STUDY REPORT

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Assessment of the Need to Adapt Buildings in New Zealand to the Impacts of Climate Change

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ASSESSMENT OF THE NEED TO ADAPT BUILDINGS IN NEW ZEALAND TO THE IMPACTS OF CLIMATE CHANGE

BRANZ Study Report SR 179 (2007) **J Bengtsson, R Hargreaves & I C Page**

Client

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Objective

Overall purpose: to determine the impact of climate change on the built environment and to generate a set of options for adaptation.

Preface

This report documents the results of Issues 1-7 for the levy-funded project '*assessment of the need to adapt buildings to the impacts of climate change*' for Building Research:

Issue ONE: Investigate what climate change predictions are likely for New Zealand. The emphasis of the investigation is on those predictions that will affect the built environment.

Issue TWO: Assess the vulnerability of New Zealand's built environment based on the predicted climate change impacts.

Issue THREE: Investigate the likely social effects of the impacts climate change may have on the built environment.

Issue FOUR: Develop maintenance/ refurbishment/ demolition models for various stock categories.

Issue FIVE: Identify the technological opportunities that may come from climate change adaptation.

Issue SIX (KEY ISSUE): Identify options for reducing the vulnerability of domestic and commercial buildings.

Issue SEVEN: Assess the financial costs of the various options identified for reducing the vulnerability of New Zealand residential and commercial buildings, and where possible identify and estimate the benefits.

Acknowledgments

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EXECUTIVE SUMMARY

The scientific evidence is very strong: climate change presents very serious global risks, and it demands an urgent global response. The objective of this report is to assess the need to adapt houses in New Zealand to climate change. Our assessment is based on medium-low and medium-high climate change scenarios from research by NIWA. To explore the building sector's vulnerability to climate change:

- The topology and condition of the national building stocks was reviewed;
- Regional and district councils were surveyed to collect climate related damages;
- Overheating conditions and energy consumption scenarios were simulated; and
- Scenario-based methodology was used to investigate social impacts.

Adaptation options and recommendations are generated for a broad range of building related climate change impacts. Economic modelling and cost benefit analyses are used to investigate the economic viability of a range of adaptation options. The Climate Change Sustainability Index is revisited as a tool to assess building climate change vulnerability.

Although the effects of climate change are expected to be less severe in New Zealand than in many other parts of the world, the key message from this report is that the strong-, early-, and coordinated action on climate change can limit potentially large social, cultural and economic costs in New Zealand.

Projected Climate Changes in New Zealand

Climate elements where we have the most confidence in expecting to see changes are: maximum and minimum temperatures, sea level, drought and fire risk, and UV radiation. For a number of other elements, the future projections are either still uncertain (e.g. wind, storms, hail) or appear likely to be within the current range of interannual variability (e.g. solar radiation, relative humidity) at most sites. There is also a general expectation of increased rainfall extremes, but further research is required before we can be confident about differences between regions.

	2030s	2080s
Annual average temperature	+0.4°C to +0.8°C	+1.0 to +2.4°C
Mean sea level rise	0.07 to 0.16m	0.23 to 0.52m
Frequency of days above 25°C	Increase	Doubling or more (except Christchurch)
Drought (1-in-20 year events)	More frequent (exc. Hokitika)	As frequent as every 5-10 years (exc. Hokitika)
Wildfire risk	Increase, esp. eastern parts	>+50% near Christchurch and other eastern parts
Days with frosts	Decrease	Half as often at the South Island
Extreme rainfall events	Increase in frequency	Doubling in frequency
Average rainfall	Increase in autumn and winter, less over spring and summer	
Flood events	Increase in frequency	Doubling in frequency
Extra-tropical cyclones	Decrease in frequency and increase in intensity (still uncertain)	
Wind	Average westerly wind component +10% the next 50-100 years	
Hail	Increase in hail occurrences (still uncertain)	
UV radiation (compared to 1980)	2% higher	0% (i.e. recovered)

Table i: Projected 50-year and 100-year climate change trends.

Vulnerability Analysis:

The Building Stock

Housing is a major capital asset with a replacement value of approximately $150 billion (in 2001 NZ dollars). The value of non-residential buildings is smaller but still significant at approximately $70 billion, followed by civil engineering structure (roads, bridges, other transport faculties, water/ sewage/ waste disposal, telecom and energy infrastructure) at $50 billion. The focus of this assessment is therefore on houses. Non-residential buildings are not examined in depth, however, many of the impacts that apply to housing will also affect non-residential buildings. Industrial buildings (warehouse, factory and farm) can largely be ignored for climate change adaptation as they are usually fairly short lived and simple buildings.

Some key facts from the inventory are:

- Total number of dwellings were in 2001 approximately 1,435,000 units, of which stand-alone houses make up 80% and low rise multi-units 18% of the stock.
- The largest proportions of houses are from the 1950s through to the 1970s, and the most multi-unit dwellings are from the 1970s.
- Very few buildings (less than 10%) in New Zealand have more than two storeys with the majority being single storey buildings.
- Approximately 70% of houses are in the 100 to 200 m2 floor area range.
- Concrete floor slab constructions are used in 92% of all new detached housings but only represent 27% of the total stock. Prior to the 1980s most (73%) new houses were constructed on suspended timber floor.
- For all ages combined the predominant cladding is clay brick for walls, and sheet steel for roofs. Timber wall claddings are predominant for pre-1970 housings. Metal tiles and concrete tile are increasingly popular as roof cladding.
- Ceiling insulation data for Wellington, Auckland and Christchurch reveal that 45 – 65% of pre-1980 housings have 50mm or less insulation.

A large number of houses constructed before the 1970s are in need for major maintenance within the next the next few years. Often the option is to replace the component rather than repair, in which case there is opportunity to provide wall insulation and double glazed windows, provide stronger fixings for roof claddings, and install ceiling insulation for skillion roofs and other hard-to-access roof spaces.

Components in Serious or Poor condition 2004 HCS			
Decade	**Percentage of houses**		
starting	Windows	Walls	Roof
1900	29	6	18
1910	20	10	20
1920	20	8	14
1930	31	31	15
1940	26	7	7
1950	16	9	4
1960	11	2	17
1970	5	6	8
1980	5	3	3
1990	0	5	2
2000	0	6	0

Table ii: Condition of selected house components

The inventory of non-residential buildings suggests that climate change adaptation should focus on institutional (hostel, health, education, social/ cultural) and commercial (hotel, retail, office/ administration) buildings rather than usually short lived industrial type buildings.

Climate Related Damage Survey

A survey was sent out to 83 regional and district councils asking for data on climate related damage to the housing stock that has occurred in recent years. The purpose of the survey was to obtain a "starting point" for assessing the present size of the climate related natural hazard events. This data was then used to assess how much damage may occur due to climate change impacts. Of the 83 authorities 31 responses were received. To get an approximate national figure the responses are weighted and it is estimated that per year:

- 280 homes in NZ suffer wind/storm damage;
- 1086 homes are damaged by flooding;
- 76 homes get damaged by coastal erosion;

Each regional and district councils was asked to estimate how many houses are expected to be flooded in case of a *50 year return period flood*. The response, weighted up to represent the whole of NZ, gives that 3604 homes are expected to be flooded. 83% (of 30 responses) indicated that the councils had maps showing areas likely to be flooded for various return period event

Thermal Comfort and Energy Consumption

Climate change will affect all types of housing found within New Zealand, in particular energy requirements for cooling. Many existing houses will require retrofitting to accommodate for the changing climate as homeowners may find that inside air temperatures (especially during summer) within their houses increasingly exceed the assumed upper acceptance level of 25ºC.

Thermal simulations with combinations of house sizes and configurations for Auckland, Christchurch and Wellington show that thermal comfort can be maintained and improved with significant energy savings for all climate change scenarios by adapting existing houses or designing new with:

- Window shading;
- Insulation of roof, floor and walls;
- Provision for natural ventilation; and/or
- Double glazing or further advanced performance (e.g. low-e argon filled windows).

Incorporating window shading to at least half of the sunny-side windows (particularly on the northern sides), and upgrading to double glazing are important consideration aspects of retrofitting if the primary objective is to save energy. Insulation helps reduce heating energy but is not as significant as a mean for reducing cooling energy consumption.

The Social Impacts

Climate change is only one among a range of major future changes within the housing sector, be they political, social, cultural or economic. The social impacts study employs a scenario-building method to scope likely future societal and housing configurations, enabling it to then assess the range of likely social impacts of climate change. Key housing adaptations relating to climate and social changes identified are:

Climate change is only recently on the housing market radar: Literature and expert sources suggest climate changes are given less importance and urgency in the public domain than many social changes, such as increases in crime, obesity and uses for technology. For the householders, fear of intruders (burglars, home invasion, peeping toms) is much greater, more immediate, and has more social and housing impacts (including choice of neighbourhood and demand for security features) than fear of climate change.

Sector dynamics limit adaptation: Housing as a business sector, as a householder investment, and as a key site for private consumption is highly vulnerable to external influences – such as global economic factors, the cost of capital, tax on capital gains, insurance sector policy in relation to housing, and local authority regulation. This means the sector's ability to develop a self-determined, coherent response to the social impacts of climate change may be limited.

Climate change promotes sector growth – and social tensions: External pressures could have a much greater effect on New Zealand society and its housing sector than anticipated local changes. The relatively benign impacts of climate change in New Zealand are likely to be a key driver of immigration with increasing ethnic diversity, and increasing social tensions. Climate and social adaptations is expected to co-evolve.

An ageing population highlights key social impacts: An aging population increasingly remaining in their own homes could result in increase in age-related vulnerabilities within housing. Research indicates other groups may be equally or more vulnerable – such as children, low income households, people with health problems or disabilities, and Maori or Pacific Island communities. Combinations of these variables with older age result in higher vulnerabilities.

Key forms of resilience are psychological toughness and community cohesion: Evidence available suggests older people, while physically more vulnerable, and may also be psychologically stronger and more able to cope with crises. In addition, lower income neighbourhoods, immigrant groups, and church communities, for example, may have levels of social cohesion that make them more resilient and speed their recovery.

Social conflicts is projected to be a major impact: Climate change's social impacts is expected to include significant social disruption and conflict over changing patterns in the value of land in coastal areas, especially where wealthy enclaves suffer significant loss in value.

Key climate change hazards are the extremes of rainfall and heat: The key climate change hazards emerging from this study are wet weather extremes (rain, wind, floods, erosion, landslips) and heat extremes (heat, water shortages/ drought). In this respect, it is worth pursuing flooding/ erosion/ landslips as a key part of a strategy for communicating the need for concern over climate change, and for appropriate housing adaptations. The storms/ flooding issues are a powerful way of engaging communities in the problems and challenges posed by climate change.

Social impacts result from climate and social interactions: In combination, house/ household resilience and preparedness (including housing adaptations) reduce social impacts, while hazards and house/ household vulnerabilities increase them. The interaction between these elements is an indicator of the relative social impact.

Impacts and Adaptation Options:

Significant impacts

Increased coastal flooding, erosion and rising water tables: The magnitude and frequency of storm-tides strongly influence coastal hazards, such as inundation and erosion. Some coastal properties are expected to become more vulnerable/unstable due to increased coastal erosion and sea level rises attributable to global warming. Other properties are projected to experience increased flooding from rivers and water run-off. It is recommended that:

- Territorial Authorities adopt a precautionary approach to coastal development;
- Sea level rise is allowed for in new drainage systems, coastal infrastructure, and buffer zones; and
- Vulnerable properties take protective measures to reduce wave energy and possibly move or abandon houses which cannot be economically protected.

Increased inland flooding: Increases in extreme rainfall events and floods are expected to have implications for storm water drainage and runoff on sections, as well as water tightness and integrity of houses. It is recommended to:

- Include increased flood risk in flood management plans.
- Take a precautionary approach to new development, and upgrade flood protections.
- Further research urban storm water mitigation strategies; rainwater collection as a means to increase resilience; and the link between increased rainfall and increased flooding.

Structural considerations of rainfall changes: Increased local erosion can lead to unstable building foundations. The extra water (especially over a prolonged period) can result in landslides which can directly undermine buildings, or else when slips occur they can impact and damage buildings. It is recommended that:

- New housing estates are based on sound geotechnical advice assuming this increase in water loading;
- Large cuts into unstable soils should be avoided; and
- Adequate drainage and soil cover is provided near critical and potentially unstable sites.

Increased overheating risk: The number of days per year with uncomfortable indoor temperatures is expected to increase, markedly in some areas. It is recommended that:

- Appropriate building design should keep indoor temperatures comfortable without using energy-intensive space cooling; and
- Increase use of passive solar design principles to reduce overheating and avoid increased energy demand.

Increased fire risk: The number of days with very high to extreme forest fire danger could increase by more than 50% in eastern parts of the country. Recommendations are to:

- Increase vigilance in residential areas near native bush and reserves;
- Introduce external building fire protection for vulnerable areas; and
- Educate to develop awareness and community responsibility for fire safety.

Indirect impacts

Greenhouse gas emissions: GHG emissions from houses are mainly from CO_2 and, for most houses, mainly during occupancy. Aspects for improvement include energy efficiency; fuel type; passive solar design; materials choice; size of house and amount of construction material; durability; and transportation demand. It is recommended that understanding is increased of the full life-cycle environmental impact of houses, including occupant effects, so that sensible and cost-effective strategies can be adopted.

Increased insurance cost: If increased rainfall or sea level rise leads to increases in flooding or storm damage, insurance premiums are expected to rise. In the worst case, insurance cover could be denied, marginalising affected communities. It is recommended that understanding and awareness of environmental impact on houses are increased to ensure the building stock can be properly insured.

Increased cost due to carbon or greenhouse gas charges: Any form of carbon charge is expected to result in increased costs of electricity and building materials. For materials the percentage increase in cost will probably be least for timber products, more for cement, much more for steel, and more still for aluminium. It is recommended to:

- Invest and plan for a carbon constrained economy;
- Adopt cost-effective energy efficiency measures to offset increased costs; and

- Adopt cost-effective renewable energy and electricity generation options.

Uncertain or minor impacts

Ex-tropical cyclones and increased wind load: Climate change science currently has conflicting assessments of changes in ex-tropical cyclones. The potential for damage to houses from any increase in ex-tropical cyclones is so large that, despite the uncertainties, this potential impact must be taken very seriously. Urgent further research into changes in ex-tropical cyclones with climate change is recommended.

Increased wind load: It will take decades to confirm increases if structurally damaging winds have increased, since these winds are extremely rare. It is recommended that the next revision of design loadings standard for wind takes changes expected due to global warming into account. It is generally not recommended to strengthen existing buildings purely based on a predicted increase in design wind-speed from climate change.

Structural considerations for increased rainfall and temperature changes: Temperature extremes and large swings will result in thermal movement of roofing, cladding, window systems and other building parts which can result in cracking and deterioration. Soil drying (and swelling in wet conditions) can affect foundations (especially clay soils). Direct effect of the temperature change effects is expected to have only minor structural consequences for buildings.

Degradation of polymers: The risk of polymer degradation is judged to be low or very low in both the 2030s and 2080s timeframe.

Pest / infestation problems: The effects of climate change within the 50-year scenario (temperature and rainfall) will cause the incidence of timber pests to change, in terms of their range and distribution. It is not likely, with such small climate changes, that insects and fungi will represent an increased hazard to building timbers. Existing New Zealand quarantine operations are effective at keeping out other, non-indigenous, termite species.

Opportunities

Decreased water heating and winter space heating: There will be greater opportunity to heat houses entirely from passive solar heating by the end of the century, especially in the Auckland and Northland regions. The required water heating energy is expected to decrease by 3.0 – 7.2% by the 2080s. It is recommended that public and industry awareness of good thermal design (especially passive solar) is increased to maximise benefits and energy savings.

Economic Modelling

Thermal simulations demonstrate the effectiveness of passive solar design to reduce vulnerability to building overheating and energy consumption for heating and cooling. Economic modelling is used to compare the economic costs and benefits of selected adaptation options:

Space Conditioning Adaptation

Existing House Retrofits

Economic cost benefit analysis suggests that insulation retrofitting of the existing housing stock should be done as soon as possible. The net present values (NPV) decrease over time, so the longer the delay in retrofitting the lower the lifetime benefit (resulting in a lower NPV).

When retrofitting existing housing stock, when feasible, it is recommended that all homes have ceiling, wall and floor insulation with no awnings installed. While awnings provide good sun protection they are quite expensive ($4,000 to $10,000 per house, depending on size).

Double glazing significantly reduce energy consumption, but in no situation modelled do they provide a greater NPV than single glazing. Still, it is recommended that double glazing retrofit is considered in all regions due to superior energy performance and demonstrated strong positive NPVs.

New Houses

Small, medium and large houses with retractable awnings on all windows with no natural ventilation (opening of windows)[1] were modelled. The most favourable configuration is commonly with better than code compliant insulation in ceiling, walls and floor, with no awnings installed. The ideal insulation levels on new houses depend on location and size.

Modelling with different window variations – single glazing, double glazing, and low-e argon filled double glazing – on houses with mid-level insulation (i.e. *better* than code compliant) showed that:

- Small houses in Auckland and Wellington have higher NPVs with single glazing. However, double glazing in these houses, without natural ventilation, is still cost effective, and saves more energy than single glazing.
- Small Christchurch and all medium and large sized houses have higher NPVs with standard double glazing windows
- No financial benefit was gained by installation of double glazed argon filled windows for any of the houses considered.

The Climate Change Sustainability Index

The Climate Change Sustainability Index (CCSI) developed by Camilleri (2000b; 2001) is an assessment of how vulnerable a building in New Zealand is to the climate change impacts: overheating, flooding (inland and coastal) and tropical cyclones. The CCSI assessment methodology is built around industry standard tools, and readily available information. The complete CCSI consists of two separate numerical ratings for:

1. House and office building impacts; and
2. Greenhouse gas emissions for space- and hot water heating.

With the latest climate change predictions of increase in fire and drought risk an extension of the CCSI could be considered.

Combined Adaptation Cost for the Existing Housing Stock

Climate change adaptation costs are calculated for the existing housing stock. The total cost, if all adaptation measures were applied would be approximately $2.3 billion, which represents about 1.3% of the value of the housing stock. The expected benefit is estimated to at least $4 billion in present value dollars (see *Figure i* below).

[1] No Natural Ventilation – Natural Ventilation is generally considered to be opening of windows. Simulations were run both with and without simulating the effects of open windows to give an idea of the difference in energy loads.

Climate change adaptation costs for the existing housing stock

Climate impact	Change to 2080	Region	Existing House numbers affected (1)	Measure	Cost per house $	Total cost $M	Benefits $M
Driving rain.	10% incr	West NZ.	172,920 (2)	More frequent maintenance (7)	219	38	?
Wind	8% loading incr	All regions	519,000 (3)	More nails in roof cladding (8)	238	124	137 (14)
Hail	Severity increase	West NZ.	162,000 (3)	0.55 mm sheet instead of 0.40mm (9)	894	145	55 (15)
Drought	Return period up 50%	North NI & east NZ	303,000	Water tanks (10)	2800	848	?
Bush Fire	Fire days up 50%	East NI and SI in bush areas	10,800 (4)	Baseboards mesh (11)	500	5	34 (16)
Sea level rises	0.2 m to 0.5 m	All	4,000 (5)	Move house inland (12)	15000	60	248 (17)
Temperature	+1.6 ^{O}C to 2.4^{O}C	All regions	390,000 (6)	Insulation R2.6 ceiling, R2.2 walls (13)	2100	819	3600 (18)
						2,039	4073

(1) Allows for 793,000 demolitions of existing stock by 2080,leaving 837,000 pre-2010 houses.
(2) Houses with painted wall surfaces are 66% of total.
(3) HCS data indicates 62% of stock is sheet steel or metal tiles roofing.
(4) From NZ Fire Service for properties with >50% bush cover in Urban Fire Districts.
(5) Assume only 1% of houses in coastal TAs are at risk of erosion/ surge.
(6) Numbers with no or poor insulation. No allowance for demolitions.
(7) Driving rain. More frequent wall maintenance 7.5 yr instead of 8 yr cycle.

Discount rate r = 5%
Period n= 50 yrs
USPWF= 18.256

Life time discount	SPPWF (7.5yrs)	2.1421
discount factors:	SPPWF (8yrs)	2.0022
r= 5%	Difference	0.1399 x wall area x $15/sqm = 219 $/house

(8) 4 more nails per sheet = $1.6/ sqm
(9) Cost differential 0.55 mm cf 0.40 mm is $6/sqm
(10) Storage tank and piping is $2,800 per house
(11) Ensure sparks are keeped out of the sub-floor.
(12) Relocate coastal houses inland, include new foundations and service connections.
(13) Insulation cost. Assume retrofit is R2.6 ceiling, R2.2 walls.

Ceiling	1120
Walls	980
	2100 $/house

PV= present value.

(14) Benefits from wind roof strengthening, as PV . Assume number roofs saved	500 per yr @	$ 15,000	per roof	) Assumes 0.1% of stock saved from
(15) Benefits from hail roof strengthening, as PV . Assume number roofs saved =	200 per yr @	$ 15,000	per roof	) damage per year for wind, hail
(16) Benefits from bush fire protection, as PV . Assume number houses saved =	11 per yr @	$ 170,000	per house	) and bush fire.
(17) Benefits from sea level rise protectn, as PV . Assume number houses saved	80 per yr @	$ 170,000	per house	) 2% saved /yr from coastal impacts.

(18) Earlier work gives NPV of $1300M Auckland, $600 M Wellington and $1200 M Christchurch climate zones. To this add $819 M insulation cost discounted by 10 years.

Figure i: *The total cost, if all adaptation measures were applied.*

The number of houses likely to be affected by each impact was calculated by using 2006 census data to work out how many houses exist in each region. The NIWA data was used to calculate what areas are susceptible to the impact in the future. It is estimated that approximately 50% of all existing houses are expected to be demolished through to 2080.

Study Recommendations:

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

R2: Develop and retrofit with consideration of increasing climate exposure and vulnerability: Regions with high climate change exposure from increased risk of flood, bushfire, temperature extremes and coastal hazards should be avoided or developed with due consideration of future climate change impacts.

R3: Use recent natural events (e.g. storms/ flooding/ erosion/ landslips) to raise awareness of climate change impacts on housing and our way of life: Housing adaptations can profitably be oriented to raising concern over storms/ flooding/ erosion/ landslips as a threat to the New Zealand way of life, with particular impact for coastal communities/ houses. Loss of iconic housing locations, lifestyles and landscapes is a powerful motivator for public concern.

R4: Learn how to communicate about climate change and adaptation: Develop a communications strategy that makes it easy for the public to understand climate change, its impacts, and the need for housing adaptation specifically.

R5: Develop behavioural change programmes: Develop behaviour change programmes that make behaviour change easy, attractive, stylish, and rewarding. Systemic programme may need to span areas such as design, building, renovating, financing, and insuring as well as ownership/ dwelling.

R6: Build the sector's proactivity: Develop a proactive approach that leverages research – such as this report – towards a coherent and effective sectoral response to climate change. Synergies may be may be achieved with initiatives that deal with health and other social issues.

R7: Orient housing adaptation to social exclusion: As the broader strategic platform it is recommended that adaptations are oriented to the more vulnerable and socially excluded groups.

R8: Integrate other sectors in future work: Coordinate building adaptation to climate change with other societal, institutional and technical drivers for change. Design of housing adaptations for climate change cannot be separated from design for other changes. Housing needs and vulnerabilities are concurrently shifting due to an ageing population, increasing obesity and so on.

R9: Reduce sector's carbon footprint: Stimulate uptake of energy efficient techniques and practices and renewable energy generation. Indirect impacts from policy instruments to reduce greenhouse gas emissions, such as increased costs from carbon or GHG charges may in itself pose a risk to tenants and the building industry.

R10: Improve confidence in projections of key climate change implications for New Zealand: Increased certainty is required for regional distribution-, direction- and magnitude of change of ex-tropical cyclones, wind, storm, hail and rainfall.

R11: Continue working with scenarios for social impacts: A central, longer-term task is to develop a 'strategic discussion' about the role and activities of housing in managing the social impacts of climate change.

R12: Develop the CCSI and include bushfire and drought risk: It is recommended that the CCSI is expanded to include building vulnerability from increased fire and drought risk.

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1. INTRODUCTION

1.1 Background and Objective

The scientific evidence is now overwhelming: climate change presents very serious global risks, and it demands an urgent global response. In terms of the long-term future, climate change is widely considered to be one of the most important challenges for the 21st century (Chapman *et al*., 2006). Much effort is needed, and is being made, to mitigating greenhouse gas (GHG) emissions in the industrialised world. However, we are long past the point where some *man induced* climate changes can be avoided, and indications of anthropogenic alterations of the climate are already seen today. The effects of the GHG already emitted into the atmosphere – and unavoidable emissions in the coming decades – will have repercussions for centuries, even millennia.

> *"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level"*
>
> – IPCC (2007a)

Climate change will have broad and far reaching effects on our society, lifestyles, economy and governance. It also has the potential to impact on buildings and the urban environment in a number of ways, such as: heavy rainfall leading to flash flooding events and subsidence, drier conditions leading to clay soil shrinkage and increased fire risk, changes in demand for space heating and summer cooling, and a changing mix of indoor-outdoor living facilities.

Overall purpose of this report is to determine the impact of climate change on the built environment and to generate a set of options for adaptation. This report aims to underpin the decisions needed to be made on what, when and how to adapt and take action.

The focus of this assessment is on houses. Non-residential buildings are not examined in depth, however, many of the impacts that apply to housing will also affect non-residential buildings. Industrial buildings (warehouse, factory and farm) can largely be ignored for climate change adaptation as they are usually fairly short lived and simple buildings. In most case the owners would demolish them if they became unusable due to climate change impacts – institutional (hostel, health, education, social/ cultural) and commercial (hotel, retail, office/ administration) buildings are more likely to be affected.[2]

The key audiences for this report are the policymakers - with the mandate to negotiate an acceptable level of risk for society and future generations – and the building industry, insurance industry and homeowners with vested interests in an intact built environment.

> *"Decision making has to deal with uncertainties including the risk of non-linear and/or irreversible changes, entails balancing the risks of either insufficient or excessive action, and involves careful consideration of the consequences (both environmental and economic), their likelihood, and society's attitude towards risk"*
>
> – IPCC (2001b)

1.2 Anthropogenic Climate Change Overview

Anthropogenic GHG emissions are a function of our combined and distributed economic (i.e. equity) activities, lifestyles and population size. A selection of the Intergovernmental Panel on Climate Change's (IPCC) key factors for projecting future atmospheric greenhouse gas emission

[2] Further evidence and rational for this scope is provided in section 3.1.1.7.1 *Non-residential building characteristics*.

and concentrations and their effect on global mean temperature and sea level rise are presented in the table below.

Table 1: *Socio-economic scenarios and their implications for atmospheric composition, climate, and sea level. Per capita income ratio (a measure of regional equity) is also a significant factor but omitted from this adapted table (IPCC, 2001a).*

Date	Global Population (billions)	Global GDP (10^{22} US$/yr)	CO_2 Concentration (ppm)	Global Temperature Change (°C)	Global Sea-Level Rise (cm)
1990	5.3	21	354	0	0
2000	6.1 – 6.2	25 – 28	367	0.2	2
2050	8.4 – 11.3	59 – 187	463 – 623	0.8 – 2.6	5 – 32
2100	7.0 – 15.1	197 – 550	478 – 1099	1.4 – 5.8	9 – 88

Based on above global scenarios for socio-economic development and consequent GHG emission scenarios; *Figure 1* below shows the ranges for expected surface warming. The variation ranges from high warming with rapid fossil fuel based economic and population growth (A1F1) to modest warming in scenario B1 where emphasis is on global solutions to economic, social and environmental sustainability. The grey bars at right indicate the best estimate (solid line within each bar) and the likely range assessed for the six scenarios (IPCC, 2007a).

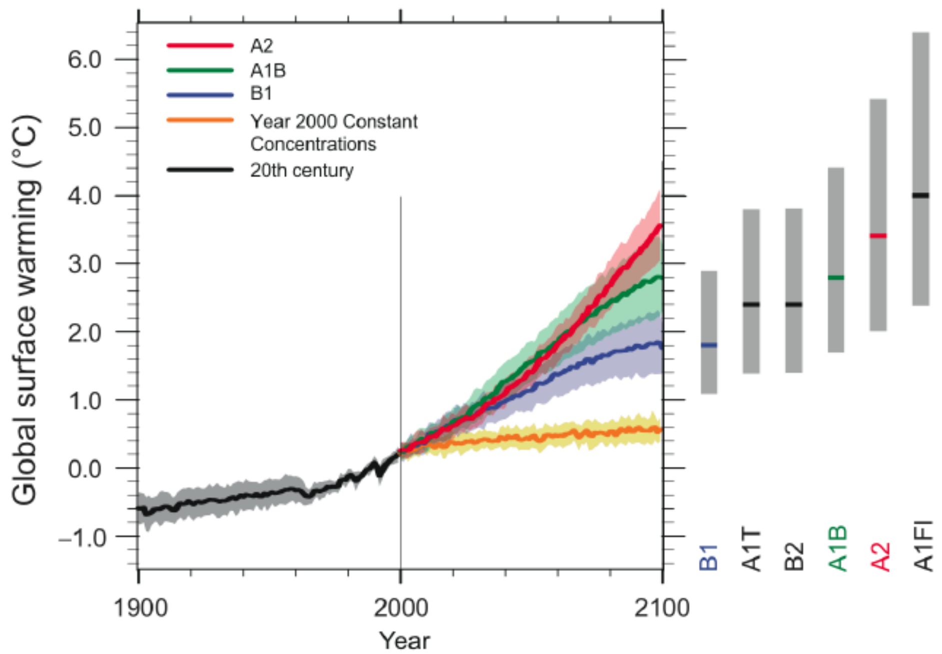

Figure 1: *Ranges for surface warming based on global scenarios for socio-economic development and consequent GHG emission. The warming scenarios in the figure are, at the time of release of this report, the latest available from the IPCC (2007a). The climate scenarios used in this report are however based on the 3rd IPCC assessment report from 2001, which has slightly different ranges, but is generally consistent.*

1.2.1 Observed Changes

Although this study reports on climate changes in the medium to long term effects from global warming are already observed today. Eleven of the last twelve years (1995 -2006) rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850). Mountain glaciers and snow cover have declined on average in both hemispheres and widespread decreases in glaciers and ice caps have contributed to sea level rise. Losses from the ice sheets of Greenland and Antarctica have very likely contributed to sea level rise over 1993 to 2003 (IPCC, 2007a).

1.2.2 Economic Implications

Nicholas Stern (2006) led a major review on the economics of climate change, concluding, amongst other things that in higher latitude regions climate change may lead to net benefits for temperature increases of 2 or 3°C, through higher agricultural yields, lower heating requirements, lower winter mortality, and a possible boost to tourism. However the increased costs of damage from extreme weather (storms, cyclones, floods, droughts, and heat waves) counteract some early benefits of climate change and will increase rapidly at higher temperatures. Costs of extreme weather alone could reach 0.5 - 1% of world GDP per annum by the middle of the century, and will keep rising if the world continues to warm. Stern's international review estimates:

- A 5 or 10% increase in hurricane wind speed, linked to rising sea temperatures, is predicted approximately to double annual damage costs, in the USA.
- In the UK, annual flood losses alone could increase from 0.1% of GDP today to 0.2 - 0.4% of GDP once the increase in global average temperatures reaches 3 or 4°C.
- Heat waves like that experienced in 2003 in Europe, when 35,000 people died and agricultural losses reached $15 billion will be commonplace by the middle of the century.

At higher temperatures, developed economies face a growing risk of large-scale shocks - for example, the rising costs of extreme weather events could affect global financial markets through higher and more volatile costs of insurance.

> The additional costs of making new infrastructure and buildings more resilient to climate change in OECD countries could range from 0.05 – 0.5% of GDP each year ($15 – 150 billion), with higher costs possible with the prospect of higher temperatures in the future (Stern, 2006).

Insurance data reveal frequent weather related losses in New Zealand with rarer very costly (in insurance payout) extreme meteorological events. The three most costly events in the last decades are according to the Insurance Council of New Zealand (2007):

- The 1968 Wahine storm cost US$178 million;
- The 1984 Southland floods cost US$114 million; and
- The February 2004 North Island floods which cost US$112 million in today's prices.

The following section with climate change scenarios from NIWA gives reason for concern that weather related losses will become more commonplace with a changing climate.

1.3 Responding to Climate Change – Adaptation and Mitigation

The United Nations Framework Convention on Climate Change (UNFCCC) identifies two responses to climate change: mitigation of climate change by reducing GHG emissions and enhancing sinks, and adaptation to the impacts of climate change. Most industrialised countries have committed themselves, as signatories to the UNFCCC and the Kyoto Protocol, to adopting national policies and taking corresponding measures on the mitigation of climate change and to reducing their overall greenhouse gas emissions. The interactions between mitigation and adaptation are described in *Figure 2* below.

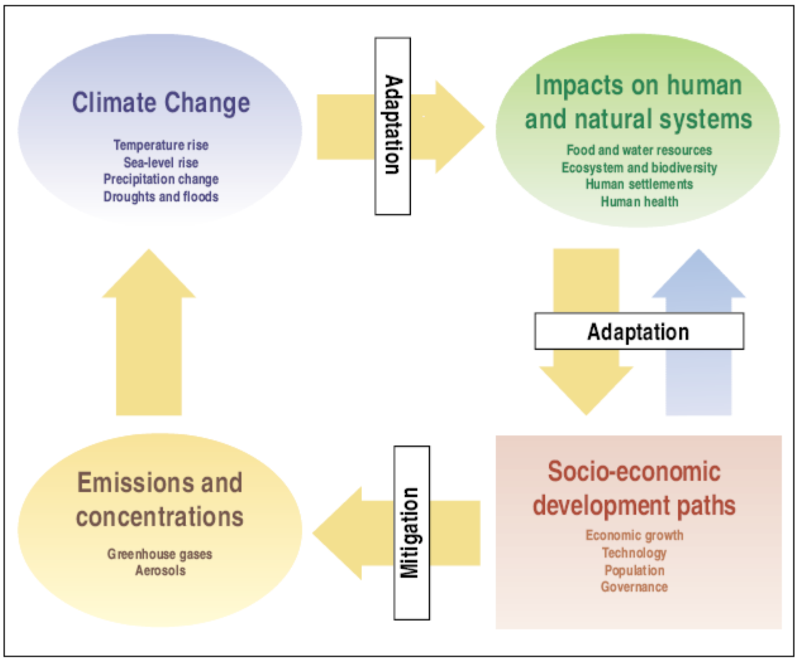

Figure 2: *Climate change – an integrated framework. Schematic and simplified representation of an integrated assessment framework for considering anthropogenic climate change. The yellow arrows show the cycle of cause and effect and the blue arrow indicates the societal response to climate change impacts (IPCC, 2001b).*

Adaptation will be required to reduce the costs and disruption caused by climate change, particularly from extreme weather events like storms, floods and heatwaves. Adaptation will also help take advantage of any opportunities, such as development of new crops or increased tourism potential. But at higher temperatures, the costs of adaptation will rise sharply (Stern, 2006).

The built environment and all it contains is integral to our survival on the planet: it accommodates and sustains individuals and families, economic activities, education and health services, and is repository of the nation's cultural heritage. The average life expectancy of a house is about 100 years in New Zealand (some will last significantly longer), so most of the houses standing now – and not forgetting those currently being built – will be around until the later part of the century and beyond to experience the more severe projected consequences from climate change.

The built environment in which we live will certainly feel the effects of a changing climate. As such, it is imperative that we take measures to adapt and mitigate our buildings against such impacts. It is neither prudent nor desirable, and indeed economically unwise in many cases (for individual properties), to wait until problems caused by climate change occur before taking remedial action (O'Connell & Hargreaves, 2004; and Jaques & Sheridan, 2006). Even the most stringent mitigation efforts cannot avoid further impacts of climate change in the next few decades, which makes adaptation essential, particularly in addressing near-term impacts. Unmitigated climate change would, in the long term, be likely to exceed the capacity of natural, managed and human systems to adapt. However, a portfolio of adaptation and mitigation measures can diminish the risks associated with climate change (IPCC, 2007b).

1.4 Structure of this Report

This assessment report is structured into six sections leading up to our concluding recommendations:

- In the following section 2 projected medium- and long term climatic changes for New Zealand are presented and discussed.
- Section 3 deals with the vulnerability of the housing sector. It is divided into three parts:
    - an overview of the condition and vulnerability of the building stock;
    - simulations of overheating and energy consumption of typical housing types; and
    - an analysis of the social implications for the built environment through the 21st century.
- Section 4 provides adaptation options and recommendations for a wide range of climate change impacts.
- Section 5.3 employs economic modelling for a number of adaptive responses. Special focus is on cost benefit analysis of the adaptation options used in the simulated assessment of overheating.
- Section 6 presents an overview and summary of the Climate Change Sustainability Index as a method for assessing climate change vulnerability of New Zealand houses and office buildings.

2. CLIMATE CHANGE SCENARIOS FOR NEW ZEALAND

2.1 Introduction

This section is based on a report prepared by NIWA to assist assessing the impacts of climate change on the New Zealand built environment. The emphasis is on climate factors that are likely to affect the built environment. For a number of these factors such as wind, storms, hail, and solar radiation the future projections are either uncertain or appear likely to be within the current range of interannual variability at most sites. For other elements the projections are more confident:

New Zealand climate elements where we have the most confidence in expecting to see changes are: maximum and minimum temperatures, sea level, drought and fire risk, and UV radiation.

Rainfall extremes and floods are expected to increase, but further research is required to increase confidence about impacts on a regional scale.

2.2 Scenarios and Preconditions

The scenarios are based on the IPCC Third Assessment from 2001. The IPCC Fourth Assessment from 2007 summarises research on climate change science and impacts that has been published since the Third Assessment. Thus, most of the information specific to New Zealand was previously available and drawn on in the production of the BRANZ report. The main area where the Fourth Assessment provides new information on the science is the updated range of global warming and global sea-level rise. However, these figures do not depart substantially from those of the Third Assessment. Specifics of downscaled scenarios based on the Fourth Assessment models will of course be different from earlier work[3].

Climate scenarios are generated for a 50-year trend (**2030s**) and a 100-year trend (**2080s**). To represent uncertainties in future global socio-economic development (see *Table 1*) two scalings – described as the **25th percentile** (medium-low) and **75th percentile** (medium-high) of the full IPCC temperature range are simulated[4]. These scalings should not be considered extremes, but rather lower and higher bound of probable developments[5]. The climate scenarios in this report are based on two downscaled global climate models: **CSIRO** and **Hadley**. In total eight scenarios are generated.

This section is a summary; the full NIWA study (Mullan *et al.*, 2006) can be downloaded from BRANZ web page: www.branz.co.nz/branzltd/pdfs/NIWABRZ07301.pdf

[3] There is no new information in the Fourth Assessment beyond what is already available in New Zealand through the Ministry for the Environment climate change guidance manual, the NIWA drought report, and other locally-produced reports that the NIWA authors of the BRANZ report are already familiar with. The Ministry for the Environment is currently updating their climate change guidance material (e.g. MfE, 2004a & b). The timeline for the publishing of this updated information is for the end of 2007.

[4] The 25% and 75% limits were chosen to cover a reasonable range of possibilities but avoiding being alarmist by stressing extremes, in either direction, which some would view as unlikely.

[5] Future scenario changes are calculated between the 'current climate', which we can think of as 1971-2000, and future 30-year climatologies centred in the "2030s" (i.e., 2020-2049) and the "2080s" (2070-2099).

2.3 Average Temperature Increases

For the 2030s, annual-average temperature increases by about 0.4–0.8°C, depending on the scenario. By the end of the century (the 2080s), the temperature is projected to increase by 1.0–2.4°C.

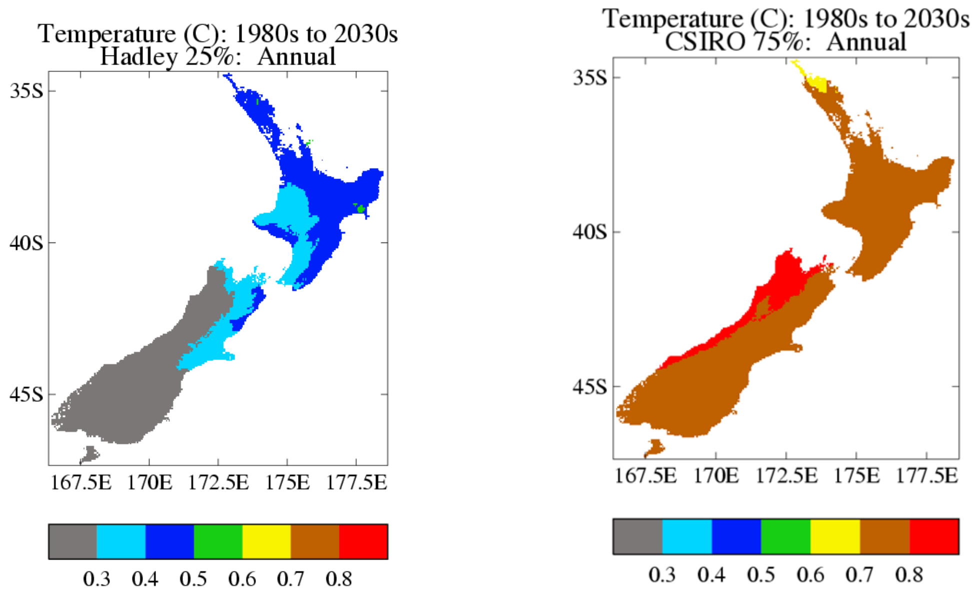

Figure 3: *Projected change in annual-average temperature (°C) between present and 2030s. The left hand figure shows the mildest scenario outcome at the 25th percentile of the IPCC range and the right hand figure the most severe scenario at the 75th percentile.*

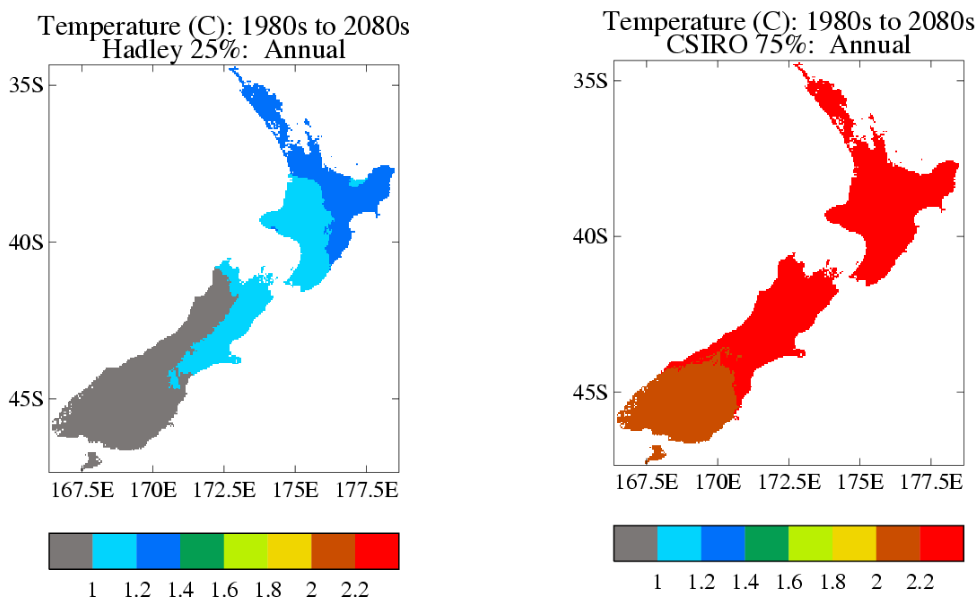

Figure 4: *Projected change in annual-average temperature (°C) between present and 2080s. The left hand figure shows the mildest scenario outcome at the 25th percentile of the IPCC range and the right hand figure the most severe scenario at the 75th percentile. Note that it is a different scale from Figure 3.*

Projected temperatures increase everywhere, with the exception of Hokitika in summer for the 2030s Hadley scenarios. The Hadley scenarios show more seasonality, with winter temperatures increasing more than summer ones. The CSIRO temperature scenarios are slightly larger in magnitude and more uniform spatially than those from the Hadley model.

2.4 Extreme Temperature

Extreme temperatures affect living comfort, and consequently the need for either space heating in winter or air conditioning in summer. Climate change scenarios show average temperatures increase this century.

High temperature extremes will increase in frequency and low temperature extremes (e.g. frost) will become less common.

The projected occurrence of high temperature extremes increases markedly with the imposed increase in average temperature. By the end of the 21st century, most of the sites except Christchurch show a doubling or more in days above 25ºC. The table below provide quantitative estimates in changes temperature extremes calculated using *weather generators* (Mullan *et al*., 2001).

Table 2: *Number of days per year with daily maximum temperatures exceeding 25ºC in current climate, and changes for future scenarios.*

Max. temp > 25ºC	Present days	Additional days 2030s	Additional days 2080s
Auckland	21.3	6.9 to 14.6	25.9 to 52.6
Hamilton	25.6	4.8 to 14.9	21.3 to 49.2
Tauranga	23.3	3.5 to 8.4	13.5 to 39.6
Wellington	2.9	0.4 to 2.0	3.5 to 13.9
Nelson	7.4	1.3 to 7.7	7.3 to 28.6
Christchurch	31.2	2.7 to 10.2	12.7 to 30.2
Hokitika	1.0	-0.2 to 0.9	1.0 to 5.3

Days with maximum temperatures exceeding 30ºC are presently uncommon in most parts of New Zealand outside the South Island east coast[6]. Although the number of such hot days increase in future scenarios, occurrences are still rare at all sites considered with the exception of Christchurch where an increase of 3 to 7 extra days (+50 to +115%) are expected by the end of the century.

Low temperature days are projected to become less frequent: by the 2080s minimum temperatures below 5°C are expected to occur only half as often at the North Island sites, and frosts (days below 0°C) are much less common. For the colder South Island sites, frosts are expected to occur only about half as often by the end of the century compared to the present climate.

2.5 Rainfall and Floods

The amount of water held in the atmosphere increases with increase in temperature (about 8% more for every 1°C rise in temperature). What is an extreme rainfall in today's rainfall climate is projected to occur about twice as often by the end of the 21st century. Climate change is expected to reduce the average recurrence interval (ARI) of high intensity storms or equivalently, for the same ARI and duration the rainfall amount increases.

Changes in frequency of flood events are expected to follow a similar pattern to extreme rainfall, i.e. doubling by the end of the century.

[6] For example, at the Auckland airport site, there is currently only about one day every 10 years where daily temperatures exceed 30ºC; by the 2080s there is projected to be about one day every year, on

The relationship of flood events to extreme rainfall will vary with characteristics of each catchment. For example, for small catchments or for the built environment with lots of paved surfaces, runoff will be rapid, so fairly short accumulation periods of up to a few hours will be most relevant to local flooding. For more extensive flooding over large catchments, extreme rainfall totals of 2-3 days will be more important.

Increases in extreme rainfall are considered likely, even where the annual average rainfall changes little or even decreases. Based on the current knowledge of climate change science the *direction of change* is considered robust. Research is continuing on quantifying the likely effects of climate change on extreme rainfalls in New Zealand to improve the certainty about the magnitude of the changes.

For average rainfall changes, there is substantial variation between sites and between models. The larger rainfall changes suggest drier conditions in the north and east of New Zealand. Seasonally, there is a tendency towards reduced rainfall in spring and summer, and increased rainfall in autumn and winter.

2.6 Sea Level Change and Coastal Hazards

Projected future global mean sea level rise, consistent with the global mean temperature increases assumed in the scenarios of this report, ranges between 0.07 and 0.16 m by the 2030s and between 0.23 and 0.52 m by the 2080s relative to sea levels in 1990.

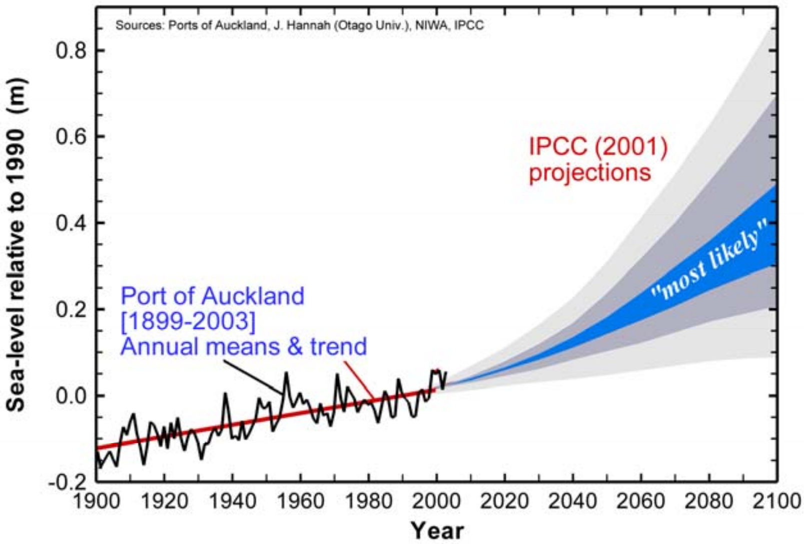

Figure 5: *Global mean sea-level rise projections relative to 1990. The blue band corresponds to the most likely range of sea level rise, the dark grey to the intermediate zone, and light grey to the upper and lower extremes. Also shown is the long-term and annual mean sea level at Auckland over the last century.*

In addition to mean sea level rise due to global warming, the sea level is determined by a number of components:

- Tides: Gravitational attraction of the Moon and Sun on Earth's oceans.
- Storm Surge: The decreases in atmospheric pressure and strong winds that accompanying storms can raise the sea level by as much as 1m, and will often be accompanied by extreme waves.

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average. This is a big percentage change, but still means that days hotter than 30ºC will remain uncommon at Auckland throughout this century.

- Long Period Oscillations:
    - Annual seasonal heating and cooling by the sun (±0.04 m to ±0.08 m);
    - Interannual 2-4 year El Niño-Southern Oscillation[7] cycles (±0.12 m); and
    - Interdecadal 20-30 years Interdecadal Pacific Oscillation[8] (±0.05 m).

2.6.1 Coastal Hazard

The occurrence of coastal hazards such as inundation and erosion, and their potential impacts on the built environment located within coastal and estuarine margins around New Zealand, will be influenced by climate change. Coastal hazards are rarely linked to only one causative factor. Rather they tend to be a complex interaction of direct and indirect human impacts on the coastal zone and natural forcing processes, such as:

- Water levels;
- Waves;
- Currents; and
- Sediment supply and re-distribution

Appendix A outlines some dominant drivers affecting coastal hazard change at various urban locations around New Zealand. These interactions can operate over a range of different time and spatial scales, for example short term erosion caused by an episodic storm events through to longer term cyclic coastal change caused by seasonal, interannual and decadal variability. It is these weather and climate-related "drivers" of coastal change, both episodic and longer-term, that will be altered most by climate change arising from global warming, mostly exacerbating the existing potential for coastal hazard problems (see: New Zealand Ministry for the Environment, 2004a).

2.6.1.1 Extreme Wave Conditions

The average westerly wind component across New Zealand is suggested to increase by approximately 10% of its current mean value in the next 50-100 years. In a general sense this will increase the frequency and potential magnitude of extreme wave conditions along the south-western coastline of New Zealand, with a subsequent reduction on the north-eastern coastline, similar to the conditions that are experienced during El Niño periods where there is also an increase in south-westerly wind conditions.

2.6.1.2 Storm-tide Levels Effect on Inundation and Erosion

Any changes in the magnitude and frequency of storm-tide levels would be important for inundation and erosion: at present, storm surge magnitude is up to 1 m above the predicted tide, and it is uncertain whether this might increase under climate change. Note, however, that even if these storm-tide levels do not increase, they will be occurring on top of a higher sea level. Projected changes in sediment yield to the coast (from changes in rainfall) are relatively small compared to the present-day interannual variability, according to a few site-specific studies.

[7] Cycle of alternate El Niño and La Niña episodes that govern climate and sea-level variations around the Pacific and Indian Oceans—commonly called the El Niño–Southern Oscillation or ENSO system.

[8] Longer "El-Niño–like" 20–30 year cycles of alternate positive and negative phases that effect the wider Pacific Ocean region, abbreviated as IPO. Since 1998 the IPO has been negative.

2.7 Drought and Fire

Droughts are expected to become more frequent in all regions considered except near the Hokitika site. A drought sufficiently severe to be ranked as a 1-in-20 year event under the present climate is likely to occur as frequently as every 5-10 years by the 2080s at all sites (except Hokitika).

Corresponding increases in **fire risk** are also considered likely over much of the country. Days per year of very high or extreme forest fire danger could increase by more than 50% by the end of the century at Christchurch and some other east coast locations.

Changes in drought risk are related to a combination of changes in evapotranspiration and precipitation. Reduced rainfall is likely to increase the risk and severity of drought, particularly if the rain falls less evenly over time (i.e. falls on fewer days).

The maps – from a NIWA report on changes in drought risk under global warming (Mullan *et al*., 2005) – show changes in potential evapotranspiration deficit and how the frequency of a present-day 1-in-20 dry year changes. For grey-shaded regions of the map, the 1-in-20 year 'drought' either becomes *less* frequent or can not be estimated because the current climate is too wet. In coloured regions there is an increase in the frequency of drought years.

For all sites except Hokitika, dry years become more frequent. For example, at Tauranga a current (actually 1972 – 2003) 20-year drought is projected to occur about once in 10 years during the 2030s.

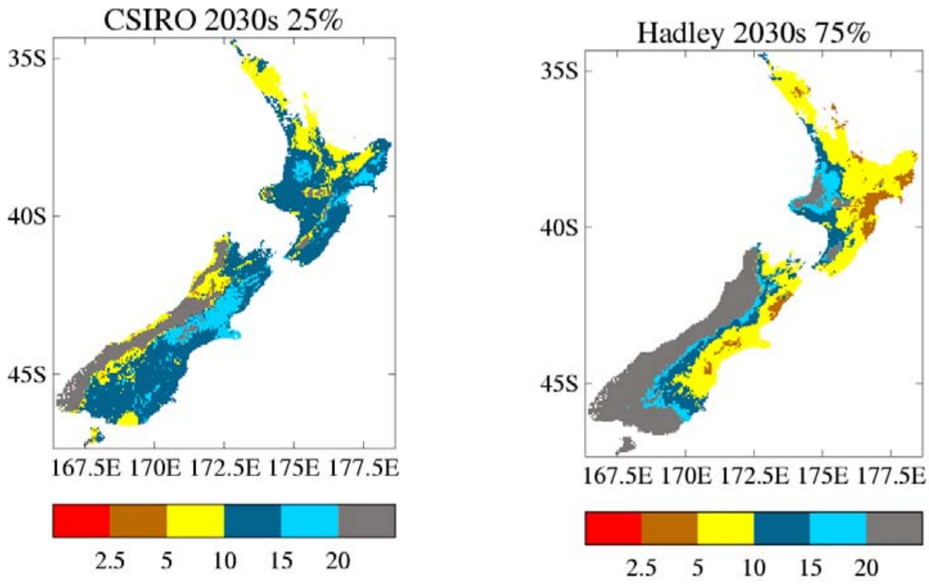

Figure 6: *Projected recurrence intervals (years) for the driest annual conditions that currently occur on average once every 20 years. The left hand figure shows the mildest scenario outcome (25% of the IPCC range) and the right hand figure the more severe (75%) for the 2030s time frame.*

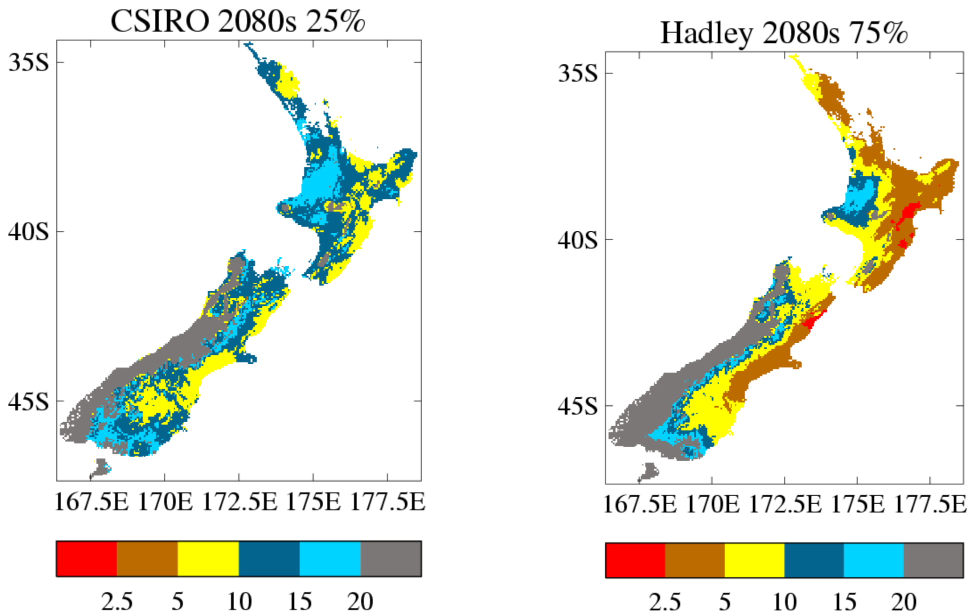

Figure 7: *Projected recurrence interval (years) for the driest annual conditions that currently occur on average once every 20 years, for low change and high change 2080s scenarios.*

2.7.1 UV Radiation

The stratospheric ozone layer is gradually recovering and is expected to be fully recovered by the end of this century.

Levels of ultraviolet radiation are expected to be about 5% lower by the 2030s compared to the peak levels of the late 1990s, due to gradual recovery of the stratospheric ozone layer; a further 2% reduction back to pre-1980 levels is expected to occur before the 2080s. Even with full ozone recovery, New Zealand UV levels will remain higher than at corresponding latitudes in the Northern Hemisphere.

2.8 Projections with Large Uncertainty or Small Changes

2.8.1 Wind and Cyclones

Tropical cyclones form over warm tropical seas in the Southwest Pacific. As the storms move southward towards New Zealand latitudes later in their lifetime, they undergo a transition with injection of cooler air, and are then known as ex-tropical cyclones.

Under climate change arising from increasing greenhouse gas concentrations, the change in *frequency* of occurrences of tropical cyclones is uncertain, but there is growing evidence that tropical cyclones will increase in *intensity*. On average a greater percentage of tropical cyclones will be in the higher strength category.

It is likely that there will be some higher intensity ex-tropical cyclones producing larger storm impacts as the 21^{st} century progresses.

Recent work suggests a decrease in the frequency of *extra*-tropical (mid-latitude) storm centres passing over the North Island in winter, with a corresponding increase in frequency south of New Zealand.

Changes in future storminess over New Zealand are still very difficult to quantify. The frequency and intensity of ex-tropical cyclones that might affect New Zealand is still quite uncertain. Only recently has some sort of consensus started to emerge of the implications for New Zealand. The most robust feature is for poleward movement in storm tracks, which has its most marked effects in the winter season – whereas in the current climate, the westerly wind belt and embedded storms tend to move northward to lie across New Zealand.

Projected wind gust changes are mostly in the range 0 to +2 m/s, so the magnitude of the change is well below the difference between the Wellington gust and the design gust for other places, and is therefore not expected to be of great consequence for building design[9].

2.8.2 Combined Wind and Rainfall

Wind driven rain can damage buildings or their contents and cause erosion. The amount of rain driven on a vertical surface is proportional to the product of the rainfall on a horizontal surface and wind-speed normal to the surface. Projected driving rain changes are uncertain, with increases in driving rain indices expected to be limited to about 10% higher than at present by the 2080s.

2.8.3 Hail

According to the IPCC Third Assessment (IPCC, 2001c), future changes in hail and lightning frequencies are uncertain. McMaster (1999) developed an index of hail occurrence for New South Wales, and applied it to simulations of future climates by three climate models. The models all agreed on the direction of change – an increase in hail occurrence – but the magnitude of the increase was very modest and within the current climate uncertainty that occurs as a result of large year-to-year variability in observed hail losses.

2.8.4 Relative Humidity

A small reduction in mean relative humidity is possible, but we would not expect this to be more than 2% by the 2080s (for a corresponding temperature increase of about 2°C).

2.8.5 Solar Radiation

Future changes in total solar radiation are expected to be small, within ±2% seasonally and tending to cancel over the year, for most sites. At Hokitika, larger reductions of up to about 5% are projected in winter and spring, because of the significant rainfall increases there under the scenarios considered.

2.9 Summary

Climate elements where we have the most confidence in expecting to see New Zealand changes are: maximum and minimum temperatures, sea level, drought and fire risk, and UV radiation. For a number of other elements (wind, storms, hail, solar radiation), the future projections are either uncertain or appear likely to be within the current range of interannual variability at most sites. There is also a general expectation of increased rainfall extremes, but further research is required before we can be confident about differences between regions.

[9] It shall be noted that projections for strong winds vary between little change up to double the frequency of winds above 30m/s by 2080s in MfE (2004b). However, there is low confidence in the projections.

3. VULNERABLITIES AND PROJECTED IMPLICATIONS

Here we assess the vulnerability of New Zealand's built environment and housing sector based on the climate change projections presented in the section *Climate Change Scenarios for New Zealand* above. The focus of this report is mainly on housing, since it the largest part of the capital stock. However, the non-residential building stock is also briefly considered. Among the expected climate change impacts on houses; indoor overheating due to a warming climate is assessed in more detail. In this section vulnerability to indoor overheating is analysed identifying three typical housing configurations and performing computer simulations of indoor temperature and heating/cooling energy consumption in a range of climate change scenarios.

First we provide an overview and condition assessment of the national buildings stock. Second we present results from the simulations of indoor overheating and energy consumption in different house configurations. In the third part of this section the social impacts from climate change are analysed.

Vulnerability is considered to be a function of exposure to climate factors, sensitivity to change, and capacity to adapt to that change. For example, building elements that are highly exposed, sensitive and less able to adapt are the most vulnerable.

3.1 Building Stock Analysis

The building stock analysis includes the typology of the stock describing the value of the segments, then details of the housing stock including numbers, location, and other characteristics that are relevant to adaptation.

3.1.1 New Zealand's Built Environment

Housing is the main capital asset with a replacement value of approximately $150 billion in 2001 dollars. Non-residential buildings are smaller but still large at approximately $70 billion, followed by civil engineering structure (roads, bridges, other transport faculties, water/ sewage/ waste disposal, telecom and energy infrastructure) at $50 billion. *Figure 8* shows the capital stock as at March 2003. More recent data is not available at the time of writing.

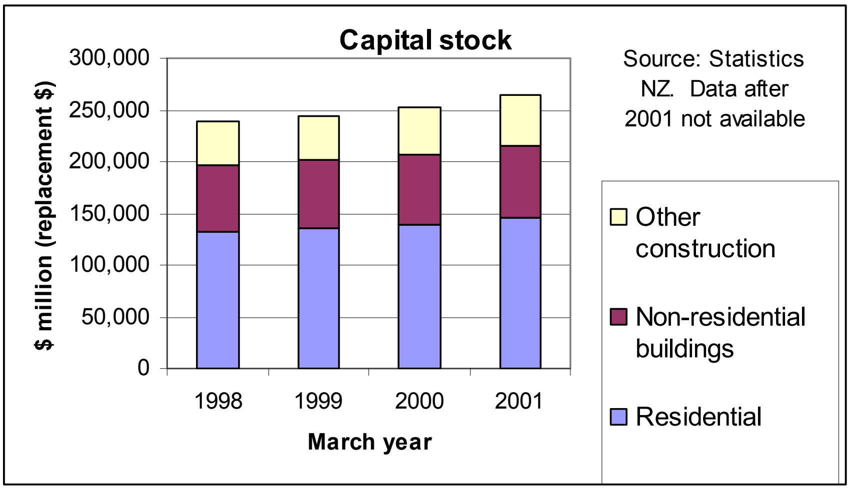

Figure 8: *Capital stock by type*

This section provides details of the housing stock:

- Housing stock by type, age group and numbers
- Average housing floor area by age group.
- Floor storey distribution

- Foundation types
- Wall and roof cladding types
- Ceiling insulation
- Selected component condition

The choice of these details is they are relevant to adaptation of the housing stock to climate change. Housing numbers and location enables regional changes (in temperature, wind, rain, etc) to be matched with the number of houses affected. Floor level distribution, foundation types, and cladding types are relevant to flood and wind gust impacts, and ceiling insulation and age group are relevant to insulation retrofit. Component condition of wall and roof cladding and windows provides data on the likelihood of replacement and hence the opportunity to upgrade for climate change. All this data is also relevant to the timing and type of climate change adaptation measures to be used.

3.1.1.1 Housing stock by type, age group and numbers

The housing types and numbers for selected territorial authorities are shown in *Table 3* below. The same data for all TAs is in the Appendix H.

Nationally 80% of housing is stand-alone, and multi-units are another 19%, most of these being low-rise.

Multi-unit housing mainly occurs in the major cities, and high-rise construction is almost all totally concentrated there. The bach/ crib category are simple dwellings (no separate kitchen/ bathroom) usually 1 to 2 rooms and occur mainly in holiday destinations. They are diminishing in number as they are upgraded to normal dwellings and are not considered to be candidates for climate change adaptation. In contrast, normally unoccupied holiday homes, (and other unoccupied housing), that are similar to normal housing, are included in the stand-alone houses category because their use may change in the future to a normally occupied dwelling.

Table 3: *House stock types by selected TA*

Housing type stock data for selected territorial authorities

	Dwelling number Total	Percentages: Stand-alone house	Low rise multi-unit (1)	Med-hi rise multi-unit (2)	Bach/ crib	Total
Far North	21786	86	12	0	3	100
North Shore	67821	77	22	1	0	100
Auckland	133848	65	29	6	0	100
Manukau	82815	81	19	0	0	100
Hamilton	42066	82	18	0	0	100
Tauranga	37158	80	19	1	1	100
New Plym	26181	85	15	0	0	100
Wellington	64152	66	26	8	0	100
Tasman	16761	86	11	0	3	100
Christch	124497	75	24	1	0	100
Queenstown	9777	69	26	1	3	100
Dunedin	45270	81	18	1	0	100
Total NZ	1435326	80	18	1	1	100

(1) Low rise are 2 storeys or less
(2) Medium/ high rise are 3 or more storeys.

The dwelling stock numbers from the 2001 census were approximately 1,435,000 as at March 2001, including both occupied and unoccupied permanent private dwellings. This includes rental housing such as that owned by HCNZ and local authorities, as well as private landlords.

Houses constructed in the 1910s and 20s are larger than those built in the 1940s and 50s including subsequent additions, and more recently average house sizes have increased markedly. Approximately 70% of houses are in the 100 to 200 m^2 floor area range.

The age distribution is shown in the *Figure 9* and the numbers from the chart are in *Table 4*

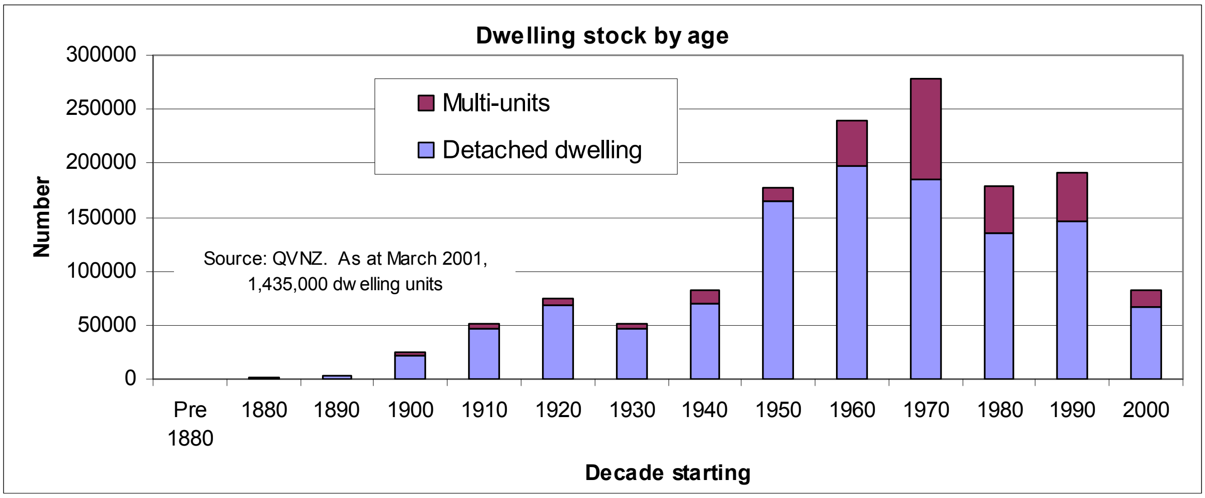

Figure 9: *Dwelling stock by age group*

Table 4: *Dwelling type per age group.*

Dwelling stock numbers			
		Numbers	
	House	Multi-units	Total
Pre 1880	483	56	539
1880	1,295	96	1,390
1890	3,083	521	3,604
1900	21,639	2,873	24,512
1910	46,699	4,601	51,300
1920	69,068	5,828	74,896
1930	46,347	4,856	51,203
1940	70,582	11,411	81,992
1950	164,036	13,193	177,229
1960	197,710	41,879	239,589
1970	185,445	92,316	277,761
1980	135,563	43,059	178,622
1990	146,364	44,371	190,734
2000	66,255	15,697	81,951
	1,154,567	280,756	1,435,323
Source: QVNZ, and 2001 census			

3.1.1.2 Dwelling Stock by Floor Area and Storey Level Distribution

The average floor area sizes of housing are shown in *Figure 10* and *Figure 11*. The storey levels distribution is shown in *Figure 12*.

Houses with an upper storey are relatively common in detached housing, with 45% of houses having an upper level. In contrast, multi-unit dwellings have a high percentage that are only one storey. *Figure 12* indicates that over 70% of all multi-units are in single storey blocks. This reflects the large building programme of “linear” type units built by both Government and private landlords in the 1960's and 1970's. In the last 3 or 4 years "vertically attached" units have outnumbered "horizontally attached" units by about 3 to 1, but in earlier years single storey and other low rise units far out-numbered medium and high-rise multi-unit construction.

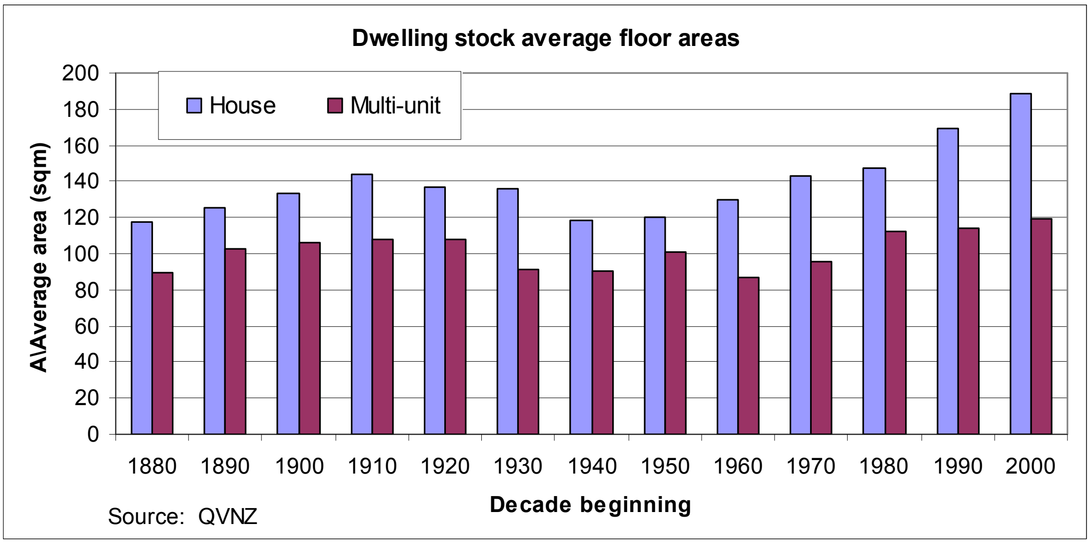

Figure 10: *Housing average floor area*

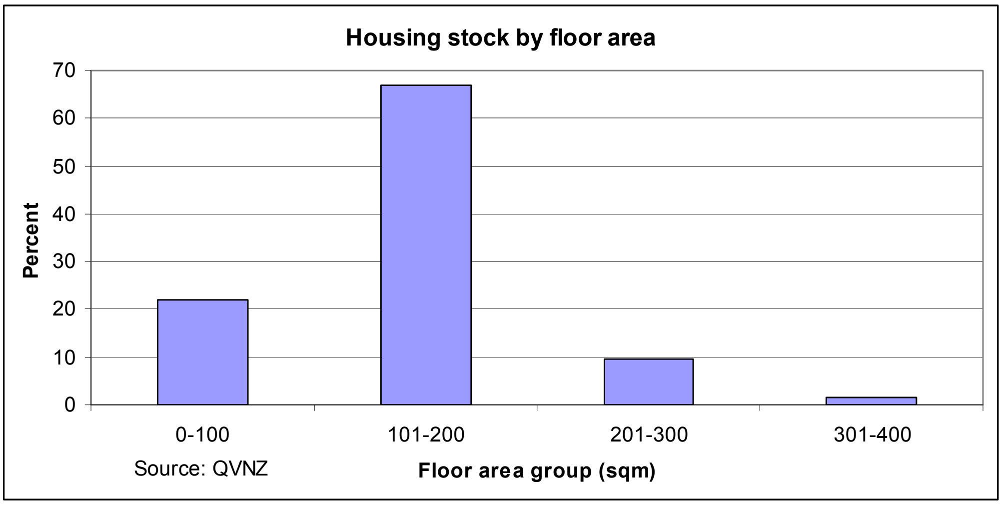

Figure 11: *Housing floor area distribution*

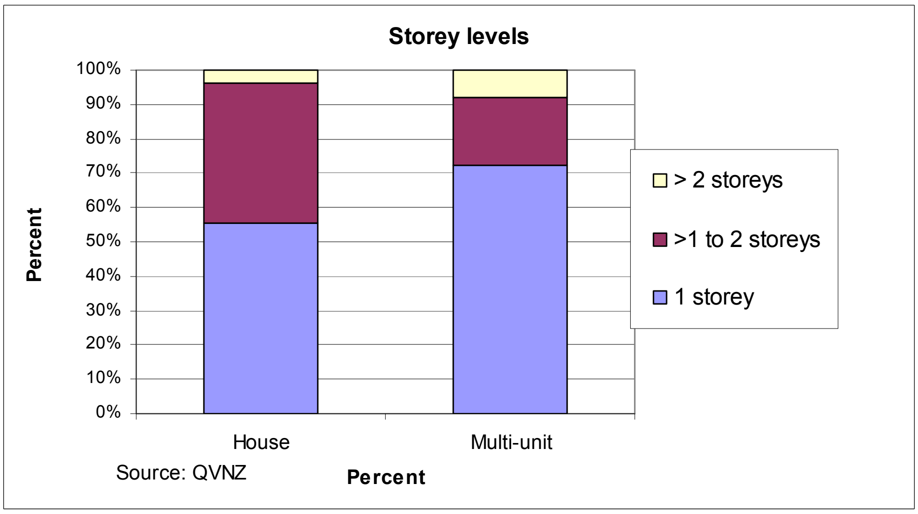

Figure 12: *Housing storey types*

3.1.1.3 Foundation types

Concrete floor slab construction now occurs in over 92% of all new detached housing but it is a comparatively recent flooring method, see *Figure 13*. Prior to the 1980's most new housing was on a suspended timber floor. The total percentage of the stock on a concrete floor is approximately 27%, so the remaining 73% has timber foundations and suspended timber ground flooring. The ground clearances in timber floor houses are quite low for some age groups, see *Figure 14*.

Prior to the first building standard in the 1940's the average ground clearance to the wall cladding is only 100 to 200 mm, whereas more modern houses are over 300 mm. This has implications for the existing stock on flood plains.

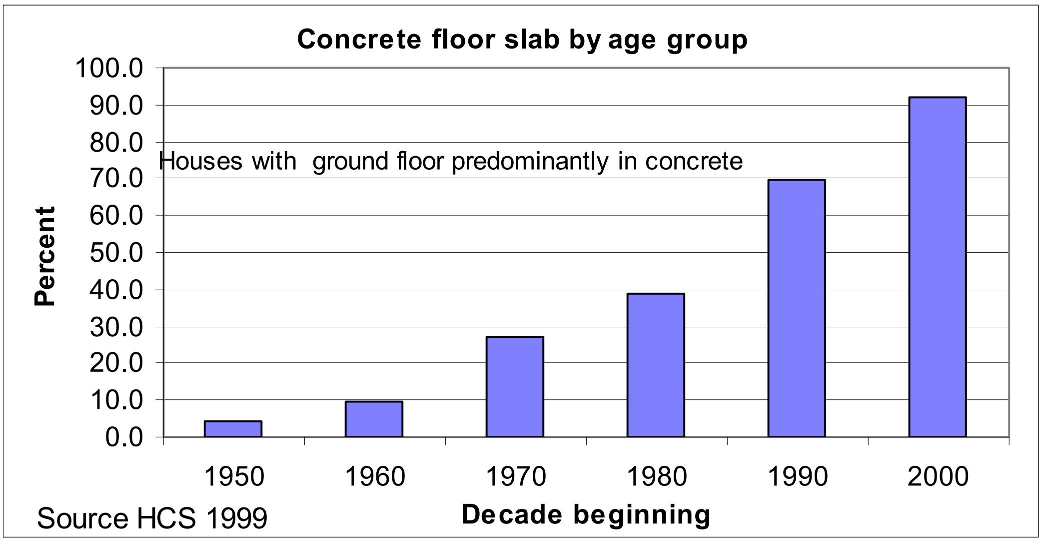

Figure 13: *Concrete slabs in houses*

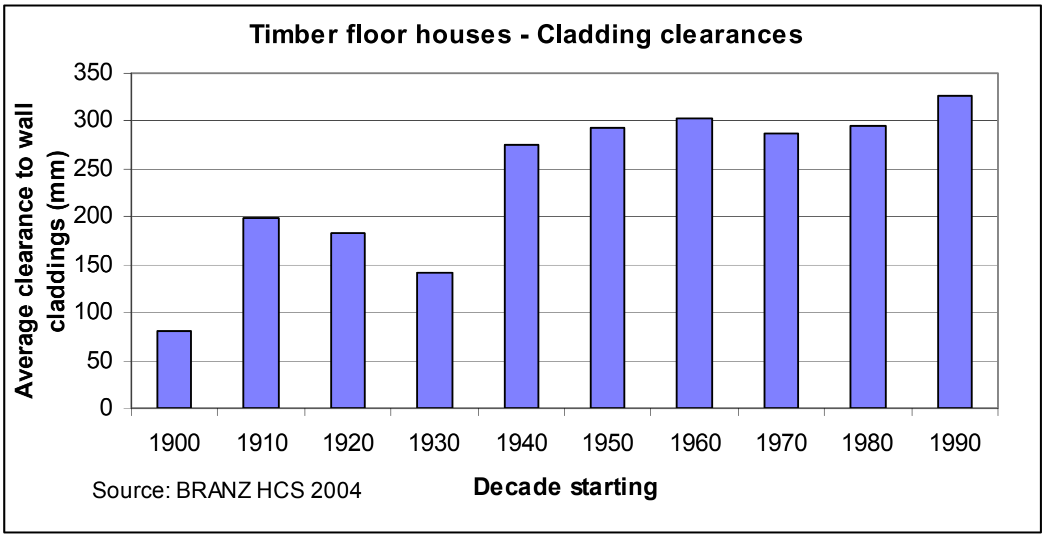

Figure 14: *Clearance to timber floor houses*

3.1.1.4 Types of Wall and Roof Cladding

The types of wall and roof claddings in the housing stock are shown in *Table 5* and *Table 6*. For all ages combined the predominant claddings are clay brick for walls, and sheet steel for roofs. Timber almost all weatherboard, while fibre cement is mainly sheets, with some planks.

The high percentage of timber occurs in earlier years and may be an issue due to more wind driven rain from climate change, particularly as building paper prior to the 1960s will have deteriorated in many houses.

Table 5: *Wall cladding in housing*

Wall cladding materials by Age						
			Percentage			
Decade	Brick/Block	Timber	Stucco	Fibre Cement	Other (1)	Total
1890	0	100	0	0	0	100
1900	0	91	0	7	2	100
1910	1	84	6	7	1	100
1920	4	80	7	7	2	100
1930	7	77	8	8	0	100
1940	15	49	24	10	1	100
1950	27	54	7	8	3	100
1960	42	44	1	10	2	100
1970	40	31	0	25	4	100
1980	39	22	3	31	6	100
1990	38	13	13	18	18	100
2000	53	8	31	0	8	100
Total	32	40	7	15	5	100

Source: House Condition Survey, 1999 and 2004
(1) Includes sheet steel, stone, PVC weatherboard, earth brick, coated polystyrene, etc)

Table 6: *Roof cladding in housing*

Roof cladding materials by Age group							
			Percentage				
Decade	Metal tile	Conc tile	Clay tiles	Membrane	Sht steel	Other (1)	Total
1890	11	0	0	0	89	0	100
1900	0	2	0	5	93	0	100
1910	10	0	3	2	81	3	100
1920	12	2	3	3	72	8	100
1930	18	8	3	2	55	15	100
1940	9	43	4	3	30	11	100
1950	10	45	2	1	38	5	100
1960	15	21	1	1	59	3	100
1970	30	38	0	3	29	1	100
1980	28	27	1	3	39	2	100
1990	27	25	0	8	39	0	100
2000	26	39	3	5	21	5	100
Total	20	28	1	3	44	3	100

Source: House Condition Survey, 1999 and 2004
(1) Includes shingles, fibre cement corrog., Onedulin, copper sheet, etc.

3.1.1.5 Ceiling insulation

Ceiling insulation from the 2004 House Condition Survey is shown in *Figure 15*. The survey covered metropolitan and rural areas adjacent to the three main cities, but other regions were not covered and the amount of insulation retrofit outside the three centres is not known. However, it is likely that the amount of ceiling retrofit will be lower than in the main centres. Most retrofit campaigns have focused on the cities, rather than rural towns though there are exceptions such as Northland and East Cape regions where EECA has funded community retrofit projects. Also Housing New Zealand Corporation is well underway in the retrofit of its rental stock of over 65,000 houses.

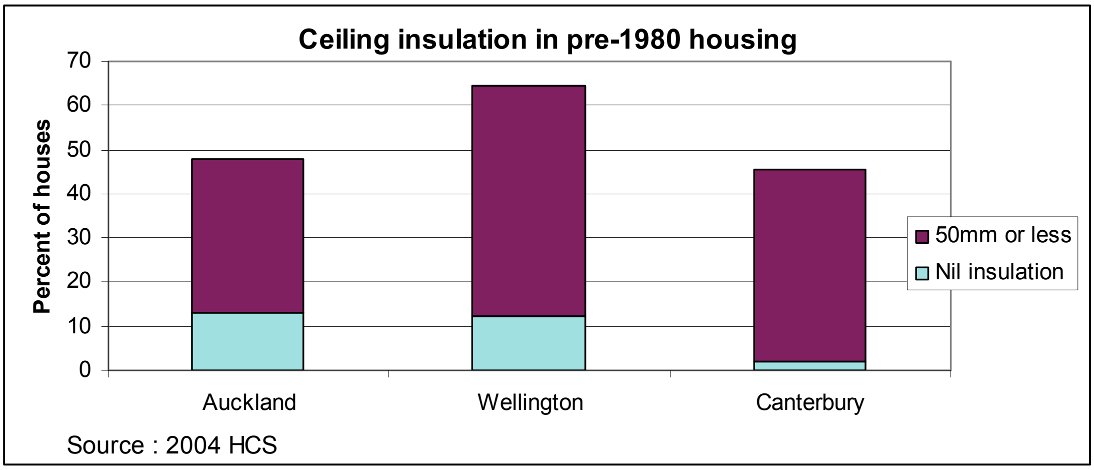

Figure 15: *Ceiling Insulation in houses*

3.1.1.6 Selected component conditions

The condition of selected components, from the 2004 HCS, is shown in *Table 7*. The percentage of houses with components in poor and serious condition gives an indication of the need for major maintenance within two years or less.

Table 7: *Condition of selected house components*

Components in Serious or Poor condition 2004 HCS			
Decade	**Percentage of houses**		
starting	Windows	Walls	Roof
1900	29	6	18
1910	20	10	20
1920	20	8	14
1930	31	31	15
1940	26	7	7
1950	16	9	4
1960	11	2	17
1970	5	6	8
1980	5	3	3
1990	0	5	2
2000	0	6	0

In many of these cases the option is to replace the component rather than repair, in which case there is opportunity to provide wall insulation and double glazed windows in the case of the wall cladding and window components, and provide stronger fixings for roof claddings, and install ceiling insulation for skillion roofs and other hard-to-access roof spaces.

3.1.1.7 Wind gust modelling, flooding and coastal erosion.

The above data indicates that sheet metal and concrete tile roofing are the most common claddings. The table in Appendix C shows house numbers by territorial authorities, and can be used to identify the house numbers in areas more likely to experience increased wind gusts. The same data, and the floor type, floor height data above can be used to assess numbers of houses affected by increased flooding, and coastal erosion, though this will be on a case study basis since the NIWA report does not include these impacts.

3.1.1.7.1 Non-residential building characteristics

The stock of non-residential buildings, by type of building, is shown in *Figure 16*. The main source for this chart is a stock model developed by BRANZ based on building consents. It was checked against the QVNZ database and gives approximately similar results, considering that the latter does not appear to pick up all buildings, particularly Government owned buildings. The chart provides floor area data and indicates that industrial type buildings (warehouse, factory and farm) are by far the largest segments. These three types are usually fairly short lived and simple buildings. In most case the owners would demolish them if they became unusable due to climate change impacts. Hence it was decided that industrial buildings can be ignored for climate change adaptation and that institutional (hostel, health, education, social/ cultural) and commercial (hotel, retail, office/ administration) buildings are more likely to be affected. Non-residential buildings are not examined further in this report, however, many of the impacts that apply to housing will also affect non-residential buildings.

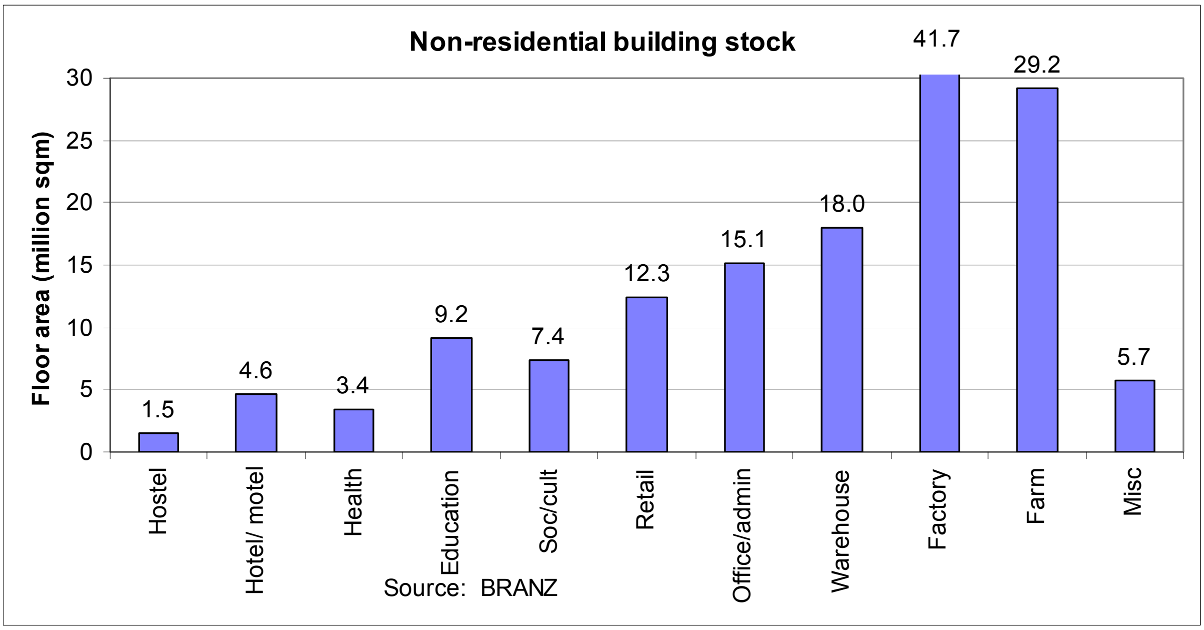

Figure 16: *Non-residential buildings by type*

3.2 Thermal Comfort and Energy Consumption

3.2.1 Introduction

The objective of this section is to investigate how climate change will affect user comfort and energy usage within the New Zealand housing stock.

The results from a number of scenarios simulated with the SunRel software modelling tool are presented and discussed. The simulations were performed to gain insights into how climate change will affect user comfort and energy usage within the New Zealand building stock. Further, the simulations form the basis for the cost benefit analysis of adaptation options to reduce vulnerability to temperature increases in section 5.1.

In total 540 simulations were run and analysed to provide an overview of how climate affect the New Zealand building stock, based on extremes (lowest and highest) of weather data. Comprehensive specification of the different house configurations simulated is provided in Appendix D. Simulations were performed for:

- Five climate scenario's were simulated (including present day);
- Three New Zealand locations (Auckland, Wellington and Christchurch);

- Three house sizes and types;
- New and existing houses;
- Three insulation/glazing options; and
- Two window shading options.

3.2.2 Summary

The results of thermal simulations with combinations of house sizes and configurations show that thermal comfort can be maintained and improved along with significant energy savings in all investigated climate change scenarios by adapting existing houses or designing new with:

- Window shading;
- Insulation of roof, floor and walls (code compliant or better);
- Natural ventilation; and/or
- Double glazing (or further advanced performance with e.g. low-e argon filled windows).

As expected, the large house configuration has by far the highest energy usage and the largest potential to lower energy usage through better design. Of the three main centres explored Christchurch has – and is expected to continue to have – higher energy consumption per house compared to Auckland and Wellington.

3.2.3 Thermal Modelling Set-up

3.2.3.1 House Configurations

Based on the *Building Stock Analysis* section above the following characteristics are found to represent a large portion of the building stock:

- 100 to 200 m2 floor area range, with one larger than 200 m2 to allow for modern houses.
- At least one house type with an upper floor.
- Timber floor: pre-1970 houses account for about half the stock and almost all are on a timber floor.
- Clay brick and weatherboard (timber or fibre cement): by far the most common claddings.
- Approximately 50% of pre-1980 houses have 50mm or less of ceiling insulation, and almost all have no wall or under floor insulation.

Appendix D gives the full details on house types and configurations used for the thermal simulations

3.2.3.2 Climate Scenarios

Scenarios with the most relative variance were chosen from the Hadley and CSIRO climate simulations and compared to present day climate data (PD06). The Hadley model yielded the most moderate climate changes when based on the 25th percentile of the full IPCC temperature range for both the 2030s and 2080s (H325 and H825). The CSIRO model produced the largest changes from present day climate when using the 75th percentile of the full IPCC range for the 2030s and 2080s scenarios (C275 and C875).

3.2.4 Thermal Simulation Results

The full set of graphs and results can be found in Appendix E: *Thermal Simulation Result Graphs*. The graphic results presented in the section below are illustrative samples, and are not selected to show extreme results in any direction. Conclusions and general comments are based on the full set of simulation results.

All results – here and in Appendix E – show heating and cooling loads modelled on inefficient heating and cooling equipment. With a heat pump the electric energy would be about 1/3.

3.2.4.1 Window Shading and Insulation

A particularly effective approach to lower energy requirements for cooling is use of window shading on sunnier (North) sides of houses.

All house types simulated have better thermal performance with **window shading**, see *Figure 17*.

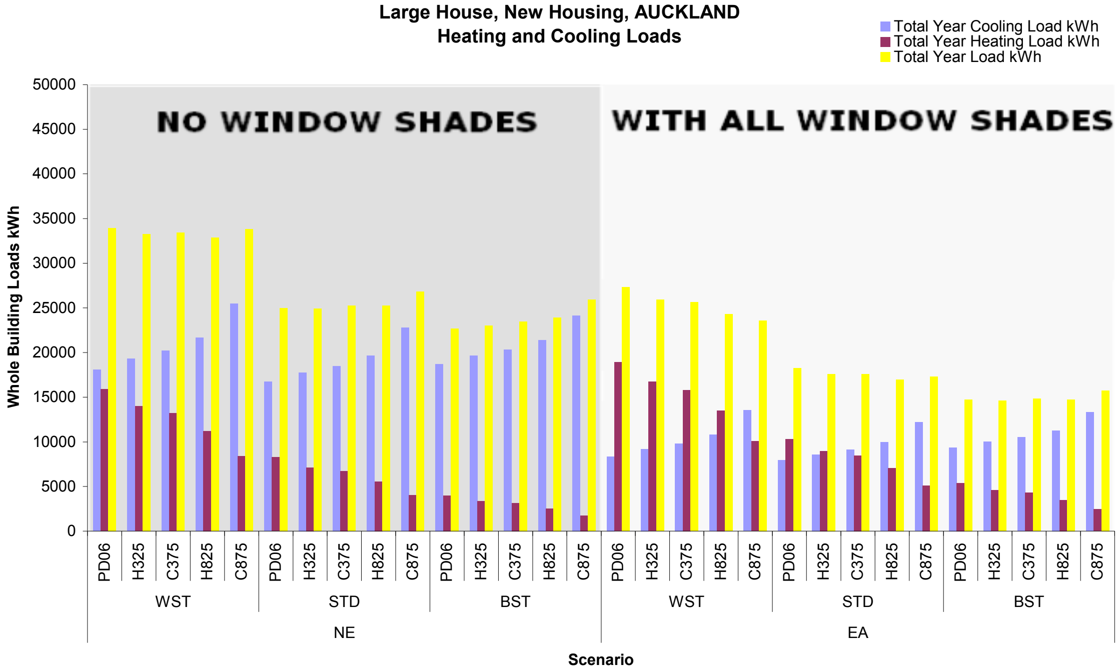

Figure 17: *Reduced energy consumption for cooling through improved insulation and window shading in large new house in Auckland climate. Energy consumption is compared for with and without window shading; three different insulation levels10. Note: the drawback of marginal increase in heating energy can be eliminated though variable-shading options, as the simulated Total Year energy consumption is based on static year-round shading.*

It is better to have higher level of insulation rather than basic code compliance or none at all. However the marginal benefits between the highest possible levels of insulation compared to standard code compliant insulation were relatively low even when simulated for 100 year climate change scenarios. *Figure 18* shows simulated energy consumptions over three insulation and shading options.

Significant energy savings can be achieved by improving from none to standard **insulation** in floor, wall, and ceiling.

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10 *Worst insulation*/glazing option with current code compliant insulation levels in floor, wall and roof with single glazed windows = **WST**; Standard housing with proposed new code compliant insulation for 2007 with higher insulation levels in floor, wall and roof and double glazed windows = **STD**; Best practical insulation levels with today's technology in floor, wall and roof and low 'e' double glazed argon filled windows = **BST**.

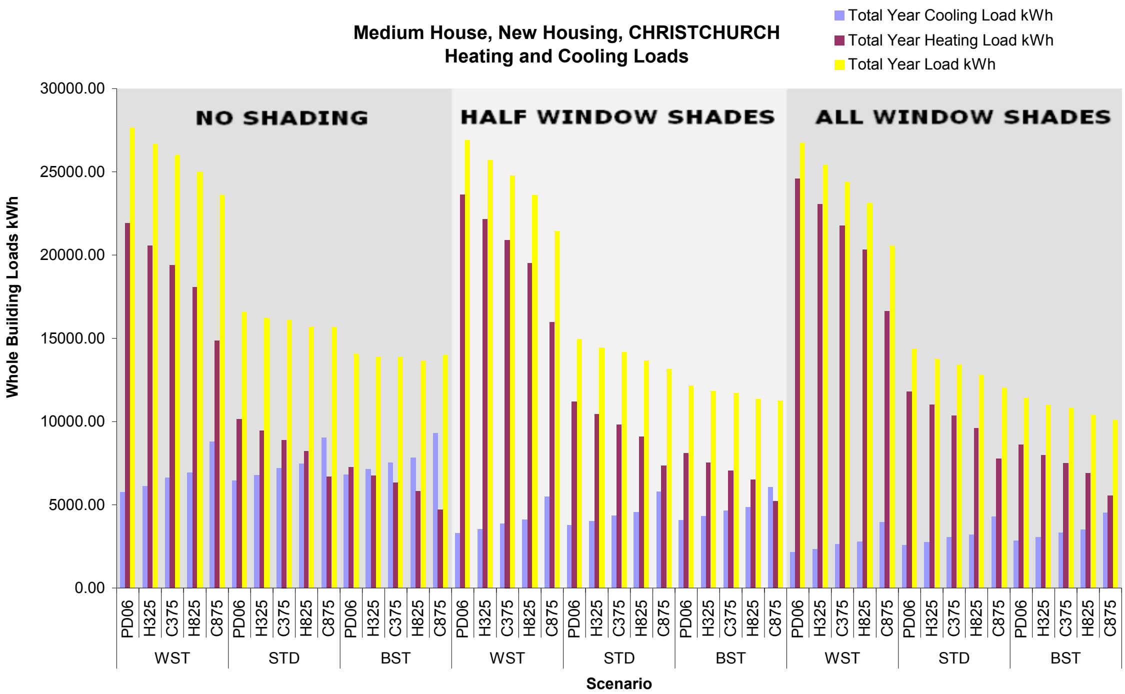

Figure 18: *Reduced energy consumption for cooling through improved insulation and window shading in medium sized new house in Christchurch climate. Energy consumption is compared for with and without window shading; three different insulation levels*[11] *Note: the drawback of marginal increase in heating energy can be eliminated though variable-shading options – as the simulated Total Year energy consumption is based on static year-round shading.*

3.2.4.2 Natural Ventilation Cooling

Simulations were run both with and without simulating the effects of open windows to give an idea of the difference in energy loads. Using **natural ventilation** (e.g. opening a window) can avoid resorting to mechanical cooling (e.g. air-con units) and still keep houses within the acceptable comfort range during summer (18 – 25ºC)[12] through all investigated climate scenarios. It is recognised that most New Zealand houses today typically use natural ventilation as means of space conditioning.

Simulations demonstrate that energy loads for cooling can be reduced by up to 25 – 50% through simply cooling through natural ventilation, compared to resorting to exclusively mechanical cooling.

Figure 19 shows simulated reduced indoors summer temperatures for existing medium sized houses in Wellington over a variety of window shading options and insulation levels. *Figure 20* shows corresponding reductions in cooling load.

[11] *Worst insulation*/glazing option with current code compliant insulation levels in floor, wall and roof with single glazed windows = **WST**; Standard housing with proposed new code compliant insulation for 2007 with higher insulation levels in floor, wall and roof and double glazed windows = **STD**; Best practical insulation levels with today's technology in floor, wall and roof and low 'e' double glazed argon filled windows = **BST**.

[12] See Appendix D for the rational behind the choice of comfort temperature range.

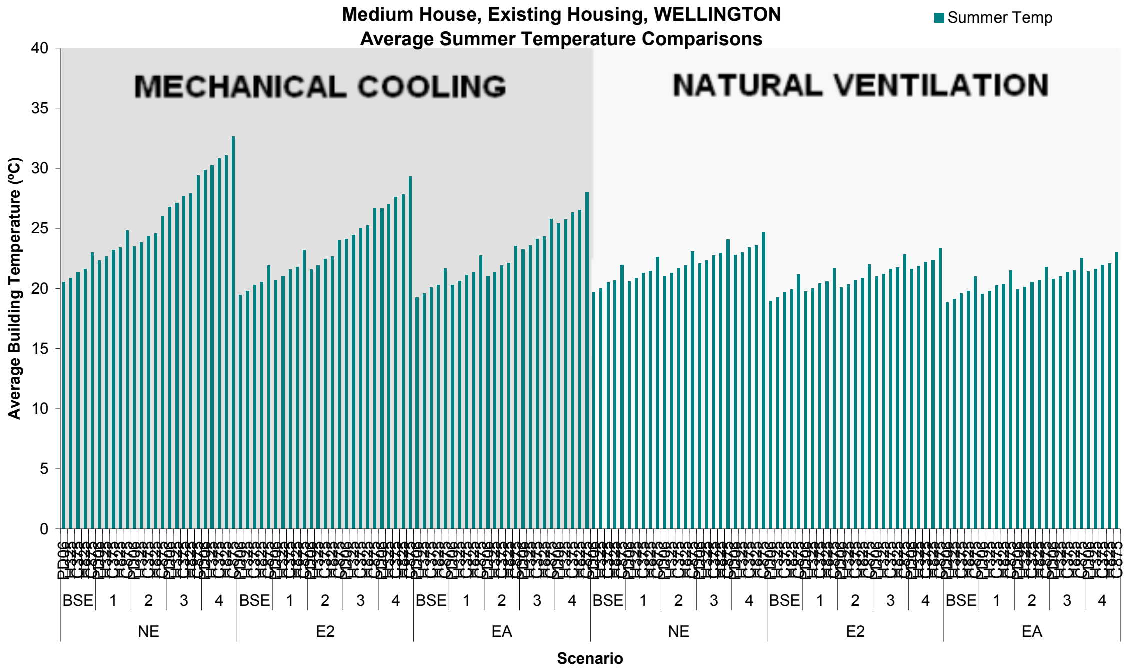

Figure 19: *Reduced average indoor summer temperature through natural ventilation for existing houses in Wellington climate. Temperatures are compared for all windows (EA) sunny-side windows (E2) and without (NE) window shading; four different insulation levels*[13]

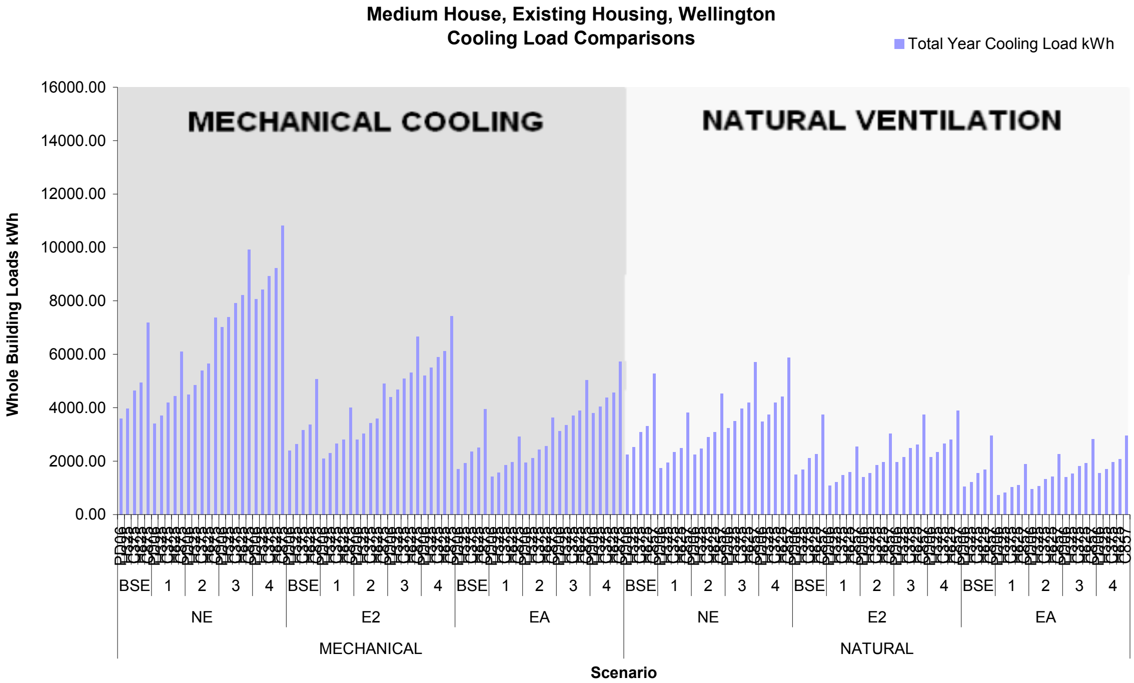

Figure 20: *Reduced cooling load through natural ventilation for existing houses in Wellington climate. Cooling loads are compared for all windows (EA) sunny-side windows (E2) and without (NE) window shading; four different insulation levels.*

The results from the simulations above must be interpreted with care. For example, one possible effect of following the graphs would be to put in window shading, which will *increase* energy demand, because of more heating energy demand, but no less cooling energy, since it isn't generally used anyway. A more sensible interpretation would be to recognise that acceptable summertime comfort can, and is, largely achieved through behavioural adaptation rather than

[13] No insulation, single glazing = **BSE**; Ceiling Insulation only, Double Glazing = **1**; Ceiling and Floor Insulation only, Double Glazing = **2**; Ceiling, Wall, Floor Insulation, Double Glazing = **3**; and Best Ceiling, Wall and Floor Insulation, Double glazing with LowE+argon, therm break aluminium frame = **4.**

through energy consuming mechanical means. These results are further quantified in the economic analysis in section 5.

3.2.4.3 Glazing Options

Across all regions and new and existing housing, there is a significant drop in energy usage when comparing single **glazing** to standard double glazing or higher.

For new housing, (both medium and small) there is up to approximately a 30% drop in energy requirements for both heating and cooling when moving from single glazing to double glazing. Additional energy saving potential at the magnitude of 10 – 15% will be achieved with double glazed, low-e, argon filled windows compared to standard double glazing[14]. Note: the simulated Total Year energy consumption in *Figure 21* below is based on static year-round shading with the drawback of marginal increase in winter heating energy. There is little difference in total energy requirements for heating and cooling[15].

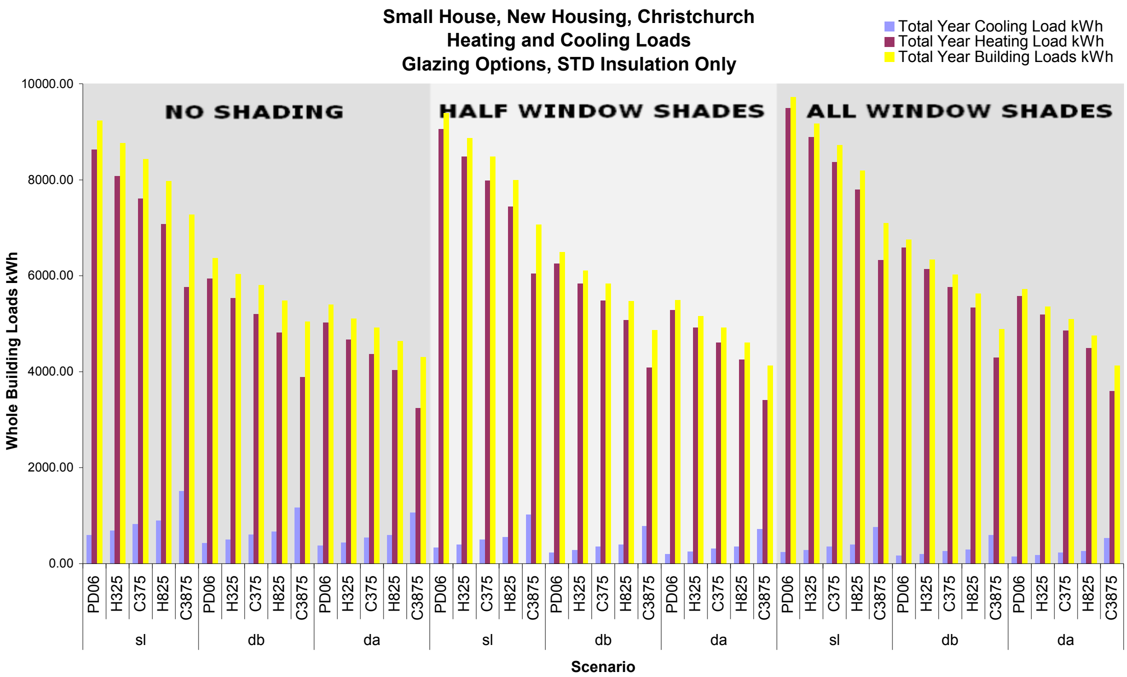

Figure 21: *Reduced heating load through improved glazing (single = si, double = db and double glazed, low-e, argon filled windows = da) in Christchurch climate. Energy consumption is compared for different window shading. Note: simulation done with year-round fixed shading, which increases heating energy load.*

Existing housing have similar results as for the above *new house* simulations, but with marginally smaller energy savings between single and double glazing (15 – 25%, depending on the location and house size). As for new houses there is less of a significant difference between *double glazed windows and double glazed, low-e, argon filled windows* (as little as 10%). Differences in window shading are difficult to gauge without further simulations looking at different shading angles during the course of the year.

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[14] There are a wide range of glazing options readily available, which include low-e solar control windows and tinted windows. However due to the large amount of simulation work required for the thermal analysis glazing variations were limited to three standard and representative variations – worst (single glazing), better (double glazing) and best (double glazed low-e argon filled windows).

[15] More work may need to be done here on awning angles, especially as the simulations were modelled on ones that could be moved depending on the angle of the sun during the course of the year but were modelled on one angle only.

3.2.5 Discussion of Results

Multi-variable thermal scenarios based on *medium-low* and *medium-high* climate change scenarios show that all types of housing in New Zealand will be negatively affected by climate change – in particular energy requirements for cooling (rather than heating as the climate is warming).

Without retrofit or new climate appropriate design, many New Zealand homeowners may find that temperatures (especially during summer) within their houses will increasingly be above the accepted comfort range (18 – 25ºC). The simulations show that comfort temperatures can be achieved as well as significant energy savings through each of the following:

- Window shading to at least half of the windows (particularly on the northern sides);
- Upgrading to double glazing or better;
- Upgrading to base insulation or better; and
- Maximised use of natural ventilation rather than use of mechanical cooling i.e. air conditioning.

On the basis of the simulations; incorporating at least double glazing into new housing and retrofitting into existing houses (with single glazing) can significantly reduce energy consumption in New Zealand homes. The modelled step to *double glazed, low-e, argon filled windows* does give additional energy savings, but of lower magnitude and at a higher material cost.

Window shadings can also play an important part of cooling interior spaces as the climate around New Zealand heats. Although on average this is expected to be only a few degrees, there will be a much higher demand for energy throughout the country. The use of window shadings on the sunnier sides especially will lower cooling loads.

The warmer climate means that there will be fewer cold days and somewhat warmer winters. Insulation has a significant impact on year-round energy consumption. The primary benefit is from reduced warming costs, and not so important for cooling energy demand.

Finally, homeowners should be encouraged to maximise the use of natural ventilation before the use of mechanical cooling i.e. air conditioning. This has been shown to keep average yearly temperatures within the acceptable comfort range and lower cooling energy requirements. Mechanical cooling would best be used as a fall back in extreme temperatures.

All of the above explored building techniques can provide energy savings and energy efficiency to reduce the risk of overheating. In the following section the economic costs and benefits are analysed in order explore economically optimal solutions.

3.3 Social Implications from Climate Change

This section is a summary; the full social study (McKernon, 2006) can be downloaded from BRANZ web page: www.branz.co.nz/branzltd/pdfs/ImpactsofCC.pdf

The aim of this section is to clarify the social impacts of climate change in relation to housing. Climate change will be one among a range of changes, be they political, social, cultural or economic. It also identifies key housing adaptations relating to climate and social changes. However, changes in one sector are likely to interact with other sectors, so making it difficult to specify exactly what social impacts will arise from climate change in New Zealand's future.

3.3.1 Background and Context

This section is based on a background of local and international research into social change in relation to sustainability, climate change/ global warming, and a number of related topics such as energy use and waste management. The research will be familiar to readers of social change literature and those in related industries, and a discussion of this extensive literature is not appropriate here. The following paragraphs intend to provide the context and background for the social impact analysis in this work:

- Empirical studies since the 1960s (Rogers, 1962) have detailed the dynamics of change in relation to the social impacts of industrialisation, and consumption in particular. These studies typically show different rates of response, and different responses, among different sectors of the community. That is, the social meanings and impacts of climate change can be expected to vary considerably, by community and over time. One result is the often-observed tensions between communities that adopt new ways of living, or adapt to changed conditions, and those that do not. We should not regard climate change as a single, timeless topic, nor that social change results in a smooth, unified process.
- Climate change/ global warming and sustainability are closely related. In the context of this report, climate change describes the effects of human activity on the environment, while sustainability describes what should be done about it, both in terms of mitigation and adaptation. That is, the topic of 'adaptation to climate change' is covered in the literature on sustainable behaviour change. While such topics are increasingly understood through the social sciences, they occur for the public as loosely-framed media and interpersonal communications about, for example, bad weather and 'being green'. Further, they arise conversationally – as topics of discussion – and are not framed as calls to action (Luhmann, 2002). So for example, people might explain unseasonable weather as climate change, but this brings no requirement to change anything about themselves or the house unless there's damage or tangible risk.
- In recent years a range of international and local studies[16] have shown awareness of climate change increase rapidly, and with this, an increase in attitudes favouring action[17], and a concern to find solutions for living. It might then be easy to assume house owners and the industries relevant to the housing sector (building and its sub-trades, finance, real estate, consumer products manufacturers, and local authorities) are starting to adapt housing to climate change issues –and some obviously are. A smaller set of studies have explored the specific meanings given to climate change and the specific behaviours that result. In fact, these show the well-known gaps between awareness, useful attitudes, and productive action applies to climate change adaptation as well. For example, research by EECA show how difficult it is to get most people to do something as simple as turn out lights or close curtains to save energy – after decades of energy-related campaigns. It follows that adapting to climate change might be a slow process.
- While the science of climate change strongly suggests it results from human activity, it makes no sense to people to attribute a particular flood or storm to one's lifestyle. That is, the systemic thinking required to grasp large-scale, diffuse, long-term issues such as climate change (or other social issues such as pollution, obesity, smoking-related cancer, and drunken driving) is alien to everyday ways of accounting for personal, day-to-day experiences and activities (Sterman and Sweeney, 2002). It is then very difficult to justify change when causes and effects (system dynamics) are not understood, when social norms in a consumer society encourage the status quo, and when any payoffs are diffuse and occur in a remote future. Asking people to change as an 'investment' in their future' only makes limited, short-term sense in the housing market, where most people change houses regularly and may not invest if they're not there to reap the benefits. Again, it appears likely adapting to climate change might be a slow process.

[16] A leading example is provided by Moxie Design Group (2006).
[17] The popularity of the film *An Inconvenient Truth* might illustrate this.

- Local and international communications strategists have developed significant responses to the issues noted above[18]. Four broad approaches are typical of these strategies, namely:
    - Allowing that impacts and changes co-exist and may undermine and/ or reinforce each other – so people need a 'road map' to know where they are, and a 'vision' to know where they're headed.
    - Thinking systemically about change – everybody participates in some way
    - Making change attractive, personal, stylish, and enjoyable – people can aspire to change and be rewarded by it.
    - Building new social norms – people need to have changes recognised and celebrated as the new status quo.

The sections that follow assume a slow rate of adaptation to climate change overall, arising from varied and evolving forms of adaptation, and from different rates among different communities. They therefore assume slow adaptation will give rise to a wide range of social impacts. However, the sections are also based on the likelihood that the New Zealand housing sector will work out how to communicate about climate change and will develop a range of programmes to influence sector behaviours.

3.3.2 Method

The Social Impacts study employs a scenario-building method to scope likely future societal and housing configurations, enabling it to then assess the range of likely social impacts of climate change[19]. The scenario-building method was chosen for its ability to analyse and represent complex changes in a coherent way. This study was carried out in four steps, namely:

1. Identify key climate changes, social impacts and house conditions[20].
2. Analyse changes and develop draft future scenarios using qualitative/ soft systems analyses (Checkland, 1981, Room and Britton, 2006)
3. Explore future scenarios with experts from diverse sectors to identify key impacts and adaptations, using 1-hour phone or face-to-face interviews (sector experts) and a brainstorming group (householders).
4. Detail key social impacts and housing adaptations with respect to climate change.

That is, the scenario method was used for its ability to integrated complex changes, and for the opportunities it afforded to analyse and crystallise key future social impacts.

3.3.2.1 Getting the problem right

A housing sector strategy for implementing housing adaptations to climate change clearly needs to be integrated with variables such as levels of adaptation among public and industry,

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[18] Foremost among local responses are those by Moxie Design Group and Mandarin Communications, while the UK Climate Change Communications Strategy provides a significant overseas example. Short versions are to be found in work by Futerra Sustainability Communications, see http://www.futerra.org/downloads/RulesOfTheGame.pdf and http://www.futerra.org/downloads/NewRules:NewGame.pdf. Sourced May 2007.

[19] Recent studies have explored the future of the housing sector and include climate change as a variable (Saville-Smith, 2000, Bates, Bayne, and Killerby, 2001, Bates and Kane, 2006). The findings of this study should be read in conjunction with those studies. To add value to their work, this study emphasised the perspective of experts from sectors *other than* housing to build a richer picture of the social impacts of climate change. Experts from the following sectors took part in the study: entertainment, urban planning, communications, housing, local authorities, public health, civil defence, telecommunications, community groups, security, aged care, and finance. A householder brainstorming group was also held to explore the impacts of social and climate change on housing from their perspective.

[20] Identified through studies by NIWA (Mullan *et al.*, 2006), MfE (Woodward *et al., 2001),* BRANZ (Clark *et al.*, 2005) and Statistics NZ (2006a, b, c, d).

population and sector growth, and regulatory inputs. But more importantly, any strategy needs to connect with the social (cultural, economic, political) dynamics of housing, both as a robust and effective way to proceed, and as a means of ensuring significant social outcomes.

It is important therefore to understand the 'right' problem in planning housing adaptations relevant to climate change, and in planning their implementation:

> The problem posed by this study is housing's relationship with social inclusion/ exclusion, as it is this which shapes what impacts are most likely to arise for a given house/ household, and the adaptations that become critical to quality of life.

This study assumes a household's ability to pay for existing housing is closely linked to their pre-existing vulnerabilities to climate and social changes, as well as their ability to pay for and implement adaptations. This view of the problem requires a link between social- and climate change adaptations: for example, the needs of a low income urban community and a wealthy coastal neighbourhood are clearly linked to very different sets of impacts and adaptations.

3.3.3 Study Findings

The key findings of this study are outlined below. First, the overall findings outline how exactly the social impacts of climate change are inter-twined with major social changes. Second, a more detailed analysis of social impacts suggests these will be powerfully shaped by dynamics of social inclusion and exclusion[21].

3.3.3.1 Climate change is only recently on the housing market radar

> For the householders, fear of intruders (burglars, home invasion, peeping toms) is much greater, more immediate, and has more social and housing impacts (including choice of neighbourhood and demand for security features) than fear of climate change.

In general both literature and expert sources suggest climate changes are given less importance and urgency in the public domain than many social changes, such as increases in crime, obesity and uses for technology[22]. The general reason is that these latter changes are evolving at a faster rate and are often more emotionally and physically tangible. This also makes them more immediate and more amenable to use by attention-seeking media and politicians. By comparison, the effects of climate change (as understood via extreme weather events) in relation to housing are transitory, localised ('somewhere else'), and usually disappear from the media after a few days.

3.3.3.2 Climate change promotes sector growth – and social tensions

> External pressures could have a much greater effect on New Zealand society and its housing sector than anticipated local changes.

The relatively benign impacts of climate change in New Zealand (compared to other countries) are likely to be a key driver of immigration. As climate change drives immigration, it also indirectly drives sector growth. One consequence of immigration is increasing ethnic diversity,

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[21] Social exclusion refers to when people are prevented from participating fully in economic, social and cultural life and/or when their access to income and other resources (personal, family, social and cultural) is so inadequate as to exclude them from enjoying a standard of living and quality of life that is regarded as acceptable by the society in which they live (EU 2001: 9, footnote 10).

[22] Climate change is however rapidly making its way into the mainstream media as an explanation for extreme weather.

and with this comes increasing social tensions. As housing in New Zealand is important to expression of social identities and status, this means tensions around neighbourhood location, house styles, and house features. Increasing social tensions direct social adaptations towards protecting identities and interests (such as choice of neighbourhoods, gentrification and security features), and may detract from climate adaptations. That is, climate and social adaptations will co-evolve, and not always in favour of adapting to climate change.

3.3.3.3 Sector dynamics limit adaptation

Concern over climate change is relatively low among both householders and industry, and all present indications suggest the sector will respond only slowly and inconsistently.

Housing is central to the economy (as a business sector as a householder investment, and as a key site for private consumption), yet is also highly vulnerable to externalities – such as global economic factors, the cost of capital, tax on capital gains, insurance sector policy in relation to housing, and local authority regulation. This means the sector's ability to develop a self-determined, coherent response to the social impacts of climate change may be limited. Direct regulatory and market interventions might be required to re-orient the sector and enable a consistent and proactive approach, but these can be expected to generate controversy and to apply in different ways across the country.

3.3.3.4 An ageing population highlights key social impacts

The ageing population modifies sector growth in two ways. First, older households are generally smaller (1 – 2 people) and may drive both renovation of existing houses and building of new ones[23]. Second, population ageing is a worldwide phenomenon so immigrants are likely to share an older age profile with the local population.

The evidence suggests older people's positive health outcomes are greater when they remain in their own home. The emerging social policy framework for *Ageing in Place* supports this, but one result will be an increase in age-related vulnerabilities within housing.

Other results may be inefficiencies in the housing stock (where small older households remain in larger houses) and slow uptake of adaptations (where elderly people postpone retrofits etc). Having said this, research indicates other groups may be equally or more vulnerable – such as children, low income households, people with health problems or disabilities, and Maori or Pacific Island communities. Combinations of these variables with older age only result in higher vulnerabilities.

3.3.3.5 Social conflicts will be a major impact

Climate change's social impacts will include significant social disruption and conflict over changing patterns in the value of land in coastal areas, especially where wealthy enclaves suffer significant loss in value.

Disruption of local social hierarchies, conflict between residents and local authorities, and slow re-configuring of social dynamics are inevitable where wealthier groups feel disenfranchised. Some displacement of middle- and lower-income suburbs might be expected through migration and gentrification of previously lower status suburbs/ areas. For the sector these shifts probably mean increasing renovation/ retrofit activity.

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[23] There is also a trend to smaller family sizes, single parent families and single person households.

3.3.3.6 Social impacts result from climate and social interactions

Relating climate-based hazards to the vulnerabilities, preparedness and resilience of specific groups can help assess the social impacts of climate change.

As an initial framework, the social impacts of climate change arise through the interaction of four elements, as illustrated by the diagram at right.

1. The nature of climate change hazards; storms, floods, landslips or heat
2. The vulnerabilities of house and household
3. The resilience of house and household
4. The preparedness of house and household

$$\text{Social Impacts} = \frac{H \times V}{R \times P}$$

H = Hazards to house/ household
V = Vulnerability of house/ household
R = Resilience of house/ household
P = Preparedness of house/ household, including housing adaptations

Figure 22: *Defining social impacts.*

In combination, house/ household resilience and preparedness (including housing adaptations) reduce social impacts, while hazards and house/ household vulnerabilities increase them. The interaction between these elements is an indicator of the relative social impact. These elements are defined in more detail in the sub-sections that follow. The definitions below represent those that were consistent and significant across all scenarios.

3.3.3.6.1 Key climate change hazards are the extremes of rainfall and heat

The key climate change hazards emerging from this study are:

- ✓ Wet weather extremes – rain, wind, floods, erosion, landslips
- ✓ Heat extremes – heat, water shortages/ drought

While there are obviously other important climate changes, such as sea level increases, these did not act as distinct influences on social impacts.

3.3.3.6.2 Key vulnerabilities are also the products of social exclusion

Key housing and household vulnerabilities are the various products of social exclusion. As an initial assumption, disadvantaged social groups are assumed to live in lower quality houses and neighbourhoods. These are likely to have relatively high vulnerability to natural hazards (though secondary hazards, such as landslips, also impact on houses/ households in higher-income coastal locations). Further, these groups are less likely to afford voluntary/ commercial housing adaptation solutions.

The social impacts of climate change will therefore be much more significant for these neighbourhoods/ houses. However, resilience may also be higher among these groups (through a mix of psychological toughness and community cohesion), as research by Finnis (2004) shows. Resilience in this context may not be well understood and a more sophisticated analysis may be merited. Key vulnerable households/ houses are summarised in the table below (note that the household categories are not mutually exclusive).

__Table 8:__ Key housing vulnerabilities

Households	Vulnerabilities
Older-person households	Limited physical mobility, limited physical resilience, limited social networks, limited ability to maintain house, higher sensitivity to cold/ wet
Low-income and unemployed income-earner households	Access limited to lower quality housing, limited ability to maintain house, limited ability to move elsewhere
Households of Maori or Pacific Islands peoples	Loss of Iwi land in coastal areas, limited ability to move elsewhere, access limited to lower quality housing, especially in iconic coastal landscapes such as the East Cape

These vulnerabilities are already relatively well-studied in social policy and implementation, and specific housing initiatives are already developing in the health sector, for example.

However, note that coastal suburbs and communities may bear the initial brunt of social impacts, including many wealthier suburban and holiday housing communities. For example, weather-related issues such as extreme weather and costal erosion may lead to re-zoning of coastal suburbs, and to changes in mortgage lending criteria and insurance premiums, including changes in the willingness of banks and insurance companies to finance exposed properties at all (see also *Increased Insurance Cost* on page 44)

3.3.3.6.3 Key forms of resilience are psychological toughness and community cohesion

Resilience may be less well understood in relation to climate and housing than vulnerability, and in fact, the workings of resilience may be counter-intuitive.

> Evidence available through recent civil defence literature (Finnis, 2004, Walton et al., 2004) suggests older people, while physically more vulnerable, may also be psychologically stronger and more able to cope with crises.

In addition, lower income neighbourhoods, immigrant groups, and church communities, for example, may have levels of social cohesion that make them more resilient and speed their recovery (Finnis, 2004, Walton et al., 2004). In parallel, some middle- and upper-income neighbourhoods may be less resilient in times of crisis than might be assumed to result from their higher levels of material resource. That is, resilience might modify vulnerability significantly. A more thorough and sophisticated analysis of resilience may be merited.

3.3.3.7 Key social impacts relate to flooding/ erosion/ landslips

In the current public domain climate change is understood via extreme weather events. As a result, the current key social impacts (and related forms of housing adaptation) relate to storms/ heavy rain and to secondary effects such as flooding/ erosion/ landslips. These are key because:

- The public are in a general state of confusion and denial about their future importance and impacts. Therefore a change in understanding of heavy rainfall events, storms, and droughts is an inherent part of adaptation
- The denial is a consequence of historical views of New Zealand as a coastal paradise (endorsed by relaxed land development policies), and so planning and regulatory changes are implicated in adaptation
- They are relatively frequent and significant in their impacts for neighbourhoods and households

- They impact on both higher- and lower-income households/ neighbourhoods in high profile (sometimes iconic) landscapes, engendering deep-felt concerns about the New Zealand way of life and providing rich material for media news and documentary programming.
- They are likely to lead to significant social displacement, and on occasion, a strong sense of disenfranchisement as groups with strong status and/ or identity links to a location are forced to move away

In this respect, it is worth pursuing flooding/ erosion/ landslips as a key part of a strategy for communicating the need for concern over climate change, and for appropriate housing adaptations. This is in line with priorities proposed by Camilleri (2000a, p. 30). The storms/ flooding issues are a powerful way of engaging communities in the problems and challenges posed by climate change.

3.3.3.8 Summarising social impacts in housing

The table below summarises key housing and social impacts of climate change.

Table 9: *Social impacts of climate change in housing*

House Factor	House Impact	Social Impact
Sanitation	Rising water table/ flooding of sewerage and waste water systems, water supply etc Water supply in drought times/ areas.	Health and well-being compromised in whole communities (e.g. Thames/ Coromandel, Greymouth) Use of household water supply becomes common in cities, with return of values such as frugality, austerity etc.
Temperature	Cooling (summer), including wind. Heating/ drying (winter), high wind may blow rain into interior	Quality of life in the home emphasised, and slower, more ‘tropical’ housing styles/ lifestyles may be adopted Protection from elements increasing valued and winter lifestyles increasingly introverted.
Security	House/ household more vulnerable to intrusion (e.g. with open-air cooling).	Fear of violence and crime against property (often from other ethnic groups) increases security features and design of homes.
Location	Exposed/ vulnerable locations – cliffs/ escarpments, flood plains etc.	Tensions over migration of wealthy from coastal prime sites to those further inland, potentially displacing lower income groups.
Mobility	Exit during emergencies, access of emergency services.	Aged and disabled are especially vulnerable, with mobility features part of generic housing design.
Health	Heat-and humidity-related conditions (e.g. skin infections), infectious illnesses (incl. insect-borne).	Young and elderly are more vulnerable to effects of heat. Preventative values and behaviours may become more common, such as use of fly-screens, air-conditioning, verandas/ awnings for open-air socialising, or planting of trees for shade.
Enjoyment	Closure of houses to the weather. Opening of houses to seasonal weathers.	Socialising and entertainment take place in protected interior of house – technologies have a key role. Socialising and entertainment take place in airy verandas and shaded garden rooms.
Overall	Changes in housing design. Changes in the value placed on current house/ neighbourhood location.	A positive shift towards a more out-doors oriented lifestyle overall, with the need for extra protection from weather extremes. An upheaval in the value of coastal property and a struggle to establish new areas/ neighbourhoods of high social status and housing values.

That is, there are a range of likely social impacts, many of which can be seen positively by the public. However, the underlying challenge to the value of coastal land/ housing is potentially highly divisive.

3.3.4 Examples of social impacts

During the early weeks of October 2006 the NZ Herald featured a number of examples of climate change's current social impacts, and subsequent articles show how these are being played out in the social domain. The articles are provided in full in Appendix B.

3.3.4.1 House lost to landslip

In the first example, a $1 million Auckland (Birkenhead) house has been evacuated and declared uninhabitable after the rear of the property slipped 40m to the sea below. The owner says he may try to strengthen the cliff in a bid to save it.

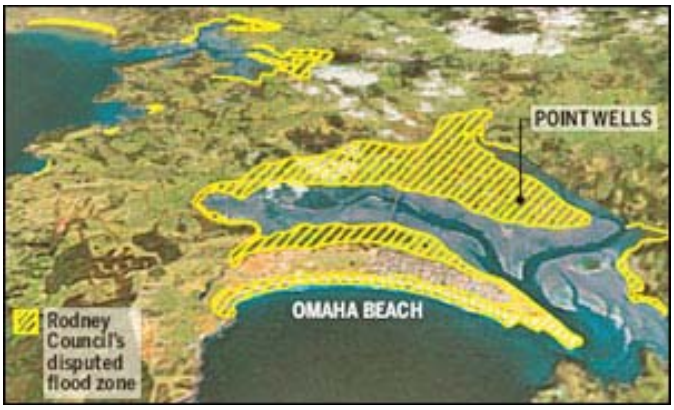
This story provides a useful reference-point for the way housing impacts have been treated in the media over recent years. That is, the report frames the landslip as a one-off event and as a threat to the one homeowner only.

Figure 23: *The slip in Awanui St. (Picture: Dean Purcell)*

3.3.4.2 Seaside houses falsely rated

In the second example, Rodney District Council placed flood risk warnings on LIM records for 242 houses in the wealthy coastal suburbs of Orewa, Manly, Whangateau Harbour, Pt Wells and Omaha (north Auckland).

The title reads 'Seaside houses falsely tagged as flood risks', attributes the warnings to council concern over liabilities arising from 'global warming and extreme weather', and cites Omaha real estate agent Michael Dow as saying the affected homes immediately lost up to a third of their value.



Local residents objected and paid for an engineer to review the criteria used for these warnings. As a result, the Council will adjust both criteria and the way these are explained on LIM reports.

This story suggests dynamics between ratepayers and Councils will shape climate change's most significant social impact. The moral seems to be that ratepayers can and perhaps should challenge risk assessment criteria imposed by risk-averse councils.

Both stories suggest a willingness to fight to preserve existing social privileges among wealthier householders and communities, rather than address the ongoing impacts of climate change. In these cases, the reader may assume that any coastal cliff property may be at risk, and any LIM warning must eventually detract from the value of land.

However, the tone and implication of these articles is that coastal properties are to be defended, perhaps heroically, against rare weather events and incompetent councils.

3.3.4.3 Beach properties facing a future without insurance

In this example, New Zealanders' strong sense of traditional property rights and love of coastal locations is placed at odds with the increasing risks from extreme weather events. As a result, insurers may be increasingly less likely to ensure at-risk coastal properties and subdivisions.

Figure 24: *Waves crash over the seawall and threaten houses. Photo / Reuters*

That is, insurance companies may emerge as the sectoral group with the most to loose, and therefore as a key driver of some forms of adaptation.

But in this article, coastal property owners are portrayed as more likely to lobby for expensive protection measures, such as seawalls, that give up their love of coastal properties. They might also engage in unlawful actions, such as dumping rock, to limit erosion around their properties.

This means rising rates to fund coastal protection and given the availability of insurance, the increased cost of insurance premiums. That is, coastal living would become a marker of social inclusion – of people with the access to the finances and political resources to protect personal interests.

4. IMPACTS AND ADAPTATION OPTIONS

In this section the objective is to capture a broad range of possible climate change impacts and adaptive responses. The analysis is underpinned by the previous sections in this report, which include: projected climate change scenarios; an assessment of the building stock vulnerabilities; user comfort and energy usage; and expected social implications.

Climate change impacts are here divided into four categories: The first part of this section assesses options for adaptation to physical climate change impact where our current understanding and confidence is strong. In the second part indirect or institutional impacts are considered. The third part addresses climate change impacts where our current understanding is either uncertain or where we believe the impacts will be minor. The final part of this section addresses expected benefits from a warmer and milder climate.

The structure and content of this section is largely adapted from BRANZ Study Report 94, *Implications of Climate Change for the Construction Sector: Houses* by Camilleri (2000a).

4.1 Significant Impacts

4.1.1 Increased Coastal Flooding, Erosion and Rising Water Tables

Climate change factor: Sea level rise

Interaction: Rainfall, ex-tropical cyclones, inland flooding

More details: *Sea Level Change and Coastal Hazards* on page 9 and *Coastal Hazards and Climate Change – A Guidance Manual for Local Government in New Zealand* (NZ Ministry for the Environment, 2004a).

Summary:

One of the most significant effects of global warming is sea level rise. The main components of this are the thermal expansion of water as it heats up and the contribution from melting of ice caps and glaciers. For the low-medium to high-medium warming scenarios NIWA (Mullan *et al.*, 2006) predicts sea level increase relative to the 1990 levels by:

2030s: 0.07-0.16 m

2080s: 0.23-0.52 m

The rate of sea level rise is expected to increase over the subsequent centuries. Rising water tables may reduce the capacity of drainage systems, in the worst case causing flooding inland when stormwater systems and rivers cannot drain into the sea. There will be some coastal properties which become more vulnerable/unstable due to increased coastal erosion and sea level rises attributable to global warming. Other properties will experience increased flooding from rivers and water run-off.

Recommendations:

1. Territorial Authorities to adopt a precautionary approach to coastal development and take increased vulnerability of coastal properties into account in modelling of flooding, coastal erosion and sea inundation.
2. Vulnerable properties to coastal erosion should increase and take appropriate protective measures to reduce wave energy and possibly move or abandon houses which cannot be economically protected.

3. Allow for possible sea level rise in new drainage systems, coastal infrastructure, and buffer zones. Territorial authorities are usually in a better position than individual house owners to take preventative action to protect against flooding by using embankments, river straightening and similar measures.

Discussion:

Figure 25: *Coastal flooding may become more frequent with climate change with severe consequences for sewerage and stormwater systems (Photo courtesy of Ministry of Civil Defence & Emergency Management, New Zealand).*

With rising sea levels, coastal flooding may become more frequent and severe. The increase in flooding risk is expected to be greatest for houses on sheltered coasts built near the high tide mark. Sandy foreshores may retreat, in the worst case by up to 50 m by the later part of the century (Hicks, 1990).

The magnitude of the impacts on coastal margins will differ between regions and even between localities within regions, depending on the localised impacts of climate change on the physical *drivers* that shape the coast[24], the natural coastal characteristics, and the influence of the built environment and anthropogenic impacts at the coast. To quantify such changes is at present extremely complex. However, the table in *Appendix A* attempts to summarise the dominant physical drivers of coastal change for a range of urban locations around New Zealand.

The increase in flooding risk with sea level rise for a sheltered coast may be greater than for an exposed, stormy coast. Houses on a sheltered coast can be built closer to the sea level than on an exposed coast, as they do not have to have a large 'safety margin' for storm surge and waves. As the likely sea level rise is a large fraction of the 'safety margin' for these houses, the risk of flooding could increase dramatically. For many exposed coasts, the rise in sea level is much smaller than the storm waves, and so there would be less effect of changes in sea level.

The water table is expected to rise in response to rising sea levels. In areas with an existing high water table, surface flooding may become more frequent, leading to damage to foundations and walls. Unbalanced or changing ground-water pressure could damage foundations. Sewerage and stormwater systems may also be damaged or rendered inoperable by rising sea levels (Mosley, 1990), possibly causing flooding well inland in low-lying areas. Sea level rise is potentially a big impact of climate change for vulnerable, low-lying areas of New Zealand.

4.1.2 Increased Inland Flooding

Climate change factor:	Change in rainfall
Interaction:	Sea level rise
More details:	*Rainfall and Floods* on page 8, *A Methodology to Assess the Impacts of Climate Change on Flood Risk in New Zealand* (Gray *et al*., 2005) and *Incorporating climate change into stormwater design - Why and how?* (Shaw *et al*., 2005)

Summary:

[24] The combined effect of sea level rise, storm surge, well waves, local waves and river sediment supply (sand/gravel/silt).

What is an extreme rainfall in today's rainfall climate is projected to occur about twice as often by the end of the 21st century. A reasonable approach is to assume return periods of floods vary in the same way as return periods of extreme rainfall.

Increases in extreme rainfall events and floods are expected to have implications for storm water drainage and runoff on sections, as well as water tightness and integrity of houses.

Recommendations:

1. Include the risk of increased flooding with climate change in flood management plans.
2. Precautionary approach to new development, and upgrading of flood protection.
3. Further research into urban storm water mitigation strategies (Shaw *et al*., 2005), such as green roofs (Banting *et al.*, 2005).
4. Further research into rainwater collection as a means to increase resilience to flood – and drought – and minimise stormwater overloading.
5. Further research into the link between increased rainfall and increased flooding.

Discussion:

The changes in heavy rainfall with climate change may result in more flooding, with consequent water damage to houses, drain damage, erosion and slips, and damage to services such as roads, pipes, and cables. Poor historic data makes flood cost estimates unreliable, but average annual flood damage cost to the nation for direct losses is estimated to around $24 – 128 million in today's prices (NZIER, 2004).

***Figure 26:** Extreme rainfall events and inland flooding will become more frequent with climate change (Photo courtesy of Ministry of Civil Defence & Emergency Management, New Zealand)*

With climate change the historical flooding Annual Exceedence Probabilities (AEPs) may rise, increasing the frequency of flooding, and increasing both the incidence and extent of flood damage to houses. The actual cost of building damage is expected to equal or exceed the change in flooding Annual Exceedence Probabilities (AEP), e.g. a fourfold increase in the AEP could result in up to a tenfold increase in the cost of building damage (Smith et al). Existing flood protection works will not reduce this impact, and could even make it worse.

Even if the high end of these increases in flooding AEPs occur, it may take decades to determine if the AEPs have in fact changed, by which time it will be too late for changes in planning or NZBC requirements to reduce the impacts of climate change induced flooding on affected houses[25].

Increases in the incidence and severity of flooding are likely to lead to increased flood insurance premiums, or withdrawal of insurance cover (see *Increased Insurance Cost* on page 44).

25 See section 6, page 34 in *Implications of Climate Change for the Construction Sector: Houses* (Camilleri, 2000a) for a discussion of the subject.

4.1.3 Structural Considerations of Rainfall Changes[26]

Climate change factor: Change in rainfall and wind

Interaction:

More details: *Rainfall and Floods* and *Combined Wind and Rainfall* on page 13.

Summary:

Increases in extreme rainfall and wind-driven rain will increase roof, site drainage and storm water drainage demand. External linings are expected to weather faster. If there is any leakage path, then the additional rain will result in more water ingress through the building envelope which may damage the structure, particularly timber framing, and also building finishes and contents.

Increased local erosion can lead to unstable building foundations. The extra water (especially over a prolonged period) can result in landslides which can directly undermine buildings, or else when slips occur they can impact and damage buildings.

Recommendations:

1. New housing estates should be based on sound geotechnical advice assuming this increase in water loading.
2. Large cuts into unstable soils should be avoided.
3. Providing adequate drainage and soil cover near critical and potentially unstable sites is recommended.
4. Local authorities should assure storm water drainage provisions are sufficient (also see recommendations *for Increased Inland Flooding* above).

Discussion:

Although expected rainfall increases listed above are only moderate, significant increases in landslides is likely unless preventative action is taken, particularly where roads have cut into hillsides.

Gutter requirements are specified directly by the New Zealand Building Code Compliance document E1/AS1 Section 5.0. Gutter size is given as a function of roof pitch and rainfall intensity in mm/hour for both internal and external gutters. It could be argued that occasional overflow is usually not a big issue for external gutters. Internal gutter overflows are more serious. If maximum rainfall intensities are expected to increase in a certain areas then the implication from the NZBC is that gutter size must also increase for new construction. The same applies to the sizing of down-pipes. Retrofitting is not recommended at this stage if it is done purely to cater for anticipated increased rainfall.

Weathering of claddings and the risk of water penetration of the building envelope is expected to increase with increased rainfall. However, these are likely to only require remedial action when problems arise. Building maintenance needs will logically increase with increased wind-driven rain. However, specific preventative actions, done purely because of a predicted increase in rainfall beyond what is required if global warming did not occur, should only be necessary in rare instances.

[26] Section based on Thurston (2006)

4.1.4 Increased Overheating Risk

Climate change factor: Temperature increase

Interaction: Solar radiation changes, wind and rainfall

More details: *Thermal Simulations*, *Average Temperature Increases* and *Extreme Temperature* on page 7

Summary:

The number of days per year with uncomfortable indoor temperatures is expected to increase, markedly in some areas. Demand for air-conditioning may increase unless more energy efficient passive cooling techniques are employed.

Recommendations:

1. Appropriate building design should keep indoor temperatures comfortable without using energy-intensive space cooling
2. Increase use of passive solar design principles, including shading using trees, to reduce overheating and avoid increased energy demand. See *Thermal Simulations* on page 37 for detailed analyses.

Discussion:

To quantify the increase in overheating with climate change, the threshold for uncomfortable indoor temperatures was defined as an outdoor daily maximum temperature of 25°C or above. The number of days with temperatures exceeding this 25°C threshold is expected to increase with climate change (see *Table 2* on page 8). The future increases in Auckland and Christchurch would be enough to create a long summer 'cooling season' lasting a month or more.

This level of prolonged discomfort is unlikely to be tolerated by most house-owners, who would be forced to take adaptive measures, possibly by installing air-conditioning (and increasing the GHG emissions from energy use). However, not all houses will be equally affected by overheating. Those houses with good solar design features such as properly shaded north- and west-facing windows, minimal west-facing windows, or provision for effective ventilation should be least affected. Houses without such features, or poor solar design, could suffer severe overheating.

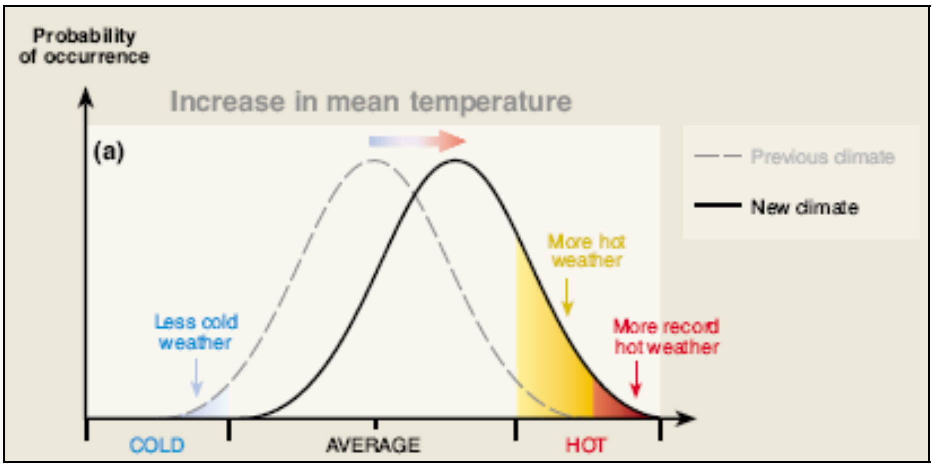


Figure 27: *Increase in mean temperature will increase the probability of more hot weather events and more days with extreme heat (IPCC, 2001a).*

4.1.5 Increased Fire Risk

Climate change factor: Change in rainfall

Interaction: Temperature increase, drought, wind, lightning

More details: *Drought and Fire* on page 11 and *Impacts of Climate Change on Long-term Fire Danger* (Pearce *et al*., 2005).

Summary:

The number of days with very high to extreme forest fire danger could increase by more than 50% in eastern parts of the country.

Recommendations:

1. Increased vigilance will be needed in residential areas near native bush and reserves.
2. Introduction of external building fire protection (e.g. external drenchers) for vulnerable areas.
3. Education to develop awareness and community responsibility for fire safety (e.g. advantages and disadvantages of staying with your house).
4. Ensure rural fire service cover increased vulnerability (e.g. for an aging population).
5. Review bush fire zones.

Discussion

The predicted increases in temperature, drought conditions and, in particular, wind have implications for the severity of exposure fires and external fire spread and the hazards of airborne embers and increased ember-strike in the urban environment (Bowditch, 2006). Further research into the impact of climate change on the increase of the potential for house to house fire spread would be beneficial for planning future building regulations (including separation distances, and external flame spread) and fire-protection and -fighting strategies for people and property protection. The research would be particularly helpful for post-earthquake fire hazards and vegetation fire progress hazards at the rural-urban interface fire (Blanchi *et al.,* 2006a and 2006b.),

The impact of climate change on the ignition of fire events that occur *within* occupied buildings may be more dependent on the changes in occupant behaviour (such as less use of active heating but greater use of active cooling) than directly relating to increases in climate conditions.

Currently the intent of fire safety in the NZ Building Code (Department of Building and Housing, 2005) is to protect life, other property and sleeping occupancies from fire, and facilitate fire-fighting. Therefore research into the applicability and potential impact of current Australian mitigation strategies (BCA, 2005 and Standard Australia, 1999) and additional New Zealand specific mitigation and protection strategies would be beneficial for protection of people and future building stock,. This would particularly help in rural-urban interface areas, and would provide a technical basis for any recommendations for changes in regulation or practices.

Figure 28: *Fire risk warning near Christchurch (Photo copyright: Ilan Kelman, 2003).*

4.2 Indirect Impacts

4.2.1 Greenhouse Gas Emissions

Climate change factor: GHG emissions, carbon charges

Interactions: Temperature increase

More details: *Thermal Simulations* on page 37, *Space conditioning adaptation* on page 51, *Increased Cost due to Carbon or GHG Charges* on page 45 and Camilleri (2000a, section 10).

Summary:

GHG emissions from houses are mainly from CO_2 and, for most houses, mainly during occupancy. Houses can be modified to reduce their GHG emissions. Aspects for improvement include energy efficiency; fuel type; passive solar design; materials choice; size of house and amount of construction material; durability; and transportation demand. These options are most feasible for new homes, but retro-fitting is effective for some of these aspects.

Recommendation(s):

Increase understanding of the full life-cycle environmental impact of houses, including occupant effects, so that sensible and cost-effective strategies can be adopted.

Discussion:

GHGs are emitted from houses at all stages of their life, from building material production, through construction, operation and demolition. CO_2 is by far the predominant GHG for houses at all stages of the life cycle, both in terms of quantity and the contribution to climate change. Manufacturing emissions are currently much smaller than occupancy emissions for energy use for most houses (Jaques *et al*., 1997). GHG emissions associated with building maintenance may be minimised by using durable, low maintenance materials.

Energy use during occupancy varies widely with the house type, location and occupancy behaviour. The thermal design of a house has a significant effect on the energy used for space heating. *Improvements* in the basic design of houses could reduce the life-time GHG emissions from energy use substantially. Examples include passive solar design, increased insulation, double glazing, and heat recovery.

Houses sited to maximise the opportunity for using public or pooled transport, or to minimise *commuting* distance would assist in minimising the GHG emissions for personal transport, which can easily exceed the occupancy GHG emissions of an entire household.

When houses are maintained or refurbished there is an opportunity for the owner to upgrade the energy and GHG performance of the house by installing energy efficient heating appliances (including solar) and extra insulation.

Increased use of air-conditioning (currently uncommon in houses but growing rapidly) could result from increased incidence of overheating, which would increase both energy GHG emissions and direct emissions of refrigerants.

4.2.2 Increased Insurance Cost

Climate change factors: Change in rainfall, sea level rise, ex-tropical cyclones

Interactions: None

More details: *Examples of social impacts* on page 35

Summary:

If increased rainfall or sea level rise leads to increases in flooding or storm damage, insurance premiums are expected to rise. In the worst case, insurance cover could be denied, marginalising affected communities.

Recommendations:

Increase understanding and raise awareness of environmental impact on houses to ensure the building stock can be properly insured.

Discussion:

The global insurance industry is acutely aware of the risks imposed by global warming. The effects and risks from climate change are very likely to affect property values through disclosure of increased hazards, as well as affect the price and availability of insurance (IPCC, 2007b; Munich Re, 2005; and Swiss Re, 2007). In New Zealand and Australia the real long-term risks of urban flooding and coastal inundation in a locality are typically not transmitted into market values or into insurance premiums, and an adverse event can cause large personal and insurance losses; withdrawal of insurance coverage; and dramatic declines in property values and personal equity (IPCC, 2001a).

The insurance costs of major catastrophic events are not contained to the affected region, but are distributed internationally. By example, the US$70 billion insurance bill from the September 11, 2001 attacks filtered through to commercial insurance premiums in New Zealand, which rose as much as 30 percent in the following months after the attack as the insurance industry sought to cover their share of the cost. The losses from Katrina could be as high as $40 billion and New Zealand businesses and homeowners are facing the prospect of insurance premium increases to help cover the bill (NZ Herald, 2005).

Regions may become increasingly difficult to insure: National Pacific Insurance pulled out of Western Samoa because of the difficulty of buying re- insurance on the world market (Pacific Islands Monthly, 1992). At least 24 re-insurers pulled out of the Caribbean following major hurricane losses, making insurance more difficult to find and more expensive (Lloyds List, 1993).

Likely increases in the incidence of flooding of one to four times by 2080 may increase the actual average annual damage to buildings in an urban area by much more, perhaps as much as 10 times in extreme cases (Smith *et al*. 1998 and Smith, 1999). If ex-tropical cyclones increase, there could be even larger increases in weather-related damage. Faced with this situation, insurers are sure to raise premiums by a similar amount, and may even decline cover, forcing the direct costs of flooding back onto house-owners, the community, or local and national government. This could have serious implications for buildings in vulnerable areas, as insurance is mandatory for most housing loans; without it banks will not issue a loan or may foreclose. Insurers are likely to take a precautionary approach to climate change, leading to rising insurance costs and limitations or denial of cover in at-risk areas (Camilleri, 2000a).

4.2.3 Increased Cost due to Carbon or GHG Charges

Climate change factor: Temperature increase, GHG emissions

Interactions: Extreme rainfalls, droughts and storm events

Detailed Analysis: Camilleri (2000a, Section 11)

Summary:

Any form of carbon charge is expected to result in increased costs of electricity and building materials. For materials the percentage increase in cost will probably be least for timber products, more for cement, much more for steel, and more still for aluminium. Costs for fuel and energy are also expected to increase if carbon charges are imposed.

Recommendations:

1. Invest and plan for a carbon constrained economy.
2. Adopt cost-effective energy efficiency measures to offset increased costs.
3. Adopt cost-effective renewable energy and electricity generation options (e.g. solar, wind, geothermal, hydro, tidal, wave and burning of biofuels).

Discussion:

Between 1990 and 2005, GHG emissions from electricity generation increased by approximately 105 percent. Under a *business as usual* scenario GHG emissions from electricity generation sector are forecast to continue to increase in the next decade (MfE and MED, 2006). Internationally GHG are increasingly being priced through taxes and emissions trading schemes and the economic literature estimate mid-range price of about \$50 a tonne of carbon, but some estimates put the price as high as \$600 a tonne within a few decades (Moncrief, 2006; and Ward, 2006). The effect on electricity price at various moderate carbon charge levels are estimated to:

Table 10: *Impact of CO_2 price on electricity costs (MfE and MED, 2006).*

	\$15/tonne CO_2	\$25/tonne CO_2	\$50/tonne CO_2
Coal Generated	1.45 c/kWh	2.41 c/kWh	4.82 c/kWh
Gas Generated	0.52 c/kWh	0.87 c/kWh	1.74 c/kWh
Geothermal Generated	0.13 c/kWh	0.21 c/kWh	0.42 c/kWh

Renewable energy sources are progressively becoming more competitive and in a carbon constrained future this development is likely to persevere. By example top quality PV modules today carry a 25-year warranty and are designed to withstand arctic cold, desert heat, tropical humidity, winds in excess of 200 kph and 25mm hail at terminal velocity. It is the view of the New Zealand Photovoltaic Association (2003) that PV technology will become increasingly economical for widespread usage throughout New Zealand over roughly the next ten years. The competitiveness of PV depends the location and on and the development of future carbon charges. The future cost of carbon emissions is unknown, and could be substantially lower or higher than in the example above (Chapman *et al.*, 2006).

Figure 29: *Renewable energy generation from wind power turbine (Photo: Duncan Babbage).*

Added carbon charges would increase energy costs for raw materials and manufacturing processes, and impose additional costs on steel, aluminium, and cement manufacturing. Timber would probably have the lowest price increase, more for cement, much more for steel and even for more for aluminium. As a rough estimate, with a carbon charge of $100-$200 per tonne of carbon, the cost of a new 100 m^2 house would increase by $400-$2000, depending on the construction type (Camilleri, 2000a).

4.3 Uncertain or Minor Impacts

4.3.1 Ex-Tropical Cyclones

Climate change factor: Ex-Tropical cyclones

Interactions: Temperature increase and sea level rise

More details: *Wind and Cyclones* on page 12.

Summary:

Climate change science currently has several conflicting assessments of changes in ex-tropical cyclones, ranging from no change to slight increases. The potential for damage to houses from any increase in ex-tropical cyclones is so large that, despite the uncertainties, this potential impact must be taken very seriously.

Recommendations:

Urgent further research into changes in ex-tropical cyclones with climate change.

Discussion:

From 1971-2004, tropical cyclones in the southwest Pacific averaged nine per year, with no discernable trend in frequency (Burgess, 2005) or intensity (Diamond, 2006). When ex-tropical cyclones strike New Zealand they do substantial damage. Cyclone Bola alone cost more than $58 million in 1988 (Insurance Council, 2007) and any increase in cyclones in New Zealand would dramatically increase weather-related damage, including structural damage from wind, increased flooding, and increased landslips.

Caution dictates that the current conservative result be treated as provisional, until further research is done.

4.3.2 Increased Wind Load[27]

Climate change factor: Wind speed and direction, ex-tropical cyclones

Interactions: None

More details: *Wind and Cyclones* on page 12 and Camilleri (2000a, page 50).

Summary:

Wind pressures are proportional to the square of the basic wind speed. Thus, a 2.5% increase in basic wind speed will increase wind pressures by 5% and a 5% wind speed increase results in a 10% pressure increase.

Current climate change science can make no reliable predictions about possible changes in wind. Even if structurally damaging winds do increase, it will take decades to confirm that increases have occurred, because these winds are extremely rare.

[27] Section based on Thurston (2006).

Recommendations:

Currently the design loadings standard for New Zealand for wind (AS/NZS 1170.2:2002) does not take into account changes expected due to global warming. It is recommended that the next revision does take this into account. However, strengthening an existing building purely because of a predicted increase in design wind-speed, beyond what is required if global warming did not occur, is not generally recommended because:

1. Most buildings do not experience a "design level" wind in their lifetime;
2. Building bracing strengthening is an expensive option given the relatively low increased risk.

Discussion:

In a large wind-storm a building is vulnerable to the following events, which are listed below in the expected order of likelihood:

1. Roofing iron/tiles blown off
2. Roof framing partially or completely uplifted
3. Garage doors blown in
4. Sliding doors blown in
5. Window/door glass broken by debris
6. Walls damaged by racking – most likely to occur if the roof is dislodged
7. Foundations racked.

When a building loses its roof membrane, its ability to transfer wind face load forces to the stronger transverse walls is largely lost and total building collapse can occur. Blown in windows/doors can result in a house being internally pressurized which increases the upward loading on the roof which can thereby lead to failure. Flying debris from roof parts is a life-risk to others. Thus, it is recommended that buildings not constructed to current standards be checked to ensure the roof and roofing materials are firmly attached and the windows/doors are adequate for the wind exposure.

A change in prevailing wind can affect ventilation, comfort, and building performance, especially for passively ventilated buildings. Increased corrosion may be a particular problem in coastal areas. If changes in prevailing winds change the exposure of a site, the structural design may be inadequate for the new conditions (NZS 4203, 1992) (Camilleri, 2000a).

As structurally damaging winds are very rare, it may take decades to determine if the incidence of extreme winds has in fact increased at a given location. To clarify the situation BRANZ sent out a survey to 83 regional and district councils asking for data on climate related damage to the housing stock that has occurred in recent years. The responses are presented in Appendix H and the data is then used to assess how much damage may occur due to climate change impacts.

4.3.3 Structural Considerations of Temperature Changes

Climate change factor:	Temperature increase
Interaction:	Driving rain
More details:	*Extreme Temperature* on page 8

Summary:

Temperature extremes and large swings will result in thermal movement of roofing, cladding, window systems and other building parts which can result in cracking and deterioration. This includes paints and sealants and other protective surface finishes. Soil drying (and swelling in wet conditions) can affect foundations (especially clay soils).

Recommendations:

The direct effect of the temperature change effects listed above is expected to have only minor structural consequences for buildings.

Discussion:

Indirect effects such as the prevalence of pests which may weaken the structure or foundation (termites and pest is discussed in the following section). Reduced durability is not considered.

4.3.4 Pest / Infestation Problems[28]

Climate change factor: Temperature increase and rainfall

Interaction: None

More details: *Average Temperature Increases* on page 7 and *Rainfall and Floods* on page 8

Summary:

2030s: The effects of climate change within the 50-year scenario (temperature and rainfall) appear to be so insignificant that it is not likely they will cause the incidence of timber pests to change, in terms of their range and distribution. Neither is it likely with such small changes that the insects and fungi will represent an increased hazard to building timbers.

2080s: The model predictions for climate changes at the 100-year scenario could result in some fungi increasing their distribution, though most of those known to attack timber framing, for example, will be little affected by 2-3°C temperature increases.

Recommendations:

Existing New Zealand quarantine operations are effective at keeping out other, non-indigenous, termite species, mainly from Australian-sourced timbers, and any future climate changes should not affect this stringent quarantine policy.

The softwood framing timber treatments and similarly specified wood-based composite treatments currently listed in AS/NZS 1604 series are proven effective means of preventing termite attack of timber building elements. These specifications could be applied to New Zealand, should it be deemed necessary, as a precautionary measure.

Discussion:

The number of days when marked changes in ambient temperatures and/or rainfall events are likely to occur should not affect the incidence of timber pests, since both insects and decay fungi would require sustained changes to their environment, somewhat higher than those found by the NIWA models, before any effects might possibly be noted. For example the two indigenous termite species found throughout New Zealand would continue to be an intermittent pest in plantations rather than pests of the built environment.

Figure 30: *NZ Building Site, showing extensive use of timber in the construction process (Source: Harry Greaves)*

[28] Section based on Greaves (2007).

The European house borer, *Hylotrupes bajulus*, will certainly adapt well to the 100-year modelled climate of New Zealand – the current climate could sustain an outbreak now, but, as with termites, sound quarantine practices appear to be adequately preventing the introduction of these insect pests. In any event, the synthetic pyrethroid treatments listed for framing, both in NZS 3640 and AS 1604.1, have the potential to control wood borers, including *Hylotrupes*, as well as to repel termite attack, and they could be applied in any future adaptation strategies.

As for the occurrence of insects and decay fungi in timber building components, the only possible scenario that might affect this is the incidence of extreme rain events, particularly wind driven rain. Such extremes of weather, as modelled by the NIWA, are expected to be about 10% higher than current driving rain indices by the 2080s. Sound building practice, together with the use of preservative treated timber for structural elements, should adequately deal with this likely impact of climate change.

Finally, it should be emphasised that today's climate and any of the possible future climate scenarios modelled should not impact on timber as a fit-for-purpose building product. A combination of sound building practice together with the use of durable timber building components, either from naturally durable species or by appropriate use of preservatives in accordance with NZS 3640, is the best insurance and the most appropriate strategy to ensure against building vulnerability, whatever the climate.

4.3.5 Degradation of Polymers

Climate change factor: Temperature increase and UV radiation

Interaction: Driving rain

More details: *UV Radiation* on page 12 and *Solar Radiation* on page 13

Summary:

Even at extreme temperature increases in New Zealand, the risk for polymeric materials will be low since the acceleration of the kinetics of degradation should be limited. In the context of material softening, high temperature increases failure in dark colours that are exposed to solar radiation. Most plastics absorb radiation in the UV range hence a reduced risk of UV degradation will result.

Recommendations:

The risk of polymer degradation is judged to be low or very low in both the 2030s and 2080s timeframe.

Discussion:

There may be opportunities for reduced formulation costs with fewer days with frost and low temperature.

4.4 Opportunities

4.4.1 Decreased Winter Space Heating

Climate change factor:	Temperature increase
Interactions:	GHG emissions, summer overheating
More details:	*Average Temperature Increases* on page 7, *Thermal Simulations* on page 37 and Camilleri (2000a, page 42).

Summary:

By 2030s the required heating energy decreases by: Auckland 12-70%; Wellington 25-33%; Christchurch 4-14%; Invercargill 12-19%.

By 2070s the required heating energy decreases by: Auckland 69-79%; Wellington 29-86%, Christchurch 9-62%; Invercargill 15-51%.

There will be greater opportunity to heat houses entirely from passive solar heating by 2070, especially in the Auckland and Northland regions (Camilleri, 2000a).

Recommendations:

1. Increase public and industry awareness of good thermal design (especially passive solar) to maximise the benefits.
2. Increase public and industry awareness of GHG emissions of space heating to maximise emissions reductions.

Discussion:

Less space heating will be required if temperatures increase with climate change. The range of energy decreases given above for each location and year reflects the possible range of temperature changes.

4.4.2 Decreased Water Heating Energy

Climate change factor:	Increased temperatures
Interactions:	None
More details:	*Average Temperature Increases* on page 7 and Camilleri (2000a, page 50).

Summary:

By 2030 the required water heating energy decreases by 1.2 – 2.4%.

By 2080 the required water heating energy decreases by 3.0 – 7.2%.

Recommendations:

None.

Discussion:

Reductions in the required hot water heating energy of about 3% per 1°C increase in temperature[29] are expected as a result of the warmer temperature of the cold water supply (Stoecklein & Isaacs, 1998).

[29] Still unpublished BRANZ research indicates decreases by 5% per 1°C increase in temperature.

5. ECONOMIC COSTS AND BENEFITS OF ADAPTATION OPTIONS

Based on climate change projections, New Zealand buildings will suffer significant impacts this century, and unless steps are taken to protect vulnerable buildings, the costs (direct and indirect) may be very high. Vulnerable buildings need to be identified, and appropriate measures undertaken to minimise costs and maximise protection. By highlighting the most significant impacts on buildings, and some practical ways of dealing with them, an effective response to climate change threats may be brought about to ensure that buildings in the future are more resilient to climate change (Camilleri, 2001).

The objective of this section is to assess the financial costs of options for reducing the vulnerability of New Zealand residential buildings, and where possible identify and estimate the benefits. This is done using economic cost benefit analyses of adaptation to temperature increase, driving rain, wind, hail, drought, bush fire, and sea level rise. The analysis is underpinned by the climate change projections in section 2 and the building stock analysis in section 3.1. The main focus is on cost benefit analysis of space condition adaptation options to cope with the expected warmer climate.

5.1 Space Conditioning Adaptation

The following economic analysis of space conditioning adaptation options is based on the thermal simulations in section 3.2. A summary of the results are provided in section 5.1.3 on page 65.

5.1.1 Retrofitting Existing Houses

The existing house stock was analysed and it was noted that approximately 51%[30] of homes built prior to 1978 had not been fitted with any or sufficient insulation (this includes homes that have been retrofitted).

Currently there are over 390,000 homes with no insulation or insufficient insulation levels.

5.1.1.1 Model Assumptions

Models were derived to analyse the effect of retrofitting these houses with different levels of insulation. A period of 55 years was used (2005 – 2060) for all models and its assumed that it would take 10 years to retrofit all the existing houses with none or poor insulation. There are three possible situations that have been modelled:

1. Start now (all retrofitting would be completed by 2015)
2. Start in 2015 (all retrofitting would be completed by 2025)
3. Start in 2025 (all retrofitting would be completed by 2035)

There are two different house types used to represent the existing stock:

1. Small house – 103m^2 with a timber floor
2. Medium house – 167m^2 with a timber floor

Based on *Figure 10* on page 17 we have assumed that half of the existing pre-1980s stock can be represented by the small house and the other half by the medium house.

In section 3.2.4 simulations were run for each house model in three regions (Auckland, Wellington, and Christchurch), for four different situations (C375, C875, H325, H825, PD06)[31]. From the simulations data was obtained for energy usage per year and peak kWh usage for 10

[30] Using QVNZ and HCS data
[31] See Glossary.

different insulation levels (each insulation level was simulated with and without awnings), as shown in

below:

Table 11: *Existing house retrofit insulation arrangements*

	Auckland				Wellington				Christchurch			
	Ceiling	Wall	Floor	Windows	Ceiling	Wall	Floor	Windows	Ceiling	Wall	Floor	Windows
Base	0	0	0	Single glazing r-0.16	0	0	0	Single glazing r-0.16	0	0	0	Single glazing r-0.16
1	r-2.6	0	0	Double glazing with aluminium frame r-0.26	r-2.6	0	0	Double glazing with aluminium frame r-0.26	r-3.2	0	0	Double glazing with aluminium frame r-0.31
2	r-2.6	0	r-1.4	Double glazing with aluminium frame r-0.26	r-2.6	0	r-1.4	Double glazing with aluminium frame r-0.26	r-3.2	0	r-1.4	Double glazing with aluminium frame r-0.31
3	r-2.6	r-2.2	r-1.4	Double glazing with aluminium frame r-0.26	r-2.6	r-2.2	r-1.4	Double glazing with aluminium frame r-0.26	r-3.2	r-2.2	r-1.4	Double glazing with aluminium frame r-0.31
4	r-3.6	r-2.6	r-2.8	Double glazing lowE + argon, therm break Al frame r-0.43	r-3.6	r-2.6	r-2.8	Double glazing lowE + argon, therm break Al frame r-0.43	r-5.0	r-2.6	r-2.8	Double glazing lowE in PVC or wood frame r-0.48

Each model used heat pumps to heat/cool the house, with the heating set at 16ºC from 11pm – 7am and 20ºC from 7am to 11pm. Cooling was set at 25ºC. The cost of a heat pump was $3,000 each, replacing these every 10 years and a coefficient of performance (COP) of 3. A study[32] has shown that over about 7000kWh per year heat pumps are more economic than conventional panels. Windows were assumed to be replaced every 30 years, and awnings every 10 years. Window prices[33] were obtained from the industry and window awning prices were obtained from Rawlinson's[34]. Exterior awning shades were placed just above certain windows (all north facing windows, and east and west facing windows if they were in living areas or bedrooms) to reduce solar gains. The simulations were run so that ventilation in the form of opening windows was incorporated to assist the heat pumps in cooling the house.

Using QVNZ data it was calculated that the Auckland model represents 54% of the existing stock, Wellington 21% and Christchurch 25%. Demolitions are also included in the models, see *Figure 31*:

[32] I Page (2006) NZBC Cl H1 review. Insulation costs benefit analysis. BRANZ Report E439 for DBH

[33] Double glazing prices have been reduced by 10% from current prices to reflect the expected economics of scale. This arises from the expanded market due to the proposed changes to the NZBC clause H1 (energy efficiency) provisions, which will make double glazing mandatory in climate zones 2 and 3 and possibly in zone 1. Note that the use of double glazing is already widespread in the south island, and the market size will more than double with the proposed changes.

[34] NZ Construction Handbook 2005. Rawlinson, Auckland

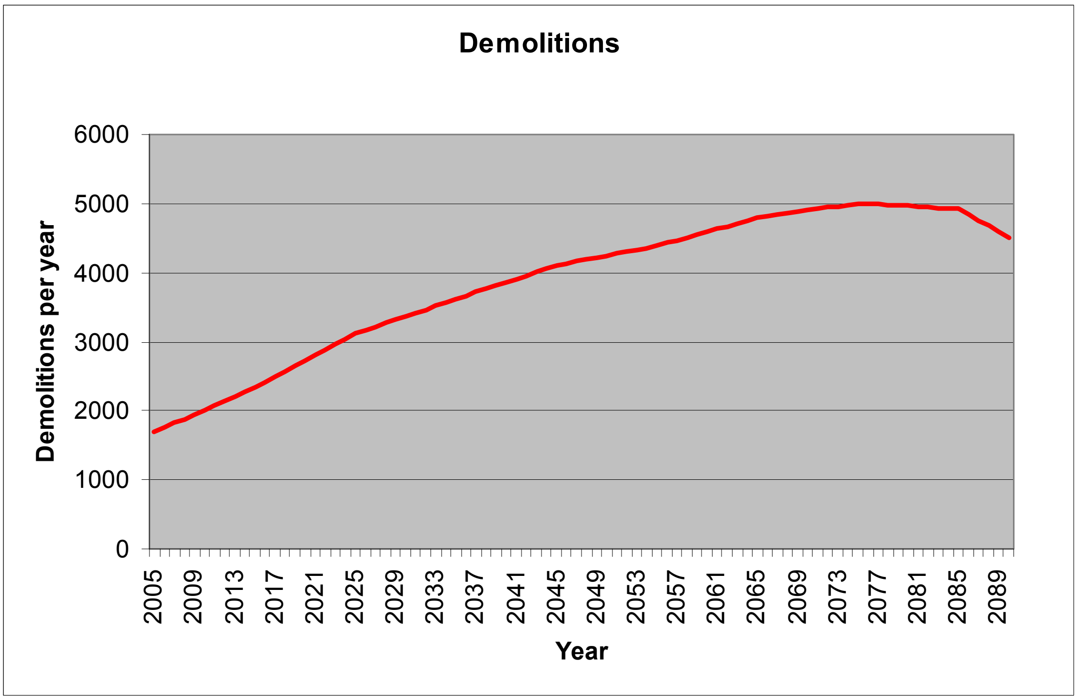


Figure 31: *Estimated demolitions per year*

The demolitions shown in *Figure 31*. are based on the demolitions model in Appendix F, using the 110 years average life option. This option has been adjusted for the existing house stock built prior to 1978 with little or no insulation. The graph above indicates that about 1700 of these houses are currently being demolished per year now. This number increases until about 2075, after which it will start decreasing over the following years. Further details of the demolitions model are in Appendix F*: Demolition Models*.

Health costs were also included in the models, based on prior research[35] it was found that a household would spend approximately $47 extra per year if they lived in an un-insulated house compared to living in an insulated house.

Finally we used a 5% discount rate to get all figures into today's dollars, and we assumed an energy price escalation of 1%. The choice of discount rate for adaptations to climate change impacts is currently a topic for debate and the long term development of energy prices is uncertain (see 4.2.3 above) Section 5.1.1.4 below includes a brief sensitivity analysis of the results with different discount rate and energy price escalation.

5.1.1.2 Insulation and Shading Configurations

The results of the simulations and models can be seen in *Figure 32* below. The NPV is the present value of energy cost savings, plus health case savings, less insulation and awning retrofit costs, for all pre-1979 houses, summed for each year through to 2060, and allowing for demolitions year by year. Further details of the calculations are in the Appendix G.

[35] Chapman et al (2005). A cost-benefit evaluation of housing insulation: Results from the NZ Housing, Insulation and Health study. Special variation for S Ward, EECA.

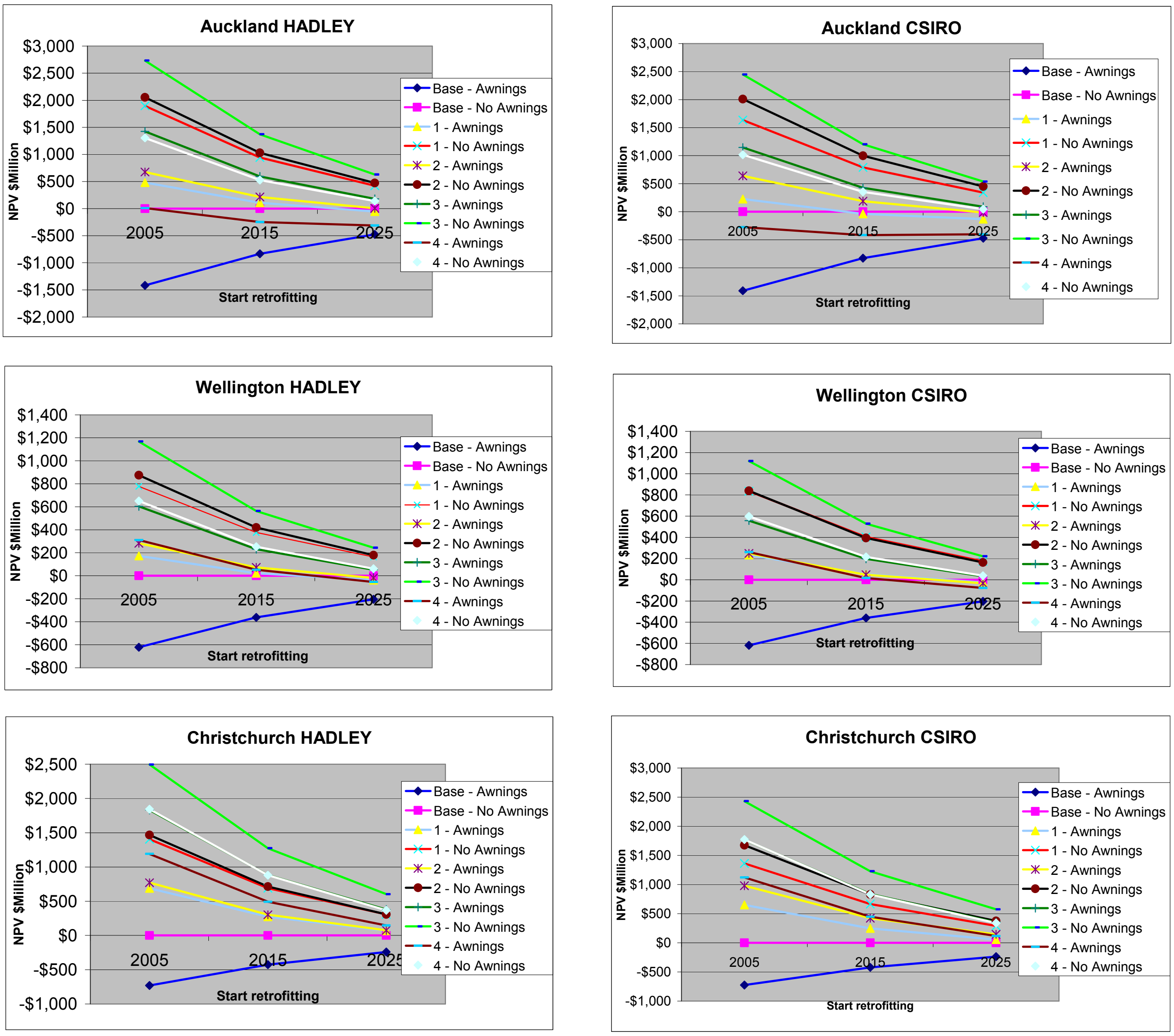


Figure 32: *The NPV of energy cost savings, plus health case savings, less insulation and window awning retrofit costs, for all pre-1979 houses, summed for each year through to 2060, and allowing for demolitions year by year.*

The general trend for each insulation level is a decreasing NPV, with each model having the 3rd insulation level (see *Table 11* above) with no window awnings as the greatest NPV at any stage in time. However because each insulation level NPV is decreasing, it is most beneficial to start retrofitting today.

In fact, in all models it is more beneficial to retrofit now at any of the top four NPV insulation levels than to retrofit in 2015 at the highest NPV level.

There are three reasons for the decreasing NPVs, one is because of the expected increase in temperature, and so higher insulation levels will not be as effective as they would be today. The second is retrofitting immediately which means that the benefits are discounted less, than with a future start. And thirdly, homes benefit from a greater number of years of savings before they are demolished, with an early start to retrofit. An interesting point to note is that the case of no insulation with just window awnings installed has an increasing NPV. This is because as the temperature increases, having window awnings becomes more beneficial in helping reducing the cooling costs; therefore as time goes along the NPV gets higher, though it still remains negative.

5.1.1.3 Glazing Configurations

Another simulation was run which expanded on the insulation level which provided the greatest NPV (3rd insulation level with no awnings). The simulations were run with three different types of glazing:

1. Single glazing
2. Double glazing
3. Double glazing with low e, argon filled aluminium

Since the initial simulations were run with double glazing, we compared the other two variations, and the NPVs can be seen below in *Figure 33*:

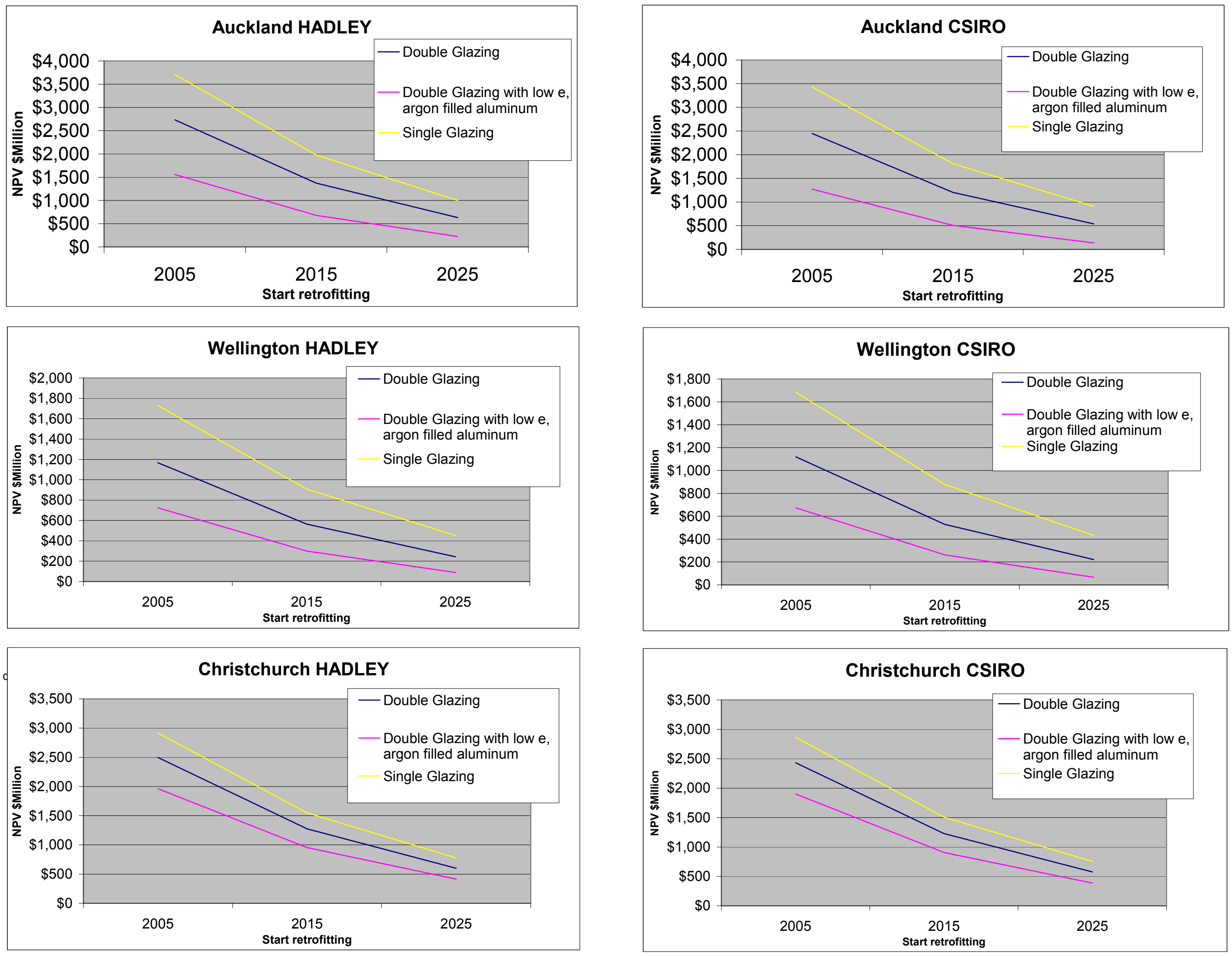


Figure 33: *NPV simulations with different glazing options on existing buildings with 3rd insulation level with no awnings for small and medium sized houses*

It can be seen in all areas and situation it's more cost effective to install single glazing instead of the two types of double glazing. Although it looks like Wellington has the biggest difference in NPV from standard double glazing to single glazing, its actually Auckland that has the biggest increase in NPV (approximately $1 Billion more) compared to Wellington's $600 million (approx) and Christchurch has an NPV gain of approximately $400 million. Note that these graphs represent the entire existing housing stock that has little or no insulation, which we estimate to be about 390,000 at this point in time.

5.1.1.4 Sensitivity Analysis of Different Discount Rates and Energy Price Escalations

Different discount and energy price escalation rates were also modelled, with the results as follows:

As the discount rate increases the present values decrease, and the difference between the lowest and highest insulation present values gets smaller. The net present values also decrease, but the results (which insulation provides the highest NPV) are still the same. The opposite happens when the discount rate decreases.

As the energy price escalation increases (energy prices increase at a higher rate), all the present values increase. The present values of retrofitting the lower insulation houses increase by more than the higher insulation homes since lower insulated house would use more electricity and therefore the present value of increased insulation goes up. With higher energy price increase the economics improves for better insulated houses. But the models still show that the economically optimal level of insulation remains the same.

> Although future temperatures are expected to increase, thermal insulation still comes out favourable because currently we under-insulate our homes by a huge amount.

5.1.2 New Houses

5.1.2.1 Model Assumptions and Set-up

Analysis was done on new homes to see what space conditioning adaptation options yield optimal economic outcome. Modelling was performed for Auckland, Wellington and Christchurch for three different house sizes and types:

1. Small house – single story 103m^2 with a timber floor.
2. Medium house – single story 167m^2 with a concrete slab floor.
3. Large house – Double story 388m^2 with a concrete slab ground floor.

Three different situations were simulated:

1. Small, medium and large houses with different insulation levels
2. Small and medium houses with different insulation levels and natural ventilation, and different window types on a particular insulation level.
3. Small and medium houses with different insulation levels and natural ventilation.

Each situation had the following assumptions:

- Houses were simulated with either partial awnings (on all north facing windows, and east and west facing windows if they were in living areas or bedrooms) or no awnings.
- 30 year time frame, starting in 2005, 2015, 2025, 2035, 2045, 2055.
- Two different future climate models, CSIRO and HADLEY.
- All houses used heat pumps to heat and cool the house, with the heating set at 16ºC from 11pm – 7am and 20ºC from 7am to 11pm. Cooling was set to start at 25ºC.
- The simulations were run so that ventilation in the form of opening windows was incorporated in the second and third situations to assist the heat pumps in cooling the house.
- Heat pumps were assumed to cost $3000, be replaced every 10 years, and have a COP of 3.
- Data was obtained for energy usage per year and peak kWh.
- Windows were assumed to be replaced every 30 years, and awnings every 10 years.

- Window prices were obtained from the industry and awnings prices were obtained from Rawlinson's[36].
- A discount rate of 5% was used and an energy price escalation of 1% was used.

The insulation levels for each house are as follows:

Table 12: *Small new housing insulation arrangements*

Small	Auckland				Wellington				Christchurch			
	Ceiling	Wall	Floor	Windows	Ceiling	Wall	Floor	Windows	Ceiling	Wall	Floor	Windows
Current	r-1.8	r-1.8	r-1.3	Single glazing r-0.16	r-1.8	r-1.8	r-1.3	Single glazing r-0.16	r-2.6	r-1.8	r-1.3	Single glazing r-0.16
Better	r-2.6	r-2.2	r-1.4	Double glazing with aluminium frame r-0.26	r-2.6	r-2.2	r-1.4	Double glazing with aluminium frame r-0.26	r-3.2	r-2.2	r-1.4	Double glazing with aluminium frame r-0.31
Best	r-3.6	r-2.6	r-2.8	Double glazing argon filled with aluminium frame r-0.26	r-3.6	r-2.6	r-2.8	Double glazing argon filled with aluminium frame r-0.26	r-3.6	r-2.6	r-2.8	Double glazing argon filled with aluminium frame r-0.26

Table 13: *Medium new house insulation arrangements*

Medium	Auckland				Wellington				Christchurch			
	Ceiling	Wall	Floor	Windows	Ceiling	Wall	Floor	Windows	Ceiling	Wall	Floor	Windows
Current	r-1.8	r-1.8	None	Single glazing r-0.16	r-1.8	r-1.8	None	Single glazing r-0.16	r-2.6	r-1.8	None	Single glazing r-0.16
Better	r-2.6	r-2.2	r-1.7	Double glazing with aluminium frame r-0.26	r-2.6	r-2.2	r-1.7	Double glazing with aluminium frame r-0.26	r-3.2	r-2.2	r-1.7	Double glazing with aluminium frame r-0.31
Best	r-3.6	r-2.6	r-1.7	Double glazing argon filled with aluminium frame r-0.26	r-3.6	r-2.6	r-1.7	Double glazing argon filled with aluminium frame r-0.26	r-3.6	r-2.6	r-1.7	Double glazing argon filled with aluminium frame r-0.26

Table 14: *Large new house insulation arrangements*

Large	Auckland				Wellington				Christchurch			
	Ceiling	Wall	Floor	Windows	Ceiling	Wall	Floor	Windows	Ceiling	Wall	Floor	Windows
Current	r-1.8	r-1.8	None	Single glazing r-0.16	r-1.8	r-1.8	None	Single glazing r-0.16	r-2.6	r-1.8	None	Single glazing r-0.16
Better	r-2.6	r-2.2	r-1.7	Double glazing with aluminium frame r-0.26	r-2.6	r-2.2	r-1.7	Double glazing with aluminium frame r-0.26	r-3.2	r-2.2	r-1.7	Double glazing with aluminium frame r-0.31
Best	r-3.6	r-2.6	r-1.7	Double glazing argon filled with aluminium frame r-0.26	r-3.6	r-2.6	r-1.7	Double glazing argon filled with aluminium frame r-0.26	r-3.6	r-2.6	r-1.7	Double glazing argon filled with aluminium frame r-0.26

5.1.2.2 Insulation and Shading Configurations – No Natural Ventilation

In this section simulations were run for small, medium and large houses in each region. There was no natural ventilation used in these models, so the only method of cooling was the heat pump. The base case is having current code required insulation levels with no awnings, and

[36] NZ Construction handbook 2005. Rawlinson, Auckland

every other simulation's NPV is based on the difference between it and the base case. *Figure 34* shows the results using the CSIRO model and *Figure 35* shows the HADLEY model results.

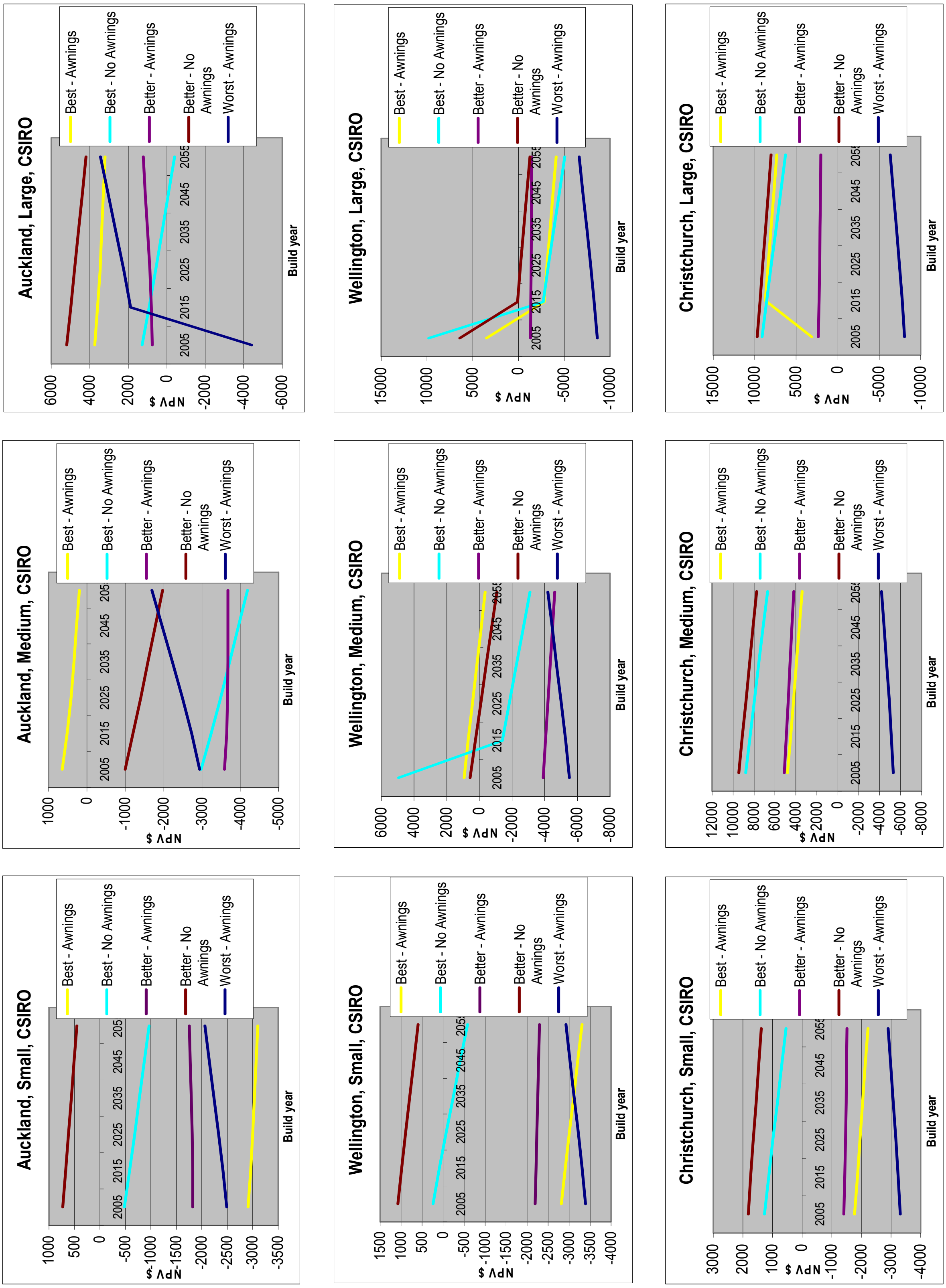


Figure 34: *NPV simulations based on CSIRO climate scenarios for new house with different levels of insulation and awnings – without natural ventilation.*

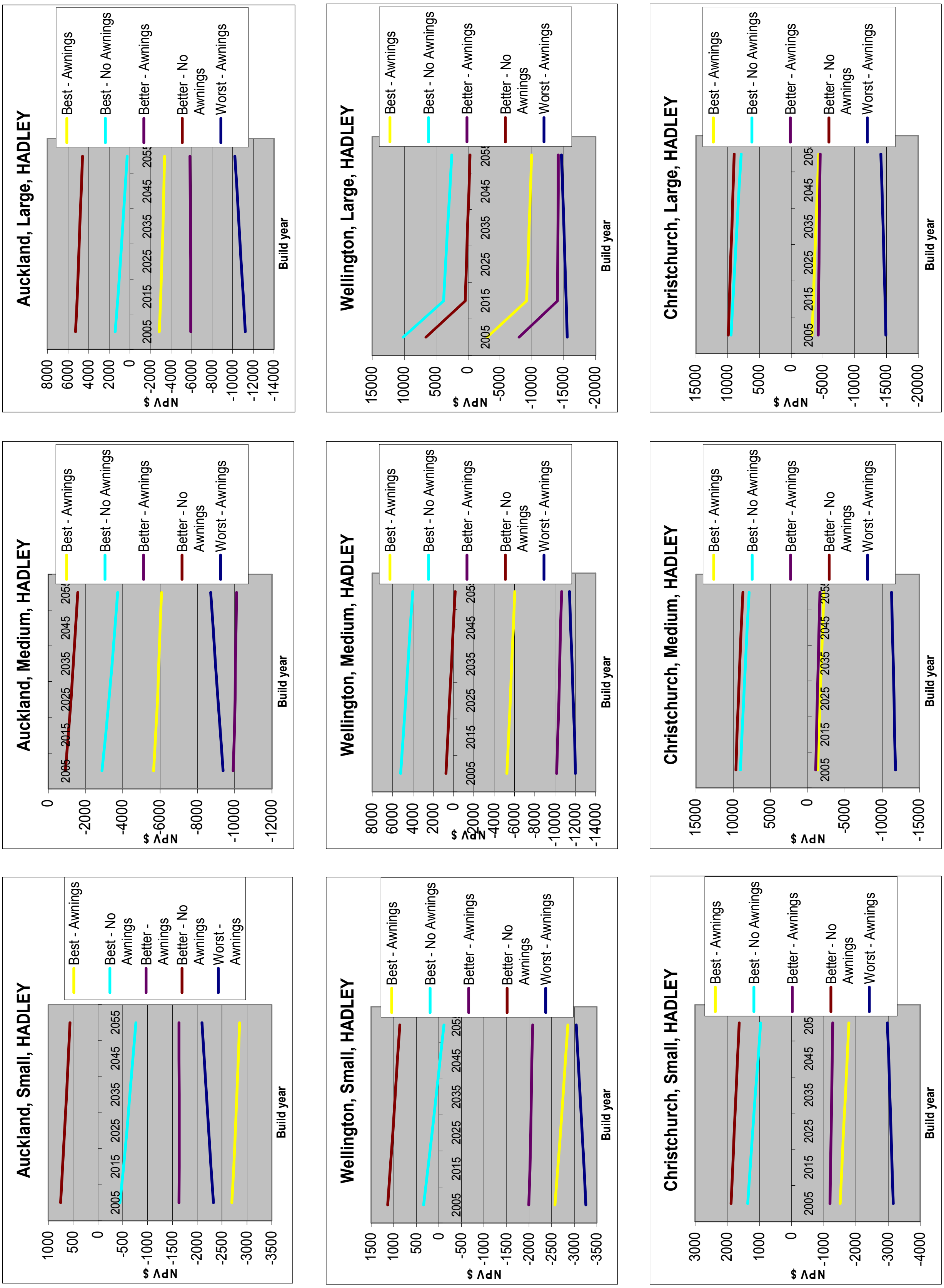


Figure 35: *NPV simulations based on HADLEY climate scenarios for new house with different levels of insulation and awnings – without natural ventilation.*

The **small house simulations** don't differ much between the CSIRO and HADLEY models, and in each region the highest NPV is *better insulation* levels with no awnings installed, the NPV is greatest in colder weather, with Christchurch having the highest NPV and Auckland having the lowest NPV.

The **medium house simulation** results differ depending on the climate model used. For the CSIRO model in Auckland the highest NPV is the best insulation with awnings installed, however in the HADLEY model the highest NPV is the base case which is the *worst insulation* level and no awnings (all other cases gives a negative NPV). For the CSIRO model in Wellington the insulation level that gives the highest NPV is the best insulation with no awnings for a house built in 2005 to approximately 2010, and then after 2010 is the best insulation with awnings. The reason for the drop in NPV for the best insulation level without awnings is due to the house requiring 3 heat pumps in 2015 and only 2 in 2005.

For medium houses in Christchurch, both models show that the highest NPV can be obtained by installing *better insulation* with no awnings. Christchurch houses also show the highest NPV out of all the regions (almost $10,000).

The **large house simulations** look different again, some of the curves have dog leg changes, this is because over time the houses either need more or less heat pumps to heat and cool the house and when a house increases or decreases the number of heat pumps its NPV changes significantly.

For large houses in Auckland and Christchurch, both the CSIRO and HADLEY models show that *better insulation* with no awnings gives the highest NPV with net present values from $5,000 to $10,000.

In the Wellington HADLEY model the best insulation with no awnings gives the highest NPV, but in the CSIRO model it depends on what year you build the house. Initially the best insulation level with no awnings provides the greatest NPV, then in about 2010 the *better insulation* level with no awnings provides the greatest NPV, but this decreases over time and at about 2020 it's most beneficial to have the *worst insulation* level with no awnings.

5.1.2.3 Modelling with Natural ventilation

Simulations were run for small and medium houses with ventilation in the form of opening windows to assist in cooling. This affected the results because less energy was used to cool the houses, which overall increased the NPVs. Another set of simulations were run to expand on the middle insulation level (*better insulation*). These incorporated two different glazing variations, single glazing, and double *glazing* argon filled in an aluminium frame. Both these simulations were run using the CSIRO and HADLEY climate models and can be seen in the figures below.

Figure 36 shows the CSIRO simulations with all insulation levels, while *Figure 38* shows the CSIRO simulations with the different glazing variations on the *better insulation* level. *Figure 37* shows the HADLEY simulations with all insulation levels, and *Figure 39* shows the HADLEY simulations with the different glazing variations on the *better insulation* level.

5.1.2.3.1 Insulation and Shading Configurations

Figure 36 shows that in Auckland the highest NPV is the *worst insulation* level with no awnings. In Wellington it gives the highest NPV if you install *better insulation* with no awnings for the small house, and after 2015 in the medium house. Prior to 2015 it would be more beneficial to install the *best insulation* level without awnings. In Christchurch the benefits are a lot higher than the other two areas. Both house sizes show it's preferable to install *better insulation* with no awnings, and the NPV is as high as $10,000 for the medium house.

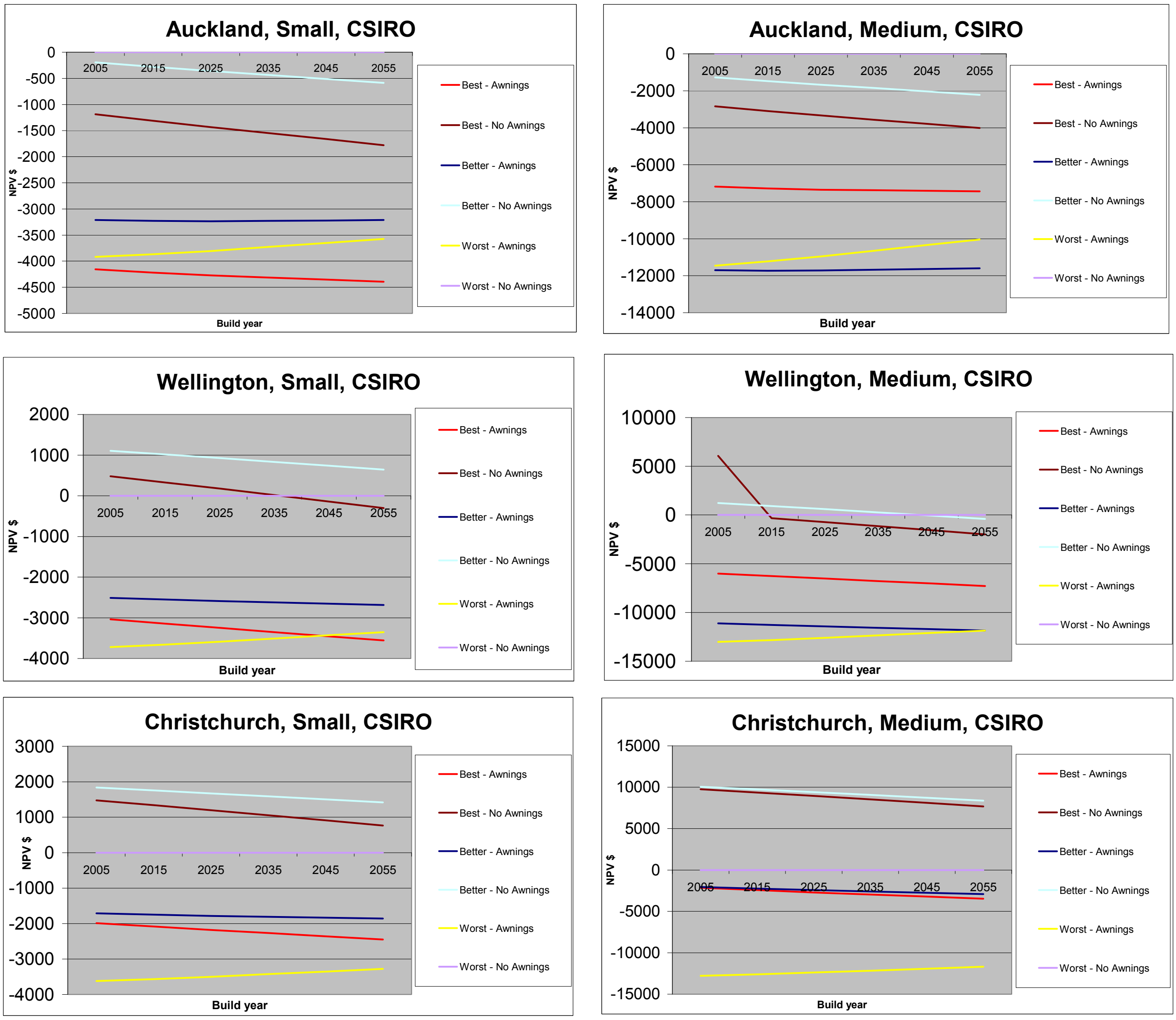


Figure 36: *NPV simulations based on CSIRO climate for new house with different levels of insulation and awnings – with natural ventilation.*

Figure 37 shows the HADLEY set of models, and they are very similar to the CSIRO models. Again in Auckland the option that gives the highest NPV is to install the *worst insulation* levels with no awnings. In Wellington the highest NPV is obtained by installing *better insulation* with no awnings in the small house and the *best insulation* level with no awnings in the medium house, while in Christchurch to get the highest NPV you have to install *better insulation* with no awnings in both houses.

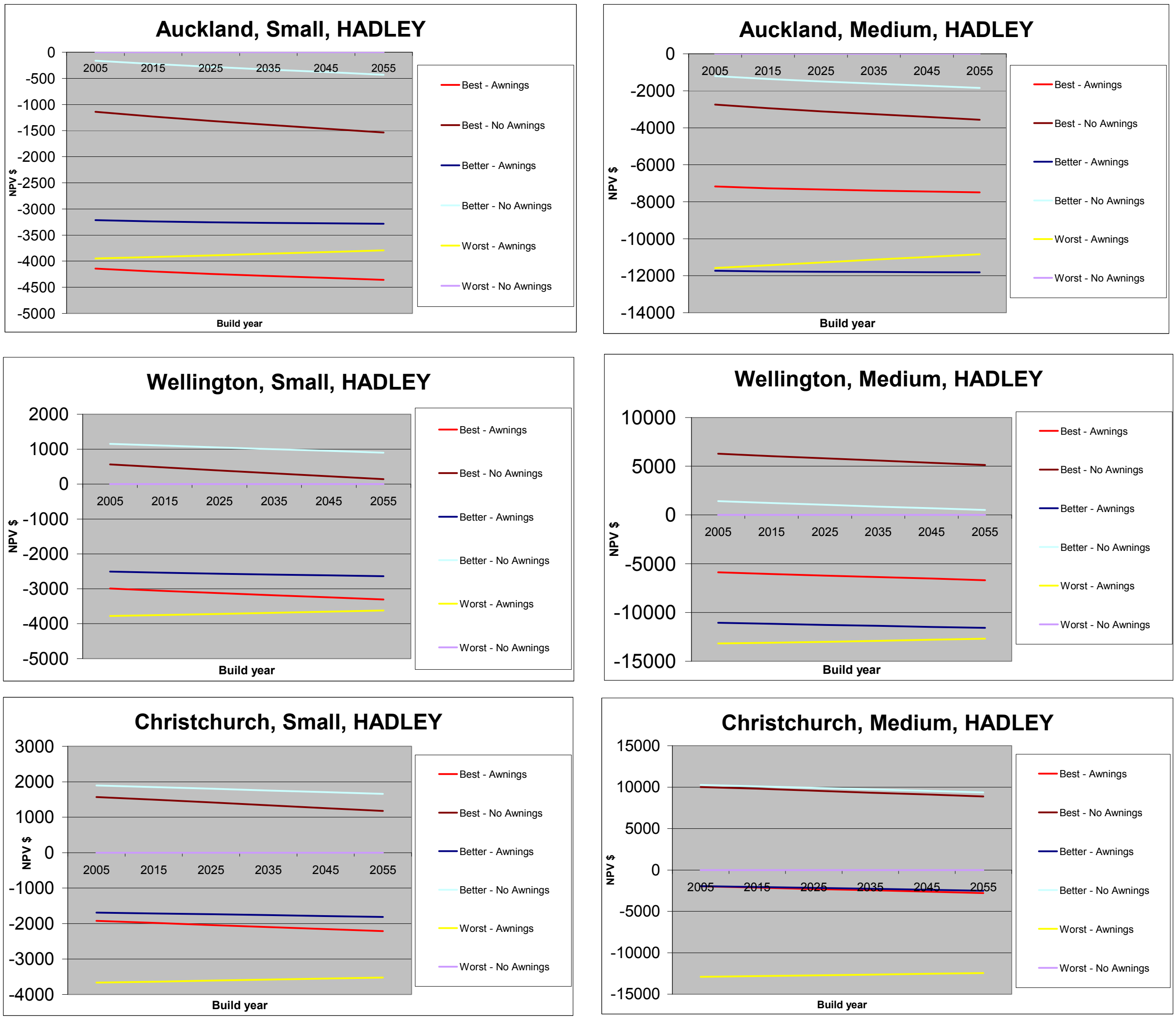


Figure 37: *NPV simulations based on HADLEY climate for new house with different levels of insulation and awnings – with natural ventilation.*

Note that no models indicate that it's best to install awnings, this is not because they don't provide significant energy savings, but because of the cost of installing them.

It is shown – primarily for Auckland and Wellington – that awnings were only economically beneficial in the previous section (5.1.2.2) where there was no allowance for natural ventilation, which of course is not a realistic situation.

5.1.2.3.2 Insulation, Shading and Glazing Configurations

Figure 38 shows the *better insulation* level, with and without awnings, with 3 different glazing variations (single glazing, double glazing, double glazing low-e with argon fill). Note that the base case (i.e. zero NPV) that the results are compared with is still the *worst insulation* level without awnings.

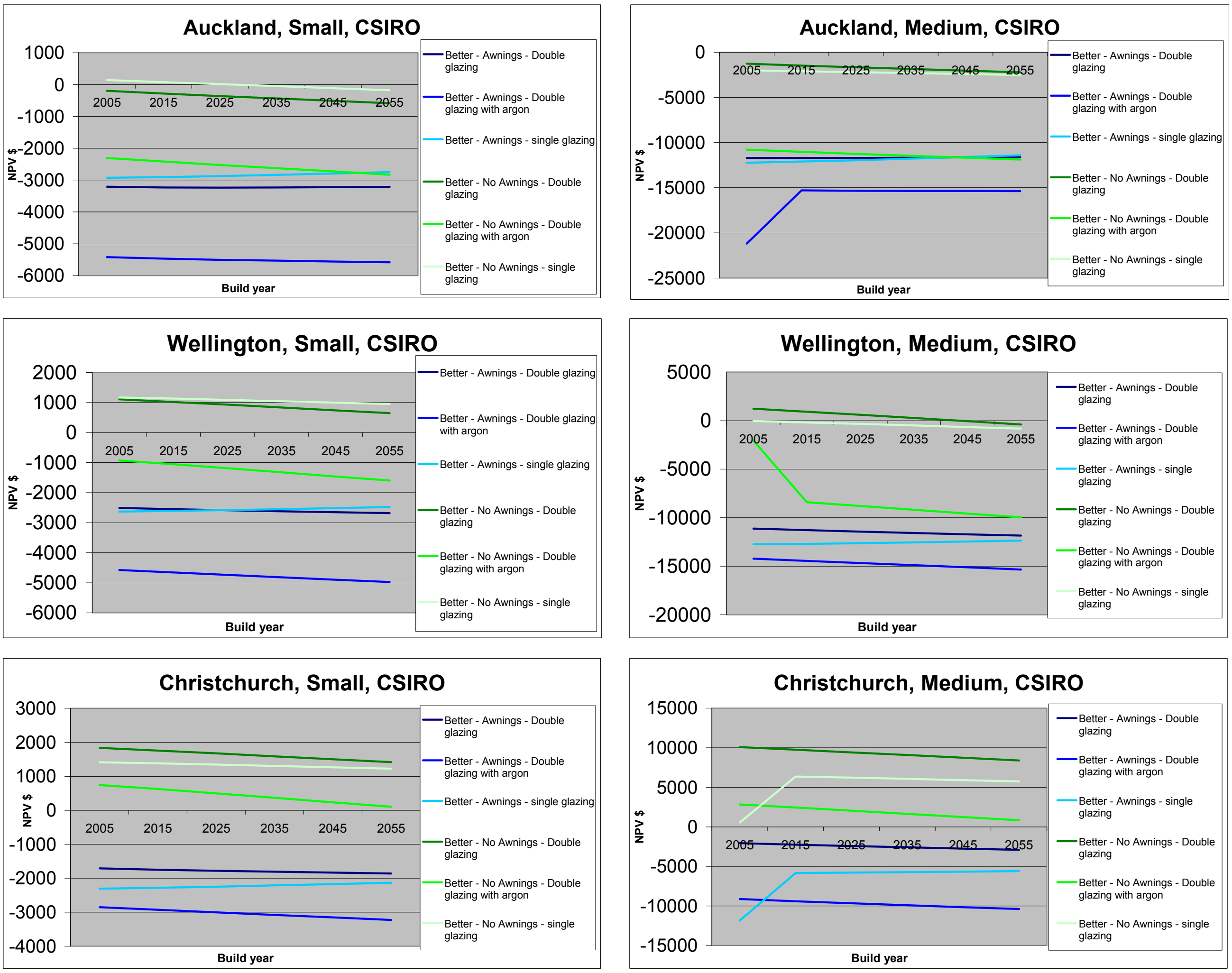


***Figure 38:** NPV simulations based on CSIRO climate for new house with different glazing and awnings – with natural ventilation.*

In *Figure 36* previously, the Auckland small houses highest NPV is actually the base case (*worst insulation* with no awnings) which has a NPV of zero. The next highest NPV is the case where you install *better insulation* with no awnings. The case in *Figure 38* above with installed single glazing windows and the *better insulation* shows a positive NPV (until about 2030), and therefore goes higher than the base case of *worst insulation* with no awnings up until 2030.

In Wellington the small house's NPV for single glazing is also higher than double glazing, however this is not the case for the medium house. In Christchurch the glazing variation that gives the highest NPV is still the original double glazing (for both the small and medium houses).

In no case is it financially beneficial to install double glazed argon filled windows, even though these provide the greatest insulation and significant energy savings.

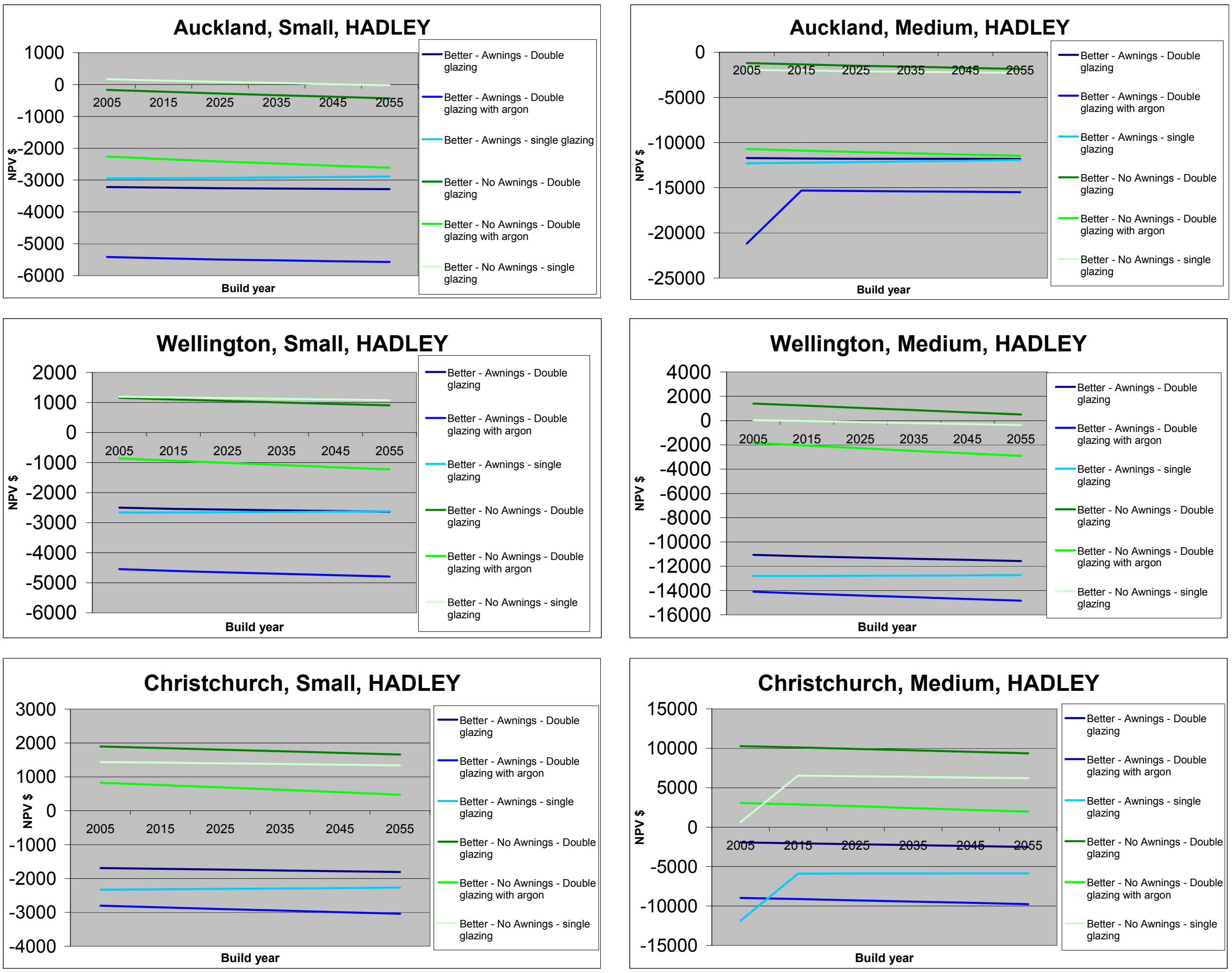


Figure 39: *NPV simulations based on HADLEY climate for new house with different glazing and awnings – with natural ventilation.*

Figure 39 shows the *better insulation* levels for the HADLEY model with different glazing options. Again these results are quite similar to the CSIRO models.

The small Auckland house in *Figure 37* shows that it gives the highest NPV when you install the *worst insulation* level with no awnings, however if single glazing was used with the *better insulation* it would give a higher NPV than the *worst insulation* level. A medium sized Auckland house would still be better off with the *worst insulation* levels though.

The Wellington small house's NPV for single glazing is also higher than double glazing; however this is not the case for the medium house. In Christchurch the glazing that gives the highest NPV is still the original double glazing (for both the small and medium houses).

Overall it shows that it is financially better to have single glazing in the warmer climates if you have a small house, but if you live in a cooler climate or have a bigger house you should install double glazing.

No situations show that's its financially better to install the best window option (*double glazed low-e with argon fill*).

5.1.3 Summary

5.1.3.1 Existing house retrofits

- Insulation retrofitting of the existing housing stock should be done as soon as possible. The net present values (NPV) decrease over time, so the bigger the delay in retrofitting the lower the lifetime economic benefit for the building (resulting in a lower NPV);
- When retrofitting the existing housing stock all homes should have the 3rd insulation level (see *Table 11*) with no awnings installed, and no upgrade from single glazing to double glazing for maximum NPV. However, double glazing retrofit still provides positive NPV (about 2/3rds of maximum NPV for most cases); and
- While awnings provide good sun protection, in no situation do they provide a greater NPV than having no awnings, therefore it is not recommended that awnings be installed if the primary objective is lower NPV[37].

5.1.3.2 New houses

✓ Models were created for small, medium and large houses with retractable awnings on all windows with no natural ventilation (opening of windows). The ideal insulation levels on new houses depends on where the house is and how big it is, see the below table for results, and *Table 12*, *Table 13* and *Table 14* on page 57 for insulation explanations.

Table 15: *Economically ideal insulation and shading per climate model (CSIRO or HADLEY) and location – assuming no natural ventilation aided cooling.*

	CSIRO			HADLEY		
	Small	Medium	Large	Small	Medium	Large
Auckland	Better - No Awnings	Best - Awnings	Better - No Awnings	Better - No Awnings	Current - No Awnings	Better - No Awnings
Wellington	Better - No Awnings	Best - Awnings	Multiple	Better - No Awnings	Best - No Awnings	Best - No Awnings
Christchurch	Better - No Awnings	Better - No Awnings	Better - No Awnings	Better - No Awnings	Better - No Awnings	Better - No Awnings

- The most favourable insulation level is commonly *Better* and with no awnings installed; and
- Models were created on small and medium houses, with ventilation in the form of opening windows to assist with cooling. The table below shows the level of insulation that provides the highest NPV:

Table 16: *Economically ideal insulation and shading per climate model (CSIRO or HADLEY) and location – assuming natural ventilation aided cooling.*

	CSIRO		HADLEY	
	Small	Medium	Small	Medium
Auckland	Current - No Awnings	Current - No Awnings	Better - No Awnings	Current - No Awnings
Wellington	Better - No Awnings	Better - No Awnings	Better - No Awnings	Best - No Awnings
Christchurch	Better - No Awnings	Better - No Awnings	Better - No Awnings	Better - No Awnings

Along with these models extra models were created to show different window variations on the middle insulation level (*better insulation*), with single glazing, double glazing, and double glazing with argon filled aluminium variations. The results showed that the small Auckland and Wellington houses had higher NPVs with single glazing, but the small Christchurch and all medium sized houses had higher NPVs with standard double glazing windows. No houses showed it was financially beneficial to install double glazed argon filled windows.

5.1.4 Discussion of the Methodology

Due to resource constraints a wide range of situations or house types were not modelled, but rather three typical house sizes by three locations and all nine combinations represent a sizable

[37] Note that awnings are static all year round which affects energy consumption negatively when heating is required.

proportion of the stock. Ideally thousands of different homes should have been modelled and the results then averaged. This would have ameliorated the drastic shifts in NPVs that can be observed and commented in section 5.1.2.2. Our analysis does not attempt to fine tune optimal levels of insulation, the ambition is to indicate broad trends over time.

5.2 Other Impacts Adaptation

This section considers the following impacts on existing housing: Driving rain, wind, hail, drought, bush fire, and sea level rise.

The number of houses likely to be affected by each impact was calculated by using 2006 census data to work out how many houses there are in each region, and NIWA data (Mullan *et al.*, 2006) to calculate what areas are susceptible to the impact in the future. The adaptation costs to mitigate the impacts are estimated in the final section of this chapter, with an estimate of benefits.

5.2.1 Mean rainfall/Increased rainfall/Driving rain

There is expected to be an increase of about 10% in wind driven rain in the North Island and western South Island, which will impact on claddings durability and maintenance. External coatings may weather faster due to the more continuous wetting of surfaces, though there could be some off-set from more frequent washing of surface contaminants. However the main assumption is that because of increased wetting there is a greater chance that water will get through the building envelope, necessitating more frequent maintenance.

For cost calculation estimates it was assumed the maintenance cycle will need to be reduced from 8 years to 7.5 years on average, for houses in regions subject to increased driving rain. Brick clad houses which account for approximately 33% of existing houses were omitted, and the remaining houses were assumed to require increased maintenance.

5.2.2 Wind

NIWA data indicates a 4.0% increase in wind speed on average for the regions by 2080, which is an increase of wind pressure of approximately 8%. To estimate the cost implications a 10% increase in the number of nails required to hold down metal roofing was assumed. The percentage of sheet metal and metal tile roofs from earlier chapters is 62% and the remainder, (concrete, membrane and clay tile roofs), were ignored. Using data from Placemakers and Rawlinson's the following cost data was established:

Costs for more nails	
Nails per SqM of roof =	4
Price per nail =	$0.20
Labour cost per m2 of roof	$0.80
Cost per SqM of roof =	$1.60
Ave cost per house =	**$238.06**

Figure 40: *Adaptation cost of using more nails to compensate for increase in wind speed*

This was based on an average roof area of 148 Sq Meters (from QVNZ data).

5.2.3 Hail

It is expected that there will be an increase in the severity of the hail events, though not in frequency. Because of this it was assumed houses will need to be upgrade to 0.55mm steel when re-roofing. This is an upgrade from the commonly used 0.4mm steel. The extra cost of using this thicker steel is $6.00[38] per square meter, which works out to be approximately $890 extra per house per re-roof.

[38] Rawlinson's construction handbook 2005

5.2.4 Fire

Days of very high or extreme forest fire danger are expected to increase in the future, which makes the fire risk higher. The areas affected most are the far north and eastern regions of the country.

Data from the NZ Fire Service identifies approximately 38,000 properties in New Zealand that are currently assessed as being at risk from bush fire, in urban fire districts, as assessed by local officers. Of these approximately 28% are in the east of both islands, identified in the NIWA report as likely to have a higher risk in future years.

Existing Housing with bush fire risk (1)		
Northland		2249
Auckland		13248
Waikato-Coro		1980
Bay of Plenty		4118
Gisborne		402
Hawkes Bay		401
Taranaki		520
Manawatu/Wanganui		250
Wellinton/Wairapar		7591
Nelson/Marl/Tasman		1354
West Coast		1144
Canterbury		1780
Otago		3197
Southland		361
		38595
Eastern regions (2)	Number	10777
	Percentage	28%

Source: NZ Fire Service.
(1) Land parcels in Urban Fire Districts where more than 50% of the area is covered by bush/ forest.
(2) BOP, Gisborne, Hawkes Bay, 20% Wellington, Canterbury, 80% Otago.

***Figure 41**: Existing housings with bush fire risk per region.*

Adaptation options to houses for the increased fire danger would be to install exterior sprinklers, install metal guttering, and to close off the baseboards to embers cannot get under the house.

Of these options the only realistic ones that would be done would be to close off the baseboards, this is because the cost associated with installing external sprinklers and installing metal gutters would be to large compared to the current risk of bush fire (there may be some extreme cases where these measure would be needed though). If in future the bush fire risk becomes as high as it does in some parts of Australia then it would be necessary to install these measures on endangered homes.

Other options that households can incorporate would be to make sure there is no bush within 10 meters of houses, cut grass and scrub close to houses, and remove loose branches on the ground. Gutters need to be clear of any flammable materials (leafs etc). There are a number of other measure households can take, which are in a booklet called “FireSmart Home Owners Manual”, put out by the National Rural Fire Authority.

5.2.5 Drought

Droughts are expected to become more frequent, with the return period of a drought likely to be halved by 2085. This will affect mainly eastern and northern parts of the country. The consequences of this could be soil cracking which can weaken building foundations.

Measures to mitigate foundation damage were not considered. Instead it was decided to only consider water storage as an adaptive measure to drier conditions.

The options are to install water tanks which collect water from the roof and store it in a water tank which is then used for laundry, toilet and outdoor use. Another option is to use greywater systems which use water from showers etc to be used in toilets. The average costs of these options are:

- $2,800 for water tanks (including pumps etc)[39]
- $2,200 for a greywater system.

The numbers affected by a drought were estimated at 303,000 houses. The adaptation costs for the affected stock therefore is as follows:

- $848 Million for water tanks (including pumps etc)
- $666 Million for the greywater system.

Only the water tanks are included in the cost table in the end section. The benefits of rain adaptive measures and water tanks have not been quantified (although they are real benefits).

5.2.6 Sea Level Rises

Sea level rises are expected to be about 0.07-0.16m in 2035 and 0.23-0.52m by 2085. With these rises comes the problem of increased coastal erosion and increased flooding from rivers. This will affect homes that are situated on the coastline.

In the event of coastal erosion or rising sea levels, houses can be moved (if they are built on piles) to an area where they are not at risk. Unfortunately this is more difficult for houses built on concrete slabs, and they might have to be demolished.

An average cost of removal, and relocation, including new foundations and services is approximately $15,000 per house.

For new homes built near the coast where the coastal erosion potential is unclear it is recommended they be built on timber piles, rather than concrete slabs. The extra cost for this, for the average new house, is $2088.

5.3 Costs of adaptation

These are summarised in the table below for existing houses.

The total cost, if all adaptation measures were applied would be approximately $2.3 billion, which represents about 1.3% of the value of the housing stock.

We have allowed for demolitions of existing houses through to the year 2080 in most cases, for calculation of total costs. Most of the adaptation measures on the existing stock only need to occur some years into the future, by which time many houses will have been demolished.

[39] Tank size 5000 litres ($1600 for tank and $1200 for pump and pipe work).

Approximately 50% of all existing houses are expected to be demolished through to 2080. The exception is for insulation retrofit where the cost is for all uninsulated existing houses, ignoring future demolitions, because the earlier the insulation retrofits occurs the better the economics of insulation, as discussed earlier.

The largest cost item is in the provision of rain water tanks and piping. It may be that expansion of central storage capacity in the existing reticulation system is a more cost effective method than individual rain water tanks. Alternatively water metering/charging may contain the need to expand capacity. But in any case this impact appears to have a significant cost implication.

An estimate of the benefits is also shown in the table, where possible. There are a number of assumptions used in deriving these, shown as footnotes in the table, and all cost and benefit data should be used with care. For example, we have assumed 0.1% of the at-risk stock, or about 500 houses per year, are saved from wind roof damage due to strengthening. However, it is difficult to calculate the effect of an 8% increase in wind forces on unstrengthened roofs.

The survey of TAs (see Appendix H) indicates approximately 280 houses are presently suffer wind damage per year so an increase to 500 per year due to increased wind forces appears reasonable.

The benefits are in present value dollars; whereas the costs are expressed assuming all the expenditure occurs now. Insulation has the largest benefit, but most of the other measures also have net benefits, i.e. the present value of the benefits exceeds the costs. The table is for the existing stock, and the unit cost for each adaptation also applies to new housing in most cases.

Climate change adaptation costs for the existing housing stock

Climate impact	Change to 2080	Region	Existing House numbers affected (1)	Measure	Cost per house $	Total cost $M	Benefits $M
Driving rain.	10% incr	West NZ.	172,920 (2)	More frequent maintenance (7)	219	38	?
Wind	8% loading incr	All regions	519,000 (3)	More nails in roof cladding (8)	238	124	137 (14)
Hail	Severity increase	West NZ.	162,000 (3)	0.55 mm sheet instead of 0.40mm (9)	894	145	55 (15)
Drought	Return period up 50%	North NI & east NZ	303,000	Water tanks (10)	2800	848	?
Bush Fire	Fire days up 50%	East NI and SI in bush areas	10,800 (4)	Baseboards mesh (11)	500	5	34 (16)
Sea level rises	0.2 m to 0.5 m	All	4,000 (5)	Move house inland (12)	15000	60	248 (17)
Temperature	+1.6 ^{O}C to 2.4^{O}C	All regions	390,000 (6)	Insulation R2.6 ceiling, R2.2 walls (13)	2100	819	3600 (18)
						2,039	4073

(1) Allows for 793,000 demolitions of existing stock by 2080,leaving 837,000 pre-2010 houses.
(2) Houses with painted wall surfaces are 66% of total.
(3) HCS data indicates 62% of stock is sheet steel or metal tiles roofing. Discount rate r = 5%
(4) From NZ Fire Service for properties with >50% bush cover in Urban Fire Districts. Period n= 50 yrs
(5) Assume only 1% of houses in coastal TAs are at risk of erosion/ surge. USPWF= 18.256
(6) Numbers with no or poor insulation. No allowance for demolitions.
(7) Driving rain. More frequent wall maintenance 7.5 yr instead of 8 yr cycle.
Life time discount SPPWF (7.5yrs) 2.1421
discount factors: SPPWF (8yrs) 2.0022
r= 5% Difference 0.1399 x wall area x $15/sqm = 219 $/house
(8) 4 more nails per sheet = $1.6/ sqm
(9) Cost differential 0.55 mm cf 0.40 mm is $6/sqm
(10) Storage tank and piping is $2,800 per house
(11) Ensure sparks are keeped out of the sub-floor.
(12) Relocate coastal houses inland, include new foundations and service connections.
(13) Insulation cost. Assume retrofit is R2.6 ceiling, R2.2 walls.
Ceiling 1120
Walls 980
2100 $/house PV= present value.
(14) Benefits from wind roof strengthening, as PV . Assume number roofs saved 500 per yr @ $ 15,000 per roof) Assumes 0.1% of stock saved from
(15) Benefits from hail roof strengthening, as PV . Assume number roofs saved = 200 per yr @ $ 15,000 per roof) damage per year for wind, hail
(16) Benefits from bush fire protection, as PV . Assume number houses saved = 11 per yr @ $ 170,000 per house) and bush fire.
(17) Benefits from sea level rise protectn, as PV . Assume number houses saved 80 per yr @ $ 170,000 per house) 2% saved /yr from coastal impacts.
(18) Earlier work gives NPV of $1300M Auckland, $600 M Wellington and $1200 M Christchurch climate zones. To this add $819 M insulation cost discounted by 10 years.

Figure 42: *The total cost, if all adaptation measures were applied would be approximately $2.3 billion, which represents about 1.3% of the value of the housing stock*

6. ASSESSING BUILDING VULNERABILITY

6.1 The Climate Change Sustainability Index (CCSI)

From earlier; three key climate change issues are expected or have the potential of causing widespread impact on buildings: overheating, flooding (inland and coastal) and ex-tropical cyclones. The Climate Change Sustainability Index developed by Camilleri (2000b; 2001) is an assessment of how vulnerable a building in New Zealand is to the impacts of these three issues. With the latest climate change predictions of increase in fire and drought risk an extension of the CCSI could be considered. The following account of the CCSI is based on the work by Camilleri and an adoption from a previous summary by O'Connell and Hargreaves (2004).

The CCSI assessment methodology is built around industry standard tools, and readily available information. The complete CCSI consists of two separate numerical ratings:

1. For impacts on a building,; and
2. For greenhouse gas emissions for space and hot water heating.

> The rating for each impact is on a scale of -2 to +5, with 0 being the reference level for normal building performance, and an 'X' rating being available for an extreme risk.

This rating scale was adopted from the Green Building Assessment Tool (GBAT). The CCSI rating is designed to be easy to apply using limited data. For some impacts a comprehensive method is used if data is available, and a simplified method is used if no data is available. *Figure 43* below gives a schematic representation of the impact assessment (excl. GHG emissions).

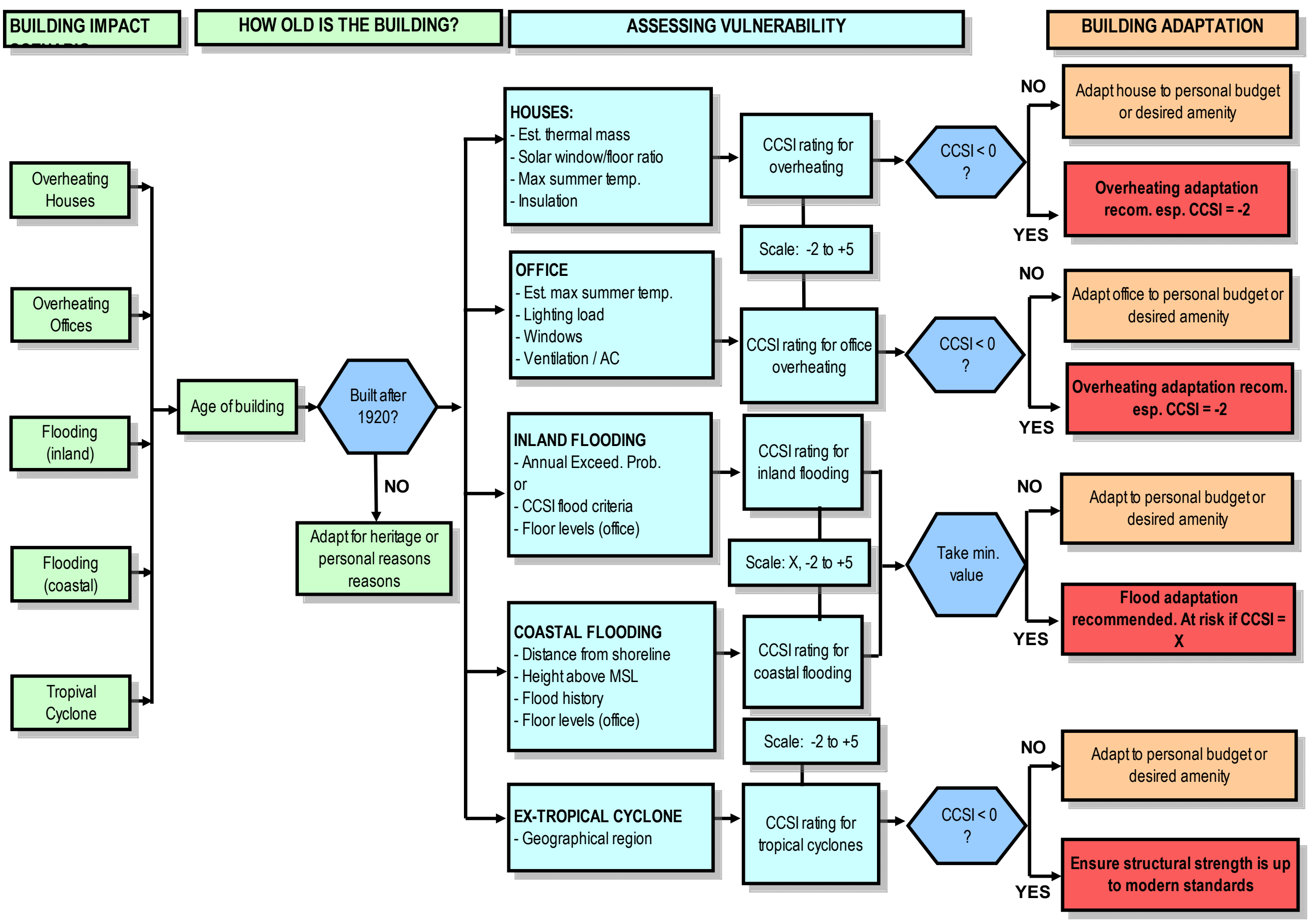


***Figure 43**: Flow chart of the building impact part of the Climate Change Sustainability Index (adapted from O'Connell and Hargreaves (2004)).*

6.1.1 The Building's Economic Life

The first stage of the assessment is to determine if the building will be standing and have a useful economic life concurrent with climate change impacts. For it to be worthwhile to adapt an existing house now against flooding, ex-tropical cyclones or overheating:

- The house should have a good chance of surviving until impacts are likely to occur;
- The impacts should be severe enough and thereafter persistent enough to justify the adaptation cost;
- The house should have a worthwhile economic life for its occupants afterwards.

The decision criteria, derived from this analysis are that on a nationwide basis:

- Houses built before the 1920s do not need to be adapted (unless for heritage- or personal reasons);
- Houses built in the 1920s to 1940s should be adapted to the earlier impacts of climate change (i.e. the 2030s climate scenarios);
- Houses built in the 1950s and later should be adapted to the more severe climate change impacts (i.e. the 2080s climate scenarios).

Cost benefit analyses indicate that it is in many cases more cost effective to adapt now than to wait another 20 years. Although it is building and context specific, it is generally more costly and difficult to retrofit as a building ages, and therefore becomes less cost effective as the building nears the end of its life.

6.1.2 Flooding

Most of the impact due to flooding will be damage to energy/telecommunication infrastructure, goods and chattels, internal features (e.g., underfloor/wall insulation), internal plasterwork and refurbishment. Additionally some properties may experience sewage intrusion (from sewer *back up*), corrosiveness of sea water (e.g. masonry damage). Properties in flood-prone coastal or inland regions may also be subject to complete obliteration from a combination of storm and tidal surges enhanced by rising sea levels.

Inland and coastal flooding are assessed separately, and then combined to give an overall flooding rating for the building. If the house scores a rating of less than '0', then some adaptation is strongly recommended. In terms of offices, the assessment is identical to that for domestic properties except that common features (e.g. floors and/or vital equipment below ground level) attract negative modifiers.

6.1.2.1 Inland Flooding

Annual exceedence probabilities (AEPs) are used to assign the CCSI credits. If AEPs are not available a flooding detectability criteria is used based on flooding history and extent of flooding records.

6.1.2.2 Coastal Flooding

As for inland flooding AEPs are used to assign the CCSI credits if data is available. If not criteria are based on height over mean sea level, distance from shore, flood history and flood record.

6.1.3 Ex-Tropical Cyclones

The action of wind on buildings causes dynamic structure loading pressure forces. Structural failure can range from removal of individual tiles or iron sheeting through to uplifting of entire roofs or walls. High wind speeds also have implications for the wind environment surrounding buildings, such as comfort and/or safety issues for pedestrians.

When a building is exposed to frequent driving rain, weathering generally occurs which can lead to higher maintenance requirements to ensure weathertightness over a building's lifetime. More effective water management systems may have to be adapted for roofs, guttering and drainage to cope with predicted greater volumes of water to ensure damage to building fabric is minimized.

The main concern with ex-tropical cyclones and storms are the effects of extreme winds and driving rain. The CCSI rating for ex-tropical cyclones is based on geographic position

6.1.4 Overheating

High temperatures inside houses and offices will affect the comfort of occupants, especially those groups deemed to be vulnerable to extremes in temperature (the elderly, infirm and young children) especially when daytime work performance or night-time sleeping is affected. When high temperatures are coupled with high humidity the likelihood of mould proliferation, strongly linked to health problems, is also increased. Positive impacts include higher night-time winter temperatures and decreased winter energy consumption.

Generic house types with broadly similar solar window to floor area ratios (SWR) are used as an *easy* mean of assessing overheating risk (e.g. glazing areas and eaves size vary with construction time/trends). Prevention of overheating is recommended for houses with a CCSI rating of 0 or less. Houses with a -2 rating have an urgent need for adaptation, as they probably suffer severe overheating already.

7. CONCLUDING RECOMMENDATIONS

There are twelve key recommendations emerging from the study:

R1: Implement a Climate Change Adaptation Plan for New Zealand

- ✓ It is essential that the climate-change planning process start now, given the longevity of housing developments and infrastructure in increasingly at-risk communities.

Local councils have an important role to play in reducing flood (inland and coastal) and fire vulnerability through development control and zoning. Direct regulatory and market interventions might be required to re-orient the sector and enable a consistent and proactive approach, but these can be expected to generate controversy and to apply in different ways across the country.

R2: Develop and Retrofit with Consideration of Increasing Climate Exposure and Vulnerability

- ✓ Regions with high climate change exposure from increased risk of flood, bushfire, temperature extremes and coastal hazards should be avoided or developed with due consideration of future climate change impacts.

This study has identified recommendations for adaptation to key climate change risk elements, with particular focus on adaptation to building overheating. As such, increased uptake of insulation in the existing housing is shown to have strong economic net benefits.

R3: Use recent natural events (e.g. storms/ flooding/ erosion/ landslips) to raise awareness of climate change impacts on housing and our way of life:

- ✓ Housing adaptations can profitably be oriented to raising concern over storms/ flooding/ erosion/ landslips as a threat to the New Zealand way of life, with particular impact for coastal communities/ houses.

Loss of iconic housing locations, lifestyles and landscapes is a powerful motivator for public concern. Note that adaptations need to be accessible to the full range of households – from the highest to lowest income – to account for flow-on effects where housing/ property values are reconfigured. Any communications need to avoid adding to social conflict.

R4: Learn How to Communicate about Climate Change and Adaptation

- ✓ Develop a communications strategy that makes it easy for the public to understand climate change, its impacts, and the need for housing adaptation specifically.

The issue of climate change (and sustainability in general) require different ways of thinking about social problems, both among communicators and their target publics. These are not obvious, and will sometimes be counter-intuitive, so communicating about climate change needs to carefully researched and developed into strategies specific to the housing sector. Best case examples currently come from sustainability-oriented communications agencies and these may be important partners in developing communications within the housing sector.

R5: Develop Behavioural Change Programmes

- ✓ Develop behaviour change programmes that make behaviour change easy, attractive, stylish, and rewarding.

Systemic programmes may need to span areas such as design, building, renovating, financing, and insuring as well as ownership/ dwelling. Behaviour change is often understood in relation to the public or consumers, it is also critical to engage housing sector, industries and institutions in behaviour change. Again, research may be required to develop programmes appropriate to the housing sector.

R6: Build the Sector's Proactivity

- ✓ Develop a proactive approach that leverages research – such as this report – towards a coherent and effective sectoral response to climate change.

This project is part of an initiative to manage the housing and social impacts of climate change proactively. To further this proactivity, some work should be directed towards mobilising a sectoral response. To that end tactical use of concerns such as flooding and social exclusion may help mobilise sector stakeholders to deal with climate change issues. Synergies may be may be achieved with initiatives that deal with health and other social issues.

R7: Orient Housing Adaptation to Social Exclusion

- ✓ As the broader strategic platform it is recommended that adaptations are oriented to the more vulnerable and socially excluded groups.

First, these groups can help establish minimal standards/ acceptable solutions for successful housing adaptations and outcomes. Second, they are relatively easily identified via measures of social inclusion/ exclusion (such as household income, ethnicity, and house condition) and so programmes to target these households/ houses are relatively simple to construct. Third, these groups may show the more significant social gains during normal weather patterns, as well as after more extreme events.

R8: Integrate Other Sectors in Future Work

- ✓ Coordinate building adaptation to climate change with other societal, institutional and technical drivers for change

Design of housing adaptations for climate change cannot be separated from design for other changes. Housing needs and vulnerabilities are concurrently shifting due to an ageing population, increasing obesity and so on. This means the housing sector can best evolve successful adaptations by working closely with sectors such as health, education, justice and urban planning. As mentioned, other sectors are already engaged in housing-related initiatives, and in this sense may actually lead the housing sector at the present time. Positioning the sector for leadership in adaptation to climate change may be an issue in itself.

R9: Reduce Sector's Carbon Footprint

- ✓ Stimulate uptake of energy efficient techniques and practices and renewable energy generation.

Policy instruments to reduce greenhouse gas emissions, such as increased costs from carbon or GHG charges pose a risk to tenants and the building industry. Energy efficiency and utilisation of renewable and low-carbon energy sources (e.g. solar, wind and biofuel) can help reduce exposure. As such, opportunities from global warming from less required water heating and winter space heating can be used to address energy price vulnerability). It is advisable to incorporate lifecycle embodied energy and lifecycle environmental impact into comparisons of building materials and construction design.

R10: Improve Confidence in Climate Science

- ✓ Improve confidence in projections of key climate change implications for New Zealand.

The results from the CSIRO and Hadley models employed in this study differ significantly in some areas. The need to adapt buildings to climate change needs to be re-evaluated as increased certainty is gained on the regional distribution-, direction- and magnitude of change for the elements ex-tropical cyclones, wind, storm, hail and rainfall.

R11: Continue Working with Scenarios for Social Impacts

- ✓ A central, longer-term task is to develop a 'strategic discussion' about the role and activities of housing in managing the social impacts of climate change.

The social scenarios developed for this study are an initial step, using the best information available from current published sources and the knowledge of experts in the study. A strategic discussion needs to be oriented to integrate and update the knowledge available from all stakeholders, to apply it to sectoral leadership, and so to initiatives within the sector. The scenario framework is a useful way of engaging other sectors in planning, in organising knowledge to anticipate changes in the sector, and in directing effective strategies and implementations.

R12: Develop the CCSI and include Bushfire and Drought Risk

- ✓ It is recommended that the CCSI is expanded to include building vulnerability from increased fire and drought risk.

The Climate Change Sustainability Index is a unique method to assess vulnerability of New Zealand houses and offices with regards to floods, ex-tropical cyclones, overheating and GHG emissions.

8. GLOSSARY

LIST OF ABBREVIATIONS AND SYMBOLS

AEP	Annual Exceedence Probabilities
BRANZ	Building Research Association New Zealand
CCSI	Climate Change Sustainability Index
CO_2	Carbon Dioxide
COP	Co-efficient of performance
CSIRO	Commonwealth Scientific and Industrial Research Organisation
C325, C375, C825 and C875	Climate scenarios based on the CSIRO9 global climate model, i.e. **C**SIRO09 in the 20**3**0s based on **25**th percentile of the IPCC temperature range (C325).
GDP	Gross Domestic Product
GHG	Greenhouse Gas
H325, H375, H825 and H875	Climate scenarios based on the HadCM2 global climate model, i.e. **H**adCM2 in the 20**8**0s based on **75**th percentile of the IPCC temperature range (H875).
IPCC	Intergovernmental Panel on Climate Change
LIM	Land Information Memorandum
NIWA	National Institute of Water and Atmospheric Research
NPV	Net Present Value
PD06	Present day climate 2006
PV	Photovoltaic
SRES	Special Report on Emission Scenarios
UNFCCC	United Nations Framework Convention on Climate Change

GLOSSARY OF TERMS

Best insulation level	An insulation and glazing configuration defined for *new houses* and used in thermal and economic simulations within this report – further defined in *Table 12, Table 13* and *Table 14* on page 57.
Climate Change	Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. (IPCC, 2001c).
CSIRO	In this report used in reference to the global climate model CSIRO09 developed by CSIRO.

Ex-tropical cyclone	Tropical cyclones form over warm tropical seas in the Southwest Pacific, quite often in the Coral Sea east of Queensland. As the storms move southward towards New Zealand latitudes later in their lifetime, they undergo a transition with injection of cooler air, and are then known as *ex*-tropical cyclones, or cyclones of tropical origin. This transition can often result in re-intensification – cyclone Bola in March 1988 is an example – and such ex-tropical cyclones are a source of extreme weather conditions for New Zealand (Mullan *et al*., 2006).
Greenhouse gas	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Beside CO_2, N_2O and CH_4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). (IPCC, 2001c).
Green roof	A roof planted with vegetation. Green roofs are primarily used for their benefits on stormwater control, reduced cooling energy and enhanced urban biodiversity and air quality.
Greenhouse effect	Greenhouse gases effectively absorb infrared radiation, emitted by the Earth's surface, by the atmosphere itself due to the same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus greenhouse gases trap heat within the surface-troposphere system. This is called the "natural greenhouse effect." (IPCC, 2001)
Greywater	Wastewater which does not contain human excreta (e.g.. used tap water and kitchen use water)
HADLEY	In this report used in reference to the global climate model HadCM2 developed by developed by the Hadley Centre for Climate Prediction and Research of the United Kingdom Meteorological Office.
Natural ventilation	Opening windows to assist cooling.
PV	Photovoltaic cells can convert light into direct current (DC) electricity.
Retrofit	Any change made to an existing structure to reduce or eliminate damage to that structure from flooding, erosion, high winds, earthquakes or other hazards. (Ref: www.csc.noaa.gov/rvat/glossary.html)
SRES	Special Report on Emission Scenarios: A report by the IPCC on GHG emissions scenarios for the 21st century based on global socio-economic development (e.g. GDP, population, wealth distribution etc.).
Standard insulation level	An insulation and glazing configuration defined for *new houses* and used in thermal and economic simulations within this report – further defined in *Table 12, Table 13* and *Table 14* on page 57.
Stomwater	Pure rainwater and anything the flowing rainwater carries along.
Tropical cyclone	A tropical cyclone (also referred to as a tropical depression, tropical storm, typhoon, or hurricane depending on strength and geographical context) is a type of low pressure system which generally forms in the tropics. (Ref: http://en.wikipedia.org/wiki/Tropical_cyclone) (For NZ conditions see: ex-tropical cyclone)

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APPENDIX A: DOMINANT DRIVERS AFFECTING COASTAL HAZARD CHANGE AT VARIOUS URBAN LOCATIONS AROUND NEW ZEALAND

	Sea –level rise	Storm surge	Swell waves	Local waves	River sediment supply (sand / gravel)	River Sediment supply (sand / silt)
Whangarei	✓	✓		✓		
Auckland						
- Hauraki Gulf	✓	✓	✓	✓		
- Harbours (east coast)	✓	✓		✓		✓
- Manukau Harbour	✓	✓		✓		✓
Tauranga						
- Harbour	✓	✓		✓		✓
- Open coast	✓	✓	✓		✓	
Napier	✓	✓	✓		✓	
Wellington						
- Harbour	✓	✓		✓		
- South coast	✓	✓	✓			
Nelson	✓	✓	✓	✓	✓	
Christchurch						
- Estuarine shore	✓	✓		✓		✓
- New Brighton coast	✓	✓	✓		✓	
Hokitika	✓	✓	✓		✓	
Dunedin						
- Harbour	✓	✓		✓		
- St Clair coast	✓	✓	✓			

Table: *Summary of the dominant drivers affecting coastal hazard change at various urban locations around New Zealand that are likely to be influenced by global climate change (Mullan et al., 2006).*

APPENDIX B: NEW ZEALAND HERALD EXAMPLES

The two examples provided here were chosen to illustrate social impacts and responses to climate change.

B.1 Landslip homeowner may strengthen cliff

Wednesday October 11, 2006

The owner of a $1 million Auckland house in danger of collapsing into the sea after a landslip may try to strengthen the cliff in a bid to save the home.

The house in Awanui Street in the North Shore suburb of Birkenhead was left precariously perched when part of the cliff collapsed into Auckland's Waitemata Harbour 10 days ago.

It was evacuated and declared uninhabitable.

However, the owner is now considering having the cliff stabilised and strengthened to stop further collapse and the house retained on the site.

The slip in Awanui St.
Picture / Dean Purcell

It was one of several options being considered, a spokesman for the North Shore City Council said.

Any decision would need council approval.

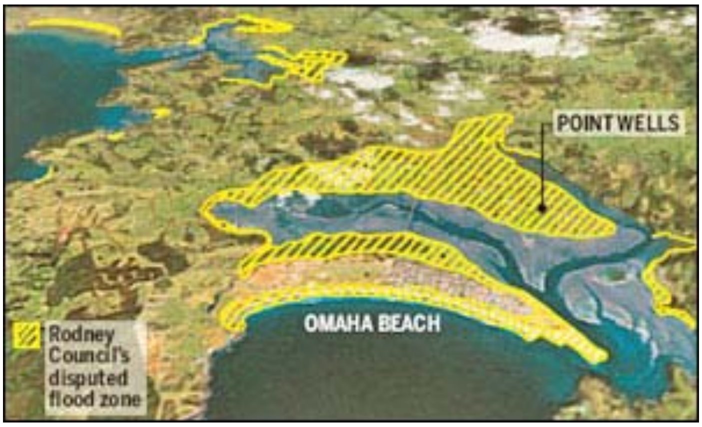
The house lost most if its back yard and two large pohutukawa trees which toppled about 40 metres into the harbour in the middle of a rain storm.

EQC engineers and geotech experts were due to meet the owner of the house to discuss its future.

- NZPA

B.2 Seaside houses falsely tagged as flood risks

Saturday October 14, 2006
By Anne Beston



Thousands of coastal homes north of Auckland may have been wrongly tagged with a hazard warning because of an exaggerated threat from global warming and extreme weather.

The mistake was discovered after a group of Omaha Beach homeowners challenged the warnings slapped on their Land Information Memorandum (LIM) by Rodney District Council.

Like other councils around the country, including Tauranga and Auckland's North Shore, Rodney is trying to protect itself from potential multimillion-dollar legal action by residents hit by severe flooding.

Orewa, Manly, Whangateau Harbour, Pt Wells and Omaha have all been affected by the LIM reports warning potential buyers the property is at risk of "coastal inundation".

A LIM is usually the first thing a potential buyer asks for because it lists any defects a home may have.

Engineer Ian Hutchinson was hired by Omaha Beach residents to check the council's calculations.

"Omaha has some wealthy and influential people and they got organised," he said. "It's like a cancer on a property when you say something like that on an LIM, but once councils have this sort of information on their files, they are legally obliged to publish it so they put something on the LIM to cover their butt."

The problems began when Rodney District Council commissioned a Tonkin and Taylor report on "coastal inundation" along its eastern coast, which has experienced a population explosion and skyrocketing land values in recent years.

The council used the report to calculate how far above mean sea level - the mid-point between low and high tide - the floor of a dwelling must be to avoid the combined risk of sea-level rise from climate change, one-in-50-year storm surges, weather patterns such as El Nino and La Nina and higher-than-normal tides.

At Omaha the figure was 5m, affecting 242 homes.

But Mr Hutchinson said sea-level data the council used were flawed and the idea rising sea levels would combine with an extreme weather event, a nasty weather pattern with a super-spring tide, was ridiculous.

"All this global warming sea-level rise is a load of garbage, sea levels have been fluctuating for ever."

The limit at Omaha should have been 3.8m, meaning only a handful, if any, properties would be affected.

Omaha real estate agent Michael Dow said the affected homes immediately lost up to a third of their value.

"The council drew a blue line showing homes all tarred with the same 'inundation' brush, it's just rubbish."

Omaha residents' association president Greg Stenbeck said lawyers helped with the case and he hoped the offending LIM notices would be removed by next month.

"There was nothing wrong with the report, it was that the council applied it willy-nilly," he said.

The council has also agreed to reword all LIM notices when one is asked for by the owner or a potential buyer.

Instead of saying the property was identified "as being within or near to land which may be subject to sea inundation", it will say the Tonkin and Taylor report did not mean the property was directly affected by the risk of inundation but was "within a range of site levels that could be affected".

The council was in the middle of revising risk levels to below 4m at Omaha and Manly but Pt Wells, Omaha Flats and Whangateau Harbour residents would have to wait for a major aerial topographical survey before LIM hazard warnings could be removed, said Rodney District spokesman Mike Isle.

That was because the data for those areas were even more limited than for Omaha Beach.

Local Government New Zealand environment manager Susan Edwards said it was standard practice at a number of councils to include information about coastal hazards on LIM reports or in district plans.

Thames-Coromandel District Council spokesman Peter Hazael said his council and Environment Waikato had taken that obligation seriously for buildings in fore-dune areas such as Cooks Beach, around Whitianga and at newly developed parts of Matarangi.

Areas within 100m from the beach were marked on LIMs as coastal hazard areas.

B.3 Beach properties facing a future without insurance

NZ Herald, 18 April 2007

Coastal property owners are likely to lobby councils hard for expensive protection measures such as seawalls if climate change makes their homes uninsurable, a natural disasters conference has been told.

Waves crash over the seawall and threaten houses. Photo / Reuters

Terry Hume, a Niwa coastal scientist, told the Auckland conference that people were still buying properties on the sea front and in high-hazard zones because they perceived the benefits outweighed the risks.

But they lacked knowledge about coastal processes and either denied risk or had blind faith that councils would help in the event of erosion.

Mr Hume said past mistakes had put coastal property in hazardous locations, too close to the sea and failing to take account of natural changes such as shoreline movement.

The level of risk was further increased as the traditional Kiwi bach was replaced by dwellings more like mansions.

A strong sense of individual property rights had to be set against the interests of the wider community which faced the possibility of rising rates to fund coastal protection and increased cost of insurance premiums.

Mr Hume said many lobby groups involved with coastal management issues were well resourced because of their often affluent and politically well-connected members.

Building insurers might not be able to calculate premiums by using historic claims experience because the past was no longer a sufficiently reliable guide to the future.

Insurance premiums might have to increase substantially, be mitigated by higher excesses or in rare cases insurance might become a thing of the past.

Mr Hume said if the insurance industry withdrew from insuring hazard-prone areas community groups would put increased pressure on councils to build hard structures such as seawalls to stop erosion and "hold the line".

It could also see unlawful actions by property owners to arrest erosion such as dumping rock.

A paper prepared by Mr Hume and Paula Blackett, policy scientist AgResearch, also warned that councils' knowledge of natural disaster risks was patchy. It said hazard mapping for natural disasters was undertaken with a different level of detail by regional and district councils.

Mr Hume said that led to a poor nation-wide picture with no standardised methodology for coastal hazard mapping and dispute among experts.

Most hazard analysis did not consider joint probabilities of events such as the occurrence of spring tides with storm surge and high waves, although such models were being developed.

Mr Hume said a sea level rise would see waves breaking higher up the shore and, with storms, would lead to more coastal erosion and flooding.

Climate Change Minister David Parker said the threat of climate change demanded policy responses which survived several electoral cycles and would require good information.

With proper planning a lot of costs from climate change could be avoided or reduced.

"Taking action now is like taking out an insurance policy for the future."

APPENDIX C: HOUSING STOCK CHARACTERISTICS

The following tables provide the housing stock by type for all TAs.

Housing type stock data					
	2001 census				
	Stand-alone house	Low rise multi-unit (1)	Med-hi rise multi-unit (2)	Bach crib	Total
Far North	18667	2529	41	549	21786
Whangarei	23034	4263	75	315	27687
Kaipara	7208	731	5	156	8100
Rodney	27617	3969	151	492	32229
North Shore	51914	14979	863	66	67821
Waitakere	47859	8520	304	228	56910
Auckland	87612	38203	7628	405	133848
Manukau	67013	15431	233	138	82815
Papakura	11467	2158	7	15	13647
Franklin	16657	1824	11	159	18651
Thames-Corom	16047	2313	42	603	19005
Hauraki	6246	596	4	33	6879
Waikato	13074	1212	15	114	14415
Matamata	9844	1211	4	18	11076
Hamilton	34485	7393	165	24	42066
Waipa	13098	1622	7	33	14760
Otorohanga	3112	277	4	27	3420
South Waikato	7671	810	12	12	8505
Waitomo	3453	357	0	45	3855
Taupo	13652	1938	19	231	15840
Western Bay of Pl	13683	1600	19	306	15609
Tauranga	29655	6980	307	216	37158
Rotorua	19729	4044	53	165	23991
Whakatane	9781	1828	23	144	11775
Kawerau	2185	260	0	6	2451
Opotiki	3034	430	4	150	3618
Gisborne	13362	2252	19	171	15804
Wairoa	3251	399	5	60	3714
Hastings	19601	4342	34	159	24135
Napier	16637	4129	69	42	20877
Central Hawke's	4501	485	4	39	5028
New Plym	22150	3834	86	111	26181
Stratford	3196	356	4	12	3567
South Tarana	9669	1017	4	54	10743
Ruapehu	5997	606	0	33	6636
Wanganui	14956	2322	38	42	17358
Rangitikei	5639	645	4	42	6330
Manawatu	9426	1098	19	69	10611
Palmerst	21673	5013	60	24	26769
Tararua	6484	634	4	24	7146
Horowhenua	10856	1751	8	108	12723
Kapiti	16293	3061	41	192	19587
Porirua	11903	2838	49	30	14820
Upper Hutt	10501	2890	28	21	13440
Lower Hutt	26689	7853	297	30	34869
Wellington	42178	16832	5073	69	64152
Masterton	8200	1228	4	36	9468
Carterton	2544	239	4	15	2802
South Wairarapa	3826	331	4	24	4185
Total South island					1058862

Housing type stock data (continued)	Stand-alone house	Low rise multi-unit (1)	Med-hi rise multi-unit (2)	Bach/crib Holiday home	Total
Tasman	14404	1778	15	564	16761
Nelson	13092	3110	31	54	16287
Marlborough	14671	2746	16	186	17619
Kaikoura	1388	235	0	27	1650
Buller	3934	542	0	102	4578
Grey	4908	618	8	69	5604
Westland	3036	429	9	54	3528
Hurunui	4395	384	0	102	4881
Waimakariri	12301	1441	7	108	13857
Christch	93794	29328	1258	117	124497
Banks Pe	4428	398	10	87	4923
Selwyn	9317	684	4	99	10104
Ashburto	9450	1406	4	54	10914
Timaru	14893	2734	22	108	17757
Mackenzie	2191	185	0	30	2406
Waimate	2974	251	0	30	3255
Chatham	258	39	0	12	309
Waitaki	8529	889	8	102	9528
Central	6578	831	13	87	7509
Queenstown	6779	2553	118	327	9777
Dunedin	36681	8018	409	162	45270
Clutha	6811	661	4	69	7545
Southland	11304	947	4	162	12417
Gore	4499	582	4	3	5088
Invercargill	17652	2537	7	36	20232
Area Out	108	18	0	0	126
Total South island					376422
Total NZ	1152483	255441	18591	8811	1435326

(1) Low rise are 2 storeys or less
(2) Medium/ high rise are 3 or more storeys.

The baches/ cribs category is determined by the census inspectors assessment, and is somewhat arbitrary as it depends on their assessment of what are very basic small temporary dwellings.

APPENDIX D: THERMAL SIMULATION CODES, ASSUMPTIONS AND SET-UP

D.1 Simulation Codes

CODE	MEANING	EXPLANATION
AU WE CH	Auckland Wellington Christchurch	
1 2 3	Region 1 Region 2 Region 3	Auckland Wellington Christchurch
Lrg Med Sml	Large House Medium House Small House	
new n ex e	New Housing New Housing Existing Housing Existing Housing	
Ne	'No Eaves'.	No windows shading devices (standard 0.6m eaves are still used)
Ea	'Eaves'.	Window Shading devices on all windows and 0.6m eaves
E2	'Half Eaves'	Window Shading devices on half of windows and 0.6m eaves
PD06 C375 C875 H325 H825	Present Day 2006 climate CSIRO, 2030's 75% CSIRO, 2080's 75% Hadley, 2030's, 25% Hadley, 2038's, 25%	 2030's 'high' 2080's 'high' 2030's 'low' 2080's 'low'
UCOH	Underheating, Overheating.	No heating or cooling is simulated, temperatures are allowed to fluctuate between highs and lows to provide an accurate output of real temperatures, overheating and underheating and so on.
HtgClg	Heating, Cooling	Heating @ 16º and Cooling @ 25º is simulated to provide an accurate output of loads required to keep the houses within a predetermined comfort range.
UCOHVnt	Underheating, Overheating. Venting.	Same as free schedule above, but including natural ventilation @ 22º
HtgClgVnt	Heating, Cooling. Venting.	Same as mechanical schedule above, but including natural ventilation @ 22º
WST	Worst – New Housing	Worst insulation/glazing option. - Current code compliance insulation levels in floor, wall and roof. - Single Glazing
STD	Standard – New Housing	Better insulation/glazing option. - Proposed new code compliance for 2007 with higher insulation levels in floor, wall and roof. - Double Glazing
BST	Better – New Housing	Best insulation/glazing option. - Best possible insulation levels with today's technology in floor, wall and roof. - Low 'e' double glazed argon filled aluminium framed windows

CODE	MEANING	EXPLANATION
Bse	Base Case/Worst Case – Existing Housing	Base scenario, no insulation, single glazing
001	Existing Housing	Insulation Scenario 1 - Ceiling Insulation only, Double Glazing
002	Existing Housing	Insulation Scenario 2 - Ceiling and Floor Insulation only, Double Glazing
003	Existing Housing	Insulation Scenario 3 - Ceiling, Wall, Floor Insulation, Double Glazing
004	Existing Housing	Insulation Scenario 4 - Best Ceiling, Wall and Floor Insulation, Double glazing with LowE+argon, therm break aluminium frame
glzg	Glazing Variations	
nda	New housing, Best glazing	Double glazed, low e, argon filled aluminium framed.
ndb	New Housing, Standard Glazing	Double Glazing
nsl	New housing, worst glazing	Single Glazing
eda	Existing housing, best glazing	Double glazed, low e, argon filled aluminium framed.
edb	Existing Housing, standard glazing	Double Glazing
esl	Existing Housing, worst glazing	Single Glazing

D.2 Simulation Assumptions an Set-up

D.2.1 Method

Through the use of the SunRel modelling tool a number of different scenarios were simulated to give an idea of how climate change will affect user comfort and energy usage within the New Zealand building stock. In all 5 climate scenario's were simulated (including present day), 3 New Zealand locations, 3 house sizes and types, 3 insulation/glazing options and 2 window shading options. In total 540 simulations were run and analysed to provide an overview of how climate affect the New Zealand building stock, based on extremes of weather data. More information on how different variations were chosen is provided in the following sections.

Simulations were run using a macro system that created the SunRel building files from 18 set base files. The macro replaced materials, heating/cooling schedules, glazing and weather files within the base files. A second macro was then used to run each of the simulations which created the output files. A further macro was to extract particular sets of data for analysis from the output files so that analysis was easy and efficient.

D.2.2 BRANZ Simulations

The NIWA report (Mullan *et al.,* 2006) has found that different models and scalings give different types of changes in New Zealand weather. In short, by the end of the 2080's, temperature increase up to 2.4ºC with little rainfall difference in C875, whereas in H875 there lower temperature increase and higher rainfalls. It was decided that as SunRel only refers to temperature, humidity etc in the weather files that it would not be beneficial to simulate using all the climate scenarios, but instead to only compare the extremes. The climate scenario's chosen to represent the extremes were PD06, H325, C375, H825, and C875. This provided us with present day data as a benchmark as well as those future climate scenario's that exhibit the high and low temperature extremes in the two future periods.

D.2.3 Locations

The NIWA report looked at the whole of New Zealand in general, but also focused specifically on 7 locations around New Zealand that were chosen to represent the range of climates found in New Zealand.

There included; Auckland, Hamilton, Tauranga, Wellington, Nelson, Christchurch and Hokitika. However due to the high amount of climate scenario's that were to be compared, and also because a very Southern climate i.e. Dunedin or Invercargill were not analysed for climate change it was decided to only use the main centres for the simulation work on the New Zealand building stock. The three locations chosen were Auckland (AU), Wellington (WE), and Christchurch (CH).

D.2.4 House Types

To follow on from simulation work previously done by BRANZ Built Environment Scientists on HEEP and the Building Code, it was chosen that three house sizes and types would also be modelled to provide a range of information on different houses.

The types of houses were:

- Small House approximately 100m^2, one storey, timber weatherboard wall cladding, sheet metal roof cladding, and timber floor.
- Medium House approximately 150m^2, one storey, masonry veneer wall cladding, sheet metal roof cladding, concrete floor.
- Large House approximately 200m^2+ two stories, timber weatherboard wall cladding, sheet metal roofing, concrete floor.

More information on how these houses were modelled is provided in following sections.

D.2.5 Variations

There has been a wide range of discussion about what kind of variations to run to look at how climate change will effect improving building design practice. It was eventually decided that as each region within New Zealand currently requires different levels of glazing and insulation then each region would be dealt with separately. Locations within Region 1 are Auckland, Region 2 are Hamilton, Tauranga, Wellington, and Region 3 are Nelson, Christchurch and Hokitika. For more information refer to SNZ PAS 4244:2003, Insulation of Lightweight-Framed and Solid-Timber Houses.
Simulations have been broken down into two sets, new housing and existing housing.

D.2.6 New Housing

It was agreed that 3 different insulation/glazing variations would be compared, as well as 3 different shading options.

The three insulation/glazing variations were as follows;

- WORST – current code compliance insulation levels in floor, wall and roof, single glazing. (Known as WST)
- BETTER – proposed new code compliance for 2007 with higher insulation levels in floor, wall and roof, double glazing. (Known as STD)
- BEST – best possible insulation levels with today's technology in floor, wall and roof, low 'e' double glazed argon filled aluminium framed windows. (Known as BST)

For full information on these variations, refer to D.5, Insulation and Glazing Variations and Construction Details.

D.2.7 Existing Housing

For existing housing there were 5 insulation/glazing variations as follows;

- BASE – no insulation, single glazing
- 001 – insulation in ceiling only, double glazing
- 002 – insulation in ceiling and floor only, double glazing
- 003 – insulation in ceiling, floor and walls, double glazing
- 004 – Highest levels on insulation in ceiling, floor and walls, double glazed, low-e argon filled aluminium framed windows.

D.2.8 Window Shading

The three shading options were as follows;

- NONE – No shading devices simulated above windows. (Known as Ne)
- HALF SHADING – Shading devices above half of the windows. (Small and medium house only) (Known as E2)
- SHADING – Shading devices simulated above windows, refer to assumptions below for information on how these were calculated and modelled. (Known as Ea)

D.2.9 Glazing

In the initial simulations, specific glazing types were used with specific insulation levels. Later simulations looked to compare how different glazing types compared to a particular ‘middle’ level of insulation.
For new housing this was modelled on STD and for existing housing it was modelled on 003.
Single, double and Double glazed low-e argon filled aluminium framed windows were all compared.

D.2.10 Schedules

The final sets of scenarios for the simulations were the use of heating and cooling schedules. Firstly each variation needed to be run using a ‘free’ heating/cooling schedule so that overheating or under heating hours could be analysed and compared between different variations. (Known as UCOH (Under cooling – Overheating) or ‘free’ Schedule.) Secondly a heating and cooling schedule was determined for most rooms and the whole house so that the energy load used to keep the houses within particular comfort levels could be analysed and compared between variations. (Known as HtgClg (Heating – Cooling) or Mechanical Schedule.) The following sections provide detailed information on how these schedules were calculated and simulated.

Later simulations looked at how natural ventilation compares with mechanical cooling. This was simulated by providing natural ventilation @ 22° on both the ‘free’ and ‘mechanical’ schedules. These then became known as HtgClgVnt (heating, Cooling, Venting) and UCOHVnt (Under cooling, Overheating, Venting).

D.2.11 Runs

- Ground Reflectance of 0.3 – Default value as given in *SUNREL Technical Reference Manual* (pg 3-3).
- Ground Temperature was taken 1m below ground level. Recorded seasonally. A full list of these can be found in D.5, Ground Temperatures.

D.2.12 Zones

- Areas were calculated from the adapted floor plan as shown at the end of this section.
- Height as found on Plans. Attic heights assumed with 15 degree roof angles. Underfloor heights assumed to be 0.8m.
- Infiltration Rate of 0.5 ACH in house and attics, and 4 ACH in underfloor zones.
- Leakage Area of 0 cm² – Default value as given in *SUNREL Technical Reference Manual* (pg 3-3).
- Solar to Air (0.2) and Solar Lost Values (0.1) are assumed values.
- Sensible Gains of 0kW in Attic and Underfloor zones - Default value as given in *SUNREL Technical Reference Manual* (pg 3-3). For all other zones sensible gain schedules were calculated based on assumed periods of time and the amount of assumed people in the space at the time for each separate zone. This information can be found in D.6, Sensible Gains.
- Latent Gains of 0 kW – Default value as given in *SUNREL Technical Reference Manual* (pg 3-3).

D.2.13 Walls

- Front and Back Side Coefficients of 11.11 and 33.33 W/m²-C respectively were assumed values.
- Solar Absorption values were distributed evenly throughout the wall surfaces, with the floor receiving a higher proportion. Walls with two or more sections/backsides are allocated solar absorption according to the percentage of the total wall length they represent.
- Wall Fractions are 100% for solid construction, 82% cavity and 18% studs for walls, 88% cavity and 12% rafters for ceilings, 90% cavity and 10% rafters/joists for roofs and timber floors.

D.2.14 Windows

- Windows sizes were specified on the plans (length x width).
- Window placements were estimated using the plans and sizes as a guide.
- The interior surface coefficient was assumed to be 8.28% and the exterior surface coefficient 29%.
- A frame percentage of 0.5% was assumed.

D.2.15 Exterior Surfaces

- The house has not been modelled to exact orientation. The floors plans modelled below show how north was modelled for the house.
- Default values of 0 have been used for the Leakage Fraction and Wind Pressure Coefficient.

D.2.16 HVAC Types

- kW Rates were those given in the Appliance Information gathered from occupants.
- The Coil Temperature of 14 is an assumed value.
- The types of HVAC used is either heating or cooling (for the Mechanical Schedule).
- Heating was set at 16º from 11pm – 7am and 20º from 7am – 11pm. This is an assumed minimum level of comfort.
- Cooling was set at 50º from 11pm – 7am and 25º from 7am – 11pm. 25º is the 'overheating' temperature used as that is the same level set in the NIWA report. Cooling is only using mechanical cooling, no natural ventilation is used. Therefore the effect of opening a window is not taken into account, so this is not a truly accurate scenario. However it does give a worst case scenario, where for example natural ventilation can not be used due to dust storms etc.

- When natural ventilation was used, cooling was simulated @ 22º from 7am – 11pm and 50º from 11pm – 7am. The ACH was set at 4.

D.2.17 Mass Types

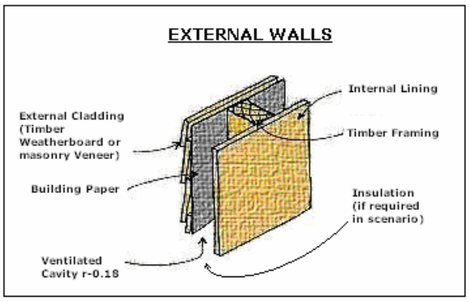
- Conductivity and Density of materials can be found under Appendix E of NZS 4214(Int): 2002.
- Specific Heat of materials can be found in *ASHRAE Handbook – Fundamentals* (pg 24.4 - 24.7).
- Thicknesses are either specified in the HEEP occupant surveys or estimated using Appendix E, NZS 2414(Int): 2002.
- The number of nodes for each material has been assumed, with all materials other that concrete 200mm thick or over having 1 node.

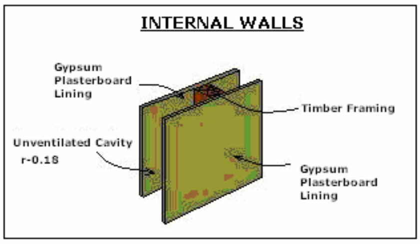
D.2.18 Wall Types

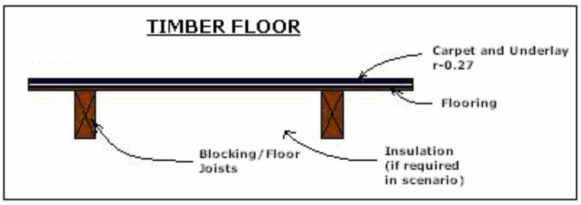
- Wall layers are entered inside to outside.
- R-values are entered where a mass type is not present or where there is more than one component (timber frame and insulation).
- Where there is more than one component the combined r-value has been calculated using the equations 5 and 6 (Section 6.8.1) of *NZS 4214*.
- The thermal resistance of materials is found in *NZS 4214(Int): 2002* Appendix E, Table E1a, b, c and d.
- The thermal resistance of air is found in *NZS 4214(Int): 2002* Appendix E, Table E3.
- R-values for insulation were found in *BRANZ House Insulation Guide* Appendix A.
- Where specific information was not supplied assumption were made as to material qualities and sizes.
- Assumed Roof, Wall and Floor compositions are shown below.

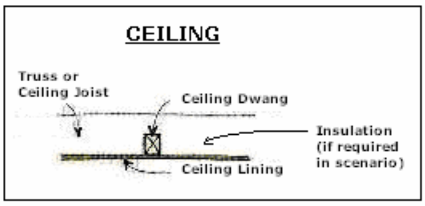
D.2.19 Glazing Types

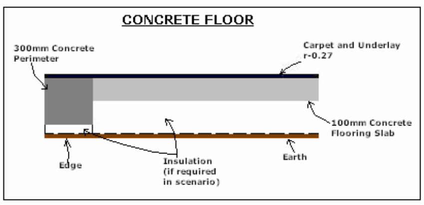
- Glazing types are defined by the relevant files.
- Glazing types included Single (WST), Double (STD), Low 'e' - argon filled - aluminium framed - double glazing (BST)

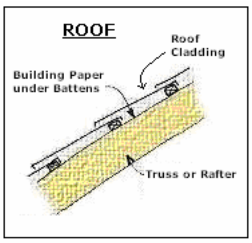












D.2.20 Overhang Types

- It is assumed there is a 600mm overhang around the perimeter of the house.
- A default value of 0.6 has been used for the Diffused Reflection; this was found in *SUNREL Technical Reference Manual* (pg 3-10).
- To create variations on window shading devices, overhangs were used. In the 'Ne' situation, this was termed as 'No Eaves', however this actually means there is no shading device over the windows, and the standard 0.6m eaves are still used. In the 'Ea' situations, this was terms a 'having Eaves', however this actually means that window shading devices were incorporated.
- To model as true a situation as possible, retractable canvas window shade devices around BRANZ were used as a basis for providing angles and widths. It was found that in order to still provide a view outside (which most occupants agreed was vital even on extreme days), a tilt angle of 66º was used. Using a window height of 1.0m (Standard BRANZ window height), an overhang projection of 0.49m was found. This was recalculated for each different window size so that a true life scenario could be modelled where every window provided a view. Window heights and shading widths information can be found in D.7, Window Shading Modelling.

D.2.21 Schedules

- Three types of schedules have been set up, as outlined in the following.
- Schedules have been used to calculate sensible gains in general household zones (not including Underfloor and attic zones) as discussed previously. These schedules are based on information given in HEEP surveys and also the distribution of appliance heat loads, these are used to calculate the sensible gain throughout the day.
- Schedules have also been used to providing heating and cooling schedules as discussed previously. These have been compiled using the estimated heating and cooling times given in the HEEP occupant surveys, with a temperature of 16ºC used as a base heating point and 25ºC as a base cooling point.
- Schedules have also been used to provide seasonal ground temperatures for each of the 5 climate scenarios used in each of the 3 locations as discussed previously.

D.2.22 Seasons

- The heating season is that specified by the occupants in HEEP survey
- Other seasons used include; all year round ('All' or Year') which runs from Jan 1st – Dec 31st, summer ('Sum') which runs from Dec 1st – Feb 28th, autumn ('Autm') which runs from Mar 1st – May 31st, winter ('Wntr') which runs from June 1st – Aug 31st and spring ('Sprg') Sep 1st – Nov 30th.

D.2.23 Stations

- Latitude, Longitude and Site Elevation were found in *ASHRAE Handbook – Fundamentals* (pg 26.42).
- Auckland was modelled on a Whenuapai weather site, Wellington was modelled on a Kelburn weather site and Christchurch was modelled on a Christchurch weather site.
- The Terrain Class value of 4 was used.
- The Shielding Class value of 4 was used.
- The weather file was produced using a combination of NIWA data and calculations.

D.2.24 Parameter

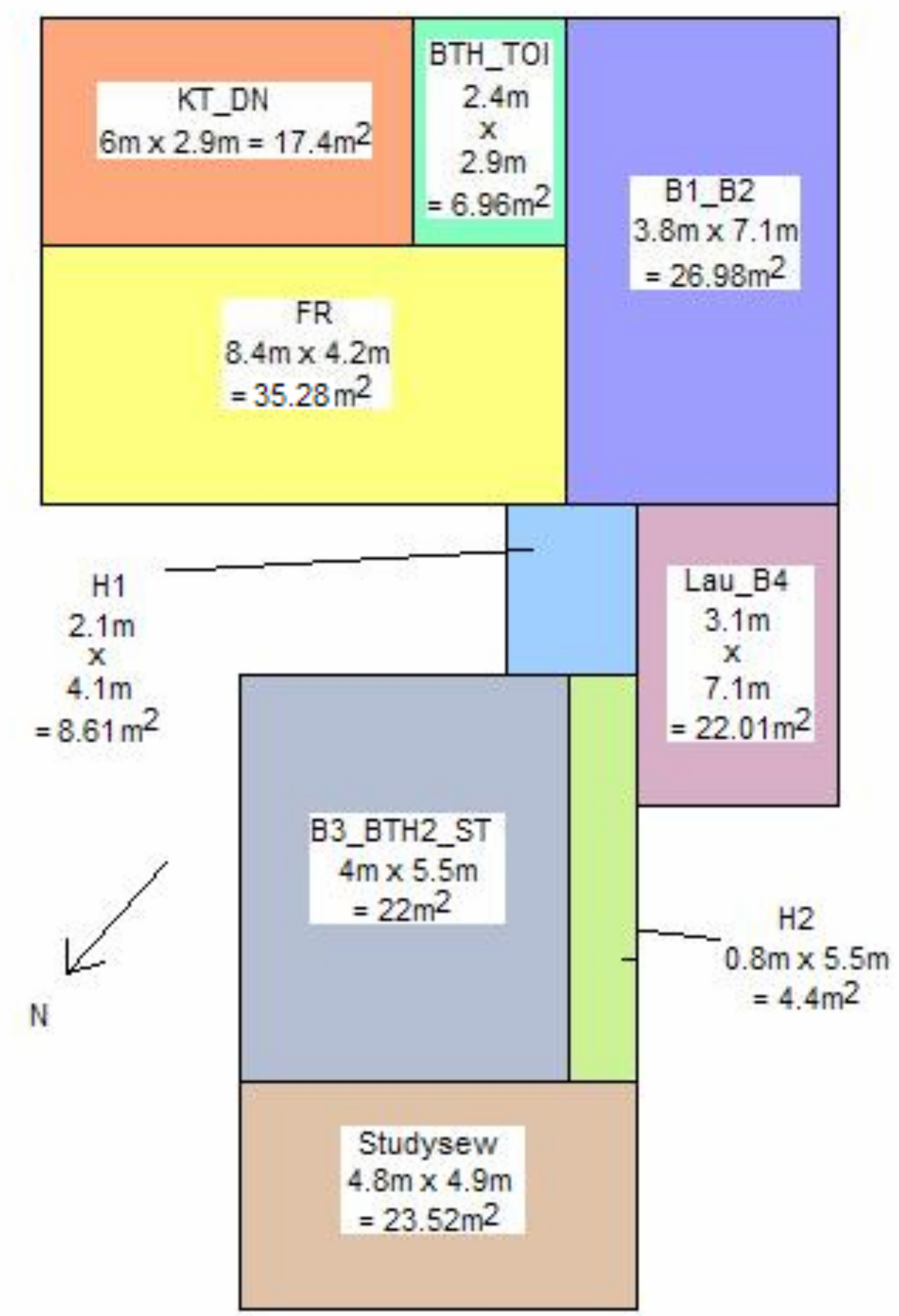
- Heating Degree Days set at 18ºC
- Cooling Degree Days set at 25ºC

•

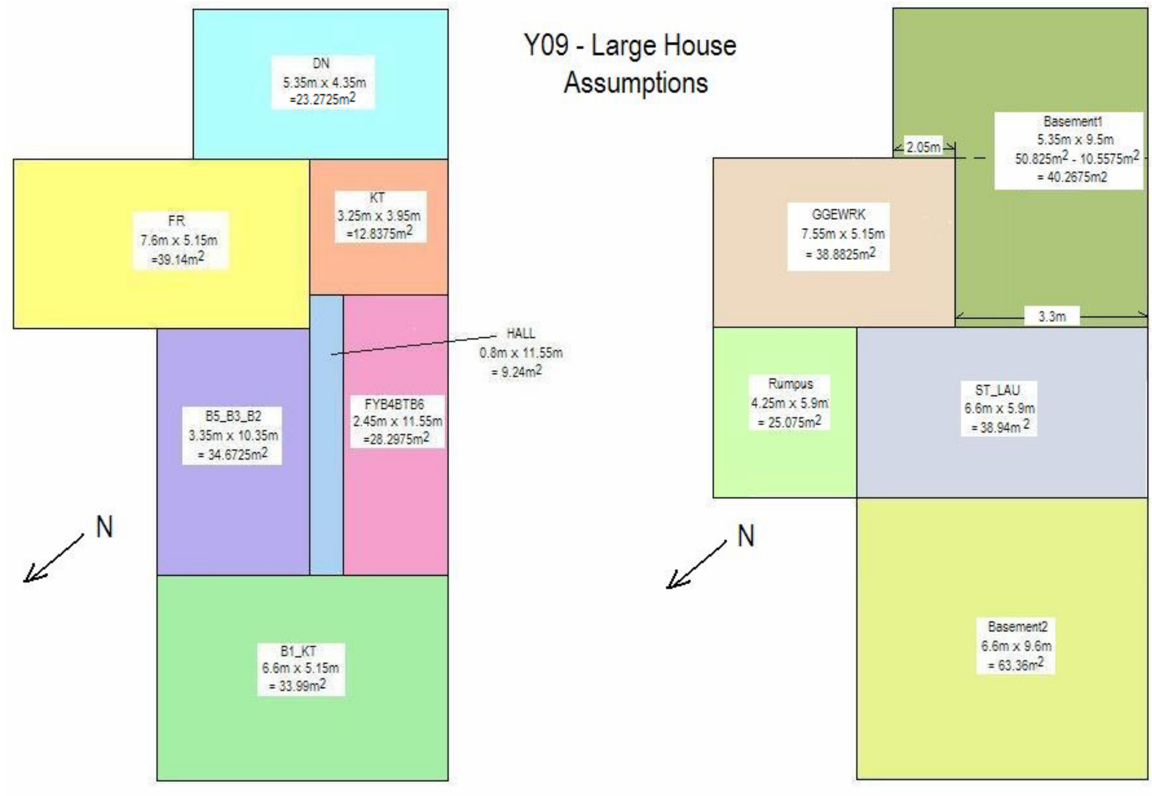
D.2.25 Adapted Floor Plans

On following pages.

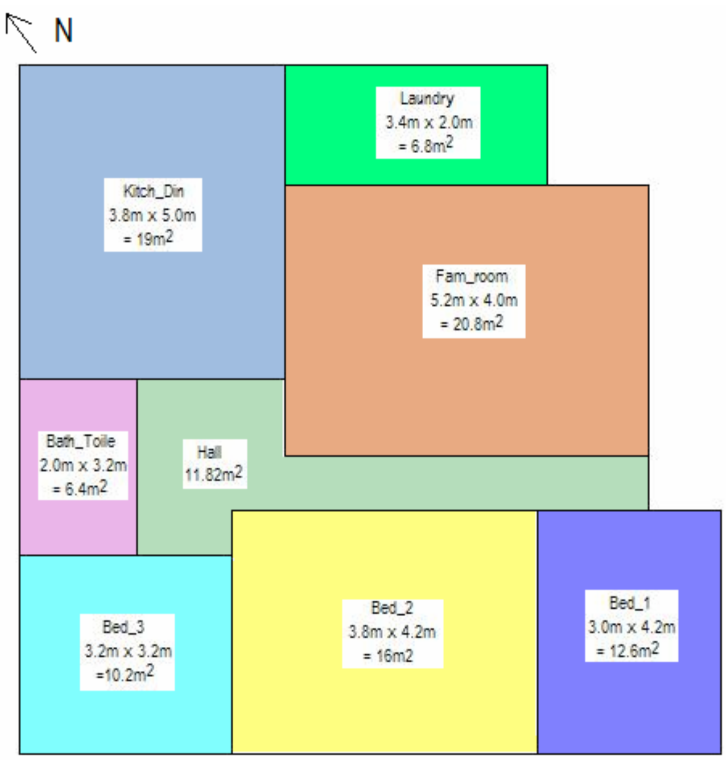
D.2.24.1 Medium House



D.2.24.2 Large House



D.2.24.3 Small House



D.4 Insulation and Glazing Variations and Construction Details

CONCRETE FLOOR		TIMBER FLOOR		INTER FLOOR (large House only)
Floor	Floor Perimeter	Floor	Floor Perimeter	
Carpet r-0.34	Carpet r-0.34	Carpet r-0.34	Carpet r-0.34	Carpet r-0.34
Plywood Flooring	Plywood Flooring	100mm Concrete Slab	300mm Concrete Slab	100mm Concrete Slab
Insulation	Joists	Insulation	Insulation	Insulation
		Earth	Edge	Gib Board

EXTERIOR WALL		INTERIOR WALL	
80%	20%	80%	20%
Gib Board	Gib Board	Gib Board	Gib Board
Insulation	100mm Studs	Air Space Cavity r-0.18	100mm Studs
Air Space Cavity r-0.18	Weather Boards or Masonry Veneer	Gib Board	Gib Board
Weather Boards			

ROOF		CEILING	INTER ROOF (large house only)
80%	20%		
Sheet Metal r-0.0004	150mm rafters	Gib Board	Gib Board
	Sheet Metal r-0.0004	Insulation	Insulation
			Plywood Flooring
			Membrane Roofing r-0.063

*Small House*NEW HOUSING INSULATION LEVELS												
	Auckland				Wellington				Christchurch			
	Ceiling	Wall	Floor	Windows	Ceiling	Wall	Floor	Windows	Ceiling	Wall	Floor	Windows
WST	r-1.8	r-1.8	r-1.3	Single	r-1.8	r-1.8	r-1.3	Single	r-2.6	r-1.8	r-1.3	Single
STD	r-2.6	r-2.2	r-1.4	Double	r-2.6	r-2.2	r-1.4	Double	r-3.6	r-2.2	r-1.4	Double
BST	r-3.6	r-2.6	r-2.8	Double, Low-e, Argon Filled, Aluminium Framed	r-3.6	r-2.6	r-2.8	Double, Low-e, Argon Filled, Aluminium Framed	r-3.6	r-2.6	r-2.8	Double, Low-e, Argon Filled, Aluminium Framed

EXISTING HOUSING INSULATION LEVELS												
	Auckland				Wellington				Christchurch			
	Ceiling	Wall	Floor	Windows	Ceiling	Wall	Floor	Windows	Ceiling	Wall	Floor	Windows
BASE	0	0	0	Single	0	0	0	Single	0	0	0	Single
001	r- 2.6	0	0	Double	r- 2.6	0	0	Double	r-3.2	0	0	Double
002	r- 2.6	0	r-1.4	Double	r- 2.6	0	r-1.4	Double	r-3.2	0	r-1.4	Double
003	r- 2.6	r-2.2	r-1.4	Double	r- 2.6	r-2.2	r-1.4	Double	r-3.2	r-2.2	r-1.4	Double
004	r- 3.6	r- 2.6	r-2.8	Double, Low-e, Argon Filled, Aluminium Framed	r- 3.6	r- 2.6	r-2.8	Double, Low-e, Argon Filled, Aluminium Framed	r-5.0	r- 2.6	r-2.8	Double, Low-e, Argon Filled, Aluminium Framed

D.5 Ground Temperatures

1-meter Earth Temperatures for use with NIWA Scenario Weather Data Files					
Site/Season	Current Climate	Scenario h325	Scenario c375	Scenario h825	Scenario 875
AUCKLAND – Whenuapai					
SUMMER Dec, Jan, Feb	20.3	20.7	21.0	21.5	22.6
AUTUMN Mar, Apr, May	17.2	17.6	18.2	18.5	19.8
WINTER Jun, Jul, Aug	11.8	12.4	12.5	13.3	14.1
SPRING Sep, Oct, Nov	15.5	16.0	16.1	16.7	17.8
WELLINGTON – Kelburn					
SUMMER Dec, Jan, Feb	17.9	18.2	18.7	18.9	20.3
AUTUMN Mar, Apr, May	15.7	15.9	16.7	16.7	18.2
WINTER Jun, Jul, Aug	10.1	10.6	10.8	11.5	12.4
SPRING Sep, Oct, Nov	13.4	13.9	14.0	14.5	15.7
CHRISTCHURCH – Christchurch					
SUMMER Dec, Jan, Feb	17.8	18.1	18.5	18.7	20.1
AUTUMN Mar, Apr, May	13.1	13.3	14.1	14.1	15.5
WINTER Jun, Jul, Aug	5.9	6.4	6.6	7.2	8.1
SPRING Sep, Oct, Nov	12.0	12.5	12.6	13.2	14.3

D.6 Sensible Gains

D.6.1 Small House

Kitchen
0.02kW per hour from 11pm – 7am
0.11kW per hour from 7am – 11pm
Used in the Kitch_Din zone all year
Lounge
0.02kW per hour from 11pm – 7am
0.09kW per hour from 7am – 11pm
Used in the Fam_Room zone all year
Bedroom
0.01kW per hour from 11pm – 7am
0.04kW per hour from 7am – 11pm
Used in the Bed_1, Bed_2 and Bed_3 zones all year
Bathroom
0.03kW per hour from 11pm – 7am
0.07kW per hour from 7am – 11pm
Used in the Laundry, Hall and Bath_Toile zones all year.

All other zones had 0kW sensible gains.

D.6.2 Medium House

Kitchen
0.02kW per hour from 11pm – 7am
0.12kW per hour from 7am – 11pm
Used in the Kt_Dn zone all year
Lounge
0.04kW per hour from 11pm – 7am
0.14kW per hour from 7am – 11pm
Used in the FR zone all year
Bedroom
0.15kW per hour from 11pm – 7am
0.07kW per hour from 7am – 11pm
Used in the B1_B2, Lau_B4 and B3_Bth2_St zones all year
Bathroom
0.02kW per hour from 11pm – 7am
0.07kW per hour from 7am – 11pm
Used in the Bth_Toi, H1, H2, and StudySew zones all year.

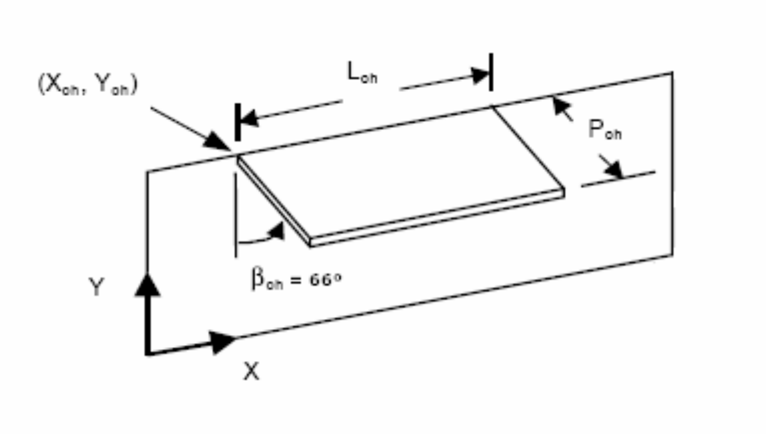
All other zones had 0kW sensible gains.

D.6.3 Large House

LARGE
Kitchen
0.01kW per hour from 11pm – 7am
0.13kW per hour from 7am – 11pm
Used in the Kt zone all year
Lounge
0.03kW per hour from 11pm – 7am
0.12kW per hour from 7am – 11pm
Used in the FR and Dining zones all year
Bedroom
0.02kW per hour from 11pm – 7am
0.1kW per hour from 7am – 11pm
Used in the B5_B3_B2, FyB4BtB6, and B1_Kt zones all year
Bathroom
0.04kW per hour from 11pm – 7am
0.12kW per hour from 7am – 11pm
Used in the Hall, Rumpus and St_Lau zones all year.

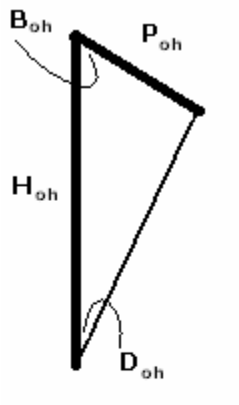
All other zones had 0kW sensible gains.

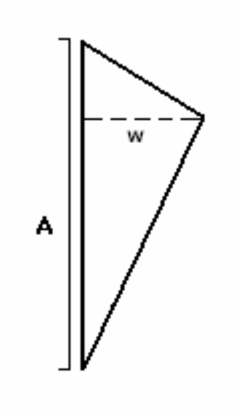
D.7 Window Shadow Modelling

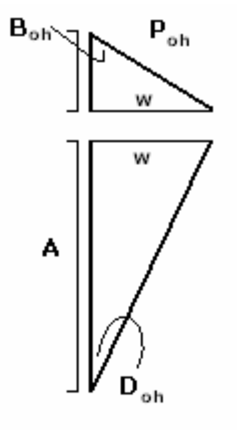


H_{oh} = Window Height
L_{oh} = Window Length
B_{oh} = Tilt angle = 66º
D_{oh} = Bottom Tilt angle = 24º
P_{oh} = Projection Length

Using the following formula the projection length of each window shading was found.







B_{oh} = 66º therefore D_{oh} = 24º
H_{oh} = A (not entirely accurate)
Therefore W = A x SIN (D_{oh})
Therefore Poh = W / (COS B_{oh})

By changing Hoh for each window height, the P_{oh} could be obtained for each different window

APPENDIX E: THERMAL SIMULATION RESULT GRAPHS

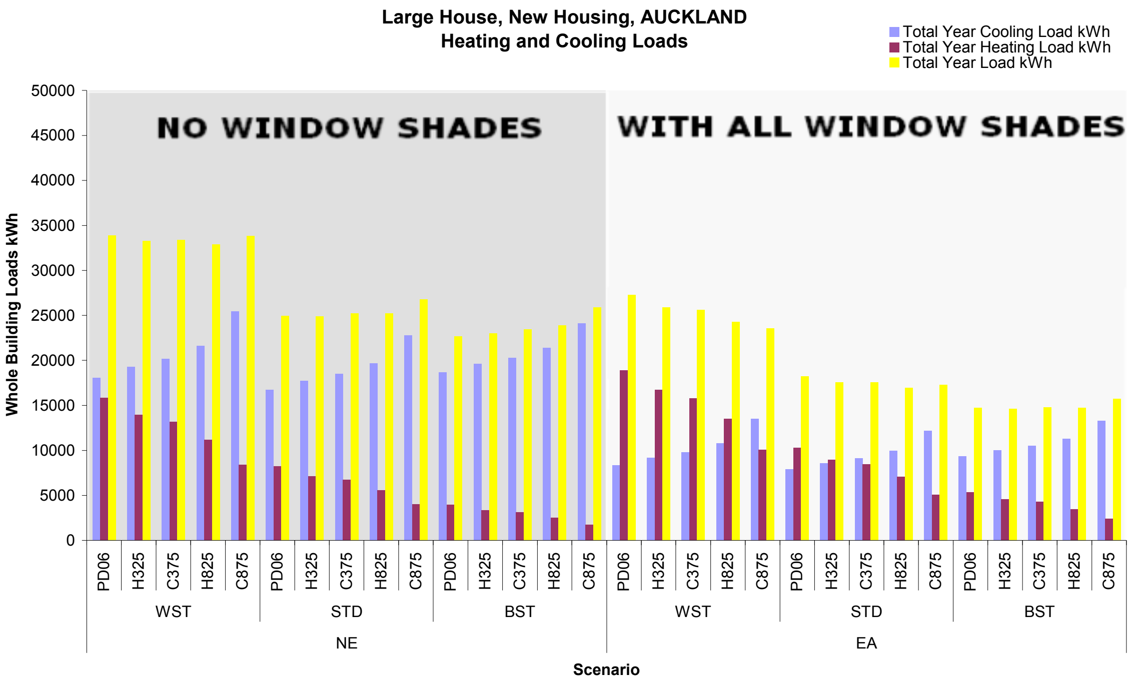
E.1 LARGE HOUSE

E.1.1 New Housing

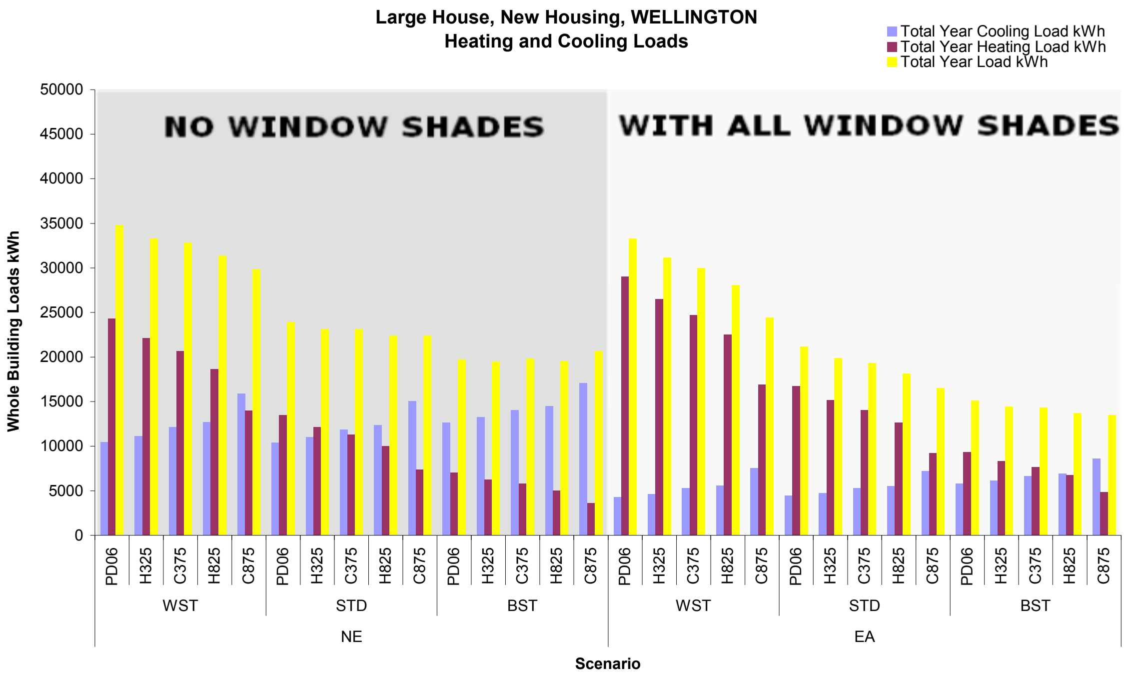
E.1.1.1 Base Simulations

LARGE HOUSE – NEW HOUSING – BASE SIMULATIONS ENERGY DROPS BETWEEN SCENARIOS				
		AU	WE	CH
NE	WST-STD	-24%	-30%	-30%
	STD-BST	-6%	-14%	-16%
EA	WST-STD	-30%	-35%	-35%
	STD-BST	-15%	-25%	-25%
NE - EA	WST-WST	-25%	-10%	-9%
	STD-STD	-30%	-17%	-15%
	BST-BST	-35%	-28%	-24%
This is comparing average drops in total energy use. These are approximate and are taken over each of the five climate scenarios.				

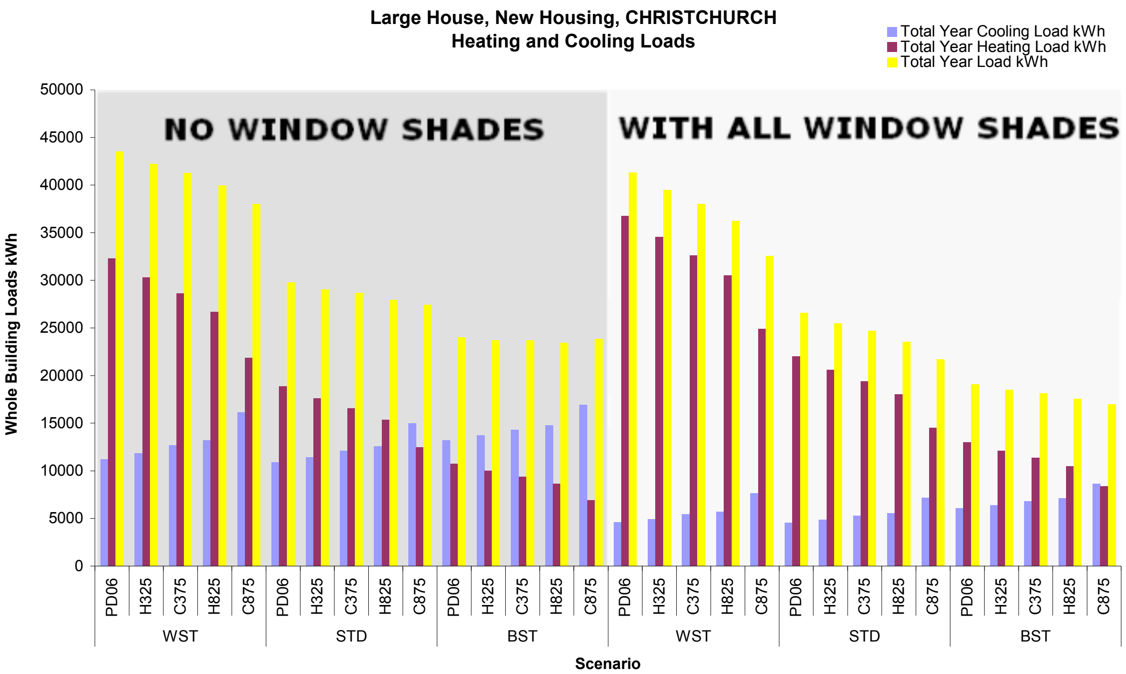
a) Auckland



b) Wellington



c) Christchurch



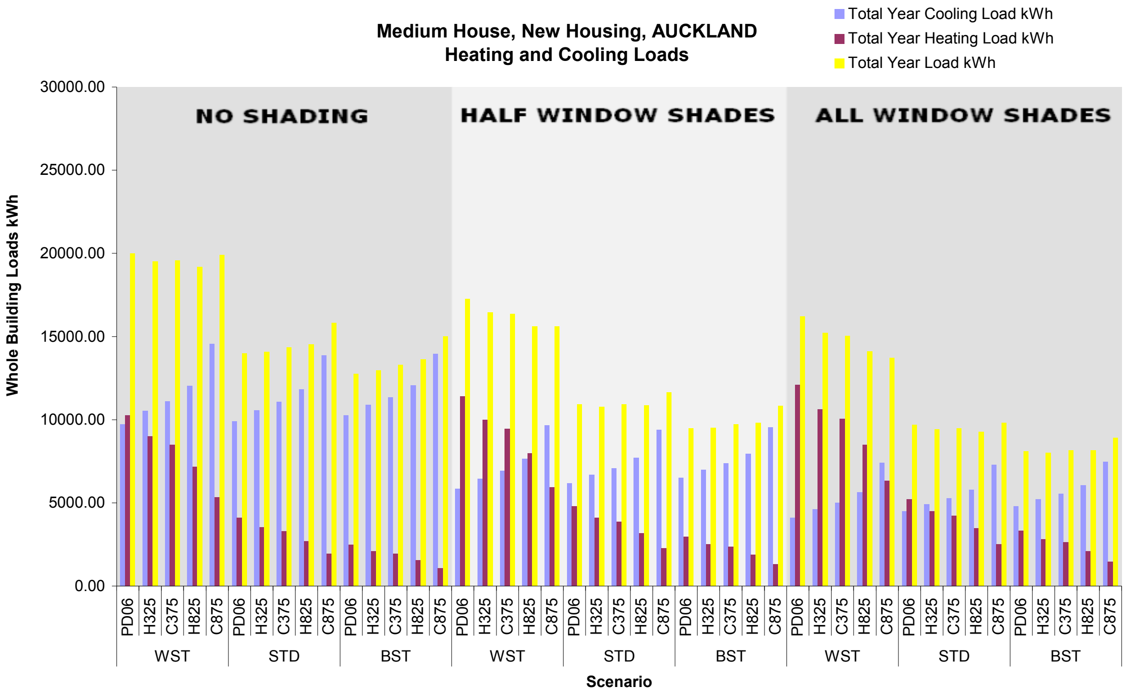
E.2 MEDIUM HOUSE

E.2.1 New Housing

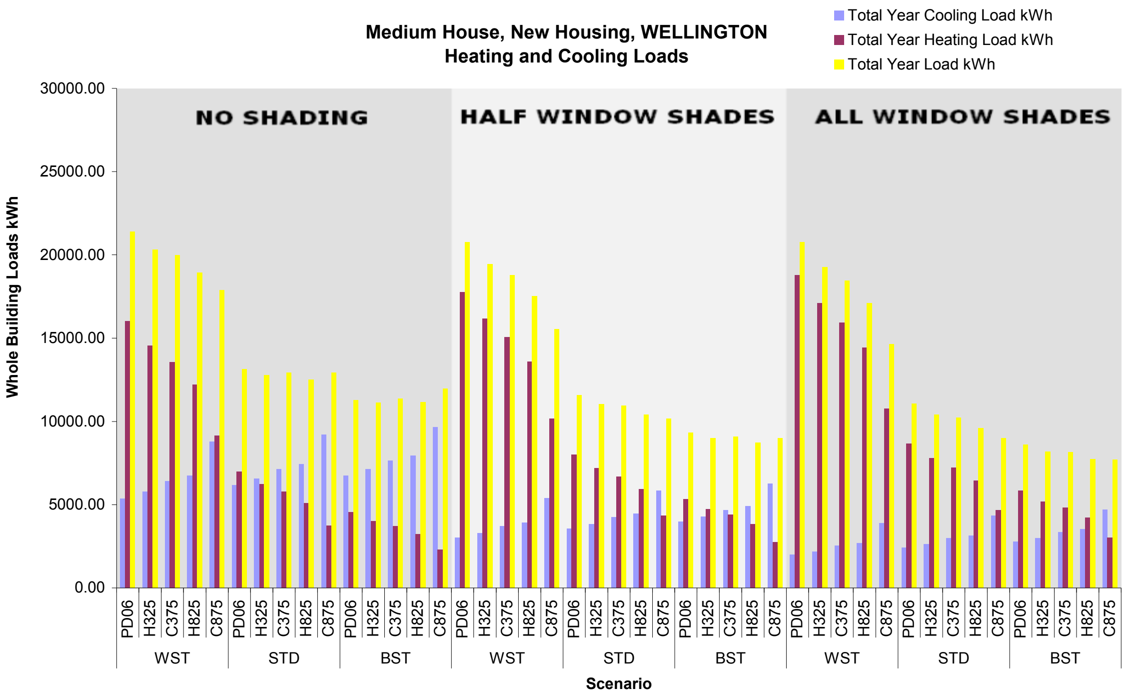
E.2.1.1 Base Simulations

MEDIUM HOUSE – NEW HOUSING – BASE SIMULATIONS ENERGY DROPS BETWEEN SCENARIOS				
		AU	WE	CH
NE	WST-STD	-26%	-35%	-37%
	STD-BST	-7%	-11%	-13%
E2	WST-STD	-32%	-40%	-42%
	STD-BST	-10%	-16%	-17%
EA	WST-STD	-36%	-44%	-45%
	STD-BST	-13%	-20%	-20%
NE – E2	WST-WST	-17%	-7%	-5%
	STD-STD	-24%	-16%	-12%
	BST-BST	-27%	-20%	-16%
NE – EA	WST-WST	-9%	-2%	-1%
	STD-STD	-14%	-7%	-6%
	BST-BST	-16%	-10%	-8%
This is comparing average drops in total energy use. These are approximate and are taken over each of the five climate scenarios.				

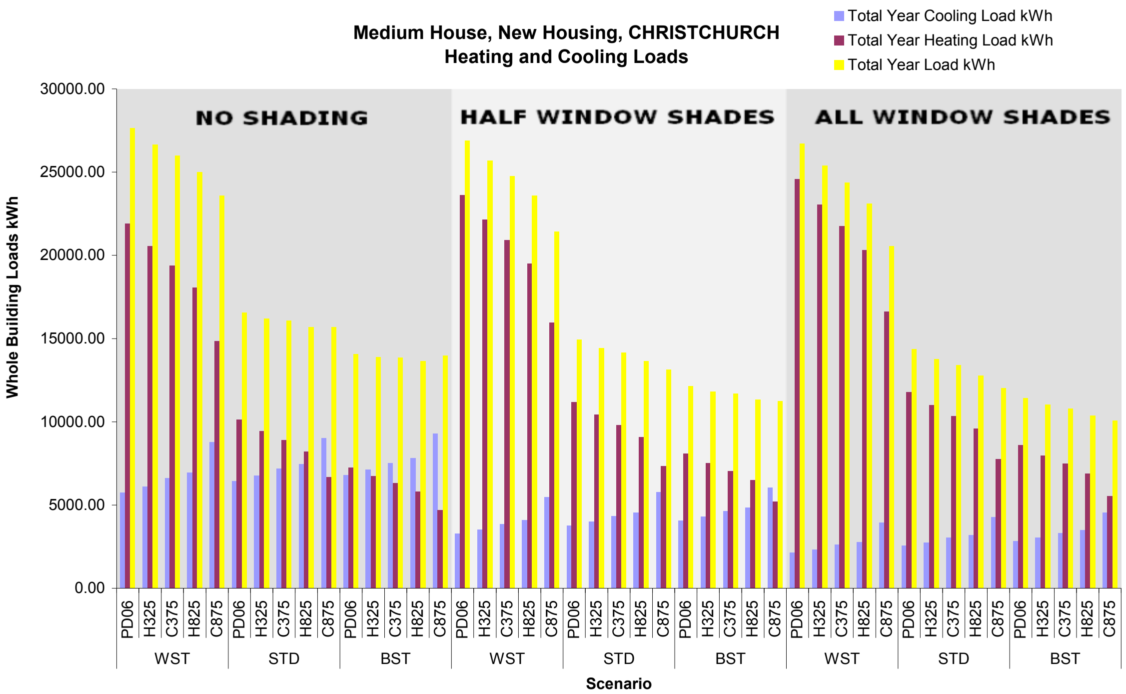
a) Auckland



b) Wellington



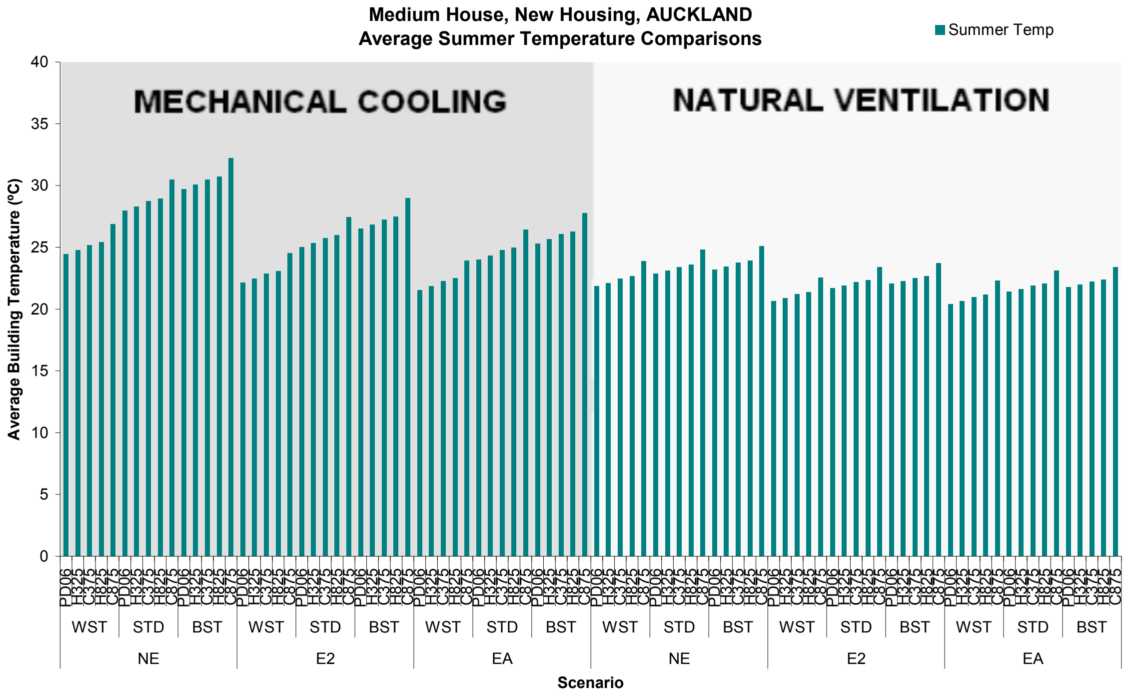
c) Christchurch

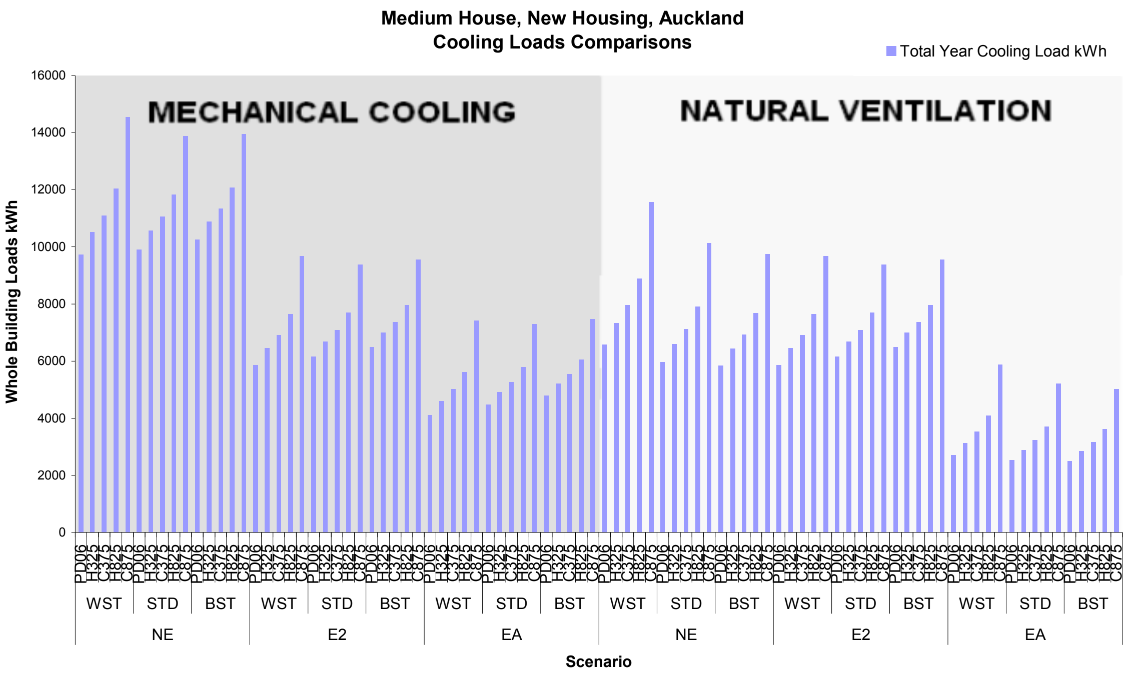


E.2.1.2 Ventilation Comparisons

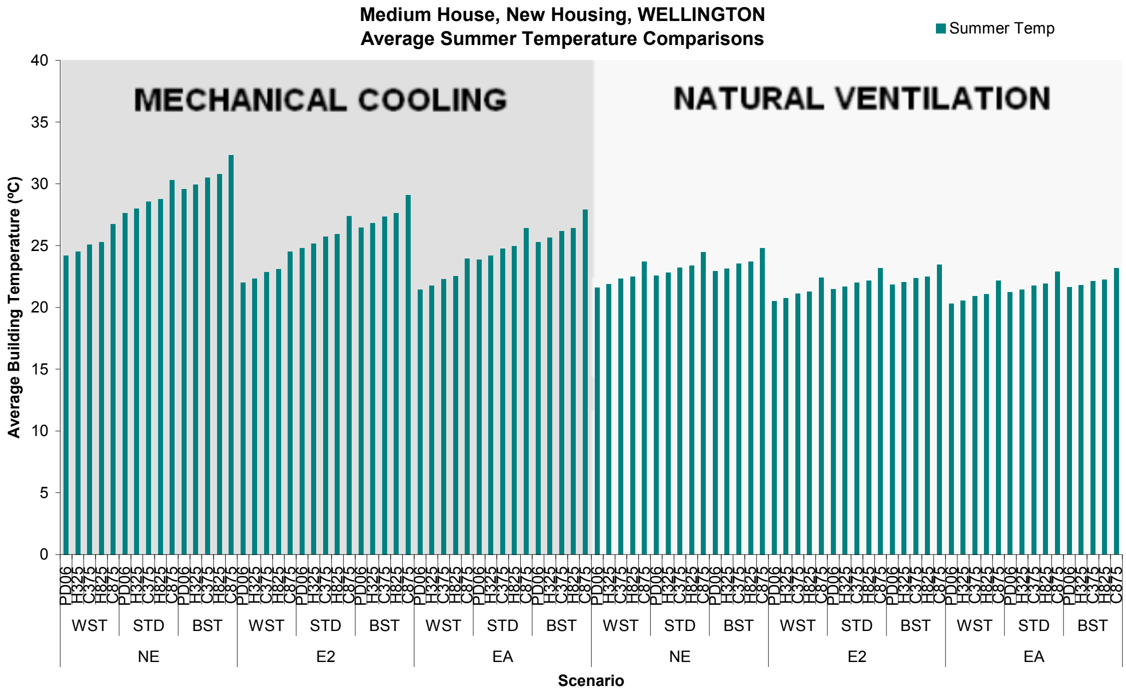
MEDIUM HOUSE – NEW HOUSING – VENTILATION COMPARISONS % OF AVERAGE TEMPERATURE IN SUMMER MONTHS					
		AU	WE	CH	AVERAGE DECREASE
NE – NE	WST	-10%	-11%	-11%	10%
	STD	-17%	-19%	-18%	18%
	BST	-22%	-23%	-22%	22%
E2 – E2	WST	0	-8%	-7%	7%
	STD	0	-14%	-14%	14%
	BST	0	-18%	-17%	17%
EA - EA	WST	-7%	-6%	-6%	6%
	STD	-12%	-12%	-11%	12%
	BST	-15%	-15%	-15%	15%
This is comparing average drops in total energy use. These are approximate and are taken over each of the five climate scenarios.					

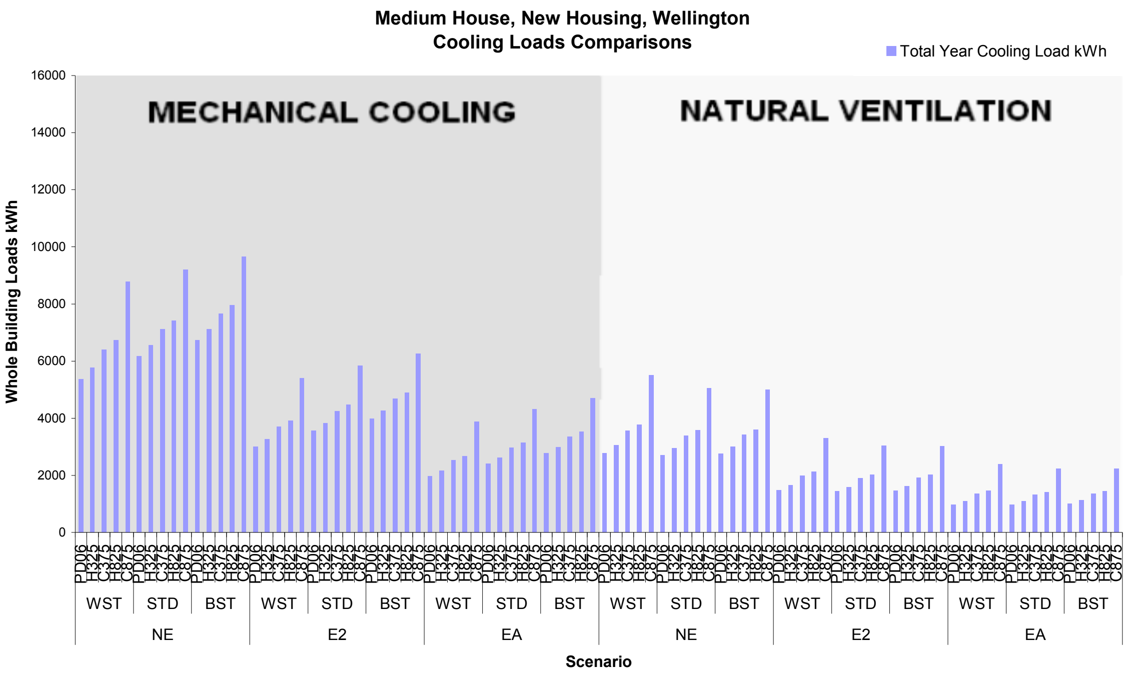
a) Auckland



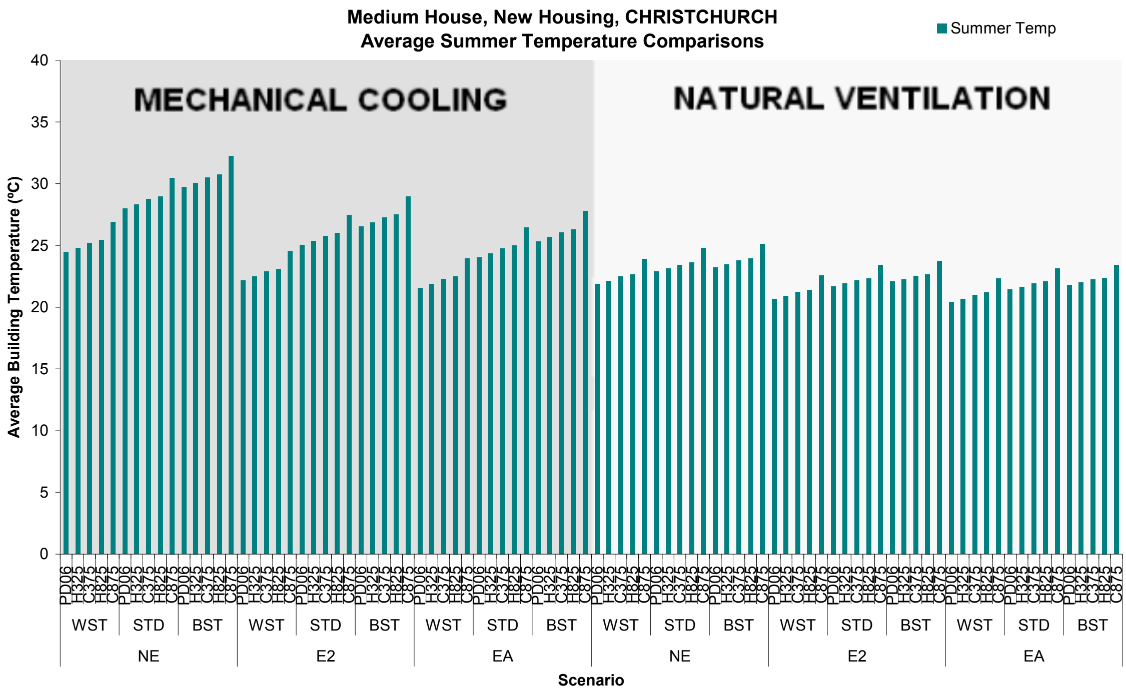


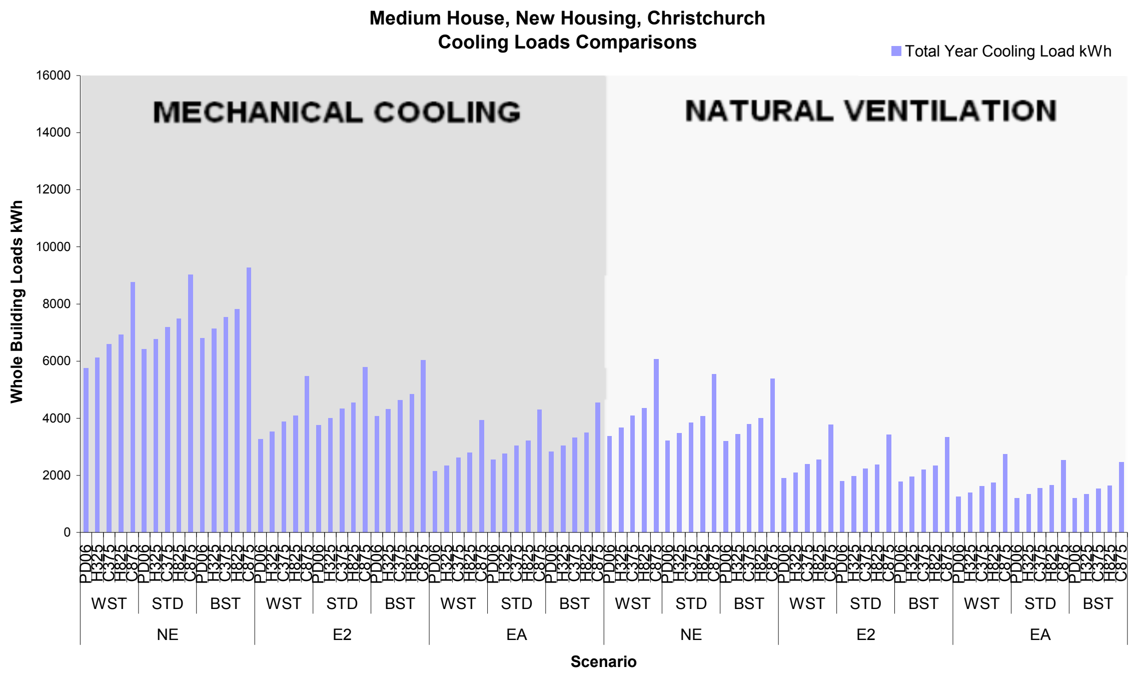
b) Wellington





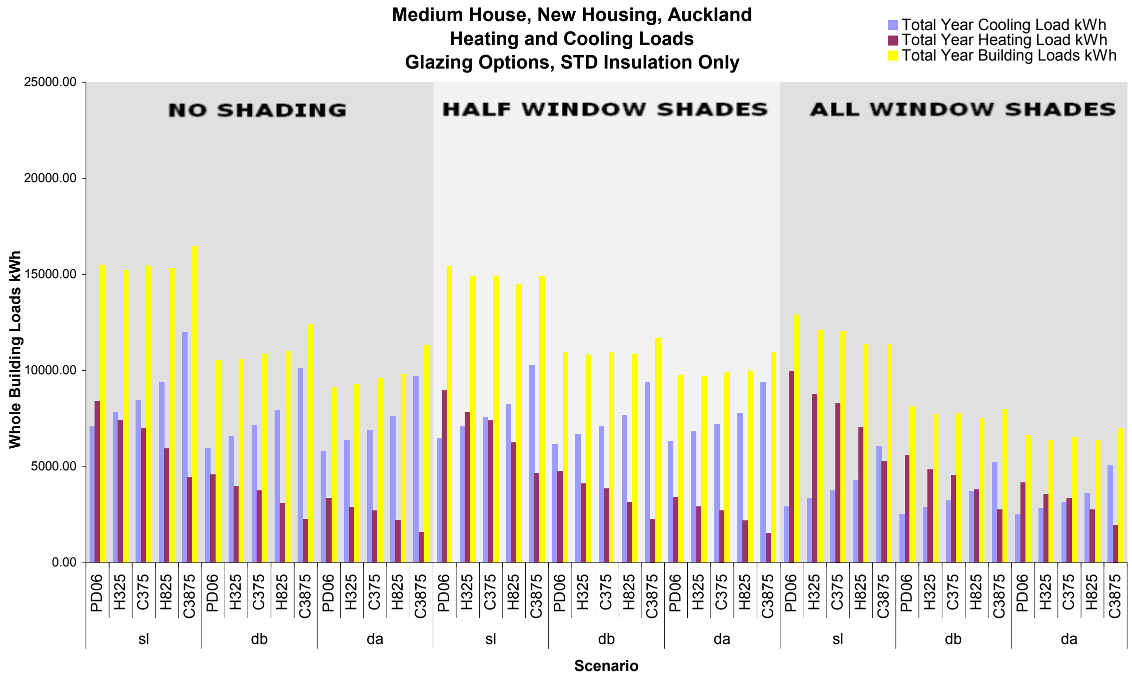
c) Christchurch



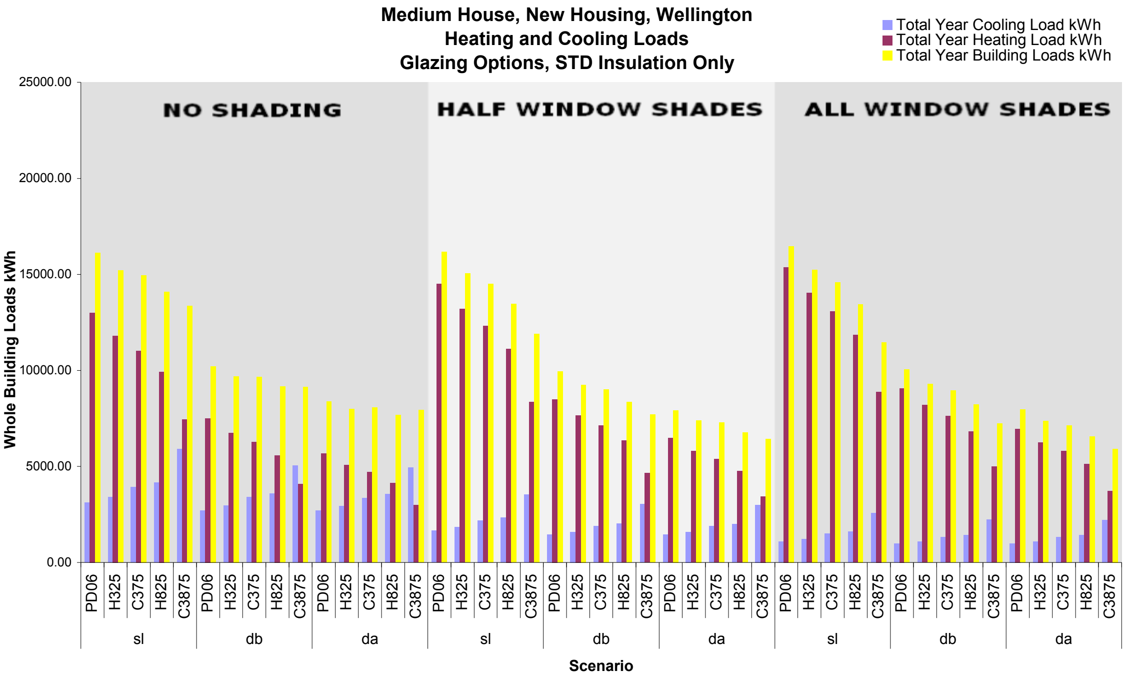


E.2.1.3 Glazing Comparisons

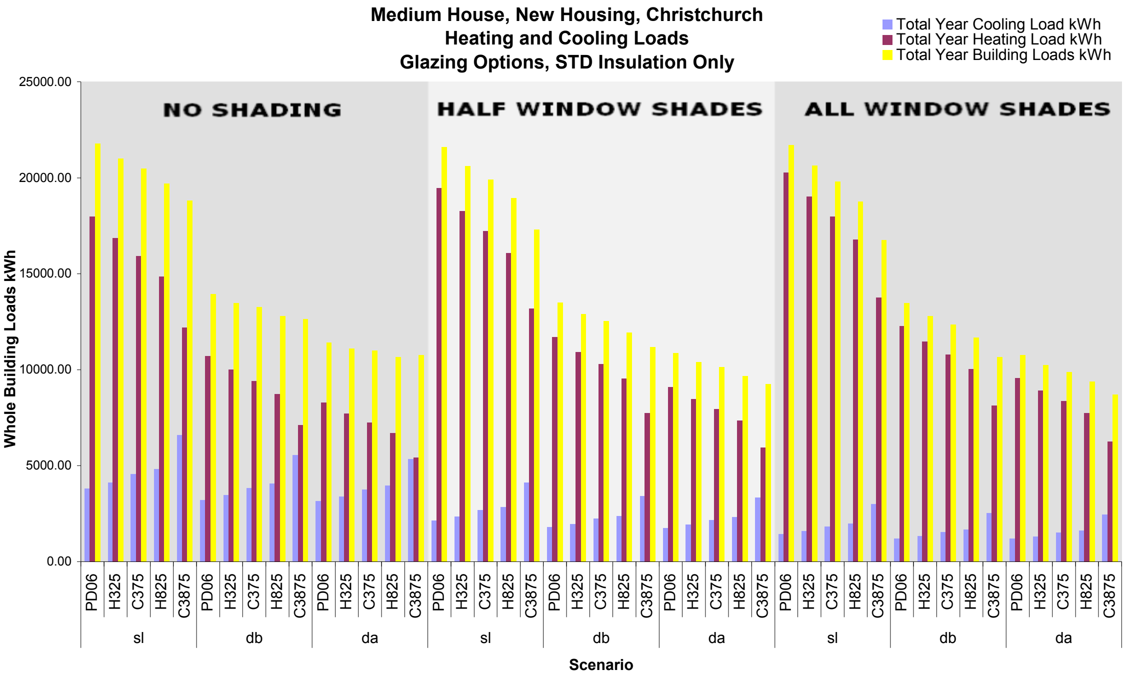
a) Auckland



b) Wellington



c) Christchurch

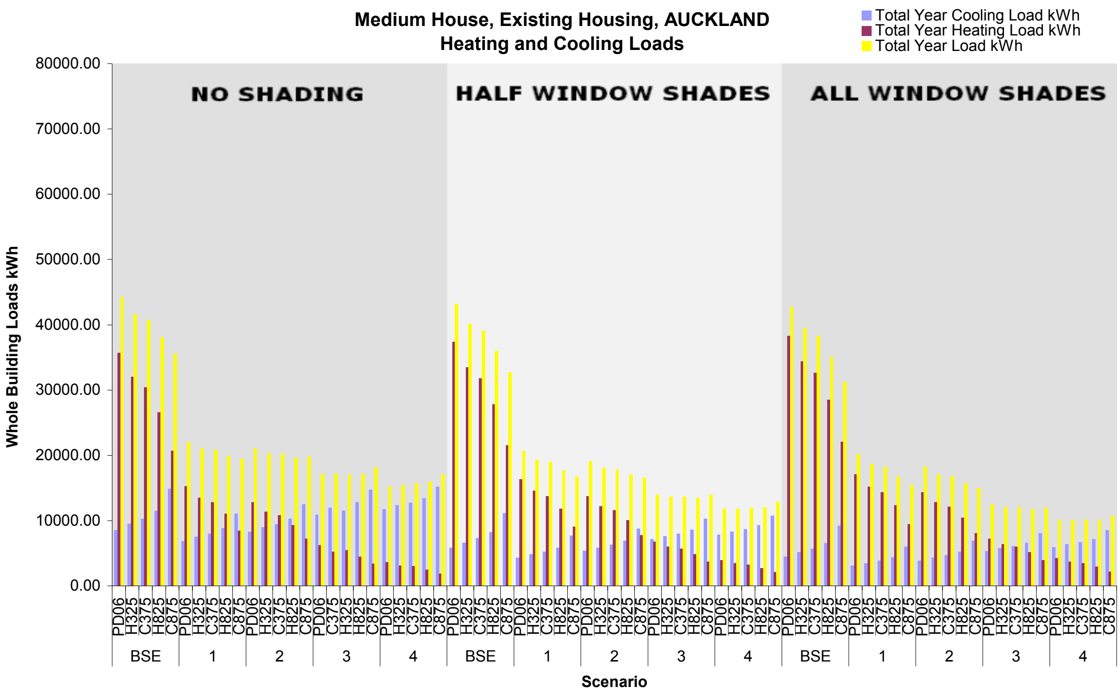


E.2.2 Existing Housing

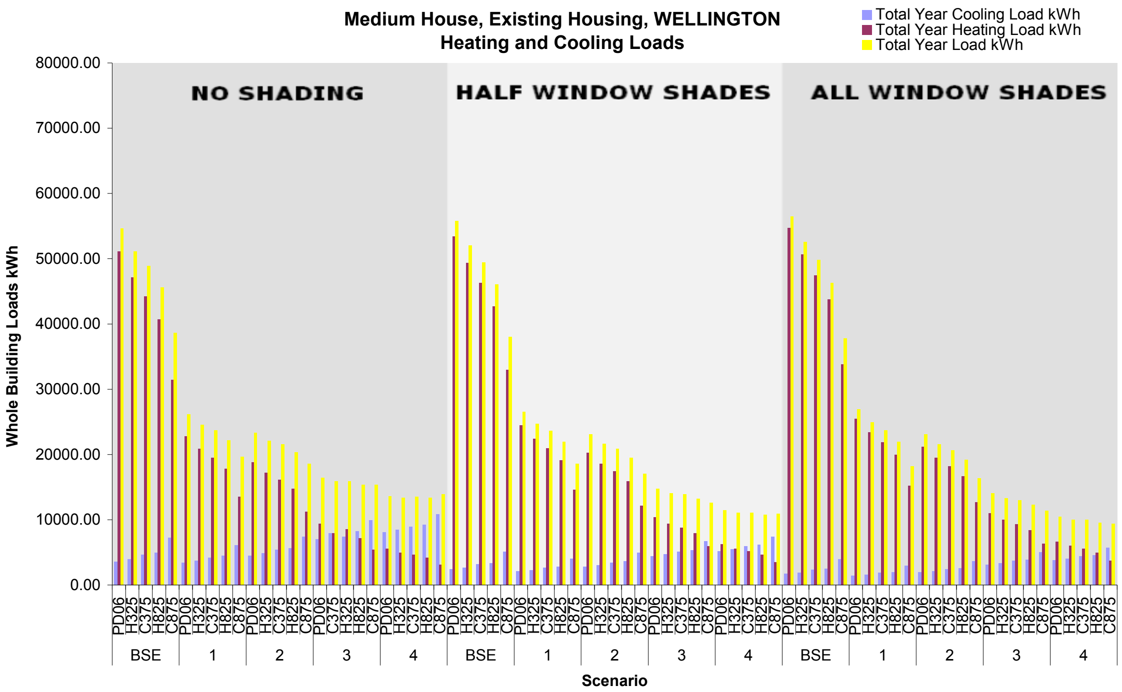
E.2.2.1 Base Simulations

MEDIUM HOUSE – EXISTING HOUSING – BASE SIMULATIONS ENERGY DROPS BETWEEN SCENARIOS				
		AU	WE	CH
NE	BSE – 001	-48$	-51%	-51%
	001 – 002	-2%	-9%	-10%
	002 – 003	-14%	-25%	-20%
	003 – 004	-8%	-14%	-18%
E2	BSE – 001	-50%	-52%	-52%
	001 – 002	-5%	-11%	-12%
	002 – 003	-22%	-33%	-35%
	003 – 004	-12%	-19%	-22%
EA	BSE – 001	-52%	-52%	-52%
	001 – 002	-7%	-12%	-13%
	002 – 003	-27%	-36%	-38%
	003 – 004	-15%	-22%	-25%
NE – E2	BSE	-5%	+1%	0
	001	-10%	-1%	0
	002	-12%	-4%	-3%
	003	-20%	-13%	-10%
	004	-24%	-18%	-15%
E2 – EA	BSE	-2%	0	0
	001	-5%	0	0
	002	-6%	-1%	-1%
	003	-12%	-7%	-6%
	004	-15%	-10%	-9%
This is comparing average drops in total energy use. These are approximate and are taken over each of the five climate scenarios.				

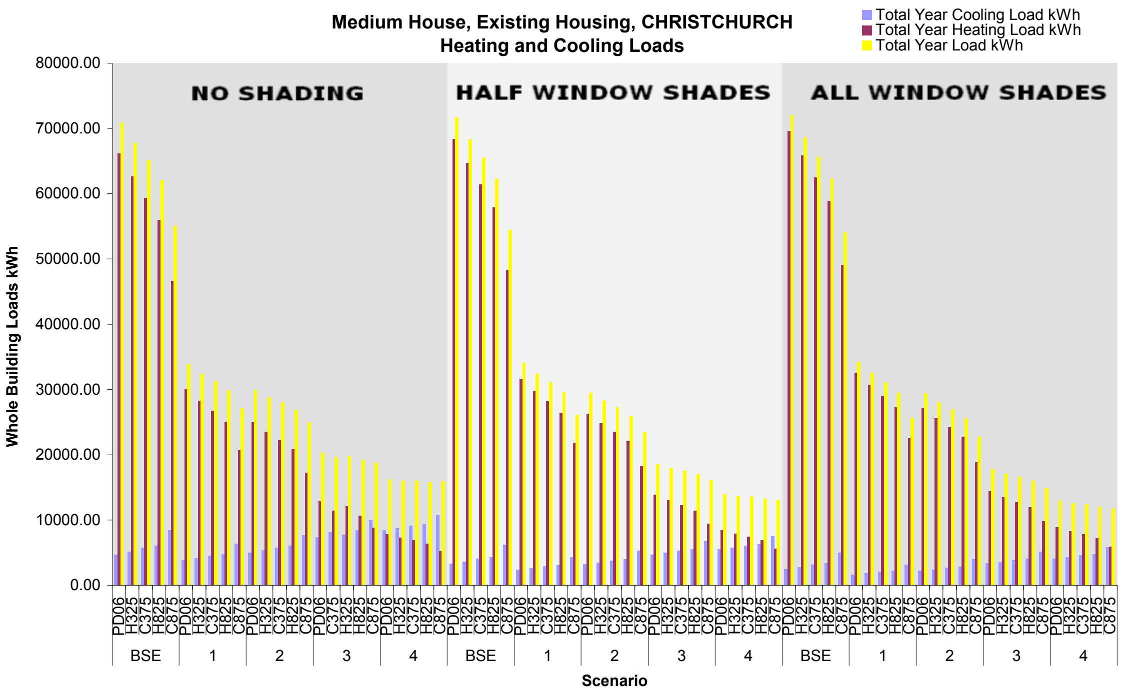
a) Auckland



b) Wellington



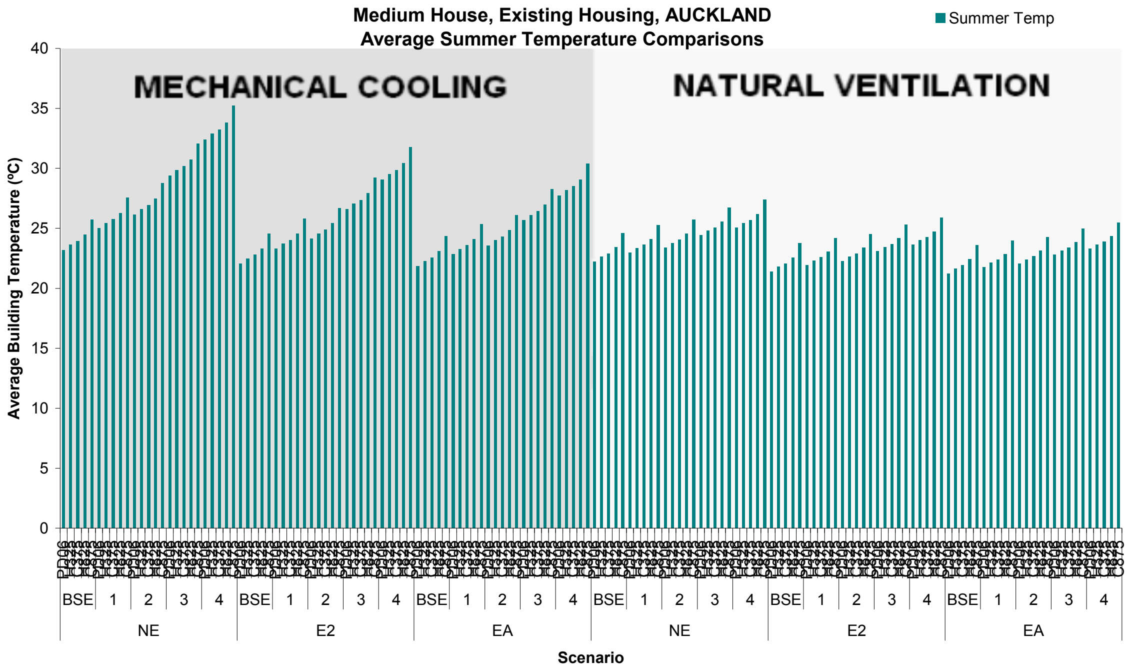
c) Christchurch

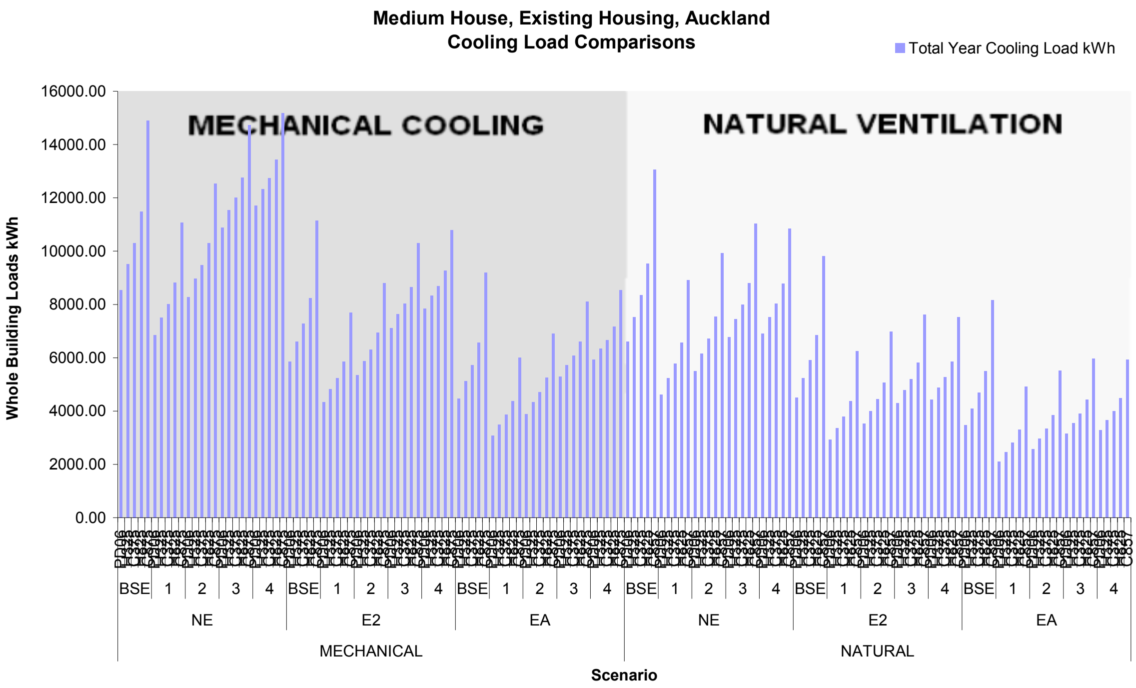


E.2.2.2 Ventilation Comparisons

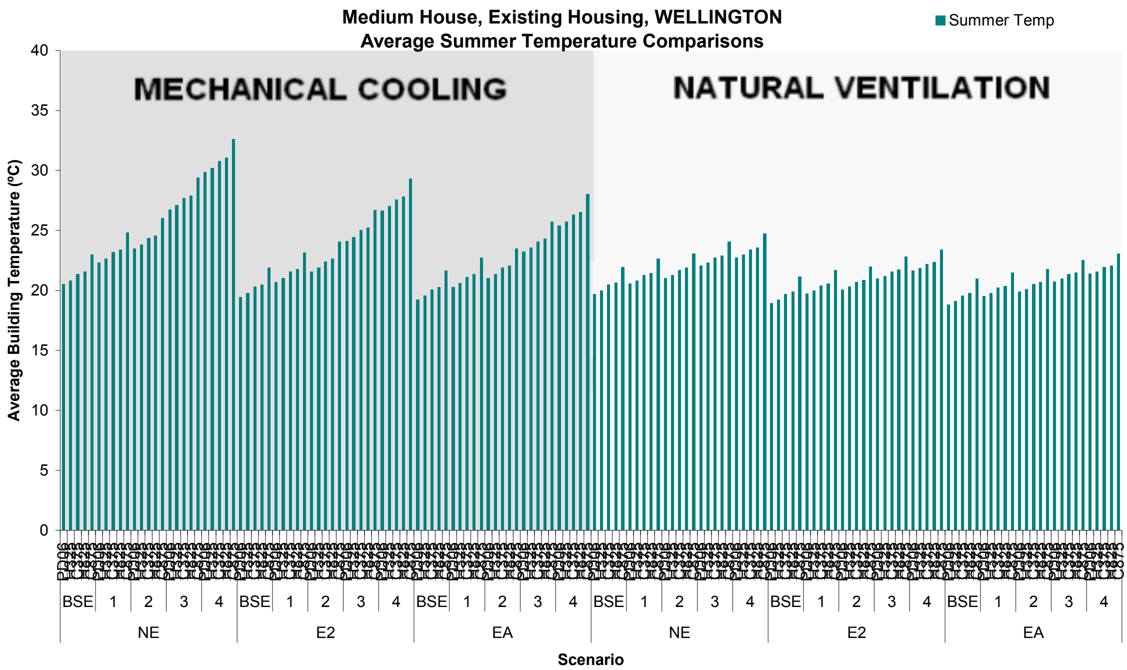
MEDIUM HOUSE – EXISTING HOUSING – VENTILATION COMPARISONS % OF AVERAGE TEMPERATURE IN SUMMER MONTHS					
		AU	WE	CH	AVERAGE DECREASE
NE – NE	BSE	-4%	-4%	-4%	4%
	001	-8%	-8%	-8%	8%
	002	-10%	-11%	-10%	11%
	003	-17%	-17%	-17%	17%
	004	-22%	-24%	-23%	23%
E2 – E2	BSE	-3%	-3%	-3%	3%
	001	-6%	-5%	-5%	5%
	002	-8%	-8%	-7%	8%
	003	-13%	-14%	-13%	13%
	004	-18%	-19%	-19%	19%
EA - EA	BSE	-3%	-3%	-2%	3%
	001	-5%	-4%	-4%	4%
	002	-7%	-6%	-6%	6%
	003	-11%	-11%	-11%	11%
	004	-16%	-16%	-16%	16%
This is comparing average drops in total energy use. These are approximate and are taken over each of the five climate scenarios.					

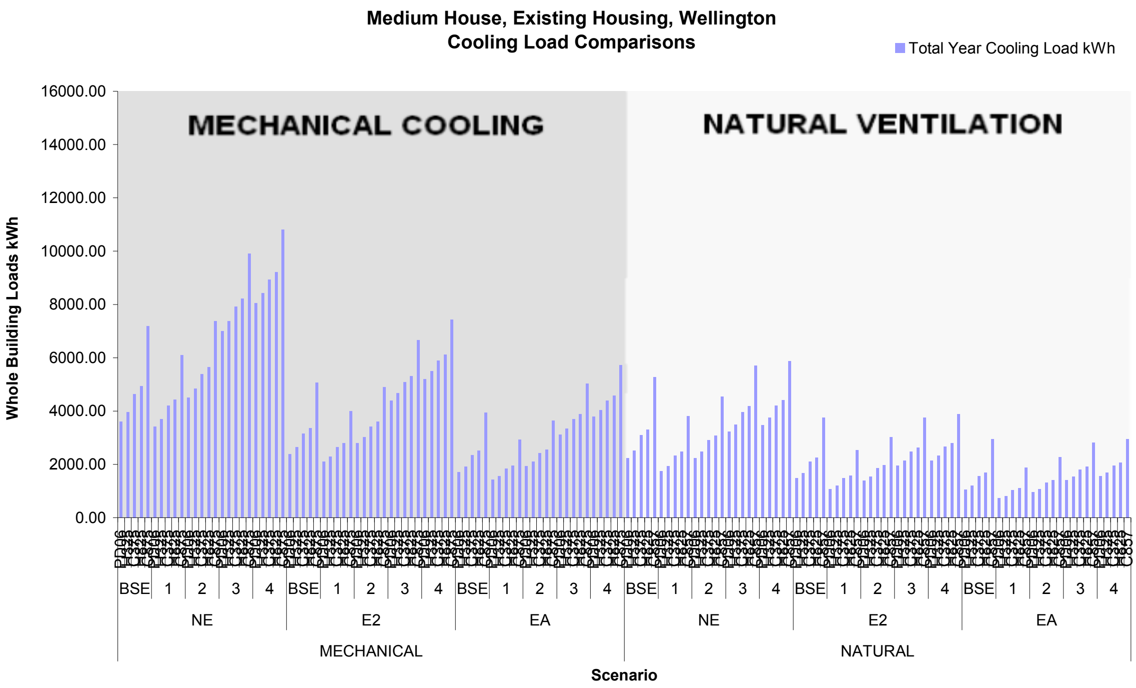
a) Auckland



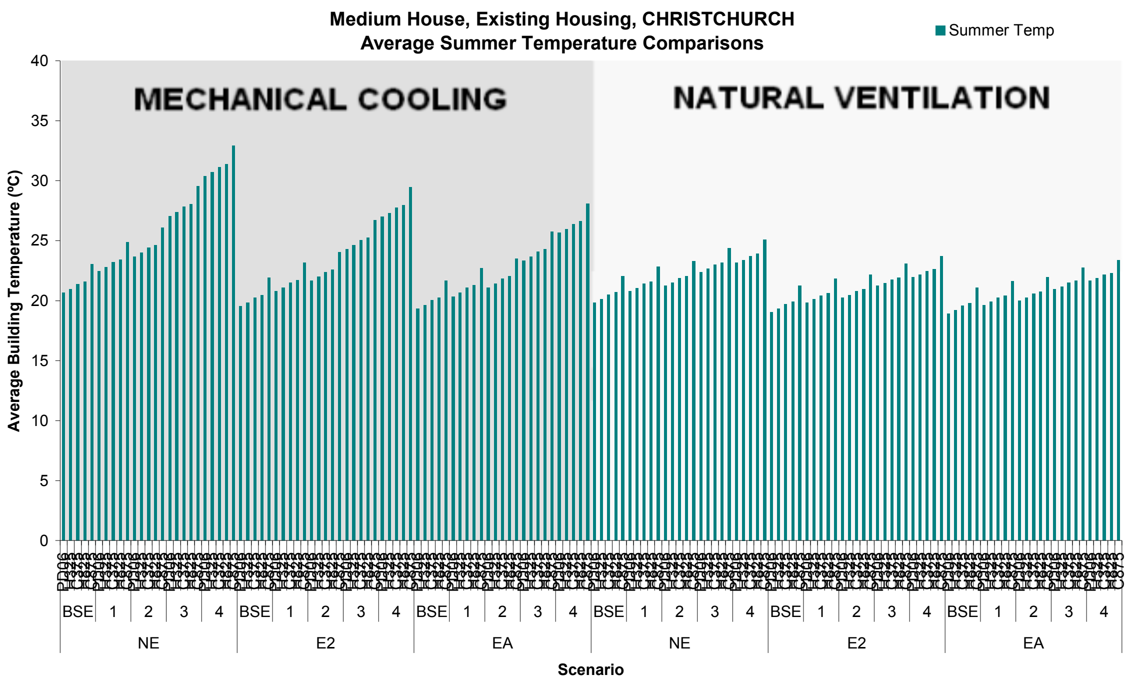


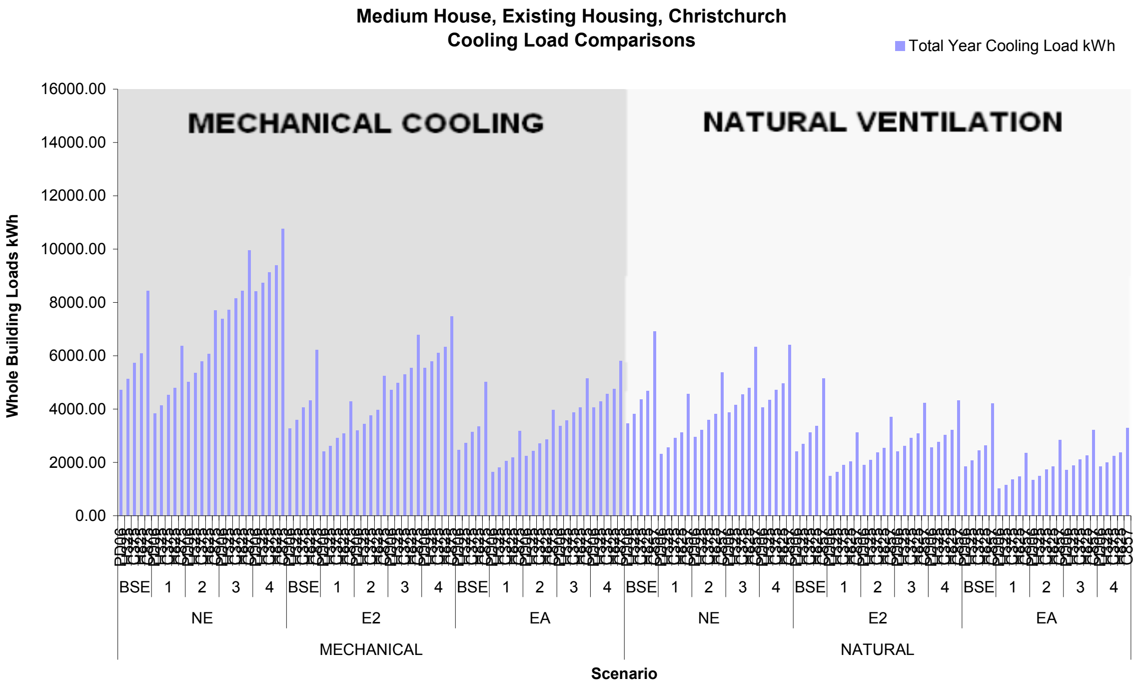
b) Wellington





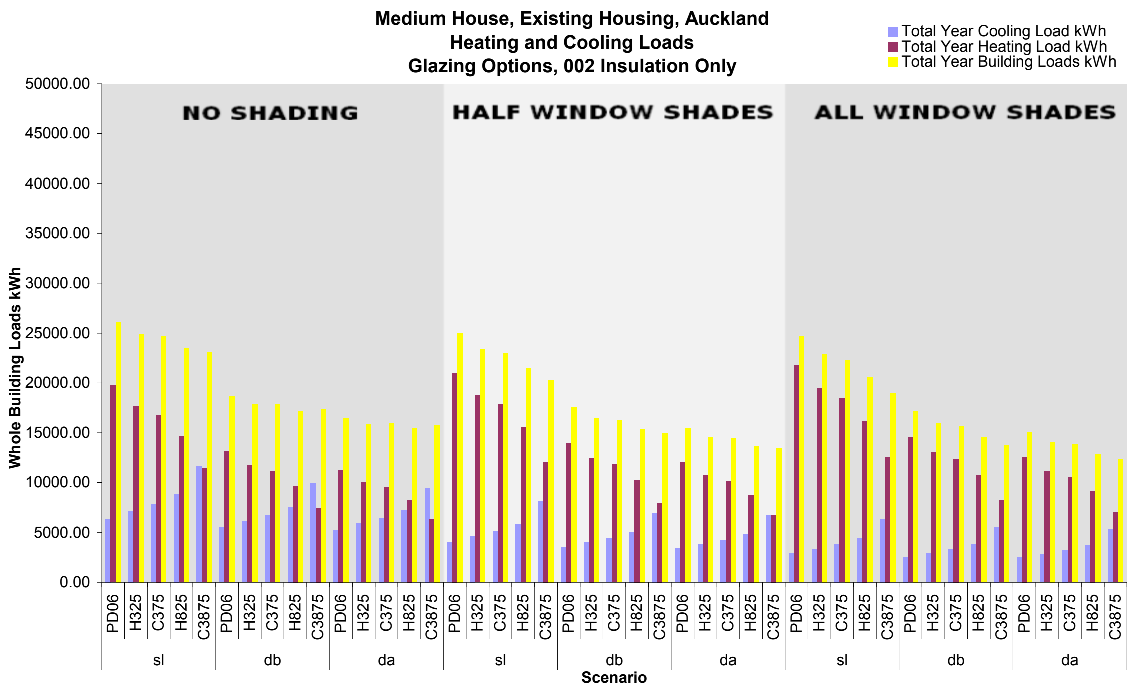
c) Christchurch



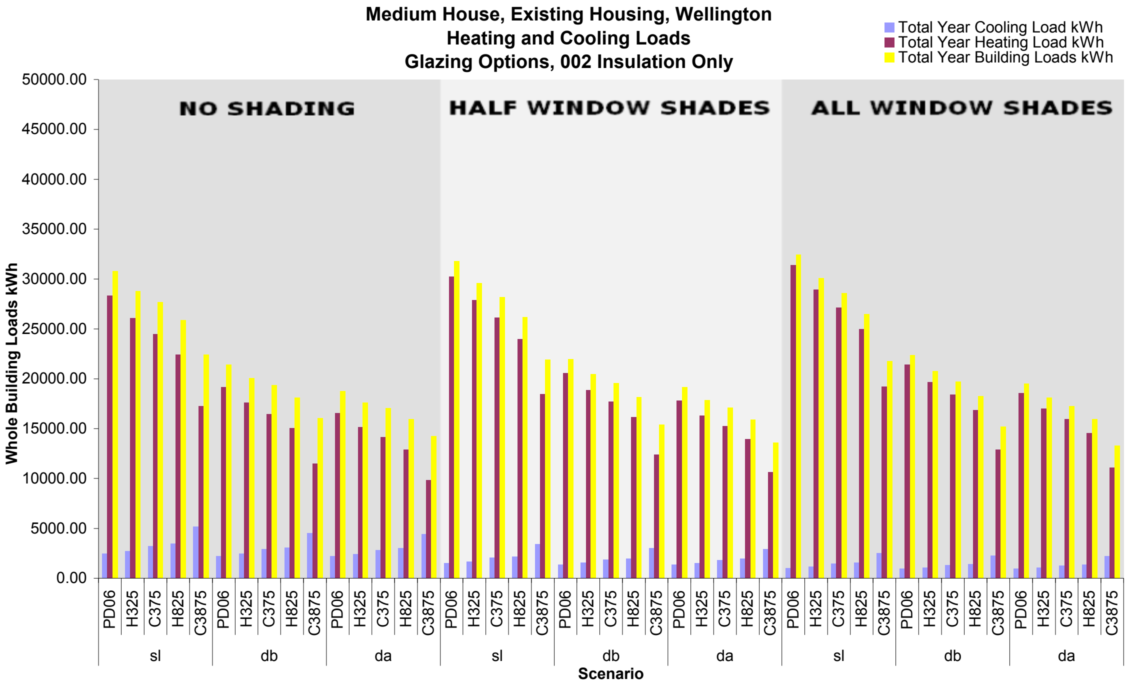


E.2.2.3 Glazing Comparisons

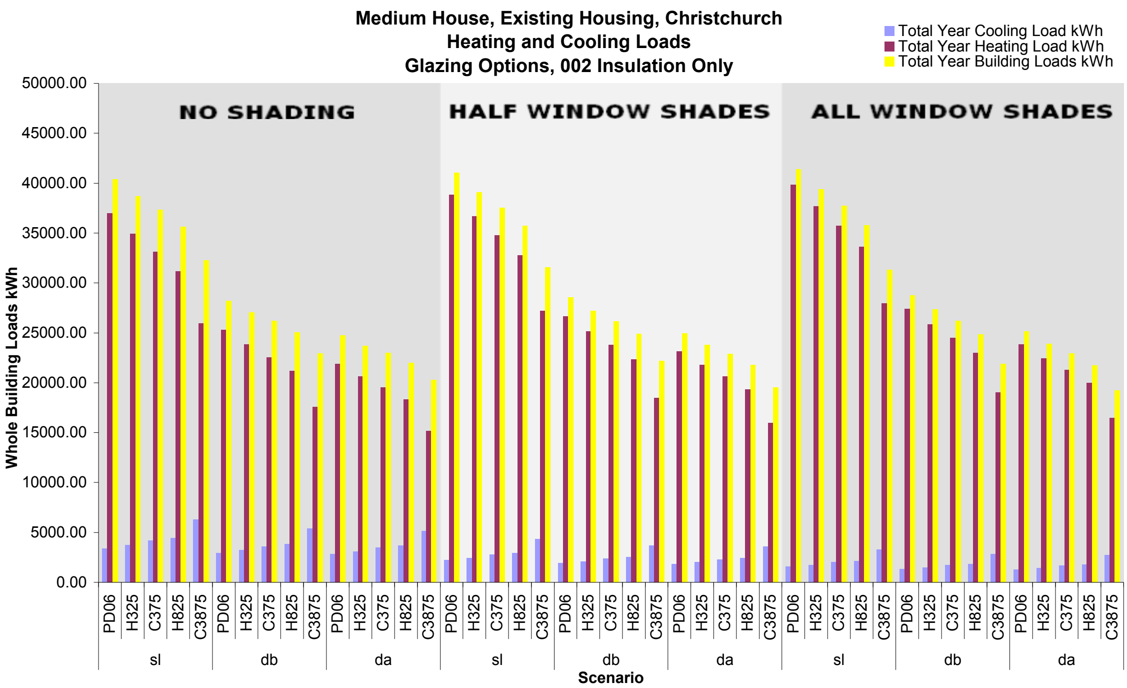
a) Auckland



b) Wellington



c) Christchurch



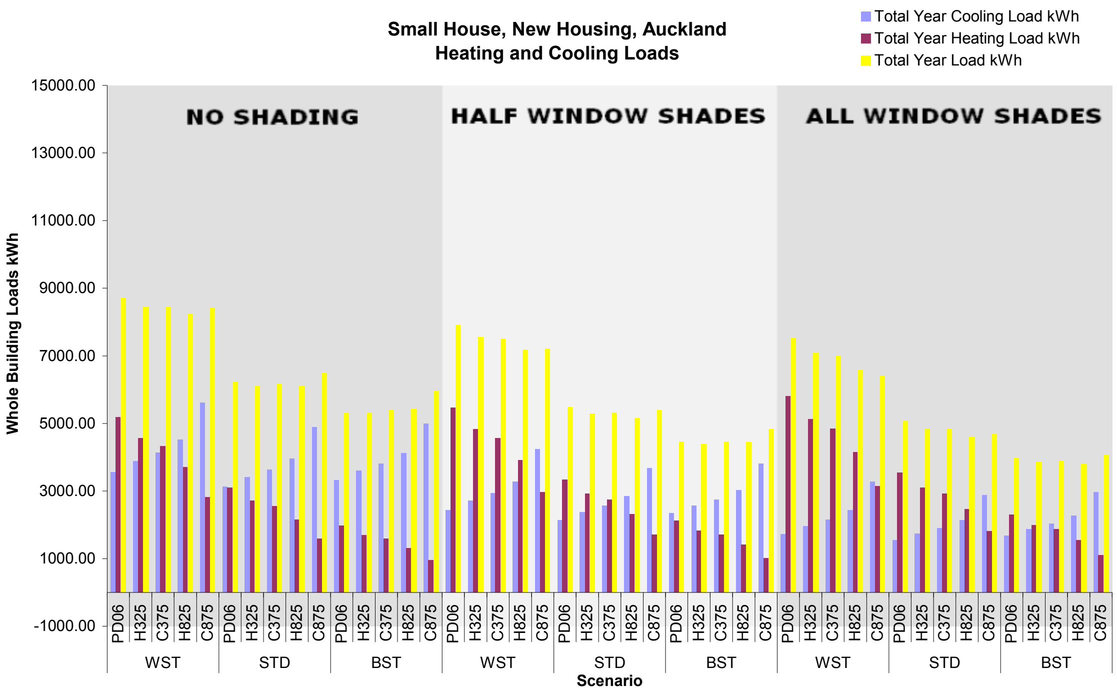
E.3 SMALL HOUSE

E.3.1 New Housing

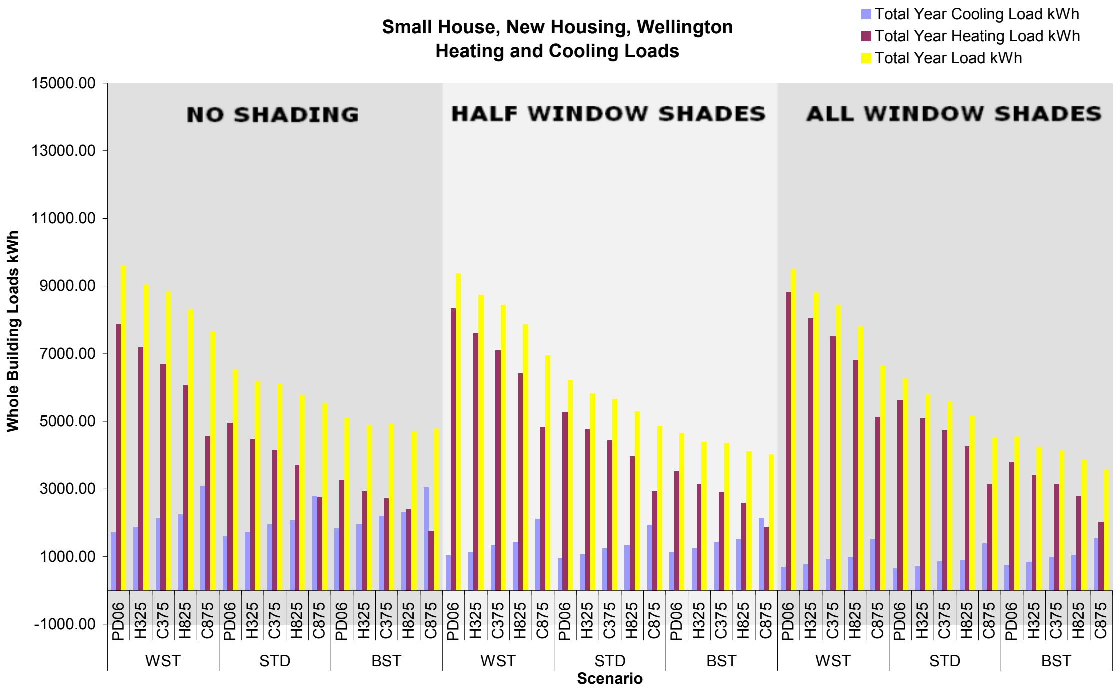
E.3.1.1 Base Simulations

SMALL HOUSE – NEW HOUSING – BASE SIMULATIONS ENERGY DROPS BETWEEN SCENARIOS				
		AU	WE	CH
NE	WST-STD	-26%	-30%	-30%
	STD-BST	-12%	-19%	-18%
E2	WST-STD	-28%	-33%	-30%
	STD-BST	-15%	-22%	-20%
EA	WST-STD	-30%	-33%	-31%
	STD-BST	-18%	-25%	-23%
NE – E2	WST-WST	-11%	-5%	-4%
	STD-STD	-14%	-8%	-6%
	BST-BST	-17%	-11%	-8%
NE – EA	WST-WST	-7%	-1%	-1%
	STD-STD	-10%	-2%	-2%
	BST-BST	-13%	-6%	-4%
This is comparing average drops in total energy use. These are approximate and are taken over each of the five climate scenarios.				

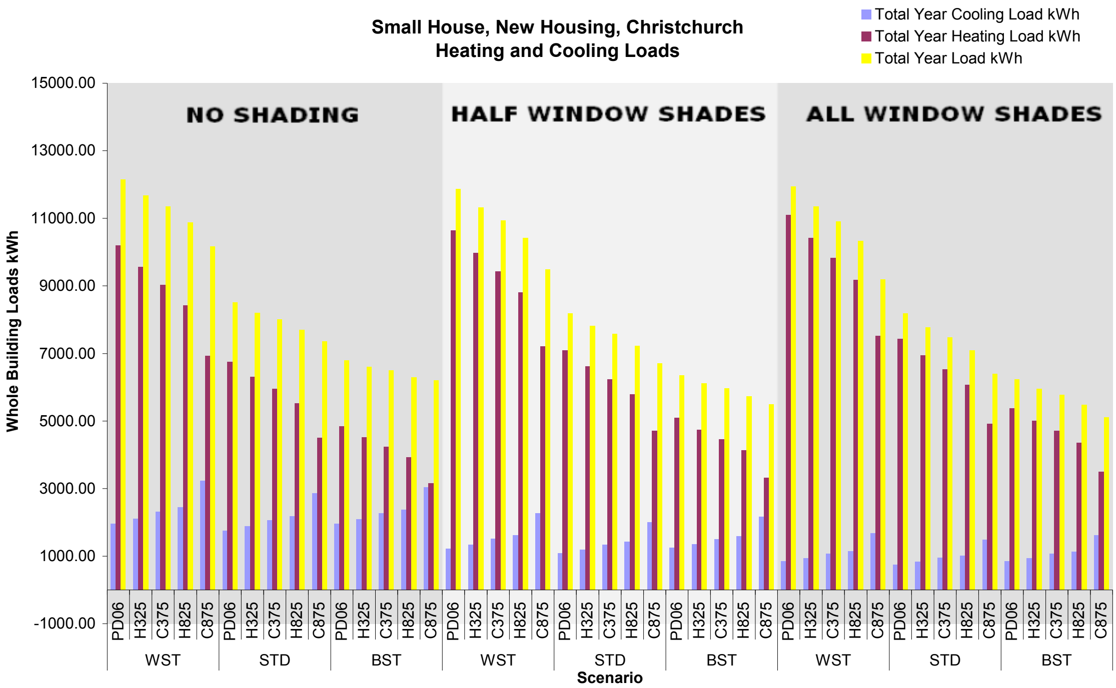
a) Auckland



b) Wellington



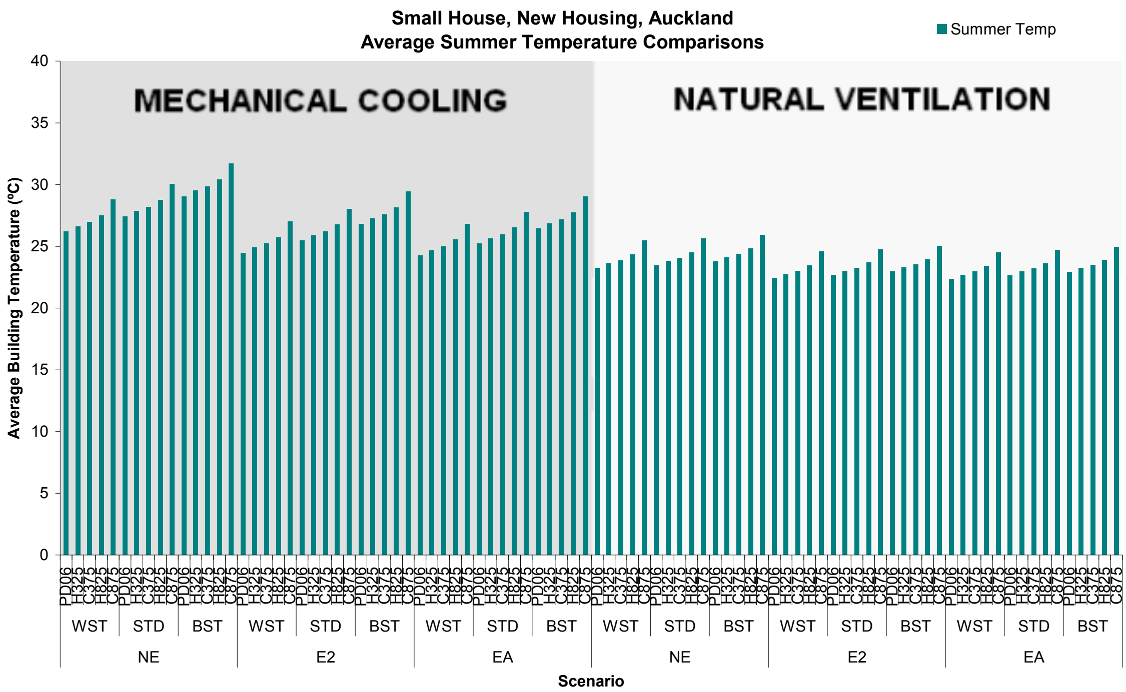
c) Christchurch

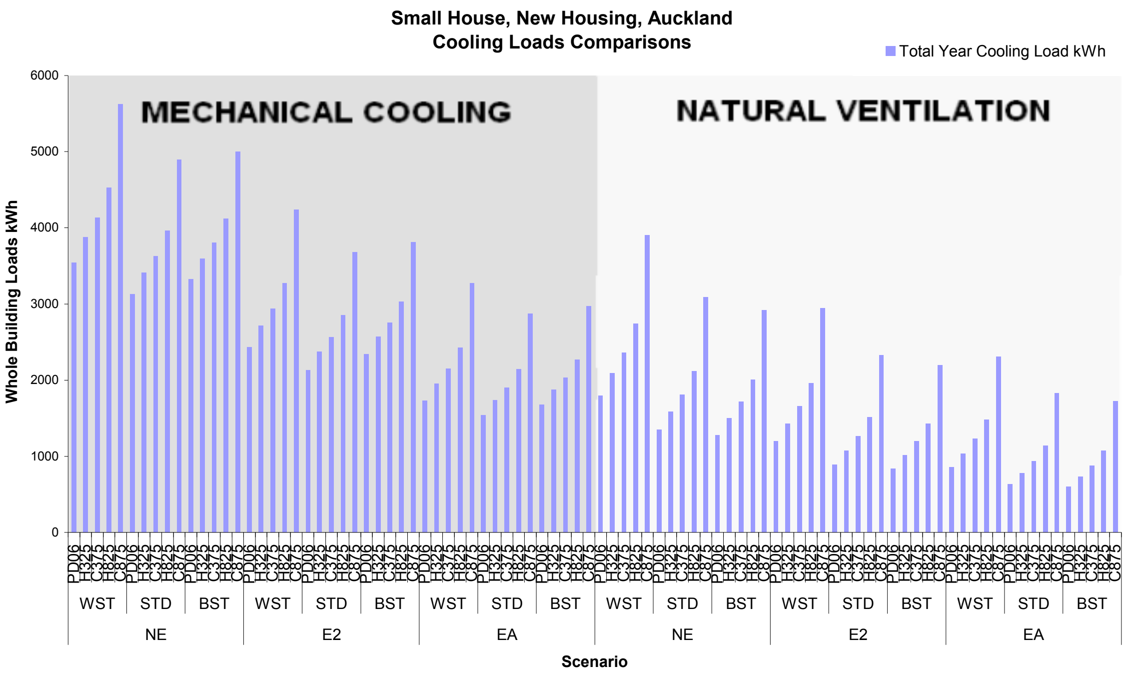


E.3.1.2 Ventilation Comparisons

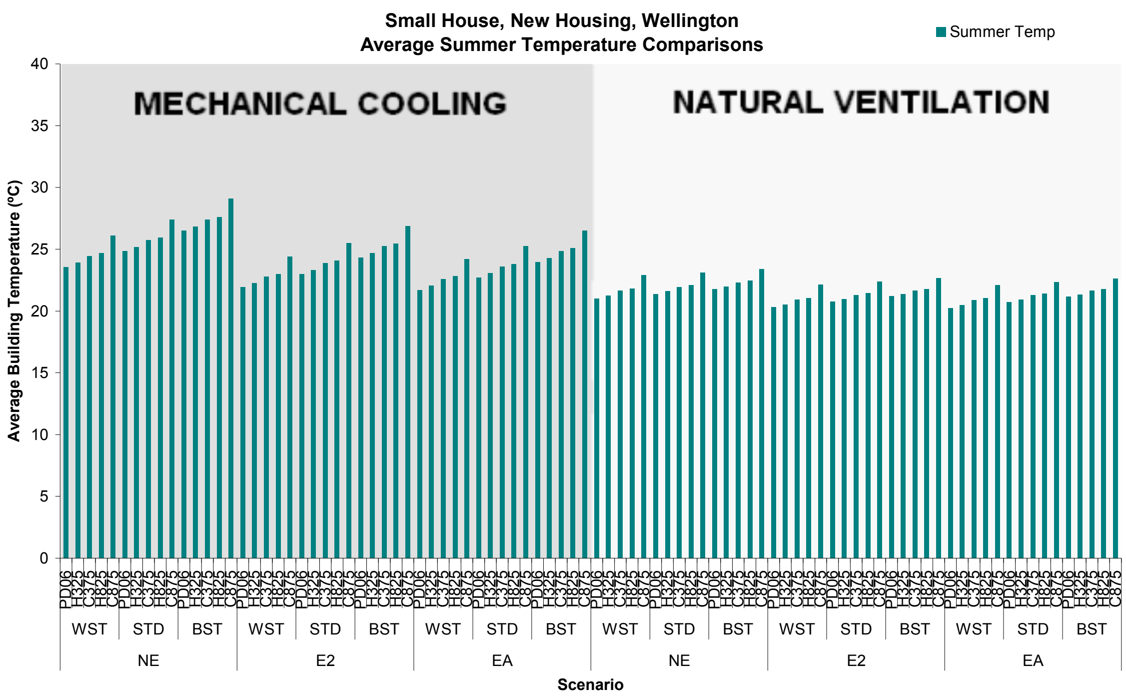
SMALL HOUSE – NEW HOUSING – VENTILATION COMPARISONS % OF AVERAGE TEMPERATURE IN SUMMER MONTHS					
		AU	WE	CH	AVERAGE DECREASE
NE – NE	WST	-11%	-11%	-11%	11%
	STD	-14%	-14%	-14%	14%
	BST	-18%	-19%	-17%	18%
E2 – E2	WST	-9%	-8%	-8%	8%
	STD	-11%	-10%	-10%	10%
	BST	-15%	-14%	-13%	14%
EA - EA	WST	-8%	-7%	-7%	7%
	STD	-10%	-10%	-9%	10%
	BST	-13%	-13%	-12%	13%
This is comparing average drops in total energy use. These are approximate and are taken over each of the five climate scenarios.					

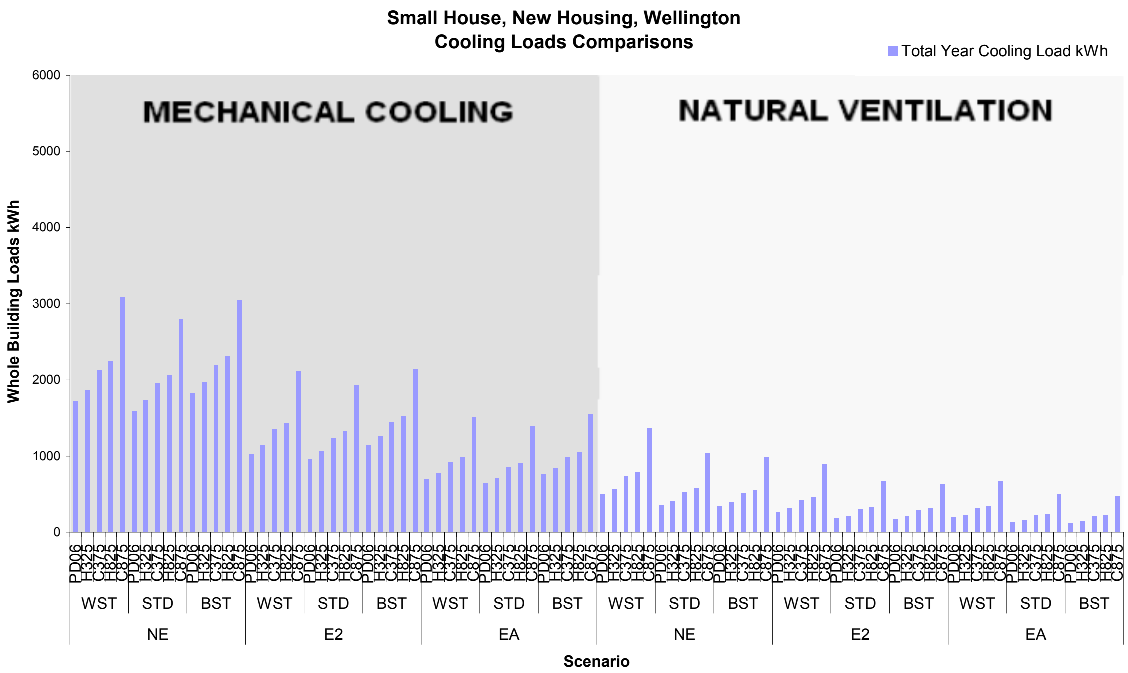
a) Auckland



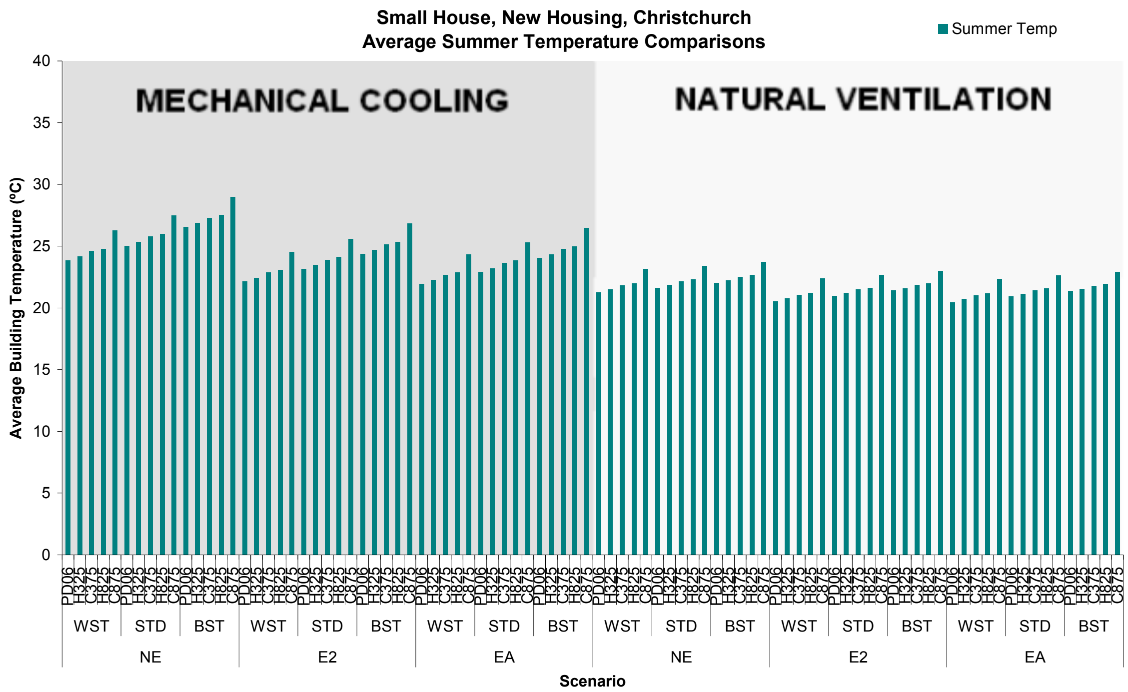


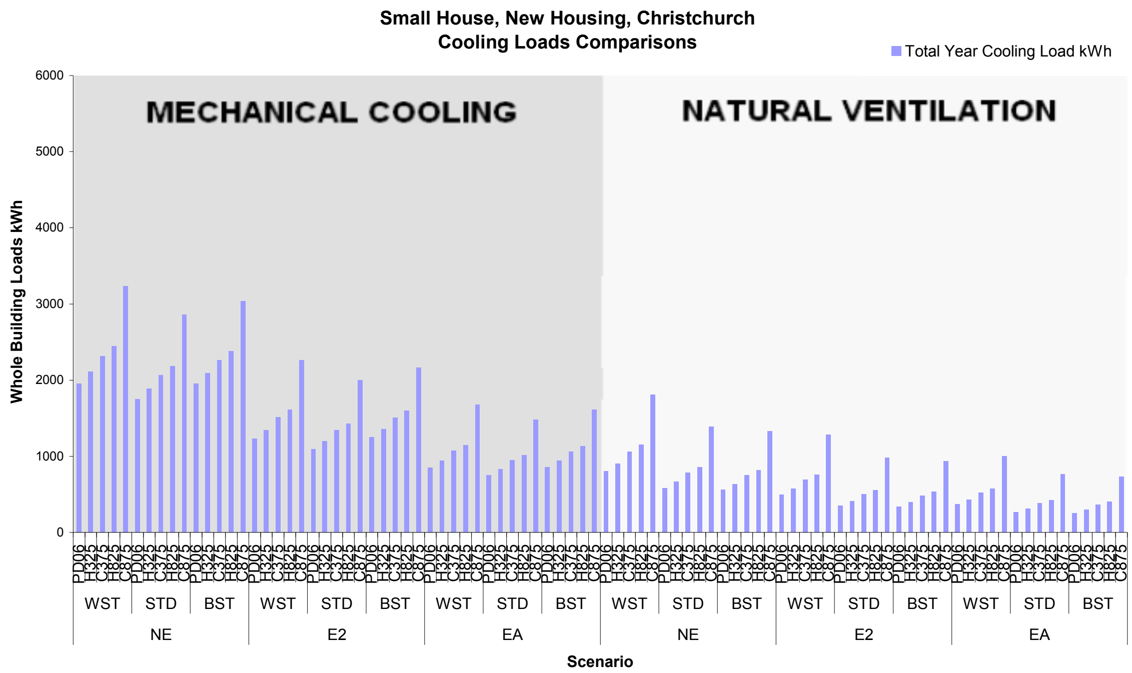
b) Wellington





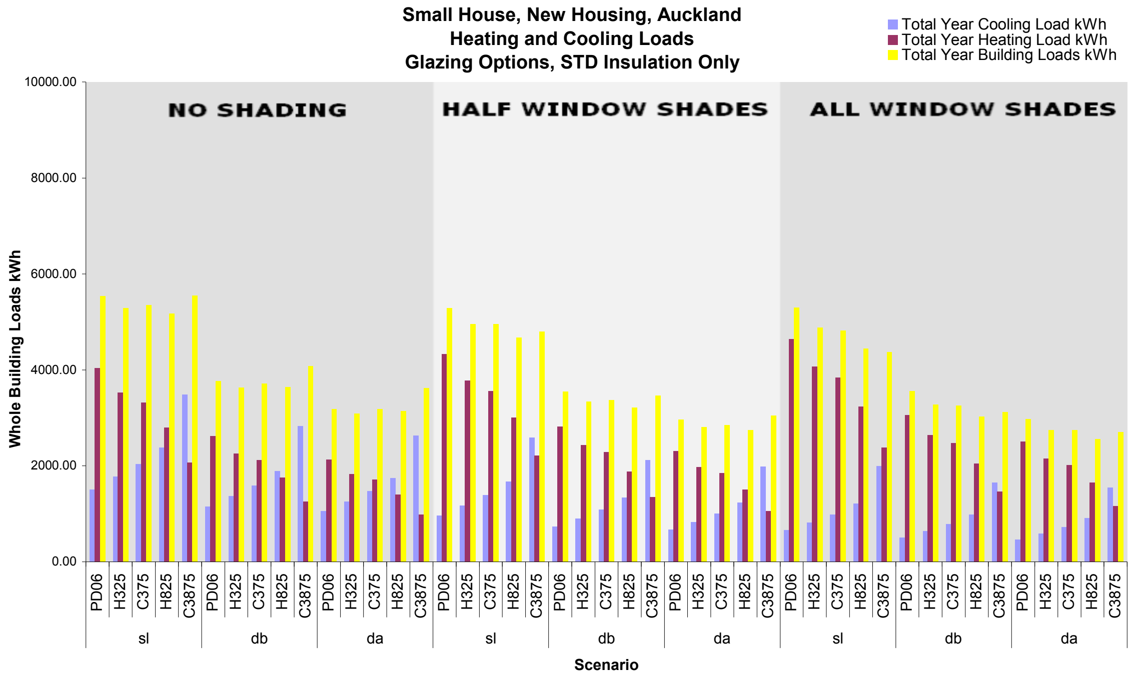
c) Christchurch



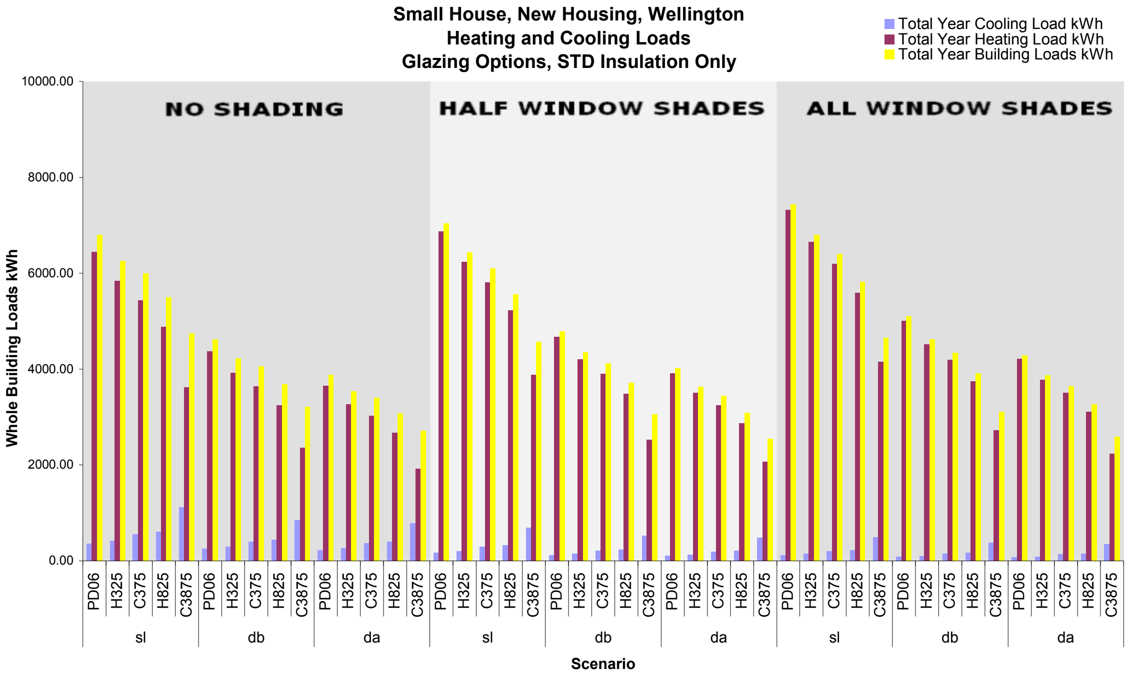


E.3.1.3 Glazing Comparisons

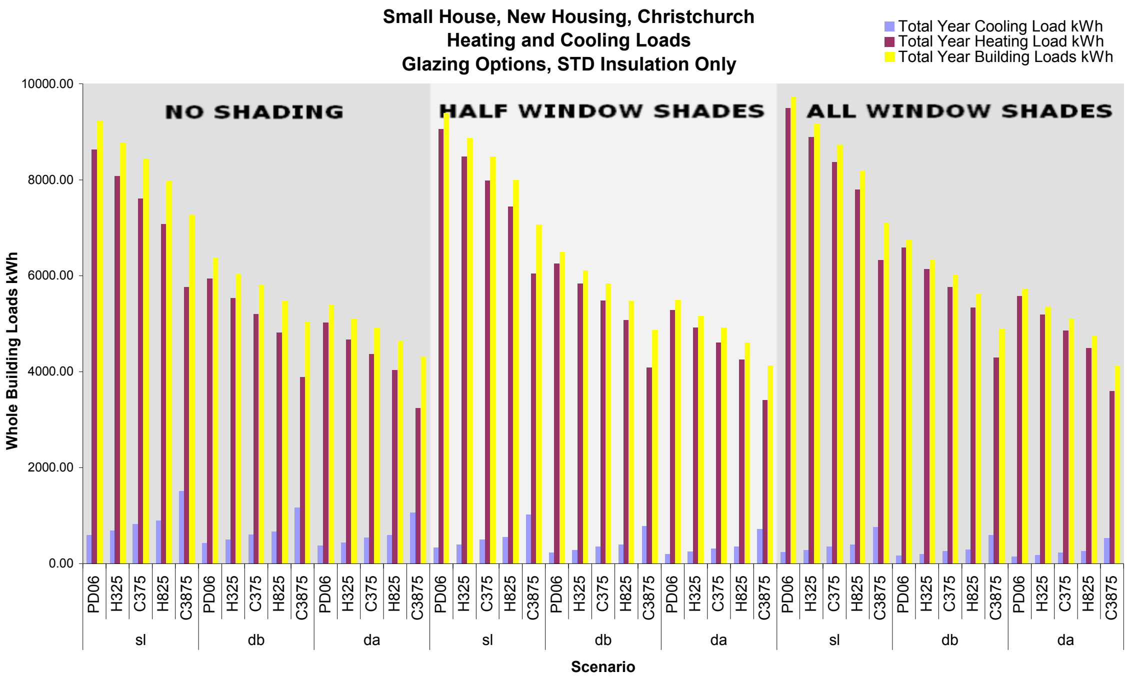
a) Auckland



b) Wellington



c) Christchurch

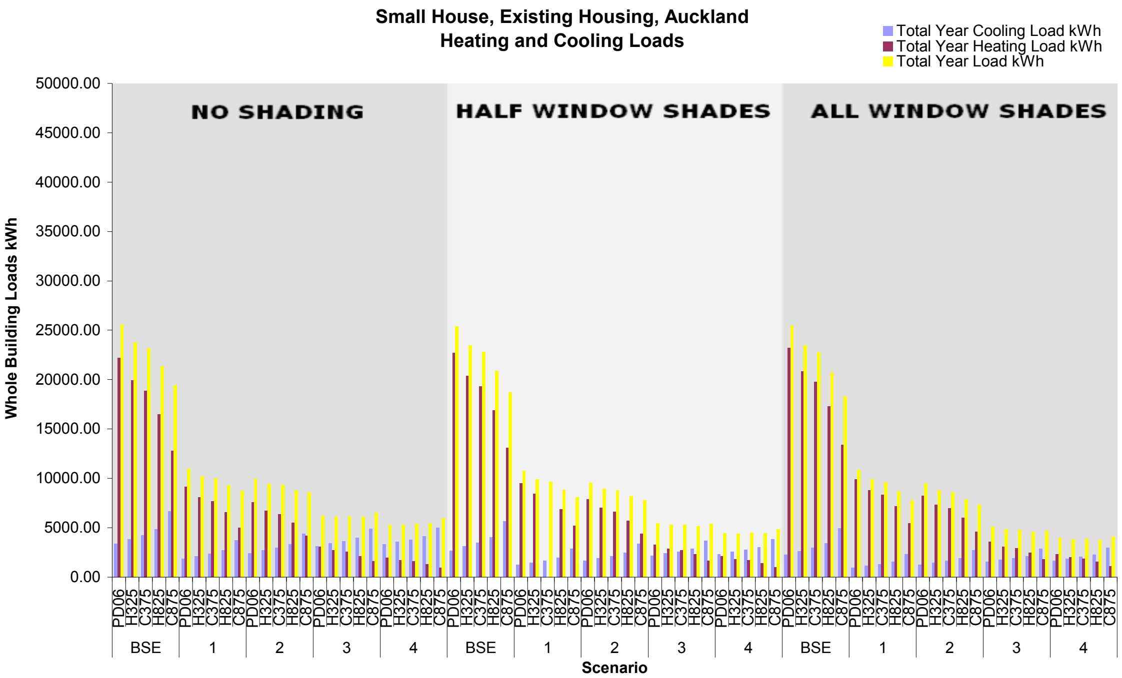


E.3.2 Existing Housing

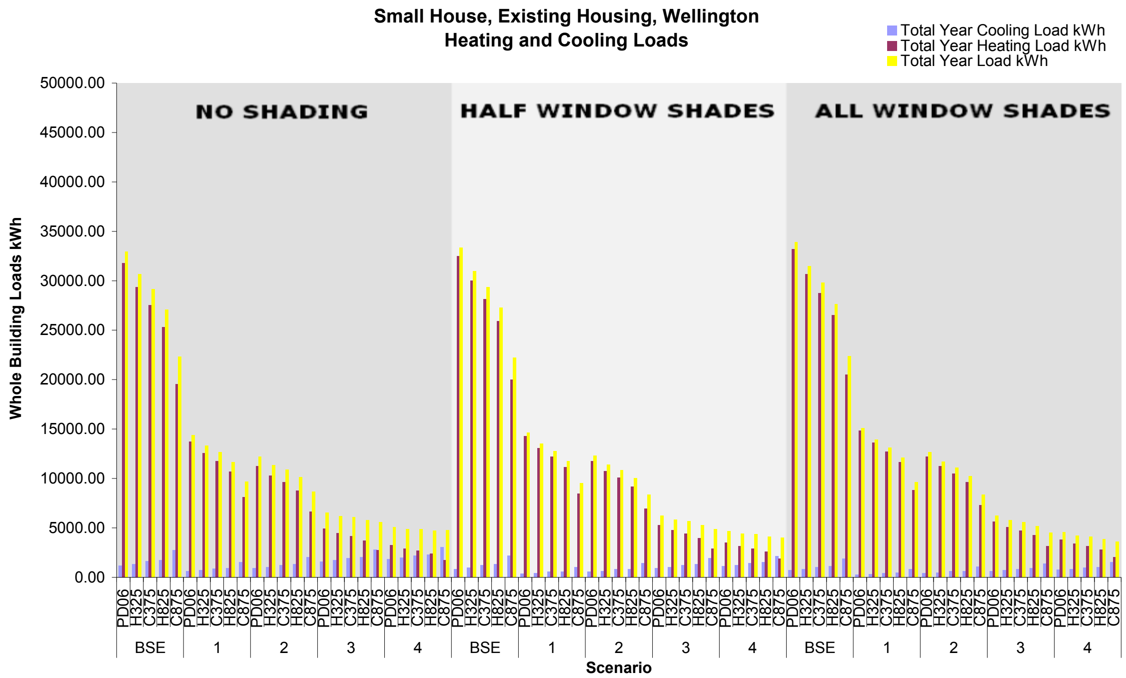
E.3.2.1 Base Simulations

SMALL HOUSE – EXISTING HOUSING – BASE SIMULATIONS ENERGY DROPS BETWEEN SCENARIOS				
		AU	WE	CH
NE	BSE – 001	-56%	-56%	-56%
	001 – 002	-6%	-13%	-13%
	002 – 003	-32%	-43%	-44%
	003 – 004	-12%	-19%	-21%
E2	BSE – 001	-58%	-56%	-56%
	001 – 002	-8%	-14%	-15%
	002 – 003	-38%	-47%	-47%
	003 – 004	-15%	-22%	-24%
EA	BSE – 001	-58%	-56%	-56%
	001 – 002	-10%	-15%	-15%
	002 – 003	-43%	-50%	-50%
	003 – 004	-18%	-25%	-26%
NE – E2	BSE	-2%	+1%	0
	001	-4%	0	0
	002	-6%	-1%	0
	003	-14%	-8%	-5%
	004	-17%	-12%	-10%
E2 – EA	BSE	-0.5%	+1%	0
	001	-1%	+3%	+2%
	002	-3%	+2%	+1%
	003	-10%	-2%	-2%
	004	-13%	-5%	-4%
This is comparing average drops in total energy use. These are approximate and are taken over each of the five climate scenarios.				

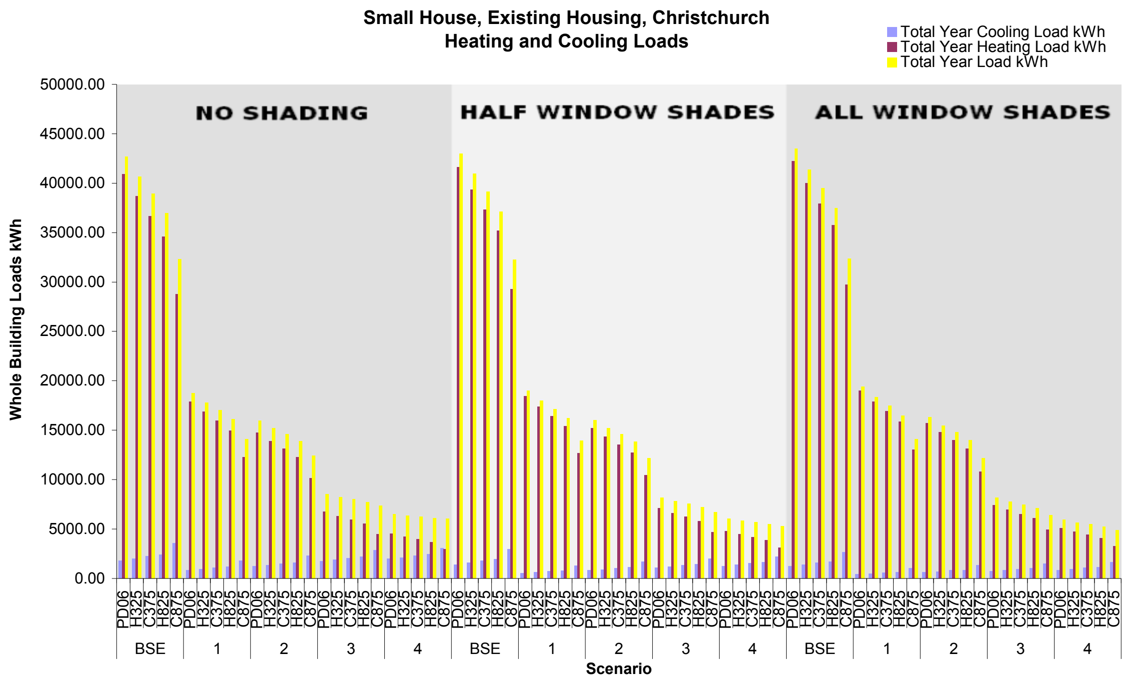
a) Auckland



b) Wellington



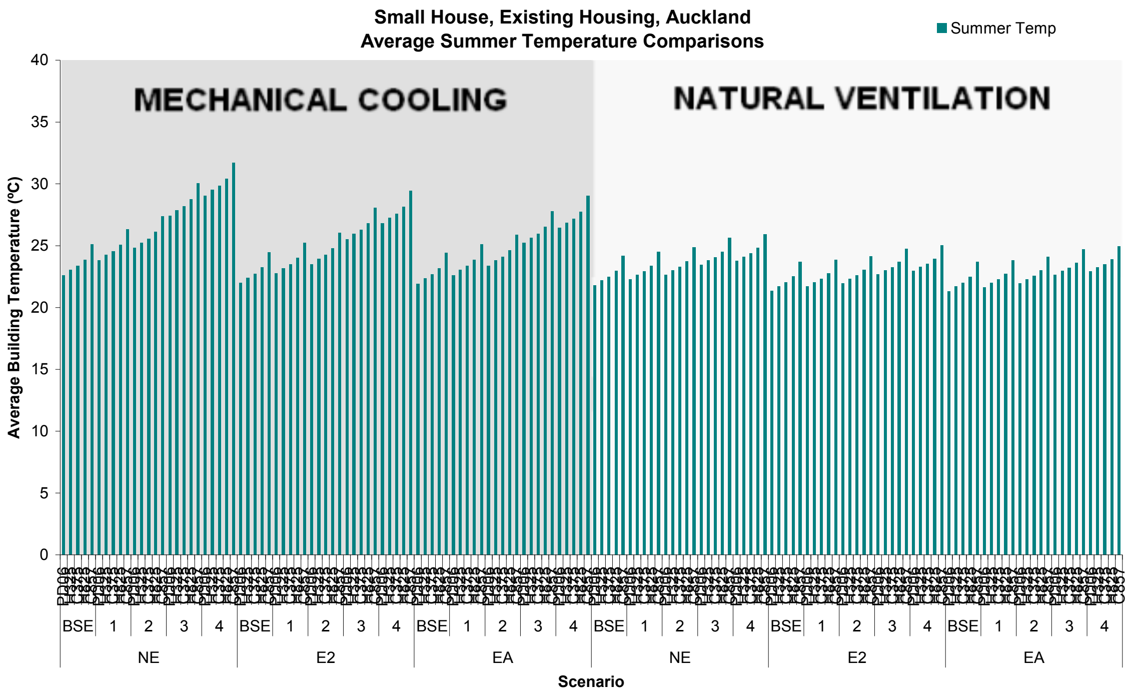
c) Christchurch

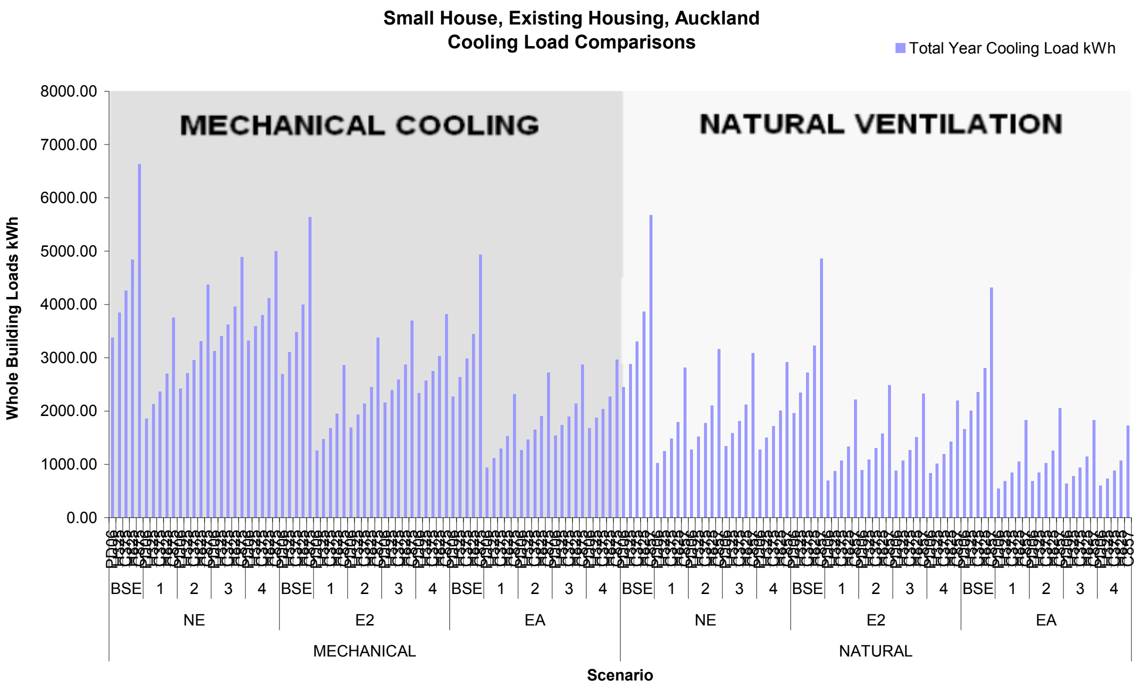


E.3.2.2 Ventilation Comparisons

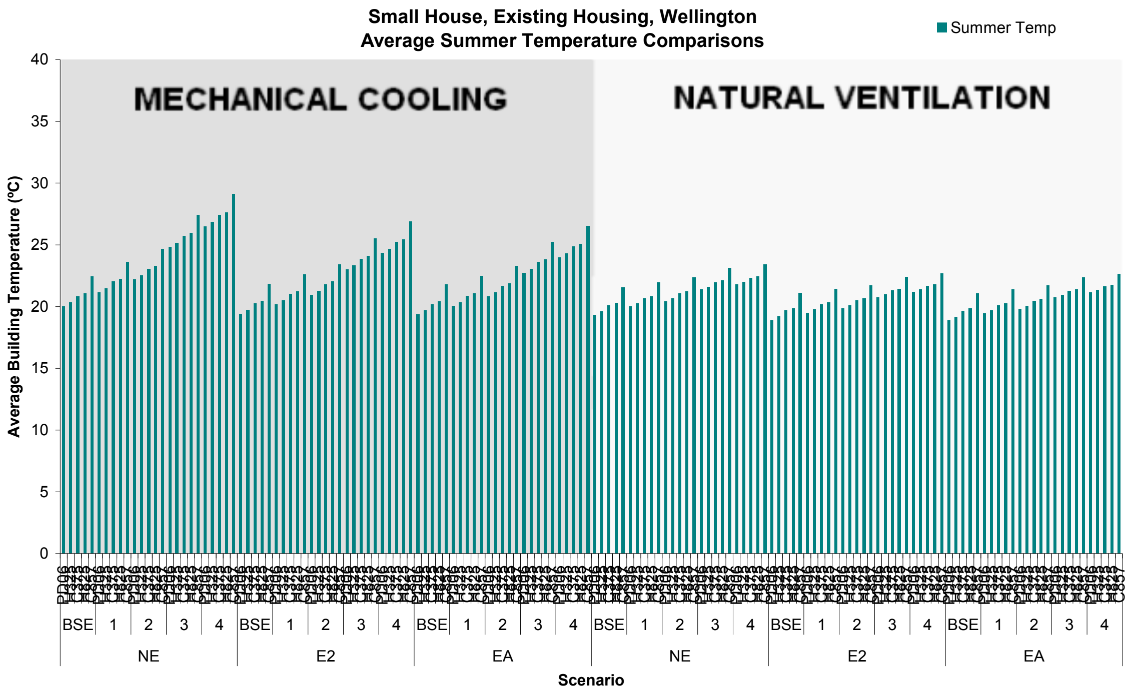
SMALL HOUSE – EXISTING HOUSING – VENTILATION COMPARISONS % OF AVERAGE TEMPERATURE IN SUMMER MONTHS					
		AU	WE	CH	AVERAGE DECREASE
NE – NE	BSE	-4%	-4%	-3%	4%
	001	-7%	-6%	-6%	6%
	002	-9%	-9%	-8%	9%
	003	-15%	-14%	-14%	14%
	004	-18%	-18%	-18%	18%
E2 – E2	BSE	-3%	-3%	-3%	3%
	001	-5%	-4%	-4%	4%
	002	-7%	-6%	-6%	6%
	003	-11%	-10%	-10%	10%
	004	-15%	-14%	-13%	14%
EA - EA	BSE	-3%	-3%	-3%	3%
	001	-5%	-4%	-3%	4%
	002	-6%	-6%	-5%	6%
	003	-10%	-10%	-9%	10%
	004	-14%	-13%	-12%	13%
This is comparing average drops in total energy use. These are approximate and are taken over each of the five climate scenarios.					

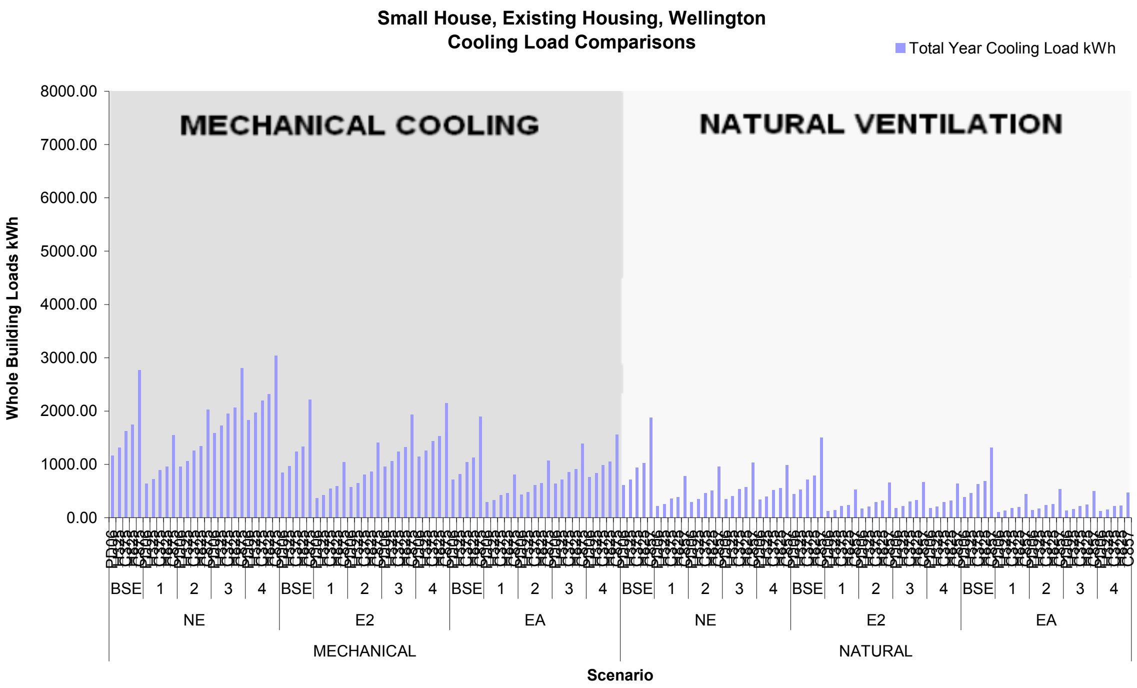
a) Auckland



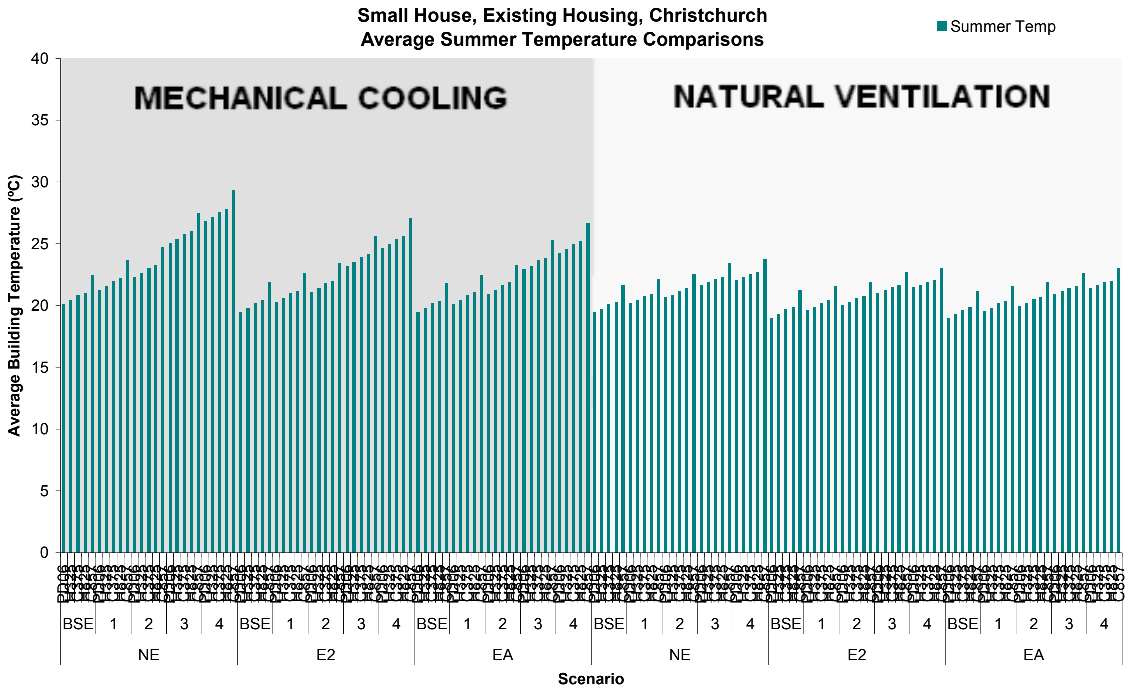


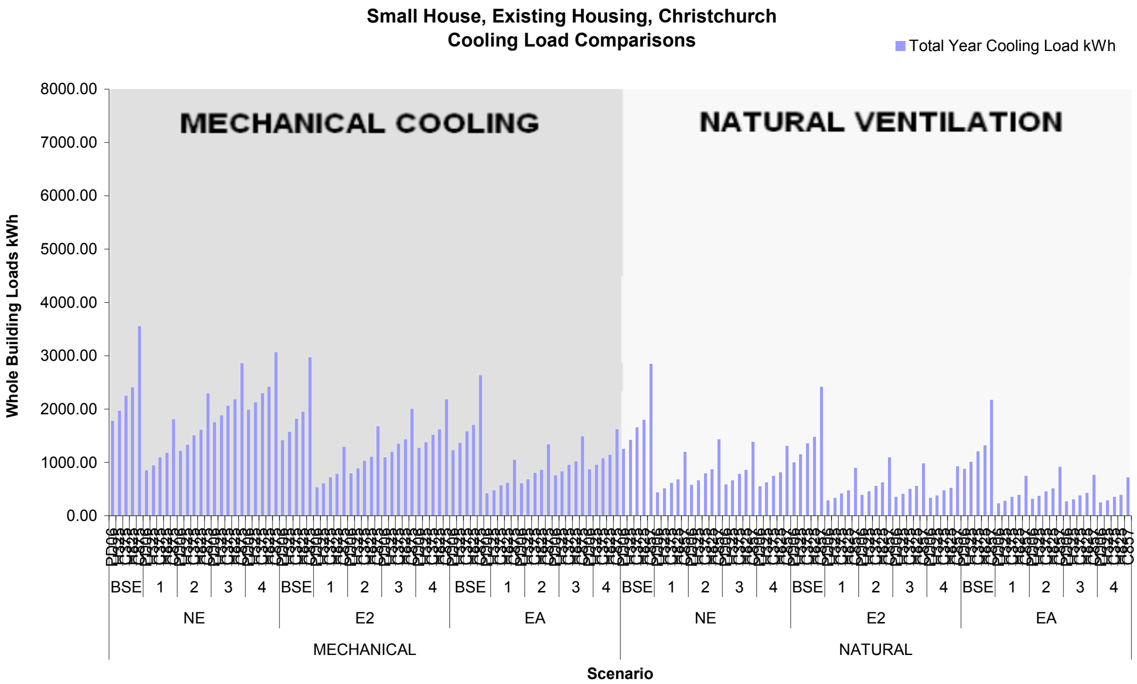
b) Wellington





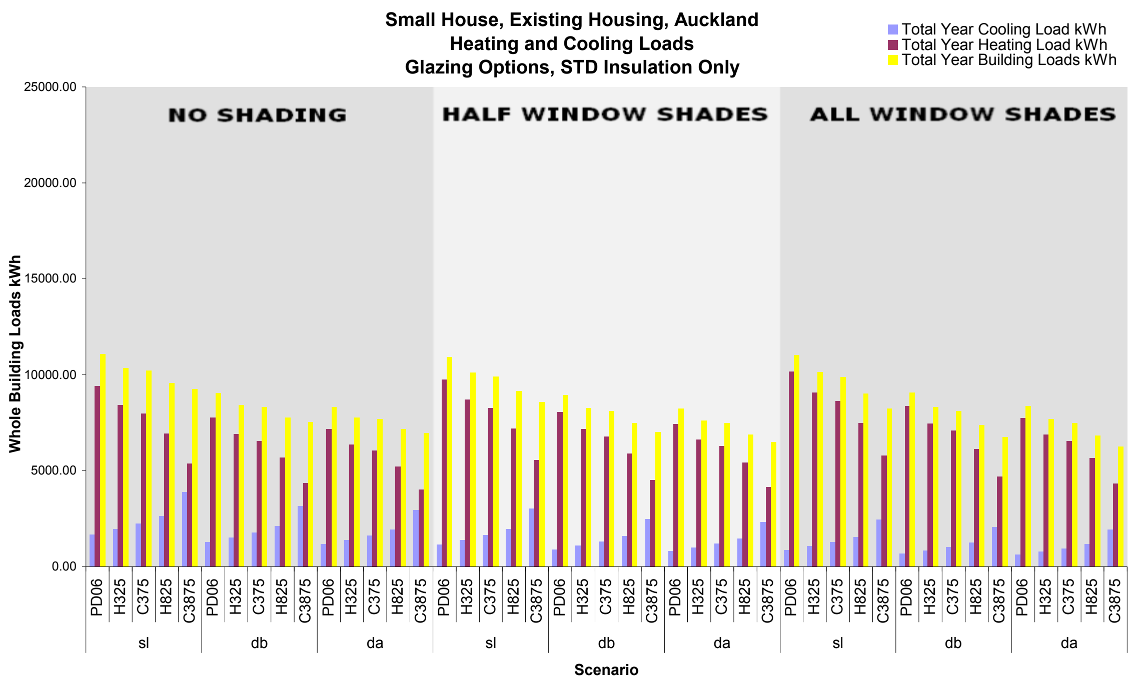
c) Christchurch



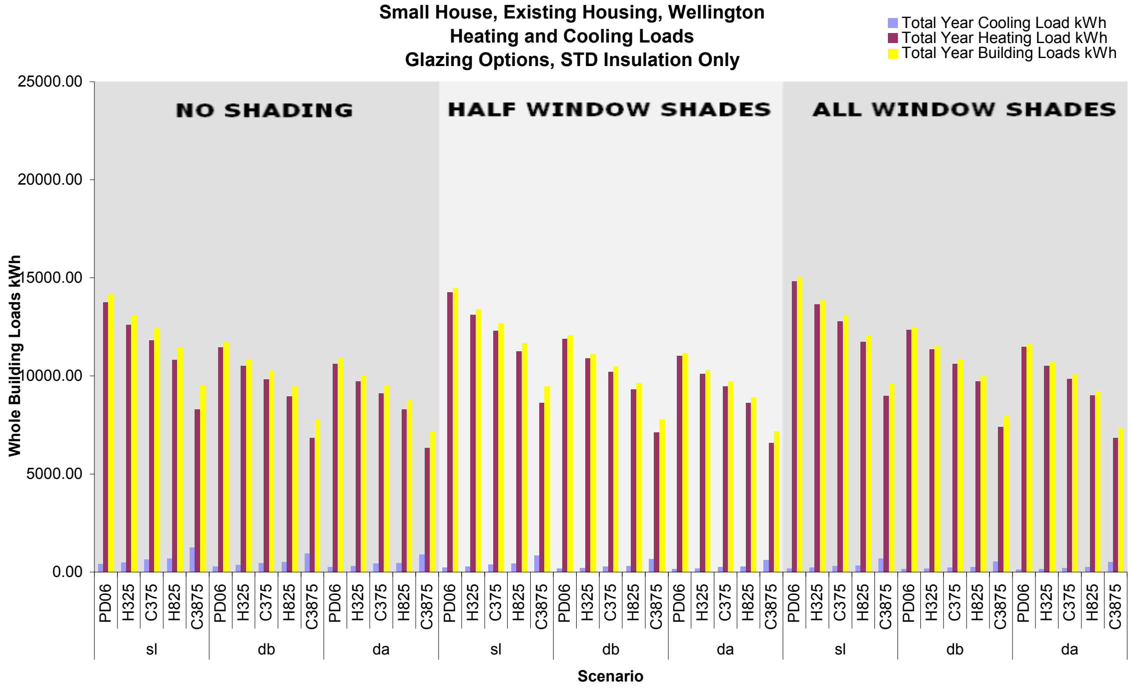


E.3.2.3 Glazing Comparisons

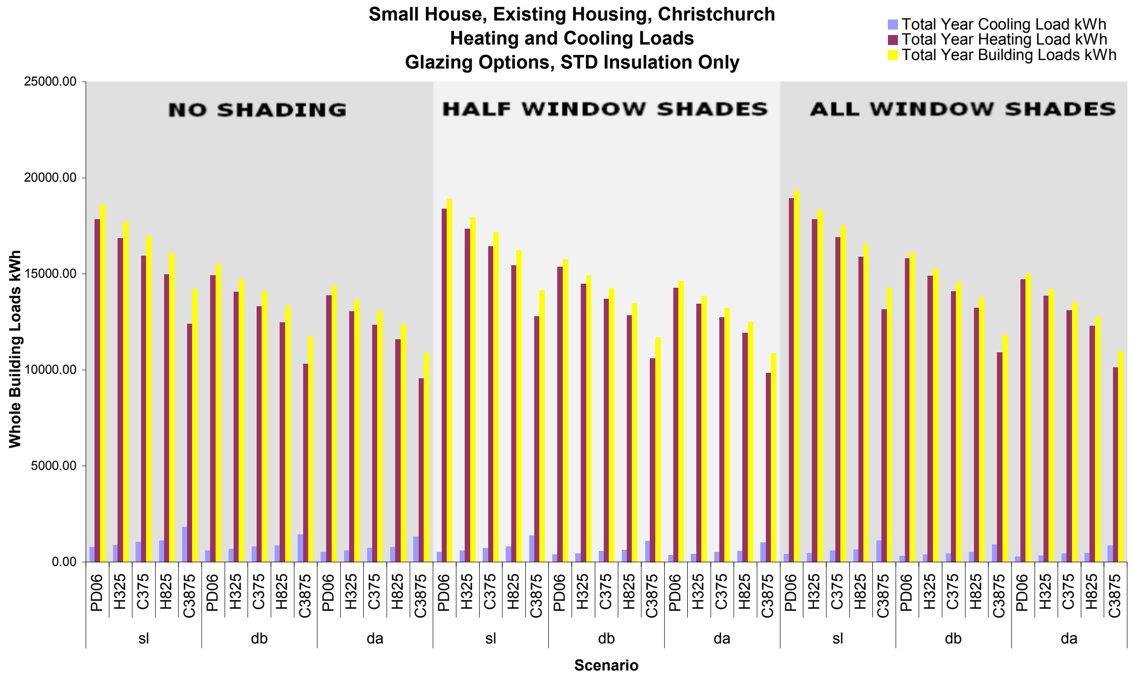
a) Auckland



b) Wellington



c) Christchurch



APPENDIX F: DEMOLITION MODELS

The rate of demolitions by year is required since this affects the number of houses requiring adaptation measures. As a starting point for modelling what is the current demolition rate? Although a building consent is required for a building demolition there is no official information collected centrally on demolitions. Using a sample of consent lists from selected territorial authorities the national demolition rate, scaled up for all TAs, is at least 1,600 housing demolitions for the year ending March 2005.[40] This is believed to be on the low side because it is known that demolition work is not always included in the work description attached to the consent. Often demolition is included on the same consent as the replacement building and the demolition description is not captured. Hence the 1,600 per year rate is a minimum number.

Three different models for demolitions are now described. They are:

- ✓ Inter-census model
- ✓ Dynamic housing stock model
- ✓ Static cohort life table model.

F.1 Inter- census model

One method for calculating demolitions is to consider the number of houses (both occupied and unoccupied) at census time and knowing the number of consents between censuses (at 5 year intervals) the demolition rate can be inferred:

House stock (t) = House stock (t-5) + Consents (5 yr period) – Demolitions (5 year period, where t = census year.

Rearranging gives:

Demolitions (5 yrs period) = House stock (t-5) – House stock (t) + Consents.

The Table below shows this model for recent censuses. It indicates demolitions ranging from -600 per year to 2,400 per year, since 1976. The variation between censuses, and negative demolitions for some periods, arises from a number of factors:

- ✓ The dwelling count at census time may not be accurate, in part because there have been changes in the definitions, and what is recorded as a permanent dwelling.
- ✓ The consent cancellation rate is not known.
- ✓ Some multi-units are converted back into single units but are not recorded as a change in new dwellings in the consent process.

[40] BRANZ (2005), Housing demolitions – BRANZ Report E392, for Energy Efficiency and Conservation Authority.

New dwelling demographic model								
			Updated Oct 2006					
Census year	**76**	**81**	**86**	**91**	**96**	**01**	**06**	**11**
							(4)	(4)
Occupied Private Dwellings (1)	923,200	1,005,489	1,088,598	1,177,662	1,276,332	1,359,843	1,471,746	1,574,894
Unoccupied dwellings (1)	84,600	97,116	107,532	122,712	113,388	147,435	158,095	163,400
All Private Dwellings (pernament	1,007,800	1,102,605	1,196,130	1,300,374	1,389,720	1,507,278	1,629,841	1,738,293
Unocc dwell as % of stock	8.4	8.8	9.0	9.4	8.2	9.8	9.7	9.4
Dwelling consents (5 years) (2)	157875	108922	96911	103597	98541	115919	135143	
Cancellations %	4.0%	2.0%	1.0%	1.0%	1.0%	1.0%	1.0%	
Dwelling consents (5 years) (2b	151560	106744	95941.9	102561	97555.6	114760	133791.6	123453
Average consents per year			19188	20512	19511	22952	26758	24691
Demolitions per year (3)		2388	483	-337	1642	-560	2246	3000

(1) Source: Statistics New Zealand
(2) Number of consents for the five years to the September proceding the census. Assume varied cancellations
(3) Derived from the proceding rows: Demolitions (t) = (Stock(t-5) - Stock(t) + Consents(5 years))/5. -ve demos implies some conversions from flats to single units.
(4) BRANZ forecasts.
Main assumptions in the model are marked by a box=

We do not have census data as yet on unoccupied dwellings in the 2006 census, so the above model estimates this for the last census, in order to derive the latest demolition rate. With the above approximations the model indicates that over the last 5 years there were about 2,200 demolitions per year.

F.2 Housing stock dynamics model (I Johnstone)

Work by Johnson[41] indicates a somewhat higher number of demolitions. This model uses derived life tables for each cohort of the housing stock. The life tables give the probability of demolition at each year of life and there are different tables for each age cohort (in 10 year age bands). The expansion rate of the stock (i.e. the volume of new dwellings) affects the life tables for each age cohort.

In Table A in the Appendix of the Johnstone paper the replacement rates (or demolition rates) are shown for various levels of new dwelling activity. Recently the number of new dwellings averaged about 30,000 per year, giving a gross gains rate of about 2.0% pa, and according to the table an annual replacement rate of 0.5% of the stock which is a demolition rate of about 7,700 per year. In other words, the Johnstone model predicts that the number of current demolitions is 7,700 per year.

F.3 Static life tables

This model is a simplified static life table model developed by BRANZ. The house cohort life profiles are based on Johnstone's results which derives an expected life of 90-110 years for typical NZ housing. The model also uses the results from the 2005 House Condition Survey which show:

- ✓ 1910s and 1920s houses are in slightly better condition that 1930's to 1950's houses, suggesting more robust construction than later decades.
- ✓ 1940's and 1950s houses have the lowest valuations, often on large sections, and are assume to be more likely cohorts for redevelopment.
- ✓ Many 1990s houses suffer from weather-tightness problems.

41 Johnstone, I (1994) "New Zealand Housing stock dynamics" Ministry of Housing: Housing Research Conference, May 1994.

The above observations were used in developing the sets of life tables for the various cohorts. These are shown in the Appendix, and using the stock numbers by cohort (see 3.1.1.1 Housing stock by type, age group and numbers on page 15) the demolition rates were derived.

The demolition numbers are in the figure below, for three different average life scenarios. They indicate an average of about 5,000 demolitions per year now, rising to 20,000 per year by about 2080. Demolitions of pre- 1978 houses, the time before mandatory thermal insulation, are shown in the first chart, and this data was used in assessing the net benefits of insulation retrofit.

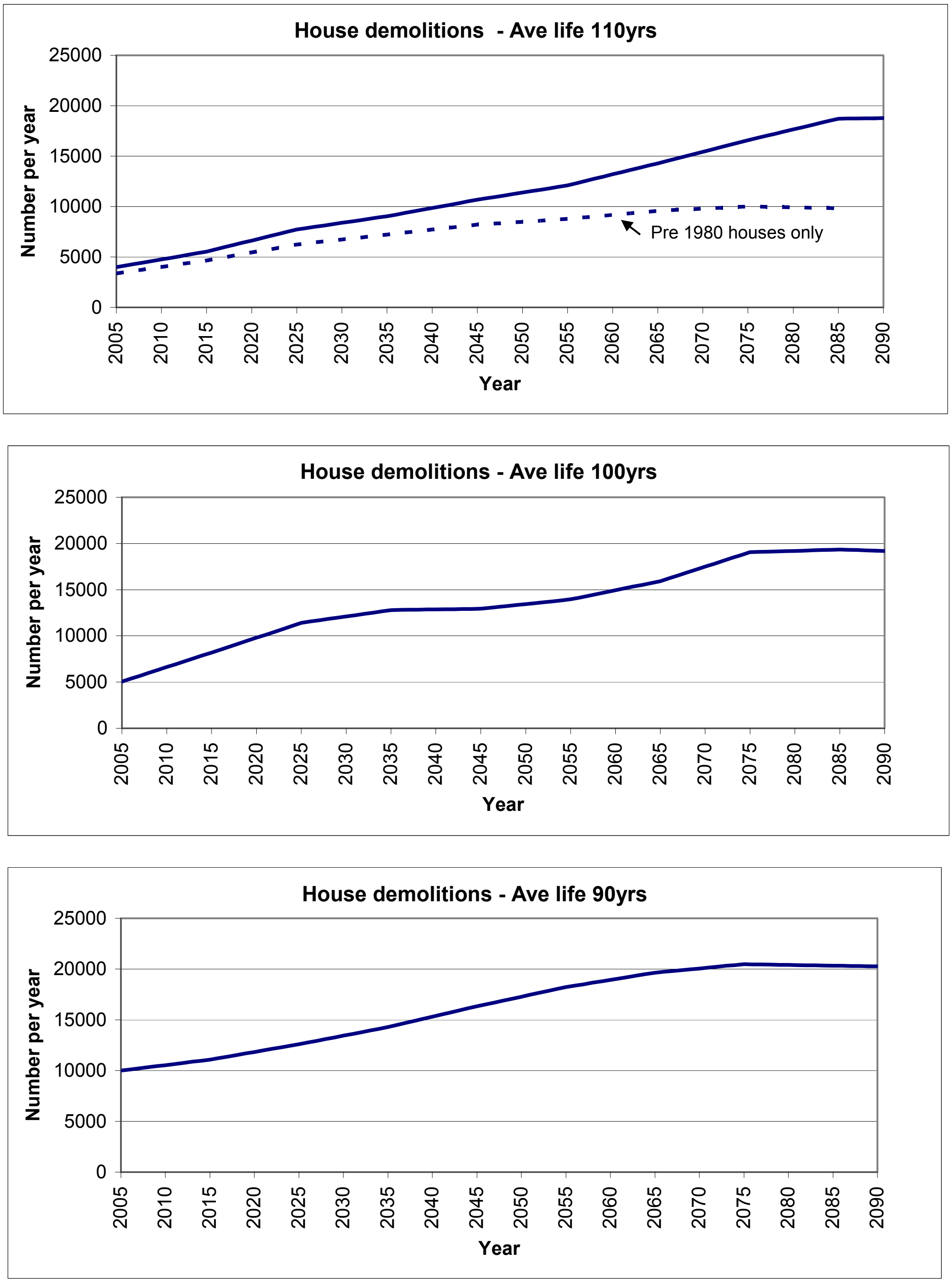


Figure 44: Demolition rates for different average life times.

APPENDIX G: FINANCIAL ANALYSIS OF INSULATION

The various insulation, glazing and shading options were analyzed using the net present value (NPV) method.

NPV (insulation option x) = Present value (option x) - Present value (base case).

The base case is either nil insulation for pre 1978 houses, or for post 1978 houses, the current building code requirements.

Present value existing houses (option x) = $Eb*Ep*USPWF_{before} + (Ea*Ep*USPWF_{after})/HPCOP$

$$+ Hn*Hc*\left[1 + \sum_{t=10\ year\ intervals} 1/(1+r)^t\right]* 1/(1+r)^{Nb}$$

$$+ G*\left[1 + \sum_{t=30\ year\ intervals} 1/(1+r)^t\right] * 1/(1+r)^{Nb}$$

$$+ Aw*\left[1 + \sum_{t=10\ year\ intervals} 1/(1+r)^t\right] * 1/(1+r)^{Nb}$$

$$+Ix*1/(1+r)^{Nb} + USPWF_{before}*H$$

This gave a present value per house retrofitted. This figure was then multiplied by the number of houses that were retrofitted (it allowed for demolitions) for the 55 years from 2005 till 2060.

Present value new houses (option x) = $(En*Ep*USPWF_{new})/HPCOP$

$$+ Hn*Hc*\left[1 + \sum_{t=10\ year\ intervals} 1/(1+r)^t\right]$$

$$+ G*\left[1 + \sum_{t=30\ year\ intervals} 1/(1+r)^t\right]$$

$$+ Aw*\left[1 + \sum_{t=10\ year\ intervals} 1/(1+r)^t\right]$$

$$+Ix$$

This gave a present value for each new house that was built.

$USPWF_{before}$ = Uniform series present worth factor = $\frac{(1+e)*(1+r)^{Nb}-(1+e)^{Nb}}{(r-e)*(1+r)^{Nb}}$

$USPWF_{after}$ = Uniform series present worth factor = $\frac{(1+e)*(1+r)^{Na}-(1+e)^{Na}}{(r-e)*(1+r)^{Na}}$

$USPWF_{new}$ = Uniform series present worth factor = $\underline{(1+e)*(1+r)^{30}-(1+e)^{30}}$

$$(r-e)*(1+r)^{30}$$

r = real discount rate (i.e. after inflation)
Nb = number of years before retrofitting
Na = number of years after retrofitting
Eb = Energy consumption before retrofitting
Ea = Energy consumption after retrofitting
En = Energy consumption for new houses
Ep = Energy price
e = energy price escalation rate (additional to CPI inflation rate).
H = Additional health costs per before retrofit insulation is installed
Ix = insulation costs for option x.
Hn = Number of heaters
Hc = Cost of heaters
HPCOP = Heat pump coefficient of performance
G = Glazing cost
Aw = Awnings cost

The following tables show all the retrofitting models and different situations. Note that these results are per house and do not represent the entire existing housing stock:

Retrofitting existing houses

House size = Small — Situation = CSIRO
Start retrofitting 2005

Insulation	Ave energy kWh/ year Before fit	Ave energy kWh/ year After fit	Total energy for period	Peak kW	Insulation Cost	Eaves Cost	PV Double glazing $	Number of heat pumps	Heater PV incl replace	PV Energy	Total PV	Net present value
Auckland					$	$	$		$	$	$	$
Base - Awnings	24318	22568	1249973	15.23	0	3266	0	4	23,049	31,895	58,210	-3,181
Base - No Awnings	24318	22679	1255515	15.23	0	0	0	4	23,049	31,979	55,028	0
1 - Awnings	24318	9348	588969	9.49	825	3266	5,481	2	11,525	21,796	42,893	12,136
1 - No Awnings	24318	9452	594173	9.49	825	0	5,481	2	11,525	21,876	39,706	15,322
2 - Awnings	24318	8243	533719	9.12	2017	3266	5,481	2	11,525	20,952	43,241	11,788
2 - No Awnings	24318	8445	543863	9.12	2017	0	5,481	2	11,525	21,107	40,129	14,899
3 - Awnings	24318	4221	332617	7.06	2487	3266	5,481	2	11,525	17,880	40,638	14,390
3 - No Awnings	24318	4612	352211	7.06	2487	0	5,481	2	11,525	18,179	37,671	17,357
3 - best windows	24318	3991	321121	6.73	2487	0	8,677	2	11,525	17,704	40,392	14,637
3 - wst windows	24318	6484	445767	8.00	2487	0	0	2	11,525	19,608	33,619	21,409
4 - Awnings	24318	3130	278103	6.49	3672	3266	8,677	2	11,525	17,047	44,186	10,842
4 - No Awnings	24318	3538	298473	6.49	3672	0	8,677	2	11,525	17,358	41,231	13,797
Wellington												
Base - Awnings	31826	29624	1640350	13.89	0	3266	0	3	17,287	40,648	61,201	-3,579
Base - No Awnings	31826	29203	1619282	13.89	0	0	0	3	17,287	40,335	57,622	0
1 - Awnings	31826	12865	802374	8.95	825	3266	5,552	2	11,525	28,201	49,369	8,253
1 - No Awnings	31826	12550	786629	8.95	825	0	5,552	2	11,525	27,968	45,869	11,753
2 - Awnings	31826	10752	696715	8.56	1992	3266	5,552	2	11,525	26,632	48,967	8,654
2 - No Awnings	31826	10528	685512	8.56	1992	0	5,552	2	11,525	26,466	45,535	12,087
3 - Awnings	31826	5047	411479	6.79	2462	3266	5,552	2	11,525	22,396	45,201	12,421
3 - No Awnings	31826	5028	410523	6.79	2462	0	5,552	2	11,525	22,381	41,920	15,701
3 - best windows	31826	4297	373983	6.50	2462	0	8,748	2	11,525	21,839	44,573	13,049
3 - wst windows	31826	7158	517036	7.61	2462	0	0	2	11,525	23,963	37,950	19,671
4 - Awnings	31826	3490	333626	6.27	3623	3266	8,748	2	11,525	21,239	48,401	9,221
4 - No Awnings	31826	3525	335364	6.27	3623	0	8,748	2	11,525	21,265	45,161	12,461
Christchurch												
Base - Awnings	41591	39407	2178300	17.11	0	3266	0	4	23,049	56,637	82,952	-3,548
Base - No Awnings	41591	39047	2160294	17.11	0	0	0	4	23,049	56,354	79,404	0
1 - Awnings	41591	17250	1070440	10.43	988	3266	6,229	3	17,287	39,261	67,031	12,373
1 - No Awnings	41591	16974	1056654	10.43	988	0	6,229	3	17,287	39,045	63,549	15,855
2 - Awnings	41591	14505	933221	9.87	2237	3266	6,229	2	11,525	37,109	60,365	19,039
2 - No Awnings	41591	14331	924500	9.87	2237	0	6,229	2	11,525	36,972	56,962	22,441
3 - Awnings	41591	7062	561059	7.52	2706	3266	6,229	2	11,525	31,272	54,998	24,406
3 - No Awnings	41591	7082	562078	7.52	2706	0	6,229	2	11,525	31,288	51,748	27,656
3 - best windows	41591	6101	513002	7.15	2706	0	9,664	2	11,525	30,518	54,413	24,990
3 - wst windows	41591	9926	704281	8.57	2706	0	0	2	11,525	33,518	47,749	31,655
4 - Awnings	41591	4962	456069	6.83	4340	3266	9,664	2	11,525	29,625	58,420	20,984
4 - No Awnings	41591	5035	459702	6.83	4340	0	9,664	2	11,525	29,682	55,211	24,193

Discount rate = 5% — Energy Price escalation = 5% — Heater cost= $3,000 — HP COP = 3 — Energy Prices: Akld 13.52, Well 13.15, Chch 13.88

Heat pumps and awnings replaced at 10 years, double glazing replaced at 30 years

Retrofitting existing houses

House size = Small — Situation = CSIRO
Start retrofitting 2015

Insulation	Ave energy kWh/ year Before fit	Ave energy kWh/ year After fit	Total energy for period	Peak kW	Insulation Cost	Eaves Cost	PV Double glazing $	Number of heat pumps	Heater PV incl replace	PV Energy	Total PV	Net present value
Auckland					$	$	$		$	$	$	$
Base - Awnings	23498	21719	1221240	15.23	0	2005	0	4	14,150	44,804	60,959	-1,929
Base - No Awnings	23498	21895	1228276	15.23	0	0	0	4	14,150	44,879	59,030	0
1 - Awnings	23498	8993	712191	9.49	506	2005	3,365	2	7,075	39,310	52,261	6,768
1 - No Awnings	23498	9149	718417	9.49	506	0	3,365	2	7,075	39,377	50,323	8,706
2 - Awnings	23498	7995	672270	9.12	1238	2005	3,365	2	7,075	38,879	52,562	6,468
2 - No Awnings	23498	8248	682378	9.12	1238	0	3,365	2	7,075	38,988	50,666	8,364
3 - Awnings	23498	4183	519789	7.06	1527	2005	3,365	2	7,075	37,233	51,205	7,825
3 - No Awnings	23498	4622	537342	7.06	1527	0	3,365	2	7,075	37,423	49,389	9,640
3 - best windows	23498	4015	513067	6.73	1527	0	5,327	2	7,075	37,161	51,089	7,941
3 - wst windows	23498	6455	610684	8.00	1527	0	0	2	7,075	38,214	46,816	12,214
4 - Awnings	23498	3146	478305	6.49	2254	2005	5,327	2	7,075	36,786	53,447	5,583
4 - No Awnings	23498	3595	496286	6.49	2254	0	5,327	2	7,075	36,980	51,636	7,394
Wellington												
Base - Awnings	30515	28209	1586083	13.89	0	2005	0	3	10,613	56,566	69,183	-2,159
Base - No Awnings	30515	27843	1571439	13.89	0	0	0	3	10,613	56,412	67,025	0
1 - Awnings	30515	12195	945530	8.95	506	2005	3,409	2	7,075	49,845	62,840	4,185
1 - No Awnings	30515	11923	934630	8.95	506	0	3,409	2	7,075	49,731	60,721	6,304
2 - Awnings	30515	10219	866468	8.56	1223	2005	3,409	2	7,075	49,015	62,727	4,297
2 - No Awnings	30515	10036	859154	8.56	1223	0	3,409	2	7,075	48,939	60,645	6,379
3 - Awnings	30515	4809	650069	6.79	1512	2005	3,409	2	7,075	46,745	60,745	6,279
3 - No Awnings	30515	4828	650847	6.79	1512	0	3,409	2	7,075	46,753	58,748	8,276
3 - best windows	30515	4127	622809	6.50	1512	0	5,370	2	7,075	46,459	60,416	6,609
3 - wst windows	30515	6879	732892	7.61	1512	0	0	2	7,075	47,614	56,201	10,824
4 - Awnings	30515	3334	591073	6.27	2225	2005	5,370	2	7,075	46,126	62,801	4,224
4 - No Awnings	30515	3403	593844	6.27	2225	0	5,370	2	7,075	46,155	60,825	6,200
Christchurch												
Base - Awnings	40319	38053	2126925	17.11	0	2005	0	4	14,150	79,271	95,426	-2,145
Base - No Awnings	40319	37738	2114309	17.11	0	0	0	4	14,150	79,131	93,281	0
1 - Awnings	40319	16607	1269082	10.43	607	2005	3,824	3	10,613	69,766	86,815	6,466
1 - No Awnings	40319	16369	1259532	10.43	607	0	3,824	3	10,613	69,661	84,704	8,577
2 - Awnings	40319	14001	1164815	9.87	1373	2005	3,824	2	7,075	68,611	82,889	10,393
2 - No Awnings	40319	13862	1159251	9.87	1373	0	3,824	2	7,075	68,550	80,822	12,459
3 - Awnings	40319	6837	878251	7.52	1662	2005	3,824	2	7,075	65,436	80,002	13,279
3 - No Awnings	40319	6890	880406	7.52	1662	0	3,824	2	7,075	65,460	78,021	15,260
3 - best windows	40319	5938	842304	7.15	1662	0	5,933	2	7,075	65,038	79,708	13,574
3 - wst windows	40319	9657	991048	8.57	1662	0	0	2	7,075	66,686	75,423	17,859
4 - Awnings	40319	4817	797480	6.83	2664	2005	5,933	2	7,075	64,541	82,219	11,063
4 - No Awnings	40319	4920	801582	6.83	2664	0	5,933	2	7,075	64,587	80,259	13,022

Discount rate = 5% — Energy Price escalation = 5% — Heater cost= $3,000 — HP COP = 3 — Energy Prices: Akld 13.52, Well 13.15, Chch 13.88

Heat pumps and awnings replaced at 10 years, double glazing replaced at 30 years

Retrofitting existing houses

House size = Small   Situation = CSIRO

Start retrofitting 2025

Insulation	Ave energy kWh/ year Before fit	Ave energy kWh/ year After fit	Total energy for period	Peak kW	Insulation Cost	Eaves Cost	PV Double glazing $	Number of heat pumps	Heater PV incl replace	PV Energy	Total PV	Net present value
Auckland					$	$	$		$	$	$	$
Base - Awnings	22679	20897	1193869	15.23	0	1231	0	4	8,687	52,943	62,861	-1,173
Base - No Awnings	22679	21148	1201400	15.23	0	0	0	4	8,687	53,001	61,688	0
1 - Awnings	22679	8667	826986	9.49	311	1231	2,066	2	4,343	50,115	58,066	3,622
1 - No Awnings	22679	8881	833394	9.49	311	0	2,066	2	4,343	50,164	56,884	4,804
2 - Awnings	22679	7777	800286	9.12	760	1231	2,066	2	4,343	49,909	58,309	3,379
2 - No Awnings	22679	8088	809613	9.12	760	0	2,066	2	4,343	49,981	57,150	4,538
3 - Awnings	22679	4182	692422	7.06	937	1231	2,066	2	4,343	49,077	57,655	4,034
3 - No Awnings	22679	4676	707233	7.06	937	0	2,066	2	4,343	49,191	56,538	5,150
3 - best windows	22679	4082	689433	6.73	937	0	3,270	2	4,343	49,054	57,605	4,083
3 - wst windows	22679	6475	761225	8.00	937	0	0	2	4,343	49,608	54,888	6,800
4 - Awnings	22679	3198	662907	6.49	1384	1231	3,270	2	4,343	48,850	59,078	2,610
4 - No Awnings	22679	3697	677877	6.49	1384	0	3,270	2	4,343	48,965	57,963	3,725
Wellington												
Base - Awnings	29203	26739	1532257	13.89	0	1231	0	3	6,515	66,241	73,987	-1,299
Base - No Awnings	29203	26435	1523112	13.89	0	0	0	3	6,515	66,172	72,688	0
1 - Awnings	29203	11507	1075293	8.95	311	1231	2,093	2	4,343	62,816	70,794	1,894
1 - No Awnings	29203	11282	1068537	8.95	311	0	2,093	2	4,343	62,765	69,512	3,175
2 - Awnings	29203	9675	1020314	8.56	751	1231	2,093	2	4,343	62,404	70,822	1,866
2 - No Awnings	29203	9537	1016192	8.56	751	0	2,093	2	4,343	62,373	69,560	3,128
3 - Awnings	29203	4576	867342	6.79	928	1231	2,093	2	4,343	61,257	69,852	2,835
3 - No Awnings	29203	4637	869192	6.79	928	0	2,093	2	4,343	61,271	68,635	4,052
3 - best windows	29203	3967	849094	6.50	928	0	3,297	2	4,343	61,121	69,689	2,999
3 - wst windows	29203	6607	928284	7.61	928	0	0	2	4,343	61,714	66,986	5,702
4 - Awnings	29203	3187	825675	6.27	1366	1231	3,297	2	4,343	60,945	71,182	1,506
4 - No Awnings	29203	3293	828877	6.27	1366	0	3,297	2	4,343	60,969	69,975	2,713
Christchurch												
Base - Awnings	39047	36656	2075846	17.11	0	1231	0	4	8,687	93,742	103,660	-1,293
Base - No Awnings	39047	36393	2067961	17.11	0	0	0	4	8,687	93,680	102,367	0
1 - Awnings	39047	15951	1454704	10.43	372	1231	2,348	3	6,515	88,826	99,292	3,074
1 - No Awnings	39047	15755	1448816	10.43	372	0	2,348	3	6,515	88,780	98,015	4,352
2 - Awnings	39047	13490	1380866	9.87	843	1231	2,348	2	4,343	88,242	97,007	5,360
2 - No Awnings	39047	13392	1377915	9.87	843	0	2,348	2	4,343	88,218	95,752	6,614
3 - Awnings	39047	6621	1174798	7.52	1020	1231	2,348	2	4,343	86,611	95,553	6,814
3 - No Awnings	39047	6714	1177579	7.52	1020	0	2,348	2	4,343	86,633	94,344	8,023
3 - best windows	39047	5791	1149888	7.15	1020	0	3,642	2	4,343	86,414	95,419	6,947
3 - wst windows	39047	9400	1258178	8.57	1020	0	0	2	4,343	87,271	92,634	9,733
4 - Awnings	39047	4686	1116740	6.83	1636	1231	3,642	2	4,343	86,151	97,004	5,363
4 - No Awnings	39047	4823	1120852	6.83	1636	0	3,642	2	4,343	86,184	95,805	6,562

Discount rate = 5%   Energy Price escalation = 5%   Heater cost= $3,000   HP COP = 3   Energy Prices: Akld 13.52, Well 13.15, Chch 13.88

Heat pumps and awnings replaced at 10 years, double glazing replaced at 30 years

Retrofitting existing houses

House size = Small   Situation = HADLEY

Start retrofitting 2005

Insulation	Ave energy kWh/ year Before fit	Ave energy kWh/ year After fit	Total energy for period	Peak kW	Insulation Cost	Eaves Cost	PV Double glazing $	Number of heat pumps	Heater PV incl replace	PV Energy	Total PV	Net present value
Auckland					$	$	$		$	$	$	$
Base - Awnings	24418	23124	1278314	15.84	0	3266	0	4	23,049	32,381	58,696	-3,223
Base - No Awnings	24418	23181	1281159	15.84	0	0	0	4	23,049	32,424	55,473	0
1 - Awnings	24418	9562	600201	9.81	825	3266	5,481	2	11,525	22,021	43,117	12,356
1 - No Awnings	24418	9620	603114	9.81	825	0	5,481	2	11,525	22,065	39,896	15,577
2 - Awnings	24418	8374	540785	9.40	2017	3266	5,481	2	11,525	21,113	43,401	12,072
2 - No Awnings	24418	8536	548869	9.39	2017	0	5,481	2	11,525	21,236	40,259	15,214
3 - Awnings	24418	4203	332263	7.23	2487	3266	5,481	2	11,525	17,927	40,686	14,788
3 - No Awnings	24418	4558	349971	7.23	2487	0	5,481	2	11,525	18,198	37,690	17,783
3 - best windows	24418	3927	318441	6.89	2487	0	8,677	2	11,525	17,716	40,404	15,069
3 - wst windows	24418	6450	444592	8.21	2487	0	0	2	11,525	19,643	33,654	21,819
4 - Awnings	24418	3078	275979	6.63	3672	3266	8,677	2	11,525	17,067	44,207	11,267
4 - No Awnings	24418	3451	294659	6.62	3672	0	8,677	2	11,525	17,353	41,226	14,247
Wellington												
Base - Awnings	32094	31037	1712334	14.57	0	3266	0	3	17,287	41,854	62,407	-3,632
Base - No Awnings	32094	30544	1687677	14.57	0	0	0	3	17,287	41,488	58,775	0
1 - Awnings	32094	13528	836889	9.30	825	3266	5,552	2	11,525	28,851	50,019	8,756
1 - No Awnings	32094	13159	818401	9.30	825	0	5,552	2	11,525	28,577	46,478	12,297
2 - Awnings	32094	11267	723833	8.86	1992	3266	5,552	2	11,525	27,172	49,507	9,267
2 - No Awnings	32094	10988	709853	8.86	1992	0	5,552	2	11,525	26,964	46,034	12,741
3 - Awnings	32094	5258	423376	6.98	2462	3266	5,552	2	11,525	22,709	45,514	13,260
3 - No Awnings	32094	5187	419828	6.98	2462	0	5,552	2	11,525	22,657	42,196	16,579
3 - best windows	32094	4429	381899	6.67	2462	0	8,748	2	11,525	22,093	44,828	13,947
3 - wst windows	32094	7387	529813	7.85	2462	0	0	2	11,525	24,290	38,277	20,498
4 - Awnings	32094	3618	341356	6.43	3623	3266	8,748	2	11,525	21,491	48,653	10,122
4 - No Awnings	32094	3605	340745	6.43	3623	0	8,748	2	11,525	21,482	45,378	13,397
Christchurch												
Base - Awnings	41885	40927	2255771	17.79	0	3266	0	4	23,049	58,011	84,326	-3,588
Base - No Awnings	41885	40517	2235253	17.79	0	0	0	4	23,049	57,689	80,738	0
1 - Awnings	41885	17966	1107723	10.78	988	3266	6,229	3	17,287	40,004	67,775	12,963
1 - No Awnings	41885	17649	1091877	10.78	988	0	6,229	3	17,287	39,756	64,260	16,478
2 - Awnings	41885	15066	962749	10.17	2237	3266	6,229	3	17,287	37,731	66,749	13,989
2 - No Awnings	41885	14852	952002	10.17	2237	0	6,229	3	17,287	37,562	63,315	17,423
3 - Awnings	41885	7313	575065	7.70	2706	3266	6,229	2	11,525	31,650	55,376	25,362
3 - No Awnings	41885	7294	574139	7.70	2706	0	6,229	2	11,525	31,636	52,096	28,642
3 - best windows	41885	6281	523477	7.31	2706	0	9,664	2	11,525	30,841	54,736	26,002
3 - wst windows	41885	10223	720567	8.80	2706	0	0	2	11,525	33,932	48,163	32,575
4 - Awnings	41885	5124	465607	6.97	4340	3266	9,664	2	11,525	29,933	58,728	22,010
4 - No Awnings	41885	5161	467480	6.97	4340	0	9,664	2	11,525	29,963	55,491	25,247

Discount rate = 5%   Energy Price escalation = 5%   Heater cost= $3,000   HP COP = 3   Energy Prices: Akld 13.52, Well 13.15, Chch 13.88

Heat pumps and awnings replaced at 10 years, double glazing replaced at 30 years

Retrofitting existing houses

House size = Small   Situation = HADLEY
Start retrofitting 2015

Insulation	Ave energy kWh/ year Before fit	Ave energy kWh/ year After fit	Total energy for period	Peak kW	Insulation Cost	Eaves Cost	PV Double glazing $	Number of heat pumps	Heater PV incl replace	PV Energy	Total PV	Net present value
Auckland					$	$	$		$	$	$	$
Base - Awnings	23800	22537	1258487	15.84	0	2005	0	4	14,150	45,611	61,767	-1,966
Base - No Awnings	23800	22629	1262140	15.84	0	0	0	4	14,150	45,651	59,801	0
1 - Awnings	23800	9302	729087	9.81	506	2005	3,365	2	7,075	39,898	52,850	6,952
1 - No Awnings	23800	9388	732513	9.81	506	0	3,365	2	7,075	39,935	50,881	8,920
2 - Awnings	23800	8182	684277	9.40	1238	2005	3,365	2	7,075	39,414	53,098	6,703
2 - No Awnings	23800	8370	691780	9.39	1238	0	3,365	2	7,075	39,495	51,174	8,628
3 - Awnings	23800	4146	522823	7.23	1527	2005	3,365	2	7,075	37,672	51,644	8,157
3 - No Awnings	23800	4524	537975	7.23	1527	0	3,365	2	7,075	37,836	49,802	9,999
3 - best windows	23800	3905	513193	6.89	1527	0	5,327	2	7,075	37,568	51,496	8,305
3 - wst windows	23800	6388	612533	8.21	1527	0	0	2	7,075	38,640	47,242	12,559
4 - Awnings	23800	3055	479213	6.63	2254	2005	5,327	2	7,075	37,201	53,863	5,939
4 - No Awnings	23800	3451	495032	6.62	2254	0	5,327	2	7,075	37,372	52,028	7,773
Wellington												
Base - Awnings	31319	30257	1680062	14.57	0	2005	0	3	10,613	58,605	71,222	-2,202
Base - No Awnings	31319	29787	1661273	14.57	0	0	0	3	10,613	58,407	69,020	0
1 - Awnings	31319	13152	995886	9.30	506	2005	3,409	2	7,075	51,426	64,421	4,599
1 - No Awnings	31319	12801	981815	9.30	506	0	3,409	2	7,075	51,278	62,268	6,752
2 - Awnings	31319	10963	908302	8.86	1223	2005	3,409	2	7,075	50,507	64,219	4,801
2 - No Awnings	31319	10701	897813	8.86	1223	0	3,409	2	7,075	50,397	62,104	6,916
3 - Awnings	31319	5110	674184	6.98	1512	2005	3,409	2	7,075	48,051	62,051	6,969
3 - No Awnings	31319	5055	672005	6.98	1512	0	3,409	2	7,075	48,028	60,023	8,997
3 - best windows	31319	4314	642348	6.67	1512	0	5,370	2	7,075	47,717	61,674	7,346
3 - wst windows	31319	7209	758146	7.85	1512	0	0	2	7,075	48,932	57,518	11,502
4 - Awnings	31319	3514	610359	6.43	2225	2005	5,370	2	7,075	47,381	64,056	4,964
4 - No Awnings	31319	3517	610469	6.43	2225	0	5,370	2	7,075	47,382	62,052	6,968
Christchurch												
Base - Awnings	41201	40194	2225757	17.79	0	2005	0	4	14,150	81,584	97,740	-2,179
Base - No Awnings	41201	39802	2210096	17.79	0	0	0	4	14,150	81,411	95,561	0
1 - Awnings	41201	17612	1322483	10.78	607	2005	3,824	3	10,613	71,577	88,625	6,936
1 - No Awnings	41201	17311	1310453	10.78	607	0	3,824	3	10,613	71,443	86,487	9,074
2 - Awnings	41201	14784	1209362	10.17	1373	2005	3,824	3	10,613	70,323	88,138	7,423
2 - No Awnings	41201	14584	1201372	10.17	1373	0	3,824	3	10,613	70,235	86,044	9,517
3 - Awnings	41201	7176	905063	7.70	1662	2005	3,824	2	7,075	66,952	81,518	14,044
3 - No Awnings	41201	7172	904889	7.70	1662	0	3,824	2	7,075	66,950	79,511	16,051
3 - best windows	41201	6175	865009	7.31	1662	0	5,933	2	7,075	66,508	81,178	14,383
3 - wst windows	41201	10056	1020266	8.80	1662	0	0	2	7,075	68,228	76,965	18,596
4 - Awnings	41201	5030	819225	6.97	2664	2005	5,933	2	7,075	66,001	83,678	11,883
4 - No Awnings	41201	5080	821227	6.97	2664	0	5,933	2	7,075	66,023	81,695	13,866

Discount rate = 5%   Energy Price escalation = 5%   Heater cost= $3,000   HP COP = 3   Energy Prices: Akld 13.52, Well 13.15, Chch 13.88
Heat pumps and awnings replaced at 10 years, double glazing replaced at 30 years

Retrofitting existing houses

House size = Small   Situation = HADLEY
Start retrofitting 2025

Insulation	Ave energy kWh/ year Before fit	Ave energy kWh/ year After fit	Total energy for period	Peak kW	Insulation Cost	Eaves Cost	PV Double glazing $	Number of heat pumps	Heater PV incl replace	PV Energy	Total PV	Net present value
Auckland					$	$	$		$	$	$	$
Base - Awnings	23181	22015	1239976	15.84	0	1231	0	4	8,687	54,268	64,186	-1,202
Base - No Awnings	23181	22141	1243778	15.84	0	0	0	4	8,687	54,298	62,985	0
1 - Awnings	23181	9080	851940	9.81	311	1231	2,066	2	4,343	51,277	59,228	3,757
1 - No Awnings	23181	9194	855348	9.81	311	0	2,066	2	4,343	51,303	58,023	4,961
2 - Awnings	23181	8024	820240	9.40	760	1231	2,066	2	4,343	51,032	59,433	3,552
2 - No Awnings	23181	8238	826670	9.39	760	0	2,066	2	4,343	51,082	58,251	4,733
3 - Awnings	23181	4111	702871	7.23	937	1231	2,066	2	4,343	50,128	58,705	4,280
3 - No Awnings	23181	4515	714995	7.23	937	0	2,066	2	4,343	50,221	57,568	5,417
3 - best windows	23181	3905	696689	6.89	937	0	3,270	2	4,343	50,080	58,631	4,354
3 - wst windows	23181	6355	770192	8.21	937	0	0	2	4,343	50,647	55,927	7,057
4 - Awnings	23181	3053	671120	6.63	1384	1231	3,270	2	4,343	49,883	60,111	2,873
4 - No Awnings	23181	3471	683661	6.62	1384	0	3,270	2	4,343	49,980	58,977	4,008
Wellington												
Base - Awnings	30544	29492	1648357	14.57	0	1231	0	3	6,515	69,626	77,372	-1,331
Base - No Awnings	30544	29048	1635050	14.57	0	0	0	3	6,515	69,526	76,041	0
1 - Awnings	30544	12786	1147194	9.30	311	1231	2,093	2	4,343	65,869	73,847	2,194
1 - No Awnings	30544	12455	1137253	9.30	311	0	2,093	2	4,343	65,795	72,542	3,499
2 - Awnings	30544	10670	1083689	8.86	751	1231	2,093	2	4,343	65,393	73,811	2,230
2 - No Awnings	30544	10427	1076424	8.86	751	0	2,093	2	4,343	65,339	72,526	3,515
3 - Awnings	30544	4972	912770	6.98	928	1231	2,093	2	4,343	64,112	72,707	3,334
3 - No Awnings	30544	4937	911700	6.98	928	0	2,093	2	4,343	64,104	71,468	4,573
3 - best windows	30544	4212	889960	6.67	928	0	3,297	2	4,343	63,941	72,510	3,531
3 - wst windows	30544	7047	975008	7.85	928	0	0	2	4,343	64,579	69,850	6,191
4 - Awnings	30544	3421	866238	6.43	1366	1231	3,297	2	4,343	63,764	74,001	2,041
4 - No Awnings	30544	3441	866835	6.43	1366	0	3,297	2	4,343	63,768	72,774	3,267
Christchurch												
Base - Awnings	40517	39428	2195757	17.79	0	1231	0	4	8,687	97,602	107,519	-1,319
Base - No Awnings	40517	39057	2184638	17.79	0	0	0	4	8,687	97,514	106,200	0
1 - Awnings	40517	17245	1530265	10.78	372	1231	2,348	3	6,515	92,334	102,801	3,400
1 - No Awnings	40517	16962	1521766	10.78	372	0	2,348	3	6,515	92,267	101,502	4,698
2 - Awnings	40517	14492	1447675	10.17	843	1231	2,348	3	6,515	91,681	102,617	3,583
2 - No Awnings	40517	14309	1442181	10.17	843	0	2,348	3	6,515	91,637	101,343	4,857
3 - Awnings	40517	7038	1224054	7.70	1020	1231	2,348	2	4,343	89,911	98,853	7,348
3 - No Awnings	40517	7049	1224398	7.70	1020	0	2,348	2	4,343	89,914	97,625	8,576
3 - best windows	40517	6069	1194989	7.31	1020	0	3,642	2	4,343	89,681	98,687	7,514
3 - wst windows	40517	9888	1309565	8.80	1020	0	0	2	4,343	90,588	95,951	10,249
4 - Awnings	40517	4937	1161029	6.97	1636	1231	3,642	2	4,343	89,412	100,264	5,936
4 - No Awnings	40517	5001	1162951	6.97	1636	0	3,642	2	4,343	89,427	99,049	7,152

Discount rate = 5%   Energy Price escalation = 5%   Heater cost= $3,000   HP COP = 3   Energy Prices: Akld 13.52, Well 13.15, Chch 13.88
Heat pumps and awnings replaced at 10 years, double glazing replaced at 30 years

Retrofitting existing houses

House size = Medium — Situation = CSIRO

Start retrofitting 2005

Insulation	Ave energy kWh/ year Before fit	Ave energy kWh/ year After fit	Total energy for period	Peak kW	Insulation Cost	Eaves Cost	PV Double glazing $	Number of heat pumps	Heater PV incl replace	PV Energy	Total PV	Net present value
Auckland					$	$	$		$	$	$	$
Base - Awnings	41920	38541	2136648	24.69	0	12248	0	5	28,811	54,705	95,764	-11,478
Base - No Awnings	41920	39550	2187096	24.68	0	0	0	5	28,811	55,475	84,287	0
1 - Awnings	41920	18051	1112129	15.38	1336	12248	15,729	4	23,049	39,052	91,415	-7,128
1 - No Awnings	41920	19066	1162899	15.37	1336	0	15,729	4	23,049	39,828	79,942	4,345
2 - Awnings	41920	16504	1034810	14.77	3267	12248	15,729	3	17,287	37,871	86,402	-2,116
2 - No Awnings	41920	17969	1108073	14.77	3267	0	15,729	3	17,287	38,990	75,273	9,013
3 - Awnings	41920	11274	773298	11.52	4029	12248	15,729	3	17,287	33,876	83,168	1,118
3 - No Awnings	41920	13576	888421	12.75	4029	0	15,729	3	17,287	35,635	72,679	11,608
3 - best windows	41920	11822	800687	12.05	4029	0	25,981	3	17,287	34,294	81,591	2,696
3 - wst windows	41920	20139	1216549	15.38	4029	0	0	4	23,049	40,648	67,725	16,561
4 - Awnings	41920	8896	654423	10.09	5949	12248	25,981	3	17,287	32,060	93,525	-9,238
4 - No Awnings	41920	11322	775701	12.00	5949	0	25,981	3	17,287	33,913	83,130	1,157
Wellington												
Base - Awnings	52478	49618	2743279	22.48	0	12248	0	5	28,811	67,596	108,656	-13,097
Base - No Awnings	52478	48475	2686141	22.48	0	0	0	5	28,811	66,747	95,559	0
1 - Awnings	52478	23188	1421769	14.44	1336	12248	15,800	3	17,287	47,968	94,639	920
1 - No Awnings	52478	22566	1390711	14.44	1336	0	15,800	3	17,287	47,506	81,929	13,629
2 - Awnings	52478	19961	1260422	13.79	3228	12248	15,800	3	17,287	45,571	94,134	1,425
2 - No Awnings	52478	19730	1248884	13.79	3228	0	15,800	3	17,287	45,400	81,714	13,844
3 - Awnings	52478	11829	853848	10.97	3989	12248	15,800	3	17,287	39,532	88,857	6,702
3 - No Awnings	52478	12491	886948	11.39	3989	0	15,800	3	17,287	40,024	77,100	18,459
3 - best windows	52478	10353	780051	10.89	3989	0	26,052	3	17,287	38,436	85,764	9,794
3 - wst windows	52478	20443	1284542	14.08	3989	0	0	3	17,287	45,930	67,206	28,353
4 - Awnings	52478	8354	680098	9.69	5871	12248	26,052	2	11,525	36,952	92,647	2,911
4 - No Awnings	52478	9321	728454	10.92	5871	0	26,052	3	17,287	37,670	86,879	8,679
Christchurch												
Base - Awnings	68857	65707	3629616	27.62	0	12248	0	6	34,574	94,131	140,953	-12,865
Base - No Awnings	68857	64920	3590296	27.61	0	0	0	6	34,574	93,515	128,088	0
1 - Awnings	68857	30850	1886782	16.84	1601	12248	18,218	4	23,049	66,796	121,912	6,176
1 - No Awnings	68857	30395	1864023	16.83	1601	0	18,218	4	23,049	66,439	109,307	18,781
2 - Awnings	68857	26562	1672371	15.89	3624	12248	18,218	4	23,049	63,433	120,572	7,516
2 - No Awnings	68857	26519	1670211	15.89	3624	0	18,218	4	23,049	63,400	108,290	19,798
3 - Awnings	68857	15805	1134513	12.34	4385	12248	18,218	3	17,287	54,997	107,135	20,953
3 - No Awnings	68857	16619	1175225	12.49	4385	0	18,218	3	17,287	55,636	95,526	32,563
3 - best windows	68857	13664	1027489	11.75	4385	0	29,239	3	17,287	53,319	104,229	23,859
3 - wst windows	68857	27369	1712722	16.34	4385	0	0	4	23,049	64,066	91,500	36,588
4 - Awnings	68857	11050	896777	10.64	7031	12248	29,239	3	17,287	51,269	117,074	11,014
4 - No Awnings	68857	12147	951631	11.70	7031	0	29,239	3	17,287	52,129	105,686	22,402

Discount rate = 5% Energy Price escalation = 5% Heater cost= $3,000 HP COP = 3 Energy Prices: Akld 13.52, Well 13.15, Chch 13.88

Heat pumps and awnings replaced at 10 years, double glazing replaced at 30 years

Retrofitting existing houses

House size = Medium — Situation = CSIRO

Start retrofitting 2015

Insulation	Ave energy kWh/ year Before fit	Ave energy kWh/ year After fit	Total energy for period	Peak kW	Insulation Cost	Eaves Cost	PV Double glazing $	Number of heat pumps	Heater PV incl replace	PV Energy	Total PV	Net present value
Auckland					$	$	$		$	$	$	$
Base - Awnings	40735	37212	2099489	24.69	0	7519	0	5	17,688	77,479	102,686	-6,986
Base - No Awnings	40735	38446	2148868	24.68	0	0	0	5	17,688	78,012	95,699	0
1 - Awnings	40735	17529	1312196	15.38	820	7519	9,656	4	14,150	68,982	101,128	-5,429
1 - No Awnings	40735	18724	1360002	15.37	820	0	9,656	4	14,150	69,498	94,125	1,575
2 - Awnings	40735	16162	1257505	14.77	2006	7519	9,656	3	10,613	68,392	98,186	-2,486
2 - No Awnings	40735	17794	1322789	14.77	2006	0	9,656	3	10,613	69,096	91,371	4,328
3 - Awnings	40735	11267	1061689	11.52	2473	7519	9,656	3	10,613	66,279	96,540	-840
3 - No Awnings	40735	13712	1159510	12.75	2473	0	9,656	3	10,613	67,334	90,076	5,623
3 - best windows	40735	12013	1091524	12.05	2473	0	15,950	3	10,613	66,600	95,636	63
3 - wst windows	40735	20072	1413915	15.38	2473	0	0	4	14,150	70,080	86,703	8,996
4 - Awnings	40735	9014	971586	10.09	3652	7519	15,950	3	10,613	65,306	103,040	-7,341
4 - No Awnings	40735	11563	1073523	12.00	3652	0	15,950	3	10,613	66,406	96,621	-922
Wellington												
Base - Awnings	50476	47363	2651679	22.48	0	7519	0	5	17,688	93,864	119,071	-7,918
Base - No Awnings	50476	46412	2613643	22.48	0	0	0	5	17,688	93,465	111,152	0
1 - Awnings	50476	22138	1642656	14.44	820	7519	9,700	3	10,613	83,277	111,929	-777
1 - No Awnings	50476	21665	1623750	14.44	820	0	9,700	3	10,613	83,079	104,211	6,941
2 - Awnings	50476	19142	1522843	13.79	1982	7519	9,700	3	10,613	82,020	111,833	-681
2 - No Awnings	50476	19056	1519383	13.79	1982	0	9,700	3	10,613	81,983	104,277	6,875
3 - Awnings	50476	11485	1216532	10.97	2449	7519	9,700	3	10,613	78,806	109,087	2,066
3 - No Awnings	50476	12276	1248200	11.39	2449	0	9,700	3	10,613	79,138	101,899	9,253
3 - best windows	50476	10237	1166609	10.89	2449	0	15,994	3	10,613	78,282	107,337	3,815
3 - wst windows	50476	19883	1552474	14.08	2449	0	0	3	10,613	82,331	95,392	15,760
4 - Awnings	50476	8203	1085263	9.69	3604	7519	15,994	2	7,075	77,429	111,621	-468
4 - No Awnings	50476	9283	1128461	10.92	3604	0	15,994	3	10,613	77,882	108,092	3,060
Christchurch												
Base - Awnings	66889	63537	3544811	27.62	0	7519	0	6	21,225	131,690	160,434	-7,795
Base - No Awnings	66889	62915	3519919	27.61	0	0	0	6	21,225	131,414	152,639	0
1 - Awnings	66889	29827	2196419	16.84	983	7519	11,184	4	14,150	116,750	150,587	2,053
1 - No Awnings	66889	29504	2183476	16.83	983	0	11,184	4	14,150	116,607	142,924	9,715
2 - Awnings	66889	25769	2034108	15.89	2225	7519	11,184	4	14,150	114,952	150,030	2,609
2 - No Awnings	66889	25852	2037399	15.89	2225	0	11,184	4	14,150	114,988	142,547	10,092
3 - Awnings	66889	15458	1621660	12.34	2692	7519	11,184	3	10,613	110,382	142,390	10,249
3 - No Awnings	66889	16385	1658729	12.49	2692	0	11,184	3	10,613	110,793	135,281	17,358
3 - best windows	66889	13525	1544337	11.75	2692	0	17,950	3	10,613	109,525	140,780	11,859
3 - wst windows	66889	26802	2075424	16.34	2692	0	0	4	14,150	115,409	132,252	20,388
4 - Awnings	66889	10892	1439004	10.64	4317	7519	17,950	3	10,613	108,358	148,757	3,882
4 - No Awnings	66889	12086	1486783	11.70	4317	0	17,950	3	10,613	108,888	141,767	10,872

Discount rate = 5% Energy Price escalation = 5% Heater cost= $3,000 HP COP = 3 Energy Prices: Akld 13.52, Well 13.15, Chch 13.88

Heat pumps and awnings replaced at 10 years, double glazing replaced at 30 years

Retrofitting existing houses

House size = Medium   Situation = CSIRO
Start retrofitting 2025

Insulation	Ave energy kWh/ year Before fit	Ave energy kWh/ year After fit	Total energy for period	Peak kW	Insulation Cost	Eaves Cost	PV Double glazing $	Number of heat pumps	Heater PV incl replace	PV Energy	Total PV	Net present value
Auckland					$	$	$		$	$	$	$
Base - Awnings	39550	35939	2066918	24.69	0	4616	0	5	10,859	92,213	107,688	-4,273
Base - No Awnings	39550	37423	2111450	24.68	0	0	0	5	10,859	92,556	103,415	0
1 - Awnings	39550	17072	1500922	15.38	504	4616	5,928	4	8,687	87,850	107,584	-4,169
1 - No Awnings	39550	18468	1542797	15.37	504	0	5,928	4	8,687	88,172	103,291	124
2 - Awnings	39550	15889	1465424	14.77	1231	4616	5,928	3	6,515	87,576	105,867	-2,452
2 - No Awnings	39550	17708	1519989	14.77	1231	0	5,928	3	6,515	87,997	101,671	1,744
3 - Awnings	39550	11335	1328796	11.52	1518	4616	5,928	3	6,515	86,523	105,100	-1,685
3 - No Awnings	39550	13939	1406933	12.75	1518	0	5,928	3	6,515	87,125	101,087	2,329
3 - best windows	39550	12292	1357521	12.05	1518	0	9,792	3	6,515	86,744	104,570	-1,154
3 - wst windows	39550	20103	1591846	15.38	1518	0	0	4	8,687	88,551	98,756	4,659
4 - Awnings	39550	9206	1264943	10.09	2242	4616	9,792	3	6,515	86,030	109,196	-5,781
4 - No Awnings	39550	11891	1345489	12.00	2242	0	9,792	3	6,515	86,651	105,201	-1,785
Wellington												
Base - Awnings	48475	45024	2562591	22.48	0	4616	0	5	10,859	110,099	125,574	-4,782
Base - No Awnings	48475	44289	2540534	22.48	0	0	0	5	10,859	109,934	120,792	0
1 - Awnings	48475	21067	1843881	14.44	504	4616	5,955	3	6,515	104,712	122,302	-1,510
1 - No Awnings	48475	20760	1834662	14.44	504	0	5,955	3	6,515	104,643	117,617	3,176
2 - Awnings	48475	18314	1761300	13.79	1217	4616	5,955	3	6,515	104,093	122,396	-1,604
2 - No Awnings	48475	18389	1763548	13.79	1217	0	5,955	3	6,515	104,110	117,797	2,996
3 - Awnings	48475	11155	1546521	10.97	1504	4616	5,955	3	6,515	102,483	121,073	-281
3 - No Awnings	48475	12092	1574637	11.39	1504	0	5,955	3	6,515	102,694	116,668	4,125
3 - best windows	48475	10154	1516501	10.89	1504	0	9,819	3	6,515	102,258	120,096	697
3 - wst windows	48475	19341	1792117	14.08	1504	0	0	3	6,515	104,324	112,343	8,449
4 - Awnings	48475	8076	1454150	9.69	2213	4616	9,819	2	4,343	101,791	122,782	-1,990
4 - No Awnings	48475	9282	1490341	10.92	2213	0	9,819	3	6,515	102,062	120,609	184
Christchurch												
Base - Awnings	64920	61307	3462227	27.62	0	4616	0	6	13,030	155,945	173,591	-4,720
Base - No Awnings	64920	60872	3449173	27.61	0	0	0	6	13,030	155,841	168,872	0
1 - Awnings	64920	28791	2486742	16.84	603	4616	6,866	4	8,687	148,224	168,997	-125
1 - No Awnings	64920	28619	2481589	16.83	603	0	6,866	4	8,687	148,183	164,340	4,532
2 - Awnings	64920	24977	2372313	15.89	1366	4616	6,866	4	8,687	147,318	168,853	18
2 - No Awnings	64920	25204	2379133	15.89	1366	0	6,866	4	8,687	147,372	164,291	4,581
3 - Awnings	64920	15137	2077104	12.34	1653	4616	6,866	3	6,515	144,982	164,632	4,240
3 - No Awnings	64920	16192	2108774	12.49	1653	0	6,866	3	6,515	145,232	160,266	8,605
3 - best windows	64920	13431	2025921	11.75	1653	0	11,020	3	6,515	144,577	163,764	5,107
3 - wst windows	64920	26268	2411035	16.34	1653	0	0	4	8,687	147,625	157,964	10,907
4 - Awnings	64920	10768	1946035	10.64	2650	4616	11,020	3	6,515	143,944	168,746	126
4 - No Awnings	64920	12073	1985200	11.70	2650	0	11,020	3	6,515	144,254	164,439	4,432

Discount rate = 5%   Energy Price escalation = 5%   Heater cost= $3,000   HP COP = 3   Energy Prices   Akld 13.52   Well 13.15   Chch 13.88
Heat pumps and awnings replaced at 10 years, double glazing replaced at 30 years

Retrofitting existing houses

House size = Medium   Situation = HADLEY
Start retrofitting 2005

Insulation	Ave energy kWh/ year Before fit	Ave energy kWh/ year After fit	Total energy for period	Peak kW	Insulation Cost	Eaves Cost	PV Double glazing $	Number of heat pumps	Heater PV incl replace	PV Energy	Total PV	Net present value
Auckland					$	$	$		$	$	$	$
Base - Awnings	42055	39406	2180583	25.70	0	12248	0	6	34,574	55,447	102,269	-11,620
Base - No Awnings	42055	40229	2221725	25.70	0	0	0	6	34,574	56,076	90,650	0
1 - Awnings	42055	18347	1127647	15.93	1336	12248	15,729	4	23,049	39,361	91,723	-1,074
1 - No Awnings	42055	19214	1170986	15.92	1336	0	15,729	4	23,049	40,023	80,137	10,512
2 - Awnings	42055	16672	1043881	15.24	3267	12248	15,729	4	23,049	38,081	92,375	-1,725
2 - No Awnings	42055	18002	1110395	15.24	3267	0	15,729	4	23,049	39,097	81,143	9,507
3 - Awnings	42055	11207	770632	11.83	4029	12248	15,729	3	17,287	33,907	83,199	7,450
3 - No Awnings	42055	13392	879875	12.29	4029	0	15,729	3	17,287	35,576	72,620	18,030
3 - best windows	42055	11602	790358	11.66	4029	0	25,981	3	17,287	34,208	81,504	9,145
3 - wst windows	42055	20087	1214635	15.54	4029	0	0	4	23,049	40,690	67,768	22,882
4 - Awnings	42055	8743	647451	10.32	5949	12248	25,981	3	17,287	32,025	93,490	-2,840
4 - No Awnings	42055	11068	763682	11.65	5949	0	25,981	3	17,287	33,800	83,017	7,632
Wellington												
Base - Awnings	52872	51828	2855768	23.61	0	12248	0	5	28,811	69,468	110,528	-13,275
Base - No Awnings	52872	50445	2786626	23.61	0	0	0	5	28,811	68,441	97,253	0
1 - Awnings	52872	24180	1473384	15.05	1336	12248	15,800	4	23,049	48,936	101,369	-4,117
1 - No Awnings	52872	23372	1432950	15.05	1336	0	15,800	4	23,049	48,335	88,520	8,732
2 - Awnings	52872	20700	1299363	14.31	3228	12248	15,800	3	17,287	46,351	94,914	2,339
2 - No Awnings	52872	20291	1278912	14.31	3228	0	15,800	3	17,287	46,048	82,362	14,891
3 - Awnings	52872	12080	868343	11.32	3989	12248	15,800	3	17,287	39,949	89,273	7,979
3 - No Awnings	52872	12586	893676	11.32	3989	0	15,800	3	17,287	40,326	77,401	19,851
3 - best windows	52872	10357	782218	10.38	3989	0	26,052	3	17,287	38,670	85,998	11,255
3 - wst windows	52872	20869	1307787	14.60	3989	0	0	3	17,287	46,476	67,752	29,500
4 - Awnings	52872	8416	685159	9.95	5871	12248	26,052	2	11,525	37,229	92,924	4,329
4 - No Awnings	52872	9249	726801	10.41	5871	0	26,052	3	17,287	37,847	87,056	10,196
Christchurch												
Base - Awnings	69306	68138	3753408	28.75	0	12248	0	6	34,574	96,315	143,137	-13,012
Base - No Awnings	69306	67163	3704701	28.75	0	0	0	6	34,574	95,551	130,125	0
1 - Awnings	69306	31982	1945615	17.44	1601	12248	18,218	4	23,049	67,961	123,078	7,048
1 - No Awnings	69306	31379	1915495	17.44	1601	0	18,218	4	23,049	67,489	110,357	19,768
2 - Awnings	69306	27430	1718044	16.42	3624	12248	18,218	4	23,049	64,392	121,531	8,594
2 - No Awnings	69306	27250	1709020	16.41	3624	0	18,218	4	23,049	64,251	109,141	20,984
3 - Awnings	69306	16178	1155450	12.67	4385	12248	18,218	3	17,287	55,568	107,706	22,419
3 - No Awnings	69306	16867	1189900	12.67	4385	0	18,218	3	17,287	56,109	95,998	34,127
3 - best windows	69306	13807	1036885	11.45	4385	0	29,239	3	17,287	53,709	104,619	25,506
3 - wst windows	69306	27988	1745940	16.86	4385	0	0	4	23,049	64,830	92,264	37,861
4 - Awnings	69306	11216	907308	10.89	7031	12248	29,239	3	17,287	51,676	117,482	12,644
4 - No Awnings	69306	12203	956675	11.20	7031	0	29,239	3	17,287	52,451	106,008	24,118

Discount rate = 5%   Energy Price escalation = 5%   Heater cost= $3,000   HP COP = 3   Energy Prices   Akld 13.52   Well 13.15   Chch 13.88
Heat pumps and awnings replaced at 10 years, double glazing replaced at 30 years

Retrofitting existing houses

House size = Medium | Situation = HADLEY
Start retrofitting 2015

Insulation	Ave energy kWh/ year Before fit	Ave energy kWh/ year After fit	Total energy for period	Peak kW	Insulation Cost	Eaves Cost	PV Double glazing $	Number of heat pumps	Heater PV incl replace	PV Energy	Total PV	Net present value
Auckland					$	$	$		$	$	$	$
Base - Awnings	41142	38474	2156111	25.70	0	7519	0	6	21,225	78,638	107,383	-7,110
Base - No Awnings	41142	39424	2194074	25.70	0	0	0	6	21,225	79,048	100,273	0
1 - Awnings	41142	17946	1334981	15.93	820	7519	9,656	4	14,150	69,776	101,922	-1,649
1 - No Awnings	41142	18913	1373651	15.92	820	0	9,656	4	14,150	70,194	94,820	5,453
2 - Awnings	41142	16386	1272561	15.24	2006	7519	9,656	4	14,150	69,103	102,434	-2,161
2 - No Awnings	41142	17809	1329490	15.24	2006	0	9,656	4	14,150	69,717	95,529	4,744
3 - Awnings	41142	11137	1062627	11.83	2473	7519	9,656	3	10,613	66,837	97,098	3,175
3 - No Awnings	41142	13402	1153231	12.29	2473	0	9,656	3	10,613	67,815	90,557	9,716
3 - best windows	41142	11651	1083163	11.66	2473	0	15,950	3	10,613	67,059	96,094	4,179
3 - wst windows	41142	19958	1415440	15.54	2473	0	0	4	14,150	70,645	87,268	13,005
4 - Awnings	41142	8757	967422	10.32	3652	7519	15,950	3	10,613	65,809	103,544	-3,271
4 - No Awnings	41142	11150	1063151	11.65	3652	0	15,950	3	10,613	66,843	97,057	3,216
Wellington												
Base - Awnings	51659	50574	2797845	23.61	0	7519	0	5	17,688	96,944	122,151	-8,065
Base - No Awnings	51659	49273	2745804	23.61	0	0	0	5	17,688	96,398	114,086	0
1 - Awnings	51659	23574	1717835	15.05	820	7519	9,700	4	14,150	85,612	117,802	-3,716
1 - No Awnings	51659	22829	1688057	15.05	820	0	9,700	4	14,150	85,300	109,970	4,116
2 - Awnings	51659	20215	1583488	14.31	1982	7519	9,700	3	10,613	84,203	114,016	70
2 - No Awnings	51659	19869	1569630	14.31	1982	0	9,700	3	10,613	84,057	106,351	7,734
3 - Awnings	51659	11847	1248767	11.32	2449	7519	9,700	3	10,613	80,691	110,972	3,114
3 - No Awnings	51659	12411	1271334	11.32	2449	0	9,700	3	10,613	80,928	103,689	10,397
3 - best windows	51659	10238	1184401	10.38	2449	0	15,994	3	10,613	80,016	109,071	5,015
3 - wst windows	51659	20499	1594855	14.60	2449	0	0	3	10,613	84,322	97,384	16,702
4 - Awnings	51659	8290	1106475	9.95	3604	7519	15,994	2	7,075	79,198	113,390	696
4 - No Awnings	51659	9173	1141802	10.41	3604	0	15,994	3	10,613	79,569	109,779	4,307
Christchurch												
Base - Awnings	68235	66952	3701602	28.75	0	7519	0	6	21,225	135,286	164,031	-7,919
Base - No Awnings	68235	66051	3665548	28.75	0	0	0	6	21,225	134,887	156,112	0
1 - Awnings	68235	31407	2279793	17.44	983	7519	11,184	4	14,150	119,533	153,370	2,742
1 - No Awnings	68235	30862	2258015	17.44	983	0	11,184	4	14,150	119,292	145,609	10,503
2 - Awnings	68235	26975	2102505	16.42	2225	7519	11,184	4	14,150	117,569	152,647	3,465
2 - No Awnings	68235	26850	2097516	16.41	2225	0	11,184	4	14,150	117,514	145,073	11,039
3 - Awnings	68235	15957	1661802	12.67	2692	7519	11,184	3	10,613	112,686	144,694	11,418
3 - No Awnings	68235	16697	1691384	12.67	2692	0	11,184	3	10,613	113,014	137,503	18,609
3 - best windows	68235	13688	1571051	11.45	2692	0	17,950	3	10,613	111,681	142,935	13,177
3 - wst windows	68235	27635	2128932	16.86	2692	0	0	4	14,150	117,862	134,704	21,408
4 - Awnings	68235	11095	1467324	10.89	4317	7519	17,950	3	10,613	110,532	150,930	5,182
4 - No Awnings	68235	12126	1508574	11.20	4317	0	17,950	3	10,613	110,989	143,868	12,244

Discount rate = 5% | Energy Price escalation = 5% | Heater cost= $3,000 | HP COP = 3 | Energy Prices: Akld 13.52, Well 13.15, Chch 13.88

Heat pumps and awnings replaced at 10 years, double glazing replaced at 30 years

Retrofitting existing houses

House size = Medium | Situation = HADLEY
Start retrofitting 2025

Insulation	Ave energy kWh/ year Before fit	Ave energy kWh/ year After fit	Total energy for period	Peak kW	Insulation Cost	Eaves Cost	PV Double glazing $	Number of heat pumps	Heater PV incl replace	PV Energy	Total PV	Net present value
Auckland					$	$	$		$	$	$	$
Base - Awnings	40229	37651	2135256	25.70	0	4616	0	6	13,030	94,050	111,696	-4,368
Base - No Awnings	40229	38726	2167502	25.70	0	0	0	6	13,030	94,298	107,329	0
1 - Awnings	40229	17611	1534046	15.93	504	4616	5,928	4	8,687	89,415	109,149	-1,821
1 - No Awnings	40229	18678	1566065	15.92	504	0	5,928	4	8,687	89,661	104,780	2,549
2 - Awnings	40229	16157	1490441	15.24	1231	4616	5,928	4	8,687	89,078	109,541	-2,212
2 - No Awnings	40229	17673	1535925	15.24	1231	0	5,928	4	8,687	89,429	105,275	2,053
3 - Awnings	40229	11108	1338950	11.83	1518	4616	5,928	3	6,515	87,910	106,488	840
3 - No Awnings	40229	13453	1409315	12.29	1518	0	5,928	3	6,515	88,453	102,414	4,914
3 - best windows	40229	11735	1357787	11.66	1518	0	9,792	3	6,515	88,056	105,881	1,447
3 - wst windows	40229	19884	1602236	15.54	1518	0	0	4	8,687	89,940	100,145	7,183
4 - Awnings	40229	8803	1269816	10.32	2242	4616	9,792	3	6,515	87,377	110,543	-3,214
4 - No Awnings	40229	11265	1343661	11.65	2242	0	9,792	3	6,515	87,947	106,496	832
Wellington												
Base - Awnings	50445	49352	2741678	23.61	0	4616	0	5	10,859	115,136	130,611	-4,888
Base - No Awnings	50445	48142	2705393	23.61	0	0	0	5	10,859	114,864	125,722	0
1 - Awnings	50445	22992	1950904	15.05	504	4616	5,955	4	8,687	109,209	128,970	-3,248
1 - No Awnings	50445	22320	1930724	15.05	504	0	5,955	4	8,687	109,057	124,203	1,520
2 - Awnings	50445	19758	1853872	14.31	1217	4616	5,955	3	6,515	108,481	126,784	-1,062
2 - No Awnings	50445	19481	1845561	14.31	1217	0	5,955	3	6,515	108,419	122,106	3,617
3 - Awnings	50445	11641	1610374	11.32	1504	4616	5,955	3	6,515	106,656	125,246	476
3 - No Awnings	50445	12269	1629198	11.32	1504	0	5,955	3	6,515	106,797	120,771	4,951
3 - best windows	50445	10149	1565610	10.38	1504	0	9,819	3	6,515	106,321	124,158	1,564
3 - wst windows	50445	20169	1866198	14.60	1504	0	0	3	6,515	108,574	116,593	9,130
4 - Awnings	50445	8188	1506785	9.95	2213	4616	9,819	2	4,343	105,880	126,871	-1,149
4 - No Awnings	50445	9127	1534934	10.41	2213	0	9,819	3	6,515	106,091	124,637	1,085
Christchurch												
Base - Awnings	67163	65718	3650632	28.75	0	4616	0	6	13,030	161,877	179,524	-4,811
Base - No Awnings	67163	64897	3625981	28.75	0	0	0	6	13,030	161,682	174,713	0
1 - Awnings	67163	30814	2603500	17.44	603	4616	6,866	4	8,687	153,590	174,362	350
1 - No Awnings	67163	30333	2589068	17.44	603	0	6,866	4	8,687	153,475	169,632	5,081
2 - Awnings	67163	26508	2474322	16.42	1366	4616	6,866	4	8,687	152,567	174,102	610
2 - No Awnings	67163	26444	2472399	16.41	1366	0	6,866	4	8,687	152,552	169,471	5,242
3 - Awnings	67163	15736	2151160	12.67	1653	4616	6,866	3	6,515	150,009	169,660	5,053
3 - No Awnings	67163	16530	2175000	12.67	1653	0	6,866	3	6,515	150,198	165,232	9,481
3 - best windows	67163	13577	2086382	11.45	1653	0	11,020	3	6,515	149,497	168,684	6,028
3 - wst windows	67163	27280	2497481	16.86	1653	0	0	4	8,687	152,750	163,090	11,623
4 - Awnings	67163	10980	2008475	10.89	2650	4616	11,020	3	6,515	148,880	173,681	1,031
4 - No Awnings	67163	12059	2040850	11.20	2650	0	11,020	3	6,515	149,136	169,321	5,391

Discount rate = 5% | Energy Price escalation = 5% | Heater cost= $3,000 | HP COP = 3 | Energy Prices: Akld 13.52, Well 13.15, Chch 13.88

Heat pumps and awnings replaced at 10 years, double glazing replaced at 30 years

APPENDIX H: CLIMATE RELATED DAMAGE SURVEY

H.1 Introduction

A survey was sent out to 83 regional and district councils asking for data on climate related damage to the housing stock that has occurred in recent years. The purpose of the survey was to obtain a "starting point" for assessing the present size of the climate related natural disasters. This data was then used to assess how much damage may occur due to climate change impacts.

H.2 Response

Of the 83 authorities a response of 31 were received. The quality of responses was mixed, with some filling out the questionnaire very well with full data, and some not being able to fill out much because they do not have the data we required. A number of councils stated that we should contact the insurance council to get the data, this was done but the insurance council suggested we contact the insurance companies directly. This was not done due to time constraints. Because of this the results are to be read with caution.

H.3 Results

H.3.1 Wind damage

Of the 31 responses, 21 councils were able to give data on wind/storm damage to houses. These 21 councils reported that they have 253,085 houses in their region, with 48 houses per year, on average, suffering some type of damage from wind/storm events. To get an approximate national figure we weighted this number up to represent the total number of houses in NZ[42], this gave a result of 280 homes in NZ suffer wind/storm damage a year. There is a mix of regions and council sizes in the returns but no major cities, so the scaled up data needs to be used with care.

The types of wind/storm damage done to a building are in the figure and table below.

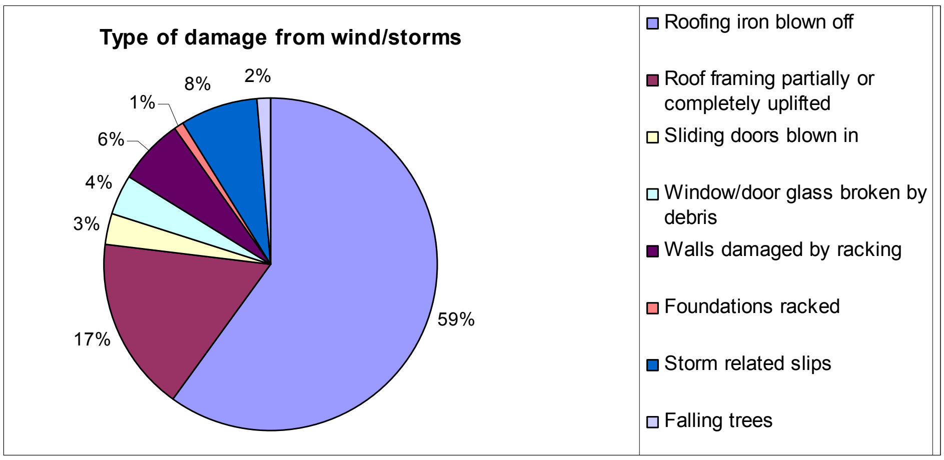


Figure 45

[42] 1,478,709. 2006 census

Damage to houses by wind/storm broken down (1)	
Roofing iron blown off	168
Roof framing partially or completely uplifted	48
Sliding doors blown in	8
Window/door glass broken by debris	11
Walls damaged by racking	18
Foundations racked	2
Storm related slips	21
Falling trees	4
Total	**280**
(1) These figures are weighted up to repersent all of NZ	

Table 17

Note that these figures in Table 17 have been weighted up to represent the whole of NZ, and the total matches the total number of wind/storm damages houses in the previous paragraph.

H.3.2 Flooding

Data was obtained for the number of houses that are damaged by flooding annually (average over the last 5 years), to which 24 councils provided a response. The total number of houses in these 24 councils regions was 284,522 and of these houses 209 were damaged by flooding per year. If we weighted this up to represent NZ it would come to 1086 homes per year. Please note that this is a simple weighted average, and does not necessarily pick-up the most flood prone areas. For example, the Wanganui/ Manawatu region is not well represented in the returns.

H.3.3 Coastal erosion

Data was obtained on how many houses were damaged by coastal erosion annually (average over the last 5 years), and 24 councils provided a response to this question. The total number of houses in these 24 councils regions was 278,085 and of these houses 14 were damaged by flooding per year. Weighting that figure would give us 76 homes get damaged by coastal erosion per year.

Note that one council considered coastal erosion to include lakes, which we included in the response.

H.3.4 Other data

30 responses were obtained for the question that asked if the councils had maps showing areas likely to be flooded for various return period event, with the results shown in the figure below:

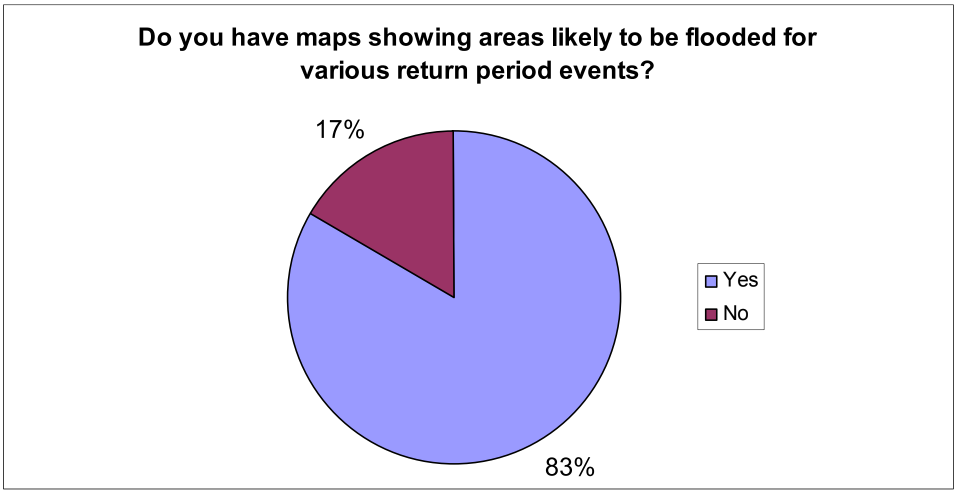


Figure 46

Question 6 which asks respondents for data on how many houses they expect to be flooded in a 50 year return period flood was answered by 20 respondents, the main reason for such a low response was the councils did not have the data we asked for. The 20 councils that filled in this question represented 182,585 houses, and they reported that 445 homes would be flooded, which is 0.24% of the total. Weighted up to represent the whole of NZ gives a figure of 3604 homes are expected to be flooded.

The last question asked if the NIWA data that was provided would be of any use, 15 responses were received for this with the results in the figure below:

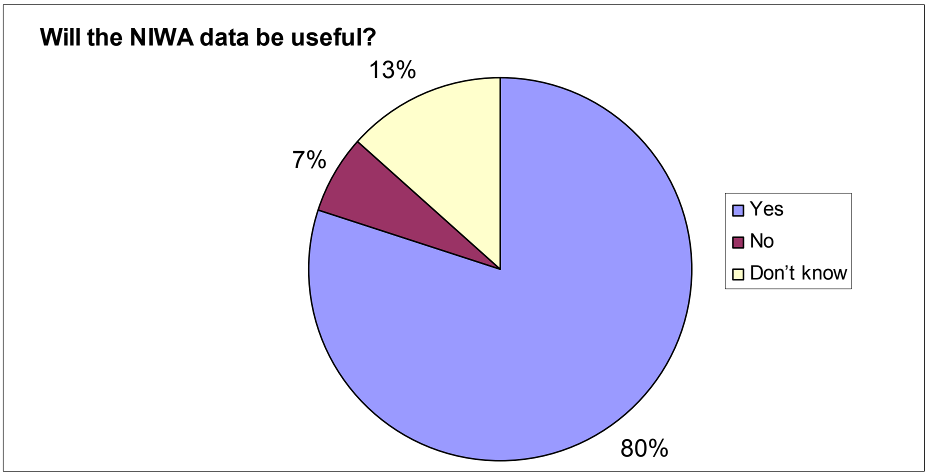


Figure 47

H.4 Councils that responded

Kaipara District Council
Papakura District Council
Environment Waikato
Thames-Coromandel District Council
Western BOP District council
Rotorua District Council
Opotiki District Council
Napier City Council
Central Hawkes Bay District Council
Hawkes Bay Regional Council
Otorohanga District Council
New Plymouth District Council
Stratford District Council
South Taranaki District
Palmerston North City Council
Taranaki Regional Council
Masterton District Council
Carterton District Council
South Wairarapa District Council
Hurunui District Council
Westland District Council
West Coast Regional Council
Ashburton District Council
Selwyn District Council
Southland District Coucil
Mackenzie District Council
Dunedin City Council
Environment Southland
Clutha District Council
Chatham Island Council

H.5 Survey form sent to all territorial authorities

Climate impacts on the housing stock - Questionnaire

This survey will help BRANZ in assessing the impact of climate change on the housing stock, and how the impacts can be mitigated.

Could you please answer the following questions for your territorial authority, or regional council?

1. Could you please estimate how many houses you have in your territorial authority? ☐

2. How many houses suffer wind-storm damage to the structure each year? (Average over the last 5 years). ☐

   – Can you split this into failure types by estimating the percentages of the total damaged houses:
     - Roofing iron blown off ____ %
     - Roof framing partially or completely uplifted ____ %
     - Sliding doors blown in ____ %
     - Window/door glass broken by debris ____ %
     - Walls damaged by racking ____ %
     - Foundations racked ____ %
     - Other, please state: ____ %

     ______________________ **100 %**

3. How many houses are damaged by flooding annually (average over the last 5 years)? ☐

4. How many houses are damaged by coastal erosion annually (average over the last 5 years)? ☐

5. Do you have maps showing areas likely to be flooded for various return period events? (We are not asking for these maps.)

   Yes ☐

   No ☐

6. Approximately how many houses are expected to be flooded in a 50-year return period flood? ☐

7. Will the NIWA data provided be useful to you in your modelling?

Territorial authority or regional council ______________________

Contact person ______________ Position ______________

Phone Number ______________ Fax Number ______________

Thank you for your response. Please return in the provided freepost envelop