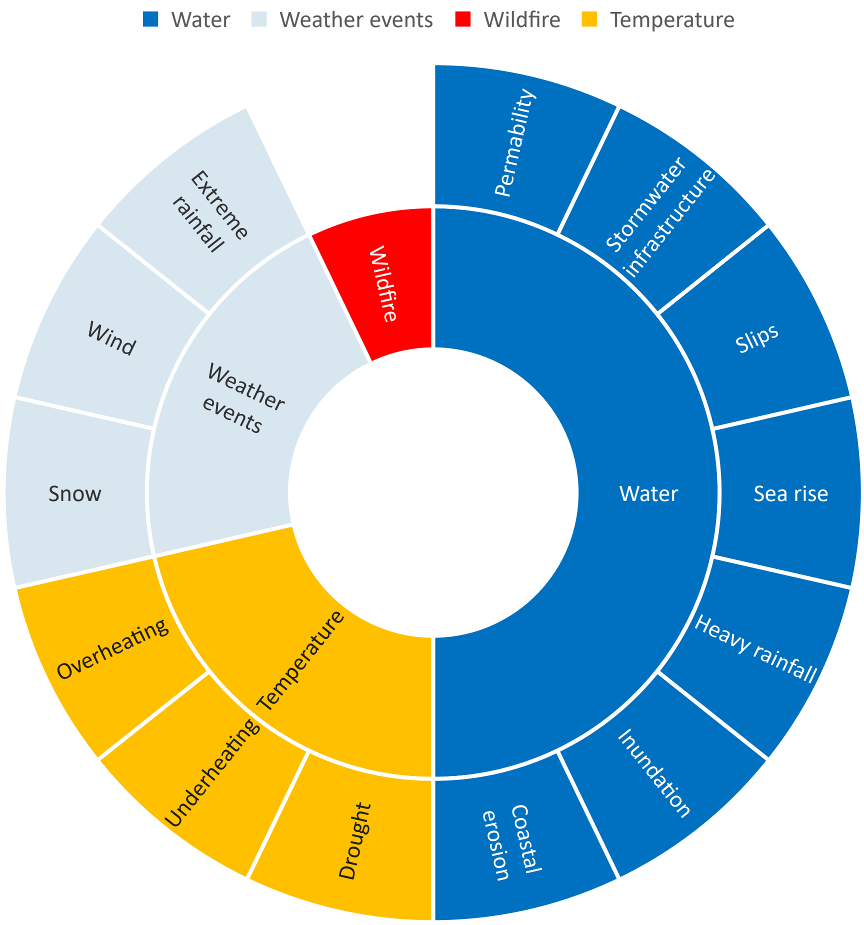
Figure 5-1 Graphic recording of stakeholder interviews



5.3.1 The current state

When asked how climate resilient our buildings are, stakeholders considered residential and commercial buildings, existing building stock and future stock, with stakeholders unanimously agreeing New Zealanders are in our infancy of responding to climate change and our buildings are not climate resilient. Stakeholders were worried current building stock would be unable to withstand climate issues and discussed the minimum standard currently required lacks addressing climate issues. When considering climate issues, stakeholders described immediate and emerging climate issues that are likely to or are already affecting New Zealand. These are shown in Figure 5.2.

Figure 5.2: Climate issues in New Zealand relevant to buildings

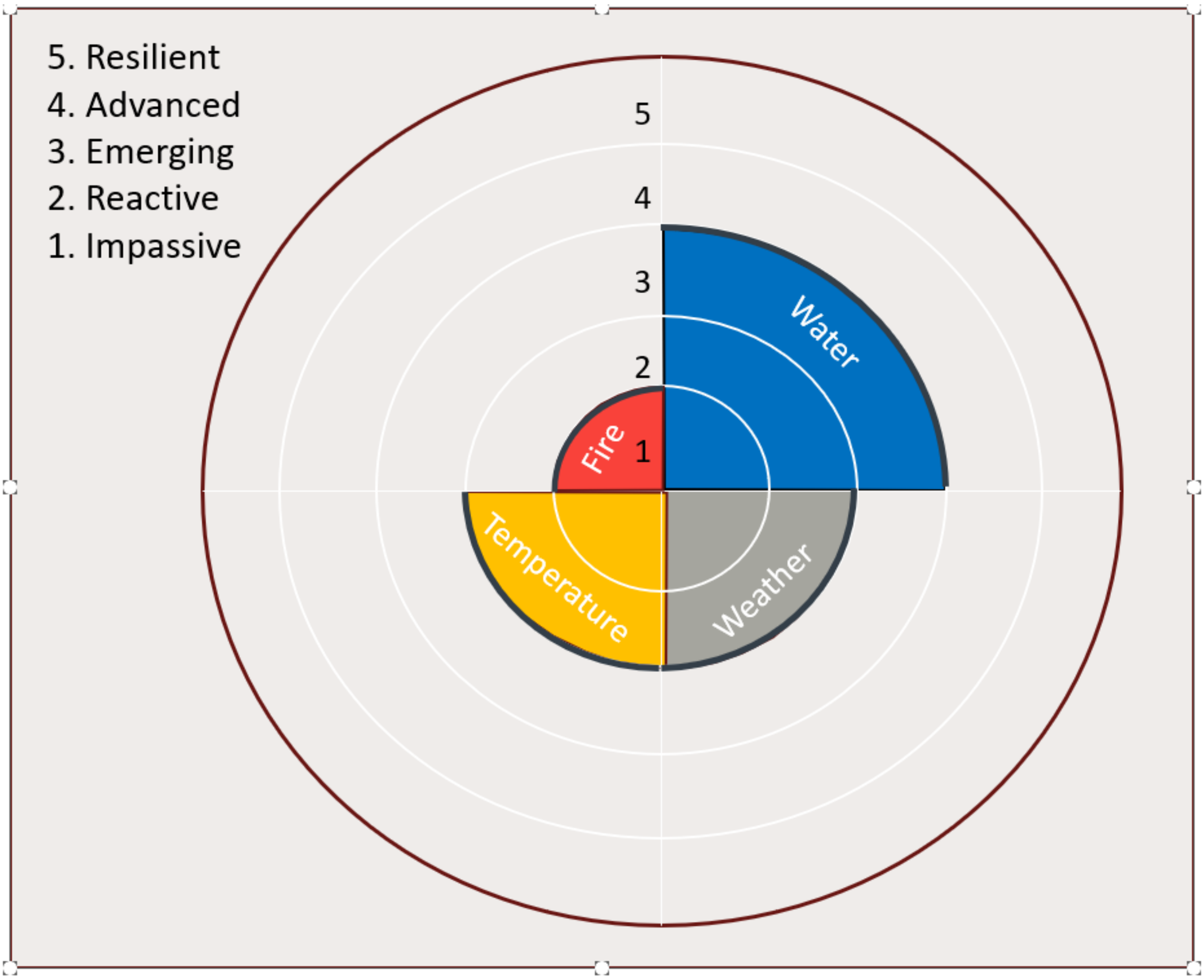


Some stakeholders focused on several individual issues, whilst many grouped issues into the following broader categories: Water, Wildfire, Temperature and Weather events. Weather events include wind, storms and snow. Water includes flooding, coastal erosion, sea rise, rainwater management, slips, stormwater infrastructure, water management, permeable areas. Temperature includes drought, overheating as well as colder periods.

Collectively, stakeholders described that there is ample evidence, international learnings and examples of effective adaptations for climate issues. Whilst there are specific research gaps, stakeholders identified that the greatest challenge is in implementing adaptations as well as planning for the construction of future climate resilient buildings. Stakeholders believed that currently new constructions would not be climate resilient in 50 years. Stakeholders noted that climate issues are interlinked, and when considering buildings in New Zealand, they are not isolated but built within systems, such as infrastructure and communities. Climate issues also interact and compound and cascade creating greater risk.

Stakeholders described New Zealand's response to climate issues in relation to buildings as emerging and in its infancy. Stakeholders identified the need to develop capacity and capability to respond well. Overall, stakeholders noted in New Zealand we have some good data. However, this is inconsistent locally with some areas collecting useful data but not across the board. Stakeholders identified significant data gaps. Based on stakeholder's perceptions, a simple maturity assessment of New Zealand's current state for each climate issue was created and can be seen in the below Figure 5.3.

Figure 5.3 Assessment of the current state of building adaptation in New Zealand from stakeholders' perceptions
(refer to Figure 5.2 for climate impacts within each theme).



Stakeholders perceived ample evidence in response to water, with adaptations being used inconsistently across New Zealand. Stakeholders had confidence adaptations were available and further focus on incentivising implementation would be beneficial. Stakeholders perceived temperature and weather to have some research and knowledge of adaptation form overseas which could be applied in New Zealand, but there are few adaptations currently occurring. Stakeholders perceived wildfire as having limited research but there are some known adaptations, however this was perceived as an issue that might affect New Zealand in the future, but was not currently a high concern for most stakeholders. Some stakeholders were concerned with wildfire, perceiving this to be a high probable risk. When discussing the current state, stakeholders described that in New Zealand there is an emerging field of expertise in responding to climate change adaptation of buildings.

> *Our homes, buildings, and places are essential for our health, wellbeing, and quality of life. However, climate change hazards can reduce their functionality and cause devastating impacts. We need to consider buildings holistically, starting with the land, the buildings and the people who live in and around them within wider communities." - Adjunct Prof Judy Lawrence. New Zealand climate change adaptation expert*

Stakeholders noted historically there have been differing approaches around managing climate impacts, such as moving people from their homes e.g. managed retreat, or engineering solutions to prevent building damage. There is a focus to strategically move people from spaces at higher risks of impact. In terms of buildings, for many communities, buildings likely to be impacted are homes and community facilities alongside infrastructure. Stakeholders discussed there are several approaches that need to be employed to produce a favourable result and climate resilient homes, buildings and communities.

5.3.2 Existing adaptations

Overall, stakeholders stated that there are existing adaptations to respond to climate issues, and there is ample evidence and good practice internationally that can be adopted to the New Zealand context. For new builds, stakeholders state knowledge and technology already exist to build climate resistant future proof low carbon buildings, but New Zealand needs to adapt.

When discussing the current state of building adaptation in response to climate issues, stakeholders noted future predictions and effective modelling as well as government priorities will provide further direction as to where policy priorities may lie in response to climate issues. Stakeholders gave examples of existing adaptations that are considered or used in New Zealand.

5.3.3 Water

Through interviews, it became apparent that New Zealand's response to water is more advanced than other climate areas. Water management encompasses a wide range of issues. Recent flooding events have driven responses to implement adaptive measures and a commitment to build back better. Stakeholders discussed sea level rises, flooding risks and ground water, alongside stormwater management and heavy rainfall. Stakeholders also highlighted overall perceptions of water as a resource.

Water management in New Zealand was described by one stakeholder as fragmented, with a focus on stormwater systems, wastewater and drinking water. Future climate risks may impact the quality and scarcity of drinking water used in buildings, as well as issues with managing storm water infrastructure. Stakeholders discussed building typologies, with greater consideration given to residential buildings, community and heritage buildings, with some consideration to commercial building such as offices, or small industry warehouses that are likely to be damaged from water issues. Stakeholders identified that local defence schemes may be a lower risk, but can aggregate to regional and national risks.

Stakeholders describe that there are adaptations for flooding available, however there is a lack of clarity on how adaptations will influence other issues and what available action is feasible for individuals. For example, lifted buildings, that are slightly higher, can be prioritised based on existing modelling data, but do not take into account accessibility and knock on impacts to altering waterflow. Stakeholders discussed a lack of interventions and understanding of implementing building resilience, now and into the future. Other adaptations that are used are consideration of the materials used in buildings to minimise waste when flooding does occur (e.g. plasterboard orientation so that not all plasterboard needs to be replaced or timber walls) and the reuse of greywater in homes. Hazards from building materials need to be considered, such as roofing to ensure the reduction of heavy metals in waterways. There are some adaptations of repurposing grey water. Materials used on the ground that may affect permeability are also being considered in future planning.

Stakeholders identified that rising sea levels mean septic tanks are vulnerable; there are also challenges in flooding and heavy rainfall in ensuring overland flow paths are clear and that people know and follow existing rules. Coastal erosion is a threat to existing buildings. For example, landfill sites on the coast that are only protected by a railway line which is an identified risk, and the loss of farmland and houses.

In some locations rainwater tanks are mandated, with challenges in the consent requirements in some of these locations. There have been changes in consent requirements, with recognition that rainwater tanks can reduce water flow during heavy rainfall events and support stormwater infrastructure. Stakeholders discussed that there are areas designed to flood that can cope with rainfall events with a probability of 1-2% of annual exceedance; however the predictions are likely to be higher. There are already design guides available for storm water management and permeable areas. Some stakeholders suggested there needs to be more regulatory incentives and implementation of existing research to make resilient homes and buildings. Stakeholders acknowledge there is a lack of consistency in models for assessing hazards such as fluvial flooding. LINZ is working on improving detailed elevation data to monitor sea level rise and water related hazards. Inland flooding is explicitly mapped in some district plans. There are also incentives to share risk data, and inform homeowners through platforms such as Health Waters which is a flood viewer to support individuals understand their water risk.

Some stakeholders provided a future view of climate resilience and adaptation to buildings from a council perspective. For example, in Timaru and South Dunedin:

For south Dunedin the impact of climate impacts in 50 years could be colossal, there are large swamp areas and reclaimed land that compounding issues may cause a significant impact. Rising sea levels (2075 surface water), frequent more intense storms, increase in rainwater (10-20%), decrease in permeable (soak) ground, failure of stormwater system. Mass flooding will result in a loss of buildings and severe damage, making places intolerable and unsafe. Smaller impacts result in value of buildings lost and wastage on replacing materials.

In the future, for South Dunedin, the future vision is to live with water differently, and to have an abundance of climate resilient buildings. This may look like housing that is built higher off the ground, floodable spaces such as parks, flooding barriers in place where needed (e.g. Library) progressively reusing and adaptations to existing buildings. In South Dunedin, the climate adaption plan responds to the communities need to make informed decisions and plan for the future, the area is at high risk of flooding, from rising sea level, increased weather events, and more frequent rain. Buildings at risk range from residential houses and commercial and public buildings, as well as light industry. New builds, in Dunedin restrictive planning, more town houses built higher and they appear well constructed, higher off the floor, and they need to be technically removable in a flood zone.

Similarly in Timaru, there are local issues responding to climate change, such as coastal erosion which threaten current infrastructure and farmland. Frequent storm events are expected to impact on existing buildings, and consideration of future building is being considered with mapping of high-risk areas.

5.3.4 Temperature

> "We're already approaching 1.5 degrees global average temperature rise over preindustrial levels and modelling shows that even if globally, we stopped emitting carbon tomorrow, we've still baked in probably 30 to 50 years of increased volatility in the climate." – Sean Fullan, Insurance Council NZ.

Stakeholders discussed specific responses in regard to temperature. Stakeholders noted that there has been increased education, regulatory changes and incentives to create watertight houses free from damp and mould. Buildings have had a greater focus on being energy efficient. Houses have better insulation but there are concerns that there is inadequate ventilation and designs could be optimised to respond to temperature changes and extreme temperatures likely to be experienced in the future. Some stakeholders discussed the need to use adaptations to respond to colder winters in some areas, whilst the majority of stakeholders raised concerns of overheating and a lack of ventilation in newer buildings due to inadequate poor design.

There are differing opinions about how temperature and ventilation should be dealt with. It was questioned whether buildings should be designed to be comfortable through passive solar design or if they should be designed with the addition of air-conditioning in mind to make buildings comfortable in response to hotter temperatures, and particularly in response to the effects of extreme heats for those who are more vulnerable such as elderly people and babies should be considered.

Stakeholders discussed that there is no standard within the building code in relation to ventilation systems beyond extraction vents and fans in the kitchen and bathroom. Several stakeholders discussed adaptations in existing buildings and new buildings such as temperature control through design with eaves, passive solar systems, shading and how differing designs and products may interact together for warm dry housing that can also be cool in summer. Some stakeholders raised differing types of insulation, green areas and roofs, optimization for temperature control of glazing and building orientation as key design adaptations for future buildings.

Stakeholders described a range of adaptations for thermal comfort and were optimistic of future solutions and changes to ensure buildings are fit for purpose and meet needs in the future. Stakeholders noted concerns on energy use, if buildings are poorly designed for thermal comfort, Heat pumps providing cooling and heating will result in higher energy use. Stakeholders did express frustration that there is a range of evidence, research and experience to implement adaptations for temperature, best behaviour change practice and guidance however these have had little uptake and are poorly incentivised or regulated.

"it may be something as simple that you need more shading to reduce the sun coming in and increasing temperatures to an uncomfortable level, or it may be that you need to reduce window area or it may be you need to change the insulation level" – Nigel Isaacs, Senior Lecturer, Victoria University of Wellington

"We've got a real opportunity and we've had a green roof on one of our assets previously, where you can absorb some of the heat of the buildings which are already there and integrating facades, I would love to see some form of legislation or policy change around that" – Stakeholder

5.3.5 Wildfire

Wildfire was mentioned by some stakeholders with various views on risk. There was some discussion that wildfires are associated more with Australia rather than an event that could be a future issue for New Zealand. Other stakeholders suggested wildfire was a high risk in some areas and suggested that adaptations, implementation lessons, educational programmes and guidelines could be guided by Australian experience.

Little was raised by stakeholders in relation to the mitigation or adaptation of the risk of wildfires in New Zealand or how New Zealand can best prepare for this hazard. One stakeholder suggested mapping of areas that could be prone to wildfires could be beneficial. One stakeholder stated that the West Coast of New Zealand is very susceptible to wildfire, and that risk is only increasing. Another stakeholder described that its likely drought and windy conditions will increase which will increase conditions when wildfires occur.

Further, adaptions used overseas could be explored to consider the applicability to New Zealand for predicting and preparing for changes in wildfire risk as a result of climate change.

"Full assessment has been done across the entire portfolio and we've worked out plans to address some of those really critical ones, the assessments have been done across both New Zealand and Australia, there are potential fire zones" - Stakeholder

"I think New Zealanders would like to be comfortable, with pleasant buildings, but whether they are prepared to do the work or invest the money to make that happen is an interesting question. Certainly, based on the experience of the last couple of years, if we think about the forest fires, the severe storm sort of come through, we are already starting to deal with the extremes of climate change" – Nigel Isaacs, Senior Lecturer, Victoria University of Wellington

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5.3.6 Extreme weather events

Stakeholders described weather events in terms of increasing heavy rainfall, snow, wind and changing weather patterns, as well as harsh solar conditions and severity of weather extremes. When discussing weather events, stakeholders described recent examples of storm events and the response of New Zealand to them. Stakeholders suggested that examining our response in greater detail to understand what works well in what context would be useful for future emergency responses. Stakeholders described that there is a likeliness of increased frequency and intensity of future storms, high winds and heavy rainfall.

In response to weather events, stakeholders noted knowledge is available and being shared to ensure buildings can withstand weather events, but overall there is still reluctance to act. There are existing solutions at the design stage for many resilience issues but stakeholders perceived that they are underused. Stakeholders suggested there is a need to educate building professionals and consumers to demand higher expectations in order to meet resilience.

Stakeholders had some confidence in future predictions of storm events, wind, snow and extreme rainfall. Stakeholders identified that storm locations were likely to shift, with greater events across the country. Impacts from weather events may be the requirement for more or less heating. Commercial buildings need to have the ability to withstand extreme weather events and to recover quickly, Buildings need weatherproofing, that could be roofing materials, cladding, double glazing and frame materials to reduce the need to replace, rebuild and even repair. There are adaptations used overseas such as hurricane/cyclone strapping and thermally insulated windows that could become more commonplace in New Zealand. Buildings may be required to withstand higher wind loads, with some areas already adapting building code requirements to include additional bracing to ensure they are robust. Greater snow loadings may also require additional bracing and strength for roofing.

5.4 Discussion

Inductive analysis of stakeholder interviews revealed four key themes found throughout the interview data, these were:

- Implementation,
- Education and awareness
- Responsibility
- Changes to future buildings.

This section will provide a brief discussion on these themes.

5.4.1 Implementation

When discussing the current and future state of New Zealand's climate resilient buildings stakeholders identified that the greatest challenge was in implementing existing knowledge and practice. Stakeholders identified that there is enough existing knowledge, research and examples of adaptations and mitigations for a range of buildings, however there were still few changes being made. Incentivisation, strategic frameworks, implementation plans and monitoring frameworks as well as increased capacity for implementation are needed to ensure buildings are climate resilient.

Stakeholders discussed that the implementation of climate change adaptation requires significant resources and funding and is a barrier to implementation. The costs have been exacerbated by underinvestment in the industry for many years, even multiple decades.

Stakeholders identified some key drivers to support the implementation of various solutions, these were Government support and direction, as well as legislative changes to the building code, the insurance sector, education and awareness to communities and individuals as well as an uptake of professionals focused on this area.

Stakeholders described some areas that are having a positive impact. These were strengthening planning regulations to guide construction materials and locations which would result in adapting materials used for new construction and retrofitting, and constructing buildings in locations that had a lower hazard risk. Prioritising energy efficiency and low greenhouse gas emissions in building design and construction would result in buildings being climate resilient. There are also useful benchmarks internationally that New Zealand could use to benchmark climate related goals to guide and prioritise future adaptations to buildings.

Stakeholders identified systematic challenges, stating planning, institutions and decision-making operate in silos, which hinder effective adaptation, for example the Building Act is often disconnected from the Resource Management Act and local government.

Stakeholders identified that there is abundant research and knowledge available, but little action due to 'a lack of political will' (Stakeholder), funding and prioritisation. Stakeholders suggested that whilst implementation frameworks are needed to create change, this is also compounded by a sense of whose responsibility is it to drive action.

5.4.2 Responsibility

Some stakeholders when discussing barriers to change and the current state commented that Government and insurance companies have begun to recognize the implication of climate change over the last few years, however the wider New Zealand population has not yet reached this point. Other stakeholders stated that the general public was woefully unaware of their climate risks in terms of housing, both as homeowners, potential buyers and renters. Stakeholders suggest that few individuals were aware or in a position to implement adaptations. Some stakeholders suggested there was currently little appetite for commercial buildings to be climate resilient, however there was some change due to carbon targets.

The view from several stakeholders was New Zealand does not want to change, and there is a lack of clarity on whose responsibility such issues may fall. Stakeholders discussed responsibilities of government, construction industry, insurance industry, organisations, communities and individuals.

Several stakeholders suggested far greater prioritization and guidance was needed form the Government, describing 'political will' as influential in responding to climate issues. Several stakeholders considered the insurance industry as a key driver to incentivise changes in areas of high risk (Carlin et al 2023, Storey et al 2020 and Boston et al 2018).

"Adaptation comes with some very difficult decisions, and nobody wants to be responsible for making those decisions… it raises lots of questions. Like, who is responsible for making a decision on where people can live? Or is it people's own responsibility? Or does the Government need to be caretaker or is it local government? Or are we being led by insurance? Who decides when it's safe in a place or not by taking away insurance, and those are very difficult decisions to go through… maybe it needs to be community led" – Stakeholder

"Having dedicated resources from central government to bring all of these different sectors, communities and agencies together to try and address this problem in a holistic way is essential. At the moment, what is playing out as a result of last year's events (Auckland Flooding, Cyclone Gabrelle) is quite a lot of conversation around the insurability of certain at risk communities and properties. To date, there's been no appetite for retreat as an industry…, insurers want to support communities throughout New Zealand. But there is risk of a true financial crisis if insurance becomes less affordable or unavailable. Banks require insurance on a property to lend, so if insurance penetration is reduced, it can result in deflated property and business values. Where communities have less insurance uptake, there is an increased liability on the Government's balance sheet.

The economic risk is very real, and while we're not in that situation yet, that is something that could develop in the future." – Sean Fullan, Insurance Council NZ.

Stakeholders identified that currently the Government buys properties that have been deemed to be an intolerable risk, if no action is taken in the adaptation space to reduce risk then it is not guaranteed that this will continue. Historically, funding has been driven towards mitigation in response to climate change, there is now a shift to adaptations and in the future there will be a significant need for both. The insurance industry has levers such as cost and limiting cover. There is a risk that insurance could become unavailable or effectively unavailable due to unaffordability which poses large economic risks to financial institutions and Government in places where homes are unable to be insured or where appropriate insurance becomes unaffordable. While there may be no 'appetite' to retreat, there was concern that we are continuing to build in areas that will expose people to current and future hazards. While adaptions are something to consider, it was outlined that these are only 'buying us time'. For example, if houses are being raised to accommodate water related hazards such as flooding, if water levels remain above ground then creative solutions will be needed.

Further, there were concerns raised in relation to the equity issues that arise from houses that become unfunctional and at risk of hazards. As people with more economic means can afford to move out of affected areas or implement adaptations, those with fewer means are unable to.

> *"There are social and economic consequences because there's a building that's become non-functional. What happens to the people that live in it? Will those properties transition to those who can least afford to live there? So people that those who are of less economic means, will they end up in those kind of buildings? and you start to get fairness and equity issues. (People) are subjected to hazards, those flow on to health impacts - you're living in a damp house that the ground is soggy and it's subject to floods. That's not going to be a particularly healthy environment." – Paula Blackett, NIWA*

Stakeholders discussed that there are difficult decisions to be made. We are slow to adapt and change. We have a lag time with buildings and we are still currently building poor climate resistant buildings in poor locations. New Zealand responds to disasters and impacts in bespoke immediate fashion rather than strategically plan for long term response of for future preparedness. Councils are aware of issues and are conducting climate risk assessments, making plans and trying different approaches. When discussing the current and future state of New Zealand's climate resilient buildings stakeholders identified that the greatest challenge was in implementing existing knowledge and practice. Stakeholders identified that there is enough existing knowledge, research and examples of adaptations and mitigations for a range of buildings, however there was still little changes. Incentivisation, strategic frameworks, implementation plans and monitoring frameworks as well as increased capacity for implementation is needed to ensure buildings are climate resilient.

Stakeholders identified some key drivers to support the implementation of various solutions, these were Government support and direction, as well as legislative changes to the building code, the insurance sector and education and awareness to communities and individuals as well as an uptake of professionals focused on this area.

Stakeholders described some areas that are having a positive impact, strengthening planning regulations to guide construction materials and locations, prioritizing energy efficiency and low greenhouse gas emissions in building design and construction. Stakeholders highlighted the need for action and caution, as whilst there are opportunities, some adaptations may cause unintended consequences. For example, Paula Blackett from NIWA mentioned that it was found during a recent flooding event that a house had drifted roughly 800m from its original site. The house had a cement foundation that had polystyrene embedded as a form of installation. The polystyrene made the building buoyant in the flood waters, which whilst beneficial for insulation was an example of a poor adaptation in response to climate issues.

There are also useful benchmarks internationally that New Zealand could use to benchmark climate related goals. Benchmarks provide opportunities to focus and prioritise future issues, and plan towards changing issues using international experience, e.g. Australia and wildfire guidelines.

Stakeholders identified systematic challenges, stating planning, institutions and decision-making operate in silos, which hinder effective adaptation. For example, the Building Act is often disconnected from the Resource Management Act and local government. There are challenges of agreement and funding mechanisms. Overall, stakeholders emphasize the need for immediate action and that in the future and now we need greater climate resilience.

5.4.3 Education and awareness

"We're at the beginning of the journey, there's still a lot of information, education and knowledge that needs to be shared within the building and construction industry." – Stakeholder

Stakeholders perceived the general public to be generally unaware to their hazard risk and mitigations available, especially for homeowners, which impacts on the adaptations used due to a lack of awareness. There is a need to contextualize and share evidence publicly in accessible and actionable formats, for example providing information that homeowners can assess their risk, and find options of adaptations, including cost and impact. There are some efforts to consolidate and share current research in an easily accessible format, but this is limited.

Stakeholders identified a lack of understanding in councils. Stakeholders including council members, discussed a diverse variance in staff and expertise available to councils, as well as a broad range of funding, priorities and resources available. Some stakeholders discussed that councils take differing views of consent approvals with clarity needed on who is responsible for determine where new construction can and should occur. There are external pressures on councils and limited direction to the prioritisation of climate issues. Several stakeholders identified that currently there is a bottom-up approach, with action being led by community organisations and with a need to demonstrate value e.g. estate agents valuing high performing energy homes and buildings above the code.

Several stakeholders raised the need for actionable insights provided to targeted audiences in accessible formats, at a professional industry and individual level, as well as national and local areas. Knowledge needs to consider existing localized solutions as well as bespoke buildings. Further, it was raised that research, resources, and lessons learnt from past experiences are not well shared. Knowing what is available and having access to this information needs to be improved.

Targeted areas stakeholders identified are homeowners, giving people tools and knowledge to demand high energy performing houses, with good design to be climate resilient. Stakeholders discussed initiatives that have successfully implemented change, such as energy performance ratings, or demonstrating individual or community hazard risks in a digestible format.

> *"One of the biggest issues in New Zealand is that as soon as research programme end, all of its findings are fragmented over the different organisations that participated in the research. There is no designated point where they keep the data, so you don't know what is already being done, you cannot build on that knowledge to look into the future." – Stakeholder*

Stakeholders describe there is a lack of clear advice and specific guidance on climate-proofing houses. There is a lack of awareness, with climate adaptation unfamiliar to many, including local councils.

5.4.4 Future building

For some stakeholders, there was a view that we could prepare and be the most climate resilient country in the world, if we adopted different building practices immediately, and built buildings now that will be climate resilient. Stakeholders state the technology exists and methodologies have been used overseas that we would need to adopt and implement. Stakeholders noted the benefits in preparing for climate change now would ensure New Zealand is more economically stable, there would be less damage to buildings and health could be improved.

Stakeholders identified that currently we have most of the technology, research and know-how available if we look and respond to overseas. Stakeholders described the construction industry as risk adverse and very reluctant to change. There is technology, techniques and approaches internationally that could be adopted in New Zealand, and here gaps exist identify further innovation needed for New Zealand. There are cost implications and issues with a lack of materials. We could be building with lower carbon materials like mass timber and invest in New Zealand manufacturing.

Stakeholders described the existing Building Code as inadequate to respond to climate risks to ensure future buildings are built to be resilient. The Building Code has a 50-year design life and takes a minimal requirement approach. Given buildings are in places longer than 50 years the planning should extend pass the 50-year timeframe. There needs to be incentives for going above and beyond the current minimal requirements or these requirements need to be changed to reach a more appropriate level of requirements.

5.5 Further research

Stakeholders provided a range of suggestions for future research that would be beneficial in responding to climate change in the adaptation of New Zealand buildings. Stakeholders suggested further research on the general public's willingness to adapt and an exploration of the publics risk threshold would be powerful evidence. Several stakeholders also suggested research to align rating schemes that are accessible to general public would be highly useful. Such rating schemes include world energy performance ratings, climate resilience ratings and hazard risk exposures (e.g. similar to car purchase performance).

Additional research suggestions from stakeholders are provided below.

Housing

- Review and evaluate process for 'building back better' to consider to what extent is it a fair, equitable and effective process.
- Understand vulnerability of existing buildings and locations by typology.
- Understand capacity of old building stock to be adapted and consider insurance and valuation impact.
- Evaluate existing homes and options to retrofit them to be climate resilient in the future.
- Explore best practice to retrofit homes whilst reducing energy consumption and considering embodied carbon.

People

- Assess the accessibility of raised buildings.
- Review accessibility and mobility issues when there is reduced flat urban space due to climate resilient needs.
- Investigate how to navigate retreat of other elements as well as people when responding to climate issues.
- Youth impacts – what are the perceptions of younger people. Generational differences that are being realized and impacting decisions.
- Identify lessons to be learnt from natural hazards to design an appropriate response regardless of where the event occurs. Evaluate what is a good response.
- Identify barriers to implementing existing adaptations to differing building typologies and locations.
- Determine level of awareness and engagement of climate resilient housing with construction industry.

Regulatory environment

- Explore strategic changes to the Building Code to be fit for the future and climate resilient such as raising minimum standards, thermal comfort design. energy performance.
- Conduct applied research of barriers to integrating form and regulatory environment.
- Funding and planning models about how to encourage adaptation.
- Identify good practice and implementation options of using an energy performance certificate for buildings.

Data collection

- Collect data on housing heights of existing structures to input with flooding models.
- Ensure standardisation of existing data collection, e.g. industry data, consent and building specifications data, water usage, projections, flooding modelling, energy performance of buildings, hazard ratings, etc.
- Identify what we do with the research and outcomes when research project finish. More open data sharing – creates a basis for making informed decisions.
- Collect case studies of adaptation that explore adaptations.
- Conduct participatory action research exploring lessons of adaptations.

Education

- Identify actionable options for homeowners in New Zealand to identify hazard risk and adaptations.
- Conduct accessible research of what has worked overseas that can be adapted to New Zealand.

6 Recommendations

6.1 Knowledge gaps

Literature and stakeholder feedback that has been reviewed suggest our current knowledge of climate change adaptation is not broad enough to motivate the action in New Zealand society that experts believe is necessary. A lack of awareness in the wider society and a lack of detailed information that is actionable contribute to this inaction.

Implementation and education are themes that are commonly highlighted, suggesting that application of existing knowledge and experiences, from both New Zealand and overseas, needs focus. A recent global survey (Ipsos 2023) found that 80% of people think "we are heading for environmental disaster unless we change our habits quickly" but only 18% of the global population view climate change as a top three concern. The research to understand people motivations and to tailor existing information for specific applications (for example, flood maps for consumers, design guides for industry or Building Code updates) is needed.

Climate impacts, and the associated adaptations, generally apply at a regional or local level, and can even change from site to site (for example, flooding). The high-level understanding of climate change impacts on buildings needs to be 'down scaled' to local areas to enable the building industry to understand the climate impacts at specific sites and to construct climate resilient buildings. In the absence of regulated standards to drive resilient design, the building industry will need relatively simple solutions that can be easily tailored to specific sites.

The impacts on buildings (both new and existing) from changes in the different climate parameters have not been quantified substantially for New Zealand. Recent extreme events give some perspective of the wider costs to society associated with some of the climate parameters (for example Cyclone Gabrielle illustrated the impacts of intense rainfall). However, the detailed costs of climate change on specific buildings, and for other climate parameters (for example snow loading), are poorly understood and unquantified. There is also some more fundamental research needed to understand how people using buildings will adapt. For example, temperature limits on overheating of indoor environments are not consistently defined and will need some basis before technical fixes to building designs can be optimised and promoted.

6.2 Priorities for consideration

Motivating action – research is needed to understand why New Zealanders do not act to mitigate and adapt to climate change, and to understand the interventions that will motivate people to act.

Our future climate - basic information on the projected climate that will affect New Zealand buildings is needed across the country, to allow the true impacts and costs of climate change on buildings to be quantified.

Impacts and costs - the impacts of climate change on the design, construction and use of new buildings, and the impacts on the use and maintenance of existing buildings is needed. This information needs a level of level of detail that will allow designers, builders and owners to account for local impacts on their buildings. Costs of these impacts need to be estimated to enable people and communities to prioritise interventions and act with confidence.

Building performance – research is needed to reevaluate the performance and environment that buildings will need to deliver in our future climate. For example, overheating is likely to become a problem as outdoor temperatures increase, but limits for indoor temperatures have not been set or agreed.

Communicating what we know – knowledge transfer to policy makers, the building industry and the general public is critical to promoting action on adapting to climate change.

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Appendix 1 - participant information sheet

Information Sheet

Project title: Climate change adaptation of buildings in New Zealand – Research Prioritisation Assessment

Researchers: Nick Locke, Dr Leoni McKelvey, Dr Edgar Pacheco, David Carradine, Casimir MacGregor, David Laversha.

Researcher Contact: Leoni McKelvey leoni.mckelvey@gmail.com | Senior Research Scientist (Social Sciences) | WSP New Zealand | 33 The Esplanade, Petone, Lower Hutt, 5012 | +64 27 293 4593

We would like to invite you to take part in our Stakeholder Engagement project. Whether or not you take part is your choice. If you don't want to take part, you don't have to give a reason. This Stakeholder Information Sheet will help you decide if you'd like to take part. It sets out why we are doing the research, what your participation would involve, what the benefits and risks to you might be, and what would happen after the research ends. We will go through this information with you and answer any questions you may have. Please, take time to read the following information carefully. Ask questions if anything you read is not clear or if you would like more information. Please, take your time to decide whether or not to take part. It is recommended that you keep this document for future reference.

WHO WE ARE AND WHAT THIS RESEARCH IS ABOUT?

WSP New Zealand is a leading engineering professional services consulting firm. We are conducting an independent project for the Building Research Association of New Zealand (BRANZ) about climate change adaptation of buildings in New Zealand. BRANZ has identified that a Research Prioritisation Assessment is needed to better understand and address the ways in which New Zealand Buildings need to change as in preparation for changes to the climate.

The wide range of buildings and climate impacts now need to be prioritised in order to focus future research needed to understand the overall impact of climate change on building design in New Zealand. Successful adaptation to climate change will require its impacts to be understood and quantified. This proposed research builds on a pilot study which investigated the effect that increasing wind speeds would have on the design of light timber framed buildings. This project will scope and prioritise the required research to identify critical gaps in our knowledge and develop a clear plan for policy makers and the building industry.

WSP has been asked to conduct a Stakeholder Engagement to gain deeper understanding from the perspective and experiences of key stakeholders. In doing so, the findings can then inform further research on the adaptation required for the priority areas that are identified.

WHAT WILL TAKING PART INVOLVE?

You will need to read this Stakeholder Information Sheet, and if you decide to participate in an interview, you will need to sign a Consent Form. We will coordinate with you a time and date for the interview. We estimate that the interview will take between 30 and 45 minutes. The interview will be conducted via Teams and recorded with your consent to facilitate data analysis. Notes will be taken by the researcher(s). A summary of the interview notes or transcript will be provided to you for editing if you wish.

WHY HAVE YOU BEEN INVITED TO TAKE PART?

We would like to interview you about your views and experiences in relation to climate change adaptations of buildings in New Zealand. By talking with those who have experience and expertise of the industry, we hope to better understand concerns and how to address them, and what future research is needed. Your contribution is important because we would like to gather a wide range of different experiences across the sector.

DO YOU HAVE TO TAKE PART?

No, your participation is completely voluntary. You have the right to refuse participation, refuse any question and withdraw at any time without any consequence whatsoever. If you agree to take part in this research, you will be asked to sign the Consent Form.

YOUR RIGHT TO WITHDRAW

Participation in this research is voluntary and you have the right to refuse to participate. You have the right to withdraw from the interview, and your consent to use any associated data, at any time without giving a reason. If you have any questions or concerns about this research, please contact the Researcher Contact – Leoni McKelvey - at any time.

WHAT ARE THE POSSIBLE RISKS AND BENEFITS OF TAKING PART?

The project team have completed a risk assessment and have determined no known risks have been identified in the participation of this interview and research project. We will endeavour to ensure information is presented in a way so that data are non-traceable to individuals.

WILL TAKING PART BE CONFIDENTIAL?

Information discussed in interviews, including personal information, will be kept confidential. Where appropriate we will use edited quotes from interviews. If used, quotes will be attributed to participants, or if preferred anonymised.

HOW WILL INFORMATION YOU PROVIDE BE RECORDED, STORED AND PROTECTED?

The data collected during this research project will be kept in storage for five years and will then be destroyed. In the case of electronic data such as audio recordings, data will initially be safeguarded by passwords on hard drives and/or cloud-based storage spaces and then deleted from all storage spaces after five years. Summaries and other hard copies of data will be shredded after five years. Consent forms will be kept separate from data and kept for five years before being destroyed. The interview recording will be only accessed by members of the project, WSP and BRANZ.

WHAT WILL HAPPEN TO THE RESULTS OF THIS RESEARCH?

The data collected during this research will be used to build an evidence base on the research needed and understanding of building adaptions needed in response to climate change. Findings from this research will be used in an internal report to BRANZ. Findings may be shared with wider audiences where appropriate such as conferences. BRANZ may publish the results online.

WHO SHOULD YOU CONTACT FOR FURTHER INFORMATION?

The Researcher Contact is Leoni McKelvey
Leoni McKelvey | Senior Research Scientist (Social Sciences) | WSP New Zealand | 33 The Esplanade, Petone, Lower Hutt, 5012 | +64 27 293 4593 | leoni.mckelvey@wsp.com

wsp.com/nz